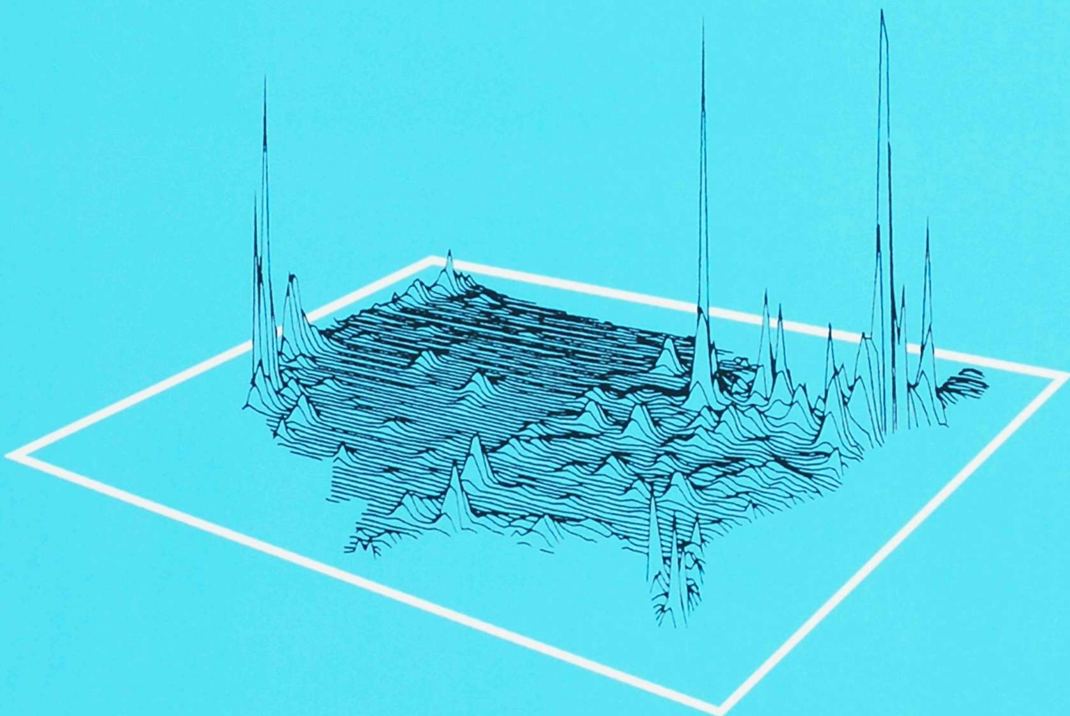


The Language of Graphics

A framework for the analysis of syntax and meaning in maps, charts and diagrams

ILLC Dissertation Series 2002-03

INSTITUTE FOR LOGIC, LANGUAGE AND COMPUTATION

For further information about ILLC-publications, please contact

Institute for Logic, Language and Computation
Universiteit van Amsterdam
Plantage Muidergracht 24
1018 TV Amsterdam
phone: +31-20-525 6051
fax: +31-20-525 5206
e-mail: illc@wins.uva.nl
homepage: http://www.illc.uva.nl

The Language of Graphics

A framework for the analysis of syntax and meaning in maps, charts and diagrams

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit van Amsterdam
op gezag van de Rector Magnificus
prof. mr. P.F. van der Heijden
ten overstaan van een door het college
voor promoties ingestelde commissie,
in het openbaar te verdedigen
in de Aula der Universiteit
op vrijdag 13 september 2002, te 14.00 uur

door

Jörg von Engelhardt

geboren te Hannover, Duitsland

Promotiecommissie

Promotores: Prof. dr. ir. Remko Scha
Dr. Peter van Emde Boas

Overige leden: Prof. Thijs Chanowski
Dr. Theo Janssen
Prof. Paul Mijksenaar
Prof. dr. Clive Richards
Prof. dr. ir. Arnold Smeulders

Faculteit der Natuurwetenschappen, Wiskunde en Informatica
Universiteit van Amsterdam

The financial support for this research project was provided by the National Institute for Public Health and the Environment (RIVM) in Bilthoven, and by the University of Amsterdam.

Cover design by Niels van der Sluijs.

Cover illustration: U.S. population in 1979, plotted by the Havard Laboratory for Computer Graphics Mapping Service. This is an example of a 'composite meaningful space', see also figure 2-30.

ISBN 90-5776-089-4

To Lieve Witteveen

the most amazing person on this planet

Contents

Acknowledgments

This thesis would *never* have been finished if I had not received an enormous amount of encouragement, support, feedback and help. I want to thank:

Remko Scha for envisioning this research, and for playing a key role in the development of the concepts that are presented here. Remko has been an inspiring supervisor, both academically and through his open-minded approach to life in general. I have always enjoyed our discussions - it seems that Remko tends to understand my ideas before I understand them myself.

Peter van Emde Boas for kindly welcoming me in his department and for supervising the evolution of my work. Peter's mathematical perspective has greatly helped to eliminate inconsistencies and to sharpen many of my initially somewhat fuzzy ideas. I am grateful to Peter's department and to the University of Amsterdam for supporting me during the certainly longer-than-expected course of this project.

Jos de Bruin for creating this research project, for arranging the financing of the project by the RIVM (National Institute for Public Health and Environmental Protection), and for providing a lot of useful feedback on countless drafts.

Clive Richards for his phonebook-sized thesis titled 'Diagrammatics', which I read while trying to live in a cave on the Canary Islands. While rats were chewing holes into my inflatable mattress, Clive's book made a lasting impression on my thinking about graphic representation. His analysis lies at the base of my thesis.

Theo Janssen for numerous useful suggestions over the past eight years, the most recent being the 'COMMENT' as an item in the standard figure caption.

Fred Lakin for reading the entire manuscript and for providing various detailed remarks which have resulted in important improvements, such as sharpening my definition of recursive syntactic decomposition; also for his idea to turn my view of written text into a figure (figure 3-17).

Matthias Mayer for repeatedly commenting on my work and for proposing valuable enhancements, one of them being the inclusion of the Glossary.

Alan Blackwell, Jeroen van Hasselt, Cees Roele, Mehdi Dastani, Dejuan Wang and **Henk Zeevat** for working together with me on publications, and for our many stimulating brainstorming sessions about systematic approaches to graphic representation.

Niels van der Sluijs for his design work (e.g. our joint contribution to the InfoArcadia exhibition, diagrams for my lectures, the cover of this thesis). In addition to designing the *form*, Niels always tries to understand my (sometimes vague) ideas, and tends to make remarks that help to improve the *contents* of my work.

Piet Westendorp, Karel van der Waarde, Peter Bogaards and **Conrad Taylor** for their help when the InfoDesign and InfoDesign-Cafe mailing lists which I founded and moderated, were growing beyond all expectations. And Piet and Karel, as well as **Paul Mijksenaar** for involving me in the editorial work on the Information Design Journal. Last but not least, Piet, Karel and Peter for their helpful and detailed feedback on my manuscripts.

Zenon Kulpa, Bob Horn and **Hari Narayanan** for reading the final manuscript and for reacting with many useful questions and comments.

Jacques Bertin, Barbara Tversky, Michael Twyman and **Richard Saul Wurman** for discussing ideas about graphic representation with me.

Janet Abrams and **John Thackara** for the opportunity to write for 'If/Then'.

Ronald van Tienhoven and **Maarten de Reus** for our very stimulating cooperation on setting up the InfoArcadia exhibition.

Dan Boyarski and **Bob Swinehart** for having me as a visitor at Carnegie Mellon School of Design.

Claus Michael Semmler and **Nicole Semmler** for generously helping me with a number of things, for example with my figures, and with my first book contribution in German. And **Kwee Tjoe Liong** as well as comic shop **Lambiek** for assisting me in practical matters.

Edwin Kisman for providing me with the opportunity to try out and practice my skills in designing publishable infographics.

Ingrid von Engelhardt (my mom) for teaching me how to make sensible flow charts when I was nine years old, and for meticulously correcting and improving the complete text of my Ph.D. thesis thirty years later.

Wolfgang von Engelhardt (my dad) for his continuous moral encouragement to finish this thesis, for his support, and both Wolfgang and his wife **Annelies** for many open and exciting discussions.

Renate Tesch and **Hallock Hoffman** for 'adopting' me for a year. That fantastic year in Southern California did it to me: My being in love with life is something I partly owe to Renate. I often wish that she was still alive.

Steph Sallaerts for making me practice essential living skills, like 'letting go'.

Ruud Beunderman for his humorous wisdom about life. And for managing to teach me how to do *more* (essential stuff) by doing *less* (non-essential stuff). And also for telling me not to worry about eating poisoned fish.

Lieve Witteveen for millions of reasons, *one* of them being that she carefully scanned and 'photoshopped' almost all figures that are contained in this thesis.

Jetty Jurrissen and **Ad Witteveen** (Lieve's mom and dad) for being like an extra pair of parents to me.

Miguel Jaspers for changing my life by setting up the blind date between Lieve and me. And for digitally polishing up my not quite print-ready files.

Sonja, Robert, Petra, Jelle, Monte, Ana, Mary, Leif, Anala and **Yvonne** for having come into my life, and for lots of help in various ways.

Mieke Zijlmans for many years of being enormously supportive.

Kenneth Coleman for his friendship and his incredible hospitality in providing me with a paradise-like second home in San Diego. In the course of the years, I have spent many months in Kenneth's garden, working on the concepts presented in this thesis.

Marc Pauly for proofreading the entire manuscript, and for preparing the Dutch version of the abstract. And, most of all, for our conversations. Every hour that I have spent with Marc discussing life, feels like a well spent hour.

Amsterdam, August 2002 Yuri Engelhardt

"Much careful labor has been expended in so arranging the book that a busy reader may get the gist of the matter by looking at the illustrations and reading only the titles and the sub-titles [...] under each illustration. [...]
Though the text gives much more detailed information concerning method than can possibly be put into any sub-titles, the reader who examines only the illustrations and the titles, without any reference to the text, will undoubtedly get a major portion of the vital material in the book."

Willard C. Brinton, 1914 (in the preface to his book 'Graphic methods for presenting facts')

About the graphic representations and their captions

A visual overview of the graphic representations that are contained in this thesis can be found in the Figure Index (pages 181-187).

The figures are divided into two groups. The largest group of figures consists of those that are enclosed in a box. Such a 'boxed' figure is included as an example specimen, and its structured caption provides a standardized analysis of the figure in terms of the developed framework (see section 5.1 for a brief discussion of this analysis). This kind of caption is not so much concerned with *what* is shown in the figure, but rather with *how* it is shown.

A few figures however are not enclosed in a box. This second group of figures serves to illustrate specific points, and their captions do not contain the complete standardized analysis.

Most of the specific terms that are used in the figure captions (and throughout the thesis) can be looked up in the Glossary at the very end of the thesis.

CHAPTER 1

Graphic Representation

"[...] as we embark on a visual information age."
MacEachren (1995, preface)

Graphic representations seem to play an increasingly important role in our lives. Whether it is a cliché or not, modern life does appear to be characterized by an ever growing access to *information*. While our common sources of information (e.g. books, newspapers) used to be mainly textual, we are now seeing more and more information presented through diagrams, pictograms, maps and charts. We see such graphic representations on paper as well as on signage and on screen. Some types of graphic representations have developed due to recent advances in computer technology, others were invented in the eighteenth century, and some can already be found on archeological objects from ancient cultures.

Various collections of beautiful graphics have been published (e.g. Tufte 1983, 1990, 1997), and several authors have discussed the cognitive advantages of graphic representations over textual representations (e.g. Wright and Reid 1973, Card et al. 1999 on pp. 15-17, Tversky 2001). However, we still know little about, for example, the internal structure of graphics. Is there a set of general compositional principles that all graphics depend on? Does the 'visual language' of graphics involve something like a 'grammar'?
Because of the increasing use of graphic representations, it is both interesting and relevant to find out more about how they work as representations of

information. This chapter offers a brief introduction to the subject of graphic representations and their 'visual language', and then provides a description of the aims of this thesis.

What exactly is a 'graphic representation'? Examples of what we would like to regard as graphic representations here include ancient maps and Egyptian hieroglyphs, but also family tree diagrams, pictorial statistical charts, and modern 3-D computer visualizations. In need of some kind of definition, we will work with the following:

> A **graphic representation** is
> a visible artifact on a more or less flat surface,
> that was created in order to express information.

The first aspect of this definition concerns the fact that a graphic representation is something visual, and that it is usually found on a more or less flat surface, for example on paper, on a wall, or on screen. In this sense graphic representations live in 'flatland', a term used by Edward Tufte in his remark that "the world portrayed on our information displays is caught up in the two-dimensionality of the endless flatlands of paper and video screen." (Tufte 1990, p. 12). Indeed, a physical, real-world model of a molecule for example would usually *not* be regarded as a graphic representation, while a drawing of it *would* be regarded as a graphic representation. Many graphic representations do show three-dimensional spaces and objects, so while the *medium of display* of a graphic representation is usually flat, *what is displayed* may certainly be three-dimensional in character. A discussion of this issue is in section 2.2.

The second aspect of our definition concerns the fact that a graphic representation is purposefully created with the goal to express information. This means that self-occurring, 'natural signs' such as footprints in the sand, are not regarded as graphic representations. Incidentally, a schematic map that is scratched into the sand with a stick, *does* qualify as a graphic representation. Note that while the term 'graphic' makes most people think of colorful stuff on paper or on a computer screen, our definition above says nothing about the medium in which the visible artifact is created.

How about the goal of expressing information? Many visible artifacts on flat surfaces are indeed created with some goal regarding the viewer. The main goal may, however, *not* be only to express *information*. Concerning graphic design, Richards makes a distinction between "the intention to amuse, delight, persuade, invigorate, provoke or otherwise stimulate" and the "intention to describe, explain, inform or instruct" (Richards 1984, p. 0/8). Of course these two categories are not mutually exclusive. In the spirit of our definition, visible artifacts involving mainly Richards' second category of intentions would be referred to as graphic representations, while those involving mainly Richards' first category of intentions might not. The chosen focus here means that this thesis will not concentrate on images in advertising, nor will it contemplate art.

Complex computer visualizations that display large amounts of data are graphic representations. So are the red dot and the blue dot on my shower faucets. According to our definition, a *photograph* may also serve as a graphic representation, especially if it is augmented with explanatory labels. Note in particular that with our definition of graphic representations we choose to include *written text* - regardless of whether it is written with pictorial hieroglyphs or with the letters of the Latin alphabet (e.g. the text you are reading now). Written text as a special case of graphic representation is discussed in section 3.2. Chapter 4 is devoted to the *classification* of graphic representations.

Having characterized what we will regard as graphic representations, we will now briefly explore the notion of the 'visual language' of such representations (section 1.1), and then discuss the aims of this thesis (section 1.2).

1.1 Visual Language

A graphic representation can be regarded as an expression of a **visual language**, and can be analyzed with regard to its **graphic syntax** and with regard to its **interpretation**. Chapter 2 of this thesis is devoted to examining the notion of *graphic syntax*, and Chapter 3 is devoted to issues related to the *interpretation* of graphic representations.

In the literature different attempts can be found to approach graphic representations with notions from the study of language, for example in Clive Richards' 'Diagrammatics', and Robert Horn's 'Visual language'. The proposals of these (and other) authors are examined and criticized throughout this thesis.

Is there *one* visual language of graphic representations, or are there *many different* visual languages? The notion of *many different* visual languages seems appropriate, allowing us to distinguish for example 'traffic-sign-languages' from 'subway-map-languages', 'quantitative-bar-chart-languages' and 'color-coded-geographic-surface-languages'. In this context a possible alternative term for 'language' is the term 'schema', such as in 'traffic-sign-schemas', 'subway-map-schemas', 'quantitative-bar-chart-schemas' and 'color-coded-geographic-surface-schemas'. Specific visual languages (schemas) can be thought of as having their own set of compositional rules and their own set of categories of graphic constituents with specific syntactic roles. Compositional rules and syntactic roles are notions of *graphic syntax*, and are discussed in Chapter 2. Sometimes legends and annotated axes help to define the specific visual language of the representation that they are part of (see the discussion of *reference objects* in section 3.3). In this sense a graphic representation may use its individual, very specific visual language. This means that designing a graphic representation of information does not only involve a *translation* of that information into a visual language, but it often also involves the very *creation* of that specific visual language (Engelhardt et al. 1996, p. 2).

In spite of the multitude of possible visual languages, these languages seem to have many general principles in common. A specific visual language can be regarded as involving a *subset* of these general principles of visual languages. Exploring such *general principles of visual languages* is the aim of this thesis. In the next section I will clarify the specific aims of the thesis in more detail.

1.2 Aims of this Thesis

Some authors comment on what they think *could* be written on the 'language' of graphics, but has *not* been written yet. For example:

> "The principles for a grammar of graphic presentation are so simple that a remarkably small number of rules would be sufficient to give a universal language."
>
> *Brinton (1914, p. 3)*

And, seventy-five years later:

> "Unlike verbal language, in which there are a set of syntactic and semantic rules which provide us with a means of disambiguating the meaning of verbal language, pictorial language has, as yet, no equivalent set of rules [...]"
>
> *Rogers (1989 p. 106)*

DECONSTRUCTING GRAPHICS

While there are authors who are very optimistic, others are very pessimistic about any search for systematic accounts of meaning in graphic representations. Critics inspired by Wittgenstein's notion of language games, and by postmodernist and deconstructionist ideas, have judged such endeavors to be naïve and even futile. For a brief discussion of relevant postmodernist views see MacEachren (1995, pp. 10-11). I completely agree with views of meaning as being a social construct, of meaning being neither fixed nor absolute, and of all interpretation being context- and culture-dependent. I agree that rhetorical and connotational aspects play an important role in many graphic representations. These insights, however, are *not in contradiction* with the notion that meaning in graphics involves phenomena with various systematic tendencies. Regardless of the degree to which such systematic tendencies or systematic principles may be driven by culture and context, they *do* seem to play important roles in the creation and interpretation of graphics. In summary, I believe that adopting the notion of 'meaning as a social construct' does not necessarily entail that one has to deny the role of systematic principles in graphic representations. It appears to be a useful endeavor to seek to understand such systematic principles in graphic representations. This thesis is devoted to that endeavor.

Compared to the postmodernist skepticism, the views of other authors go to the opposite extreme:

> "The principles of information design are universal - like mathematics - and are not tied to unique features of a particular language or culture." *Tufte (1990, p. 10)*

> "Graphics is a tool that obeys universal laws that are unavoidable and undisputable". *Bertin (2000/2001, p. 5)*

The framework proposed in this thesis is concerned with such possible 'universal' principles of graphic representation. These principles are claimed to be *universal* in the sense that they seem to extend across cultures and across the broad spectrum of different types of graphic representations. In this thesis I will *not* discuss culture-specific visual symbology, such as culture-specific meanings of colors, or culture-specific meanings of pictorial symbols. Such issues concern *specific visual vocabularies*. Instead, I will concentrate on *general principles of visual languages*.

But what does the framework proposed here add to the various frameworks that can be found in the literature? Well, there are three main aspects that distinguish the framework proposed here from existing frameworks. This thesis proposes a *comprehensive* and *unifying* framework for analyzing the visual language of graphic representations in general, and for analyzing their *graphic syntax* in particular. In the following paragraphs I will briefly elaborate on what it is that makes this framework *syntactic, comprehensive,* and *unifying*.

A SYNTACTIC FRAMEWORK

I mentioned in section 1.1 that several attempts can be found in the literature to approach graphic representations with syntax-related notions. Such attempts include Michael Twyman's 'Schema for the study of graphic language' (1979), Clive Richards' 'Diagrammatics' (1984), Robert Horn's 'Visual language' (1998) and Card, Mackinlay and Shneiderman's approach to 'Visual structures' (1999). The merits and shortcomings of these approaches are examined at the appropriate points throughout the course of the thesis.

One of the main aspects that are missing in the existing approaches is *recursiveness* of the syntactic analysis. However, a recursive nesting of syntactic (de-)composition rules in the sense of Noam Chomsky's generative grammars seems to be what is needed for the analysis of graphic structures. In this thesis we propose such an approach (described in section 2.1). Note that an exception to the lack of recursiveness in existing syntactic approaches is Lakin's (1987) work, which is discussed at the end of section 2.1.

A second main aspect that is missing in the existing approaches is a *broad inventory* of syntactic principles that are involved in graphic representations, which would enable the syntactic analysis of the structure of any randomly chosen graphic representation. The existing approaches seem to describe only subsets of these syntactic principles. In general, the use of visual attributes such as size, shape, and color is well studied, while the role of spatial structure has received much less attention (concerning spatial structure think for example of phenomena such as superimposition, labeling, multiple charts aligned along a shared axis, etc.). In this thesis we claim to offer such a broad inventory of syntactic principles (in section 2.5).

A third main aspect that is missing in the existing approaches is a description of the different *syntactic roles* that graphic objects may play within a graphic representation (e.g. a graphic object may serve as a *surface locator in a metric space*, or as a *label* for another graphic object, or as a *connector* between two other graphic objects, etc.). In this thesis we examine these different syntactic roles (see subsection 2.5.3).

In summary, no detailed and broadly applicable framework has been developed yet concerning the recursive syntactic principles in graphic representations. Proposing such a universal grammatical framework for understanding graphic representations is one of the main aims of this thesis. Chapter 2, titled 'Graphic syntax', is devoted to this aim. Our general approach to graphic syntax is based on the principle that syntactic structure parallels semantic structure - see our remarks about compositionality of meaning in section 2.1.

A COMPREHENSIVE FRAMEWORK

Most of the existing literature on graphic representation covers only specific aspects of graphics (e.g. structural aspects, semiotic aspects, classification), or it covers only certain types of graphics, such as maps (e.g. MacEachren 1995), pictograms (Horton 1994), or statistical graphics (e.g. Card et al. 1999, Wilkinson 1999). In contrast, the approach proposed here is claimed to be 'comprehensive' in the sense that:

- it integrates *various different aspects* of graphic representations into *one coherent framework*. For example,
  - *structural* aspects (*graphic syntax*) are discussed in Chapter 2,
  - *semiotic* aspects (*type of correspondence*) are discussed and related to structural aspects in section 3.1,
  - *classifications* of graphic representations are discussed and related to structural and semiotic aspects in Chapter 4.
- it can be applied to the *complete spectrum of graphic representations*, from maps to bar charts, from pictorial illustrations to written text, and from single pictograms to complex multipanel computer visualizations. Specific visual languages (e.g. 'the language of traffic signs', 'the language of

color-coded vegetation maps', 'the language of Venn diagrams') can be thought of as having their own set of composition rules, and their own set of categories of graphic constituents with specific syntactic roles. In the existing literature no general notion of graphic syntax has been proposed that would be able to account for the broad spectrum of graphic structures that are generated by these various visual languages.

The forty 'boxed' example figures that are contained in this thesis serve to illustrate the broad range of graphic representations to which the proposed framework can be applied. In addition to a brief syntactic analysis (according to Chapter 2), the caption of each example figure includes an assessment of the type(s) of correspondence that are involved in the figure (according to section 3.1), and a general classification of the figure (according to Chapter 4).

As a side remark, note that the essence of the proposed framework does not lie in the choice of *terms* - all terms used in this framework could be exchanged for alternative terms - but in the existence and interaction of the *phenomena* that are referred to by these terms.

The existing work that comes closest to having the same aims as this thesis is Richards' 'Diagrammatics' (1984). Richards offers a quite comprehensive approach and a (very basic) analysis of syntactic principles ('grouping, linking, and variation'), although he is not concerned with discussing or 'unifying' existing graphic theories (see below). Richards' work is discussed and sometimes criticized throughout this thesis.

A UNIFYING FRAMEWORK

Several approaches can be found in the literature that explicitly state as their goal to offer a terminology for discussing graphic representations (e.g. Tufte 1983, pp. 10, 15; Richards 1984, pp. 1/4, 10/1). However, no author so far has offered an analysis of how the proposed vocabulary relates to the already existing jungle of terminology for discussing graphics, proposed by other authors. Nobody has mapped out how the various proposed terminologies could be related to each other. Doing exactly that is another aim of this thesis.

One of the reasons for the confusing diversity of terminology for discussing graphic representations is that the literature comes from a wide variety of different disciplines - from graphic design to statistics, and from computer visualization to semiotics. Twyman (1979) has commented on the lack of integration between the disciplines that are concerned with graphic representation:

> "Those who study letter forms [...] are likely to be practising typographers or historians of printing; those who

> study the iconography of paintings are likely to be art historians. Though related to one another in that both are concerned with forms of graphic language, the two disciplines hardly interact. To a large degree the same must be said of other fields of scholarship concerned with graphic language within a theoretical framework, such as semiology, psychology, topology, anthropology, palaeography, linguistic science, and cartography."
>
> *Twyman (1979, p. 119)*

An impressive inventory of concepts from different disciplines has been accomplished by Alan MacEachren with his book 'How maps work'. However, while MacEachren discusses a broad range of issues relating to graphic representation, his work is basically restricted to the field of cartography, and does not examine issues such as the possible uses of spatial arrangement for representing non-geographical information.

In this thesis an attempt is made to integrate all relevant approaches and concepts from the literature into one consistent framework that can serve as a 'unified theory of graphic representation'. Throughout the thesis the detailed distinctions made by the relevant authors are thoroughly analyzed and compared with each other in terms of the proposed unifying framework. 'Theory comparison tables' are included in various sections to provide overviews and matchings of terminologies. Finally, section 5.2 offers terminology translations, arranged per graphic theory.

NOT A NORMATIVE FRAMEWORK

An aspect of graphic representations that falls *outside* the aims of this thesis is the prescription of 'rules of good design'. Like academic work in linguistics, the work presented here is *descriptive* in the sense that it examines occurring phenomena, rather than *prescriptive* in the sense of postulating rules of 'correctness'. Studies like the one presented here may however help to provide the concepts and the terminology that are necessary for discussing the phenomena that are involved in good and bad design.

STATIC VERSUS DYNAMIC AND INTERACTIVE GRAPHICS

We are limiting our current analysis to *static* graphic representations. In the light of the numerous existing research projects on *dynamic* and *interactive* visualization, our chosen scope may at first glance seem surprising (for seminal publications in the area of automatic and interactive visualization see for example Mackinlay 1986 and Card et al. 1999). Note that, despite the fascinating developments of electronic media, the amount of *static* diagrams, charts and infographics that is being published in books, magazines and newspapers has only been growing. Explaining something through a good graphic representation, in a textbook for example, is usually an exciting and worthwhile challenge, even if you can not click on it. Of course, analyzing the visual language of dynamic and interactive graphic representations will be a logical following step. Most concepts that are discussed in this thesis *do* apply to dynamic and interactive graphic representations. However, animation and interaction involve various additional aspects that are not accounted for here. In the context of this thesis we decided to take one step at a time: We will first try to understand static versions of graphic representations, before we will try to understand dynamic and interactive versions.

Having stated the major aims of this thesis, we will begin with an analysis of *graphic syntax* (Chapter 2), followed by an analysis of the *interpretation* of graphic representations (Chapter 3). We will then briefly discuss *classifications* of graphic representations (Chapter 4), and finally *apply* the framework developed here to the analysis of graphic representations and to the analysis of existing graphic theories (Chapter 5).

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:

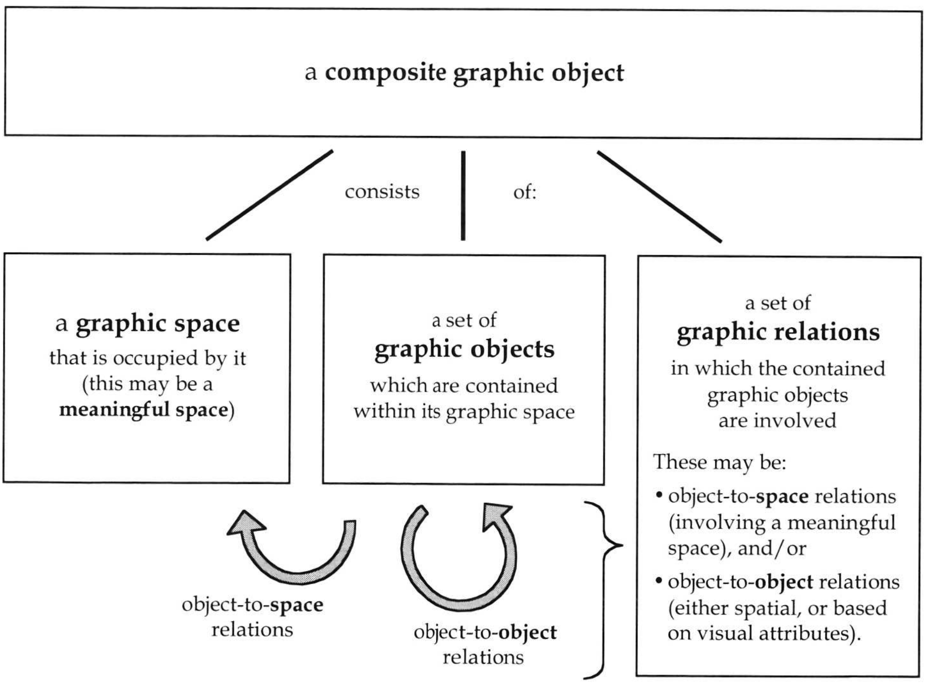


FIGURE 2-01: The proposed syntactic decomposition of graphic representations. A graphic object may itself be a composite graphic object, thus this decomposition can be applied recursively.

Recursive application of the proposed syntactic decomposition:

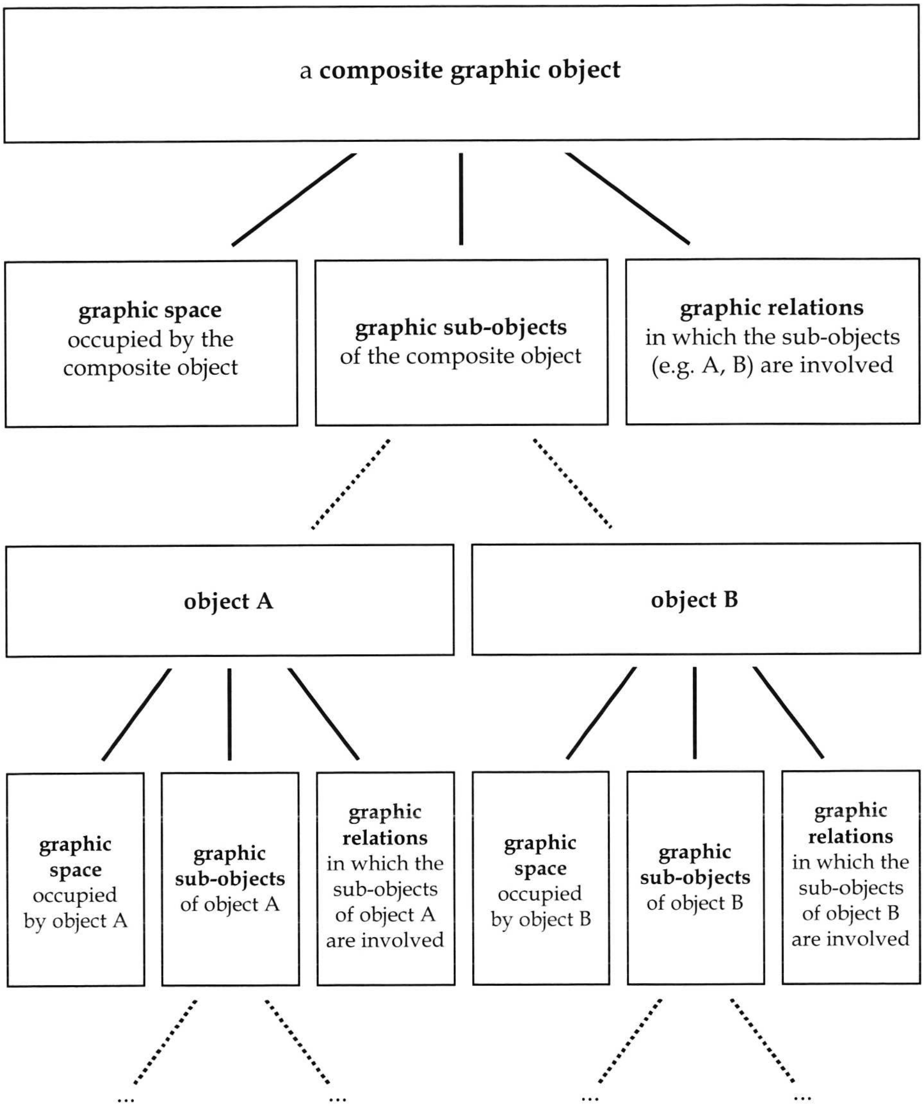


FIGURE **2-02**: An illustration of the recursive nature of the proposed decomposition.

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.

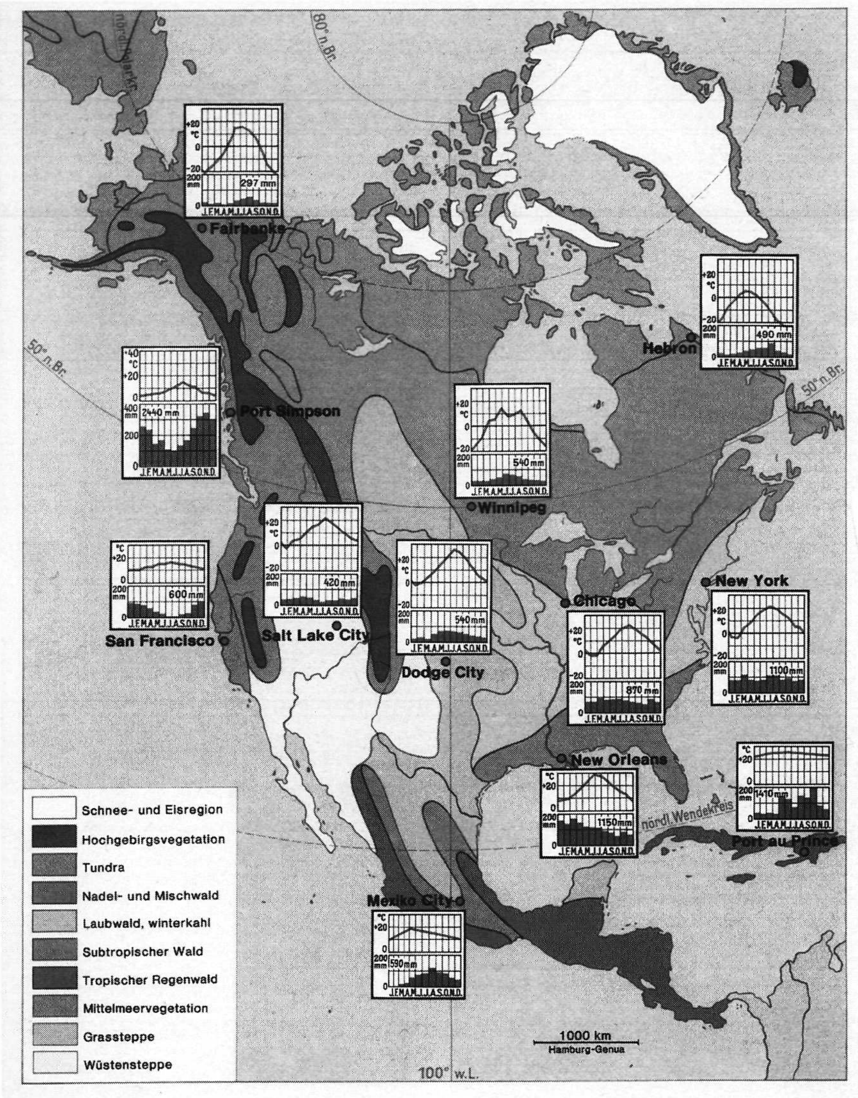


FIGURE 2-03: Vegetation map of North America, with annual temperature- and rainfall charts. Original is in color. SOURCE: Degn et al. 1973, p. 5.

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).

2.3 Graphic Objects

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 se n-sations 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.

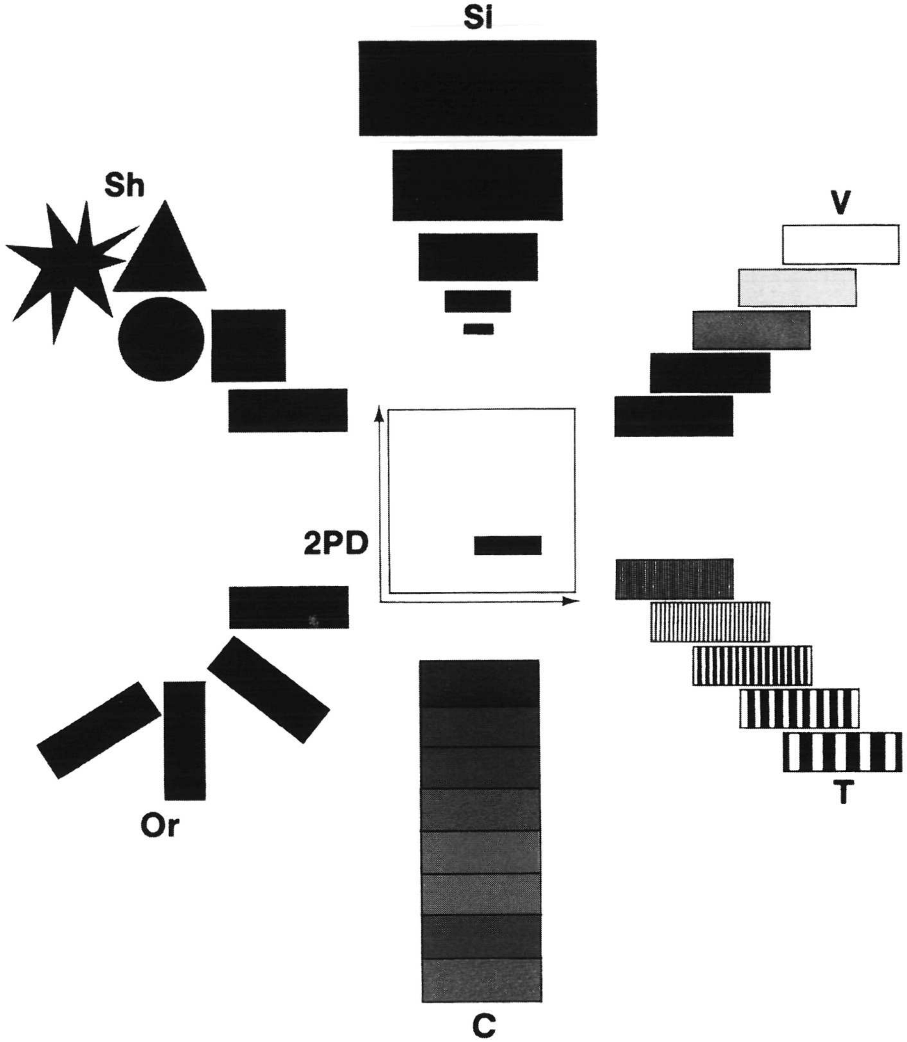


FIGURE 2-04: Bertin's visual variables. SOURCE: Bertin 1967/1983, p. 43.
COMMENT: The figure shows Bertin's set of "visual variables" that can be used in graphic representations: size (Si), value (V), grain (T), color (C), orientation (Or), shape (Sh), and the two spatial dimensions of the plane (2PD).

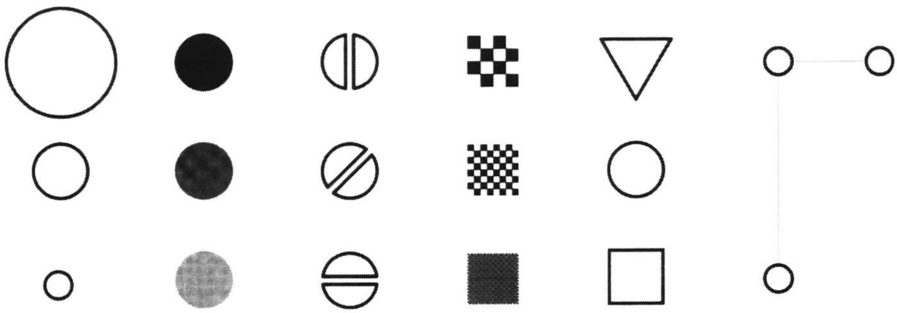


FIGURE **2-05**: Another representation of Bertin's visual variables.
SOURCE: Mullet and Sano 1995, p. 54.
COMMENT: In this figure we see from left to right: size, value, orientation, grain, shape, and the two spatial dimensions of the plane. Color is not pictured here.

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' (Wilkinson 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.

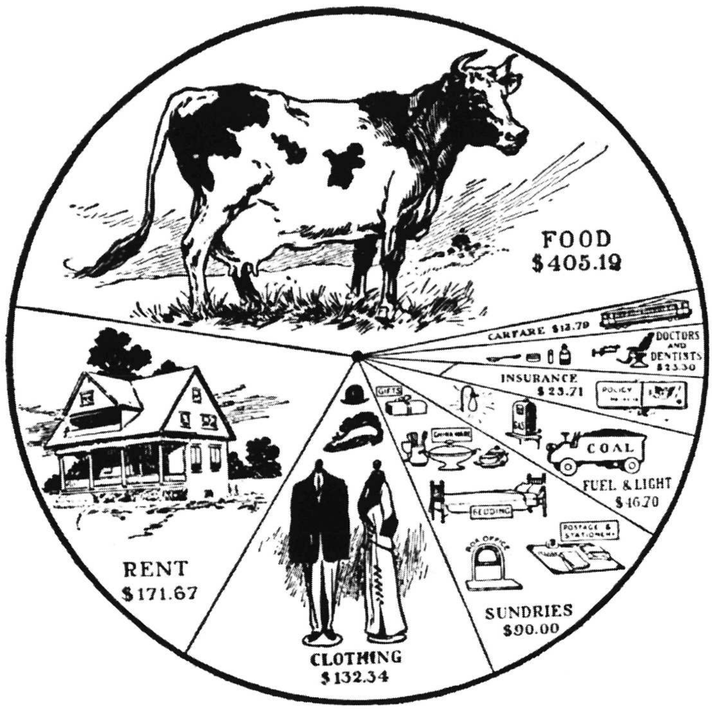


FIGURE **2-06**: 'Disposition of a family income of $900 - $1000'.
SOURCE: Brinton 1914, p. 6.
COMMENT: This figure serves to illustrate *proportional division*.
SYNTAX OF SPATIAL STRUCTURE (2.5): A *proportional division* of a *composite graphic object* along a circular axis. The segments contain *graphic 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:

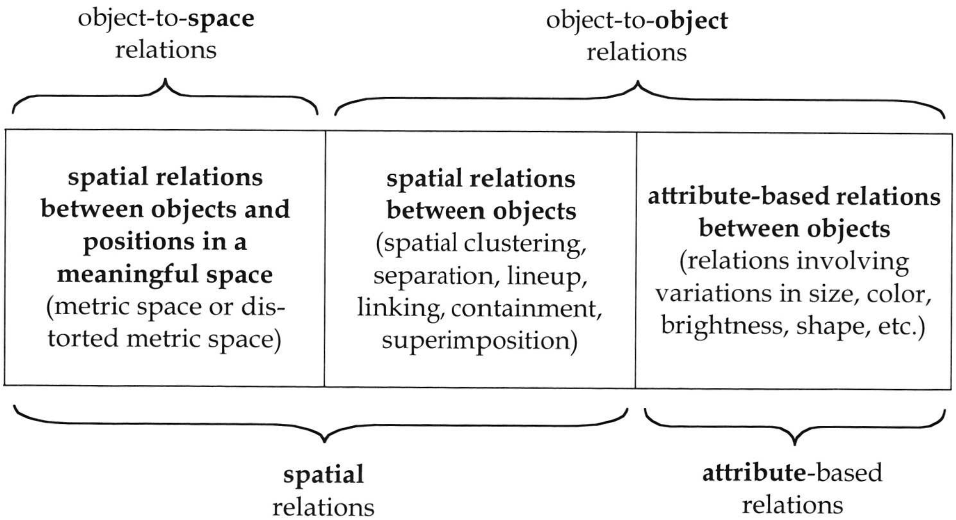


FIGURE **2-07**: The different types of *graphic relations*.

"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.

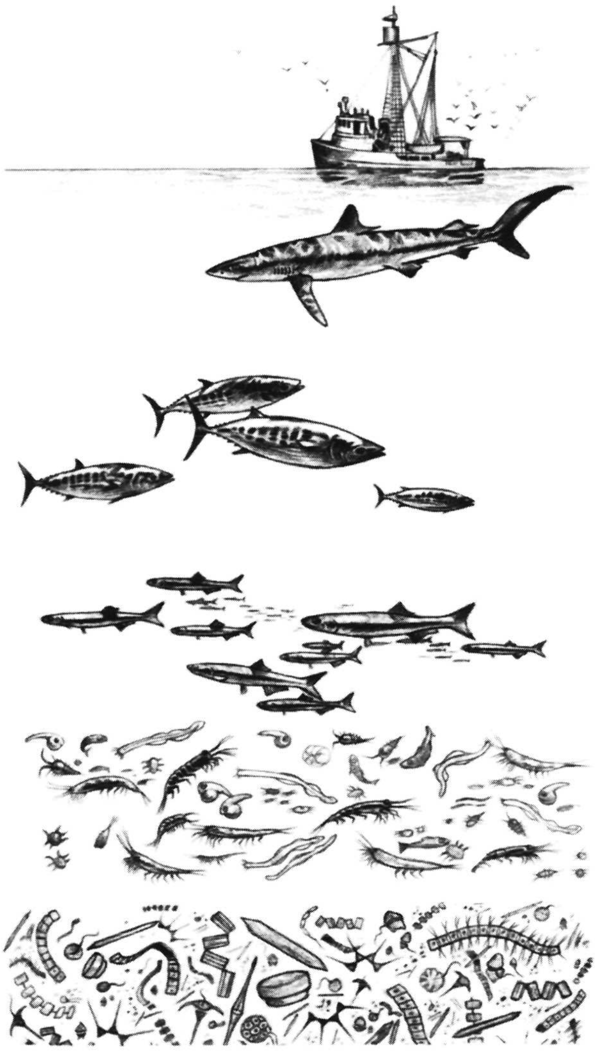


FIGURE **2-08**: The food pyramid of the ocean. SOURCE: Wallace 1978, p. 383.
COMMENT: This figure serves to illustrate *spatial clustering*.

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 *metaphoric* 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.

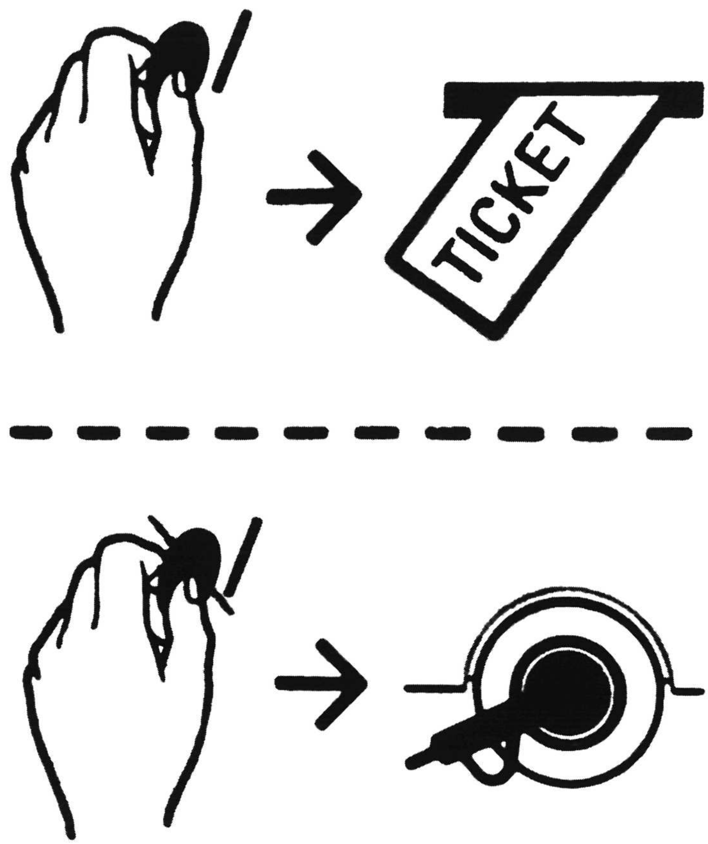


FIGURE 2-09: If you put money in the machine, you will get a parking permit ('ticket'). If you don't, you will get a wheel clamp. SOURCE: City of Amsterdam.

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*.

Train No.	3701	XM 3301	3801	A 67	3 3803	3 3201	A3 51	3 3703	3 3807	3 3203	A3 61	3 3809	A3 47	3 3901
	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M
New York, N.Y.	12 10	12 40	1 30	3 52	4 50	6 10	6.25	6 35	6 50	7 10	7.30	7.33	7 45	7 50
Newark, N.J. P	12 24	12 55	1 44	4 07	5 04	6 24	6 38	6 49	7 04	7 24	7 45	7 47	7 59	8 04
North Elizabeth	...	...	...	...	...	...	...	...	...	7 30	...	...	...	8 10
Elizabeth	12 31	1 03	1 51	...	5 11	6 31	...	6 56	7 11	7 32	...	7 54	...	8 13
Linden	12 36	...	1 56	...	5 16	6 36	...	7 01	7 15	7 37	...	7 59	...	8 18
North Rahway	...	...	...	...	...	...	...	7 03	...	7 39	...	...	...	8 20
Rahway	12 40	1 11	2 00	...	5 20	6 40	...	7 06	7 20	7 42	...	8 03	...	8 24
Metro Park (Iselin)	12 44	...	2 04	4 26	5 24		6 56	7 10	7 25		8 04	8 07	8 15	
Metuchen	12 48	...	2 08	...	5 28	...	...	7 14	7 29	...	...	8 11	...	...
Edison	12 51	...	2 11	...	...	...	...	7 17	7 32	...	...	8 14	...	...
New Brunswick	12 55	...	2 15	...	5 35	...	7 05	7 21	7 35	...	...	8 18	8 25	...
Jersey Avenue	1 02	...	2 18	...	...	...	...	7 28	...	...	...	8 21	...	...
Princeton Jct. S		...	2 31	...	5 50	...	7 19	...	7 50	...	...	8 34	8 41	...
Trenton, N.J.	...	...	2 42	4 58	6 03	...	7 28	...	8 01	...	8 31	8 44	8 52	...

FIGURE **2-10**: Section of a train timetable.

SOURCE: New Jersey Transit 1985 (reproduced in Tufte 1990, p. 54).

COMMENT: This figure serves to illustrate the combination of *horizontal separation* and *vertical separation*.

SYNTAX OF SPATIAL STRUCTURE (2.5): A table, involving the *simultaneous combination* of *horizontal ordered separation* and *vertical ordered separation*. (Concerning the vertical separation, note that subsets of stations are separated by separators, while the lineups of individual stations within each cluster are not separated by separators.)

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The *horizontal ordering* represents an ordering in *departure time*, involving *metaphoric* correspondence. The *vertical ordering* can be regarded as representing an ordering in *space* - in that sense it involves *literal* correspondence.

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

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).

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).

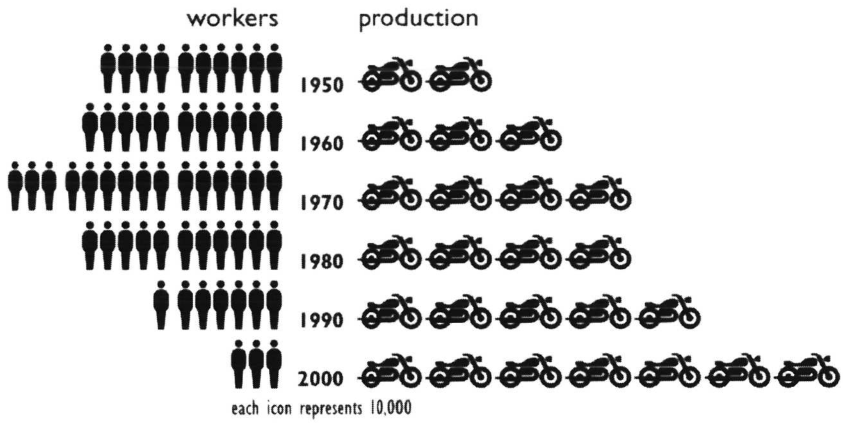


FIGURE **2-12**: The changing ratio of the number of produced motorcycles and the number of workers involved in their production.
SOURCE: N. Holmes 2000/2001, p. 137.

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). VISUAL ATTRIBUTES: 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.

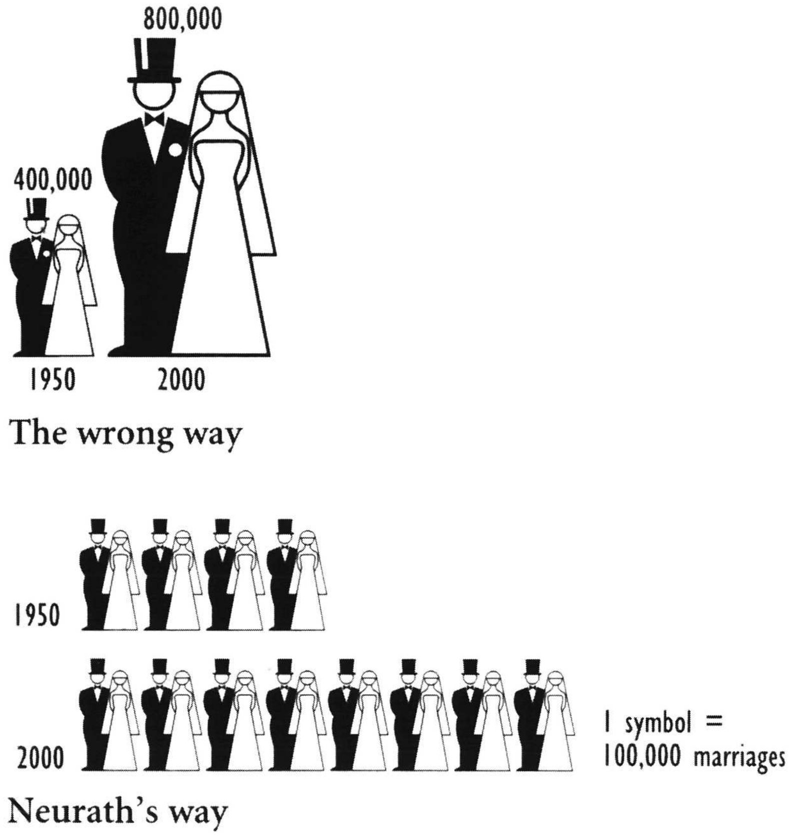


FIGURE 2-13: Two ways of expressing numerical comparisons.
SOURCE: N. Holmes 2000/2001, p. 137.

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 TYpographic 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).

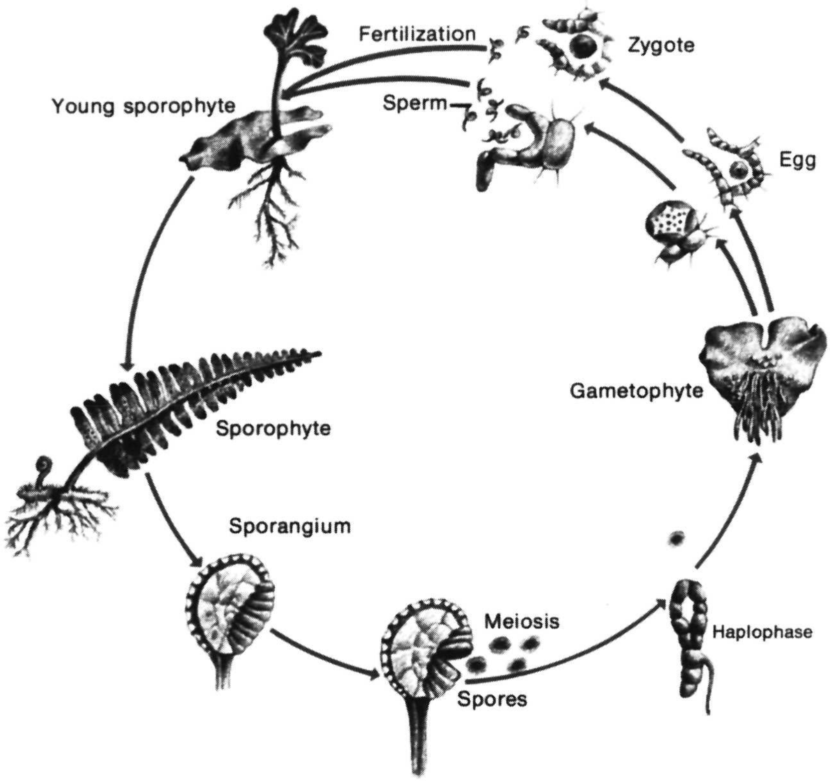


FIGURE 2-14: The life cycle of a typical fern. SOURCE: Wallace 1978, p. 157.

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*.

FIGURE **2-15**: London Underground diagram. SOURCE: London Transport.

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 *metaphoric* 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*).

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".

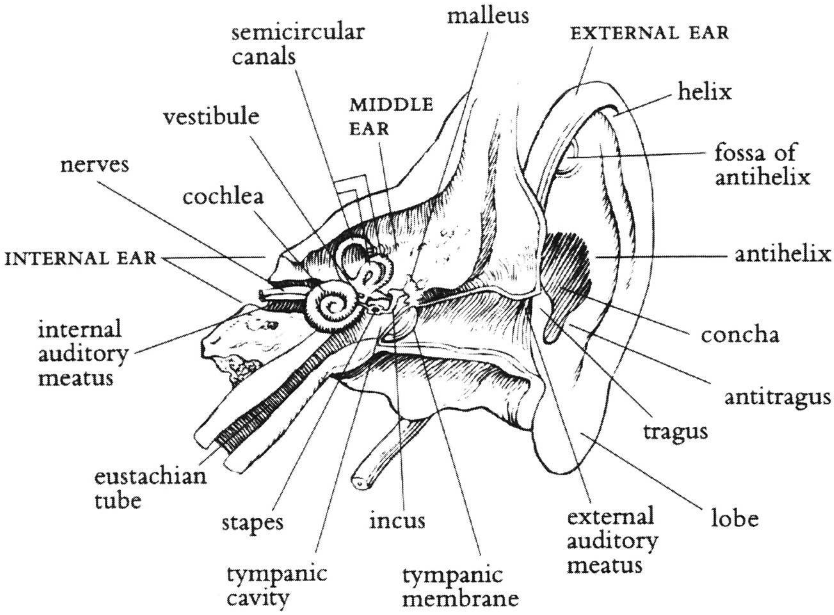


FIGURE **2-16**: The ear. SOURCE: Tufte 1997, p. 74.

COMMENT: This figure shows a type of connector that serves to establish a pair-wise 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*.

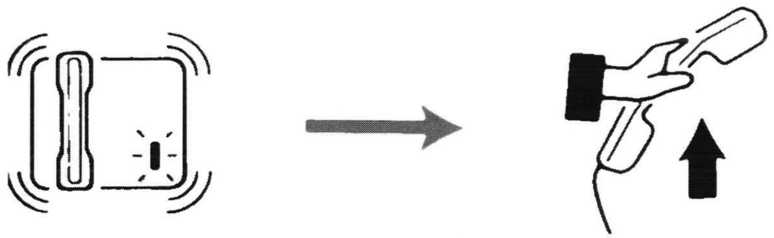


FIGURE **2-17**: When it rings, pick up the phone!
SOURCE: Mijksenaar and Westendorp 1999, p. 90.
COMMENT: This figure shows that not all arrows are *connectors* (a connector links two graphic objects): The object on the right contains an arrow that is not a connector but a 'movement arrow'.
SYNTAX OF 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 *metaphoric* correspondence. VISUAL ATTRIBUTES: The shapes of the pictorial objects involve *literal* correspondence, while the general shape of arrows involves *metaphoric* 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.

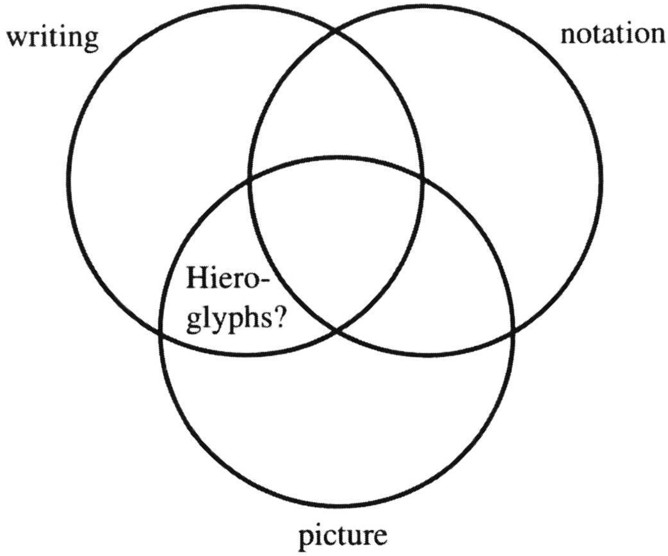


FIGURE **2-18**: An illustration of the question: Should hieroglyphs be classified both as writing and as pictures? SOURCE: Adapted from Elkins 1999, p. 85.

COMMENT: This figure that shows *containment* by overlapping *containers*.

SYNTAX OF SPATIAL STRUCTURE (2.5): *Labeled* overlapping *containers* (the three labeled circles), and one contained object (the text "Hieroglyphs?").

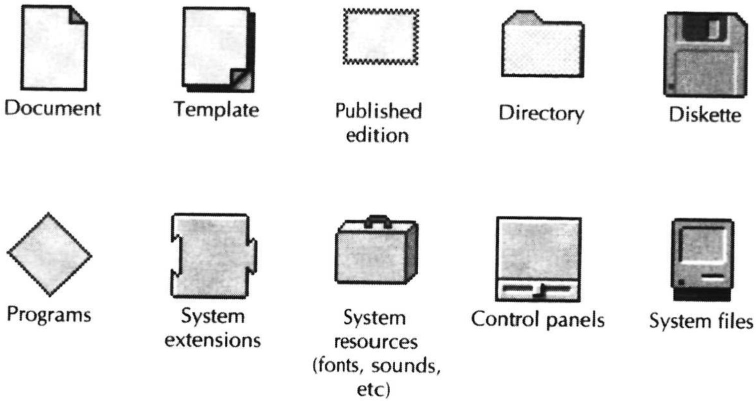
TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: This containment represents a *conceptual* containment, involving *metaphoric* correspondence. Compare with figure 3-05, in which containment is meant in a *physical, literal* way.

TYPE OF GRAPHIC REPRESENTATION (4): A *grouping diagram*.

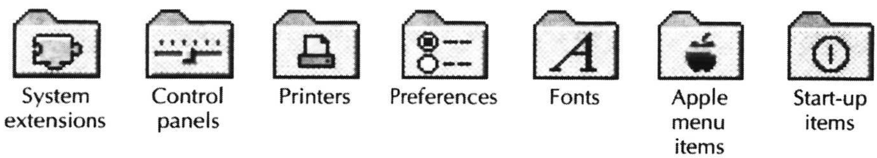
AN APPLICATION OF CONTAINMENT: COMPOSITE SYMBOLS

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).

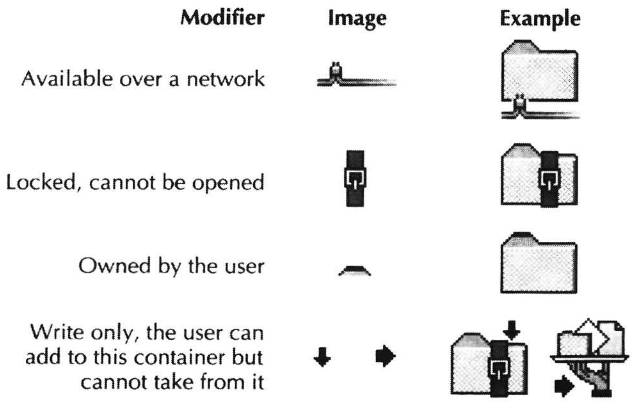
> A **composite symbol** is a graphic object that is composed of a small number of *elementary graphic objects* (often two) which are arranged in a conventionally fixed arrangement, usually involving a *containment* or *superimposition* of the smaller object in or on the bigger object. Most composite 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.



Shown above: different **content** objects for Apple file icons.



Shown above: different **modifier** 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.

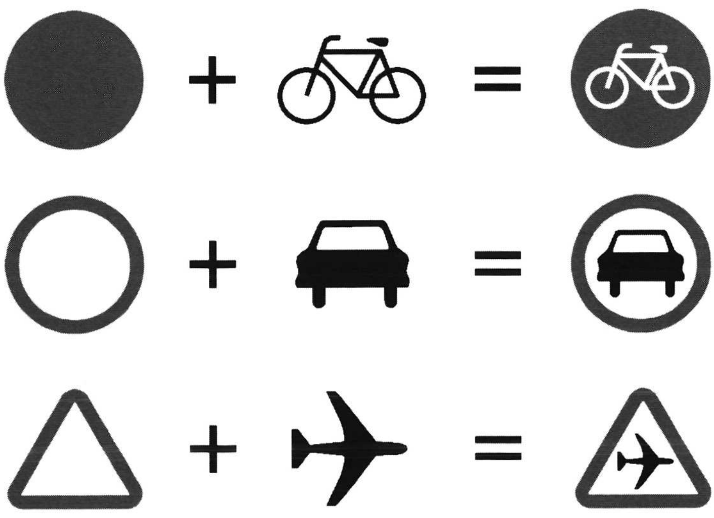


FIGURE 2-20: Certain traffic signs are composite symbols with a systematic composition grammar.
SOURCE: Adapted from Dreyfuss 1972, p. 28. Recreated by C.M. Semmler.
COMMENT: This figure shows how a traffic sign of this type (right column) is composed of a *container* object (left column) and a *content* object (middle column).

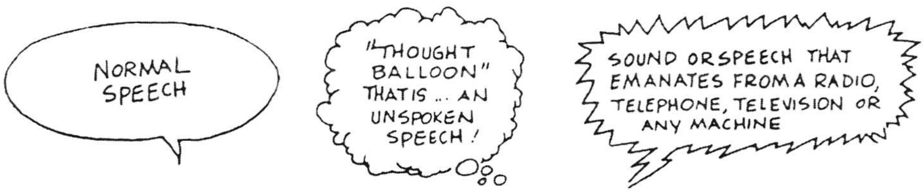


FIGURE 2-21: Word balloons in comics. SOURCE: W. Eisner 1985, p. 27.
COMMENT: Another example of *containment* by *containers*. Like traffic signs, such word balloons in comics involve different meaningful types of containers.

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 (**✕**) 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.

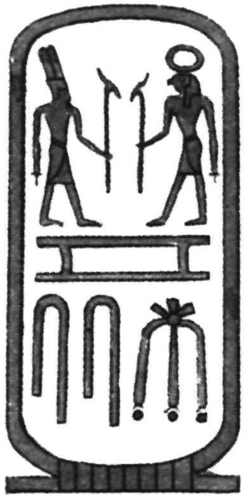


FIGURE **2-22**: A Royal name in Egyptian hieroglyphs. SOURCE: Jean 1992.
COMMENT: This is an ancient example of the use of *container* objects in graphic representations.
SYNTAX OF SPATIAL STRUCTURE (2.5): A *container* object filled with other objects.
TYPE OF CORRESPONDENCE (3.1): Some of the contained 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).

Richards 1984 *graphical means**	Lakoff 1987 *image schemata*	Horton 1994 *ways to show relationships*	Horn 1998 *visual topologies*	Card et al. 1999 *topological structure*	This thesis *object-to-object relations*
proximity	-	cluster, separate by blank space	proximity grouping	-	spatial clustering
alignment	linear order schema	arrange along a line	-	-	lineup
connec-tivity	link schema	connect	network	connection	linking by a connector
enclosure	container schema	box, frame	-	enclosure	containment by a container
-	-	separate with rules and lines	boundary	-	separation by a separator
-	front-back schema	put in front, overlap	-	-	super-imposition

* 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.

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 illustration in figure 2-45): 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.*

	object-to-*space* relations example: a line on a map that stands for a river	object-to-*object* relations example: a textual label consisting of the river's name
an object is anchored to:	one or more points in a meaningful space	one or more other objects
exactness of spatial positioning:	'tight' anchoring (fixed positioning)	'loose' anchoring (degree of freedom)
can express relationships of:	order, proportion, direction	association, dissociation, order

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**.

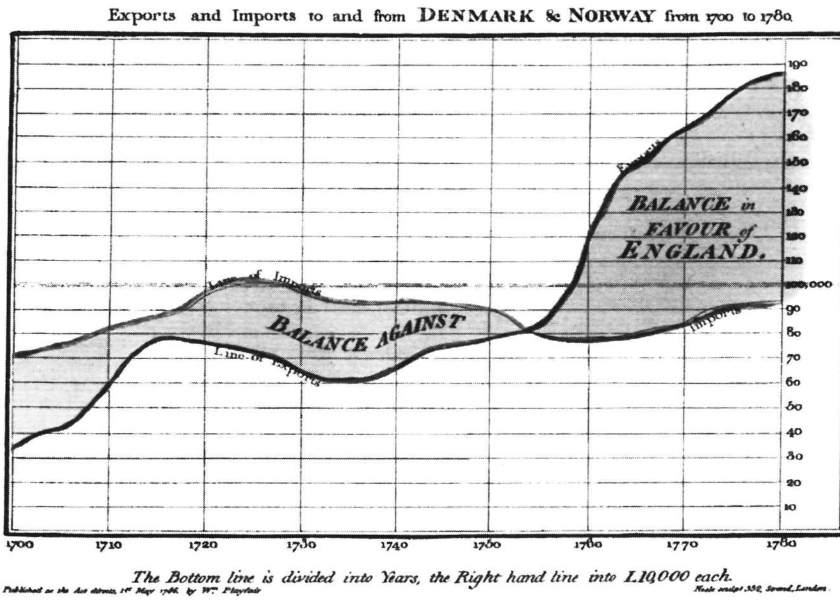


FIGURE 2-25: One of the first known statistical charts, showing exports and imports. SOURCE: 'The commercial and political atlas' by William Playfair, 1786 (reproduced in Tufte 1983, p. 92).

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.*

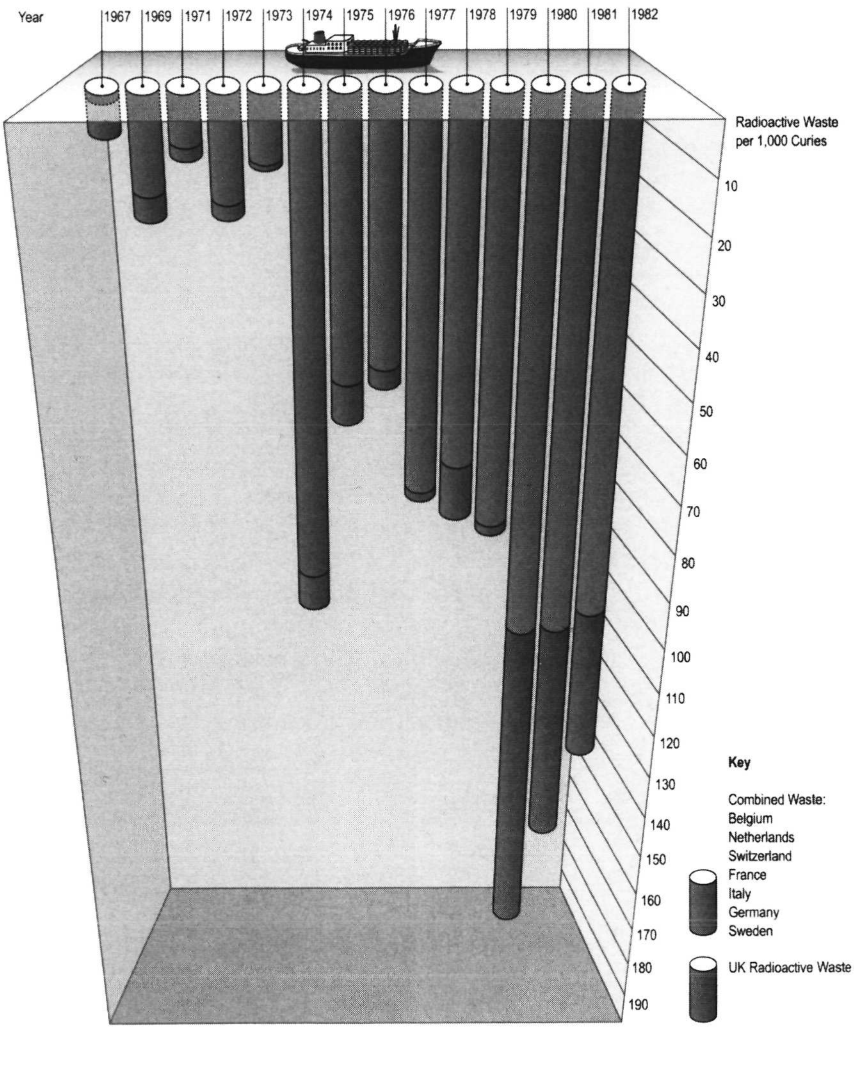


FIGURE 2-26: Amount of radioactive waste (in Curies) dumped into the sea per year by European countries. SOURCE: Bounford 2000, p. 161.

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 subobjects 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.)

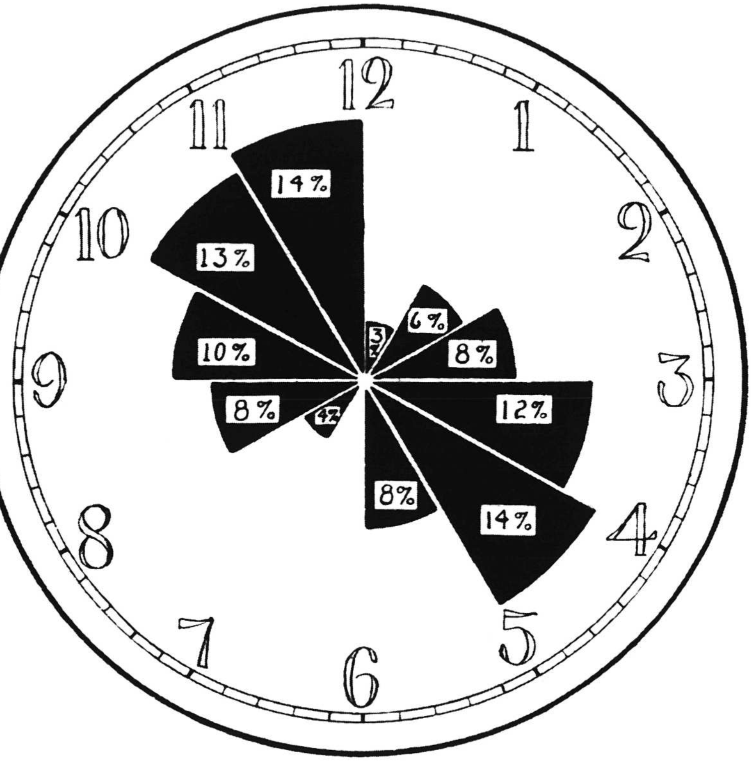


FIGURE 2-27: Percentages of occupational accidents per hour of the working day. SOURCE: Ratté 1924.

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*.

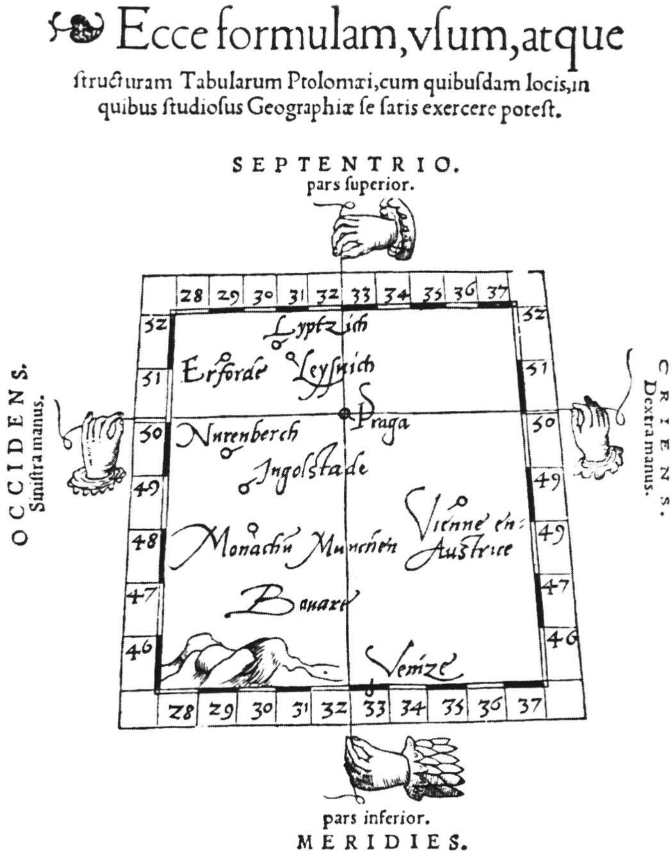


FIGURE **2-28**: A map showing, among other cities, Prague, Vienna and Venice. SOURCE: From the 1546 edition of 'Cosmographia' by Petrus Apianus (reproduced in Tufte 1983, p. 22).

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*.

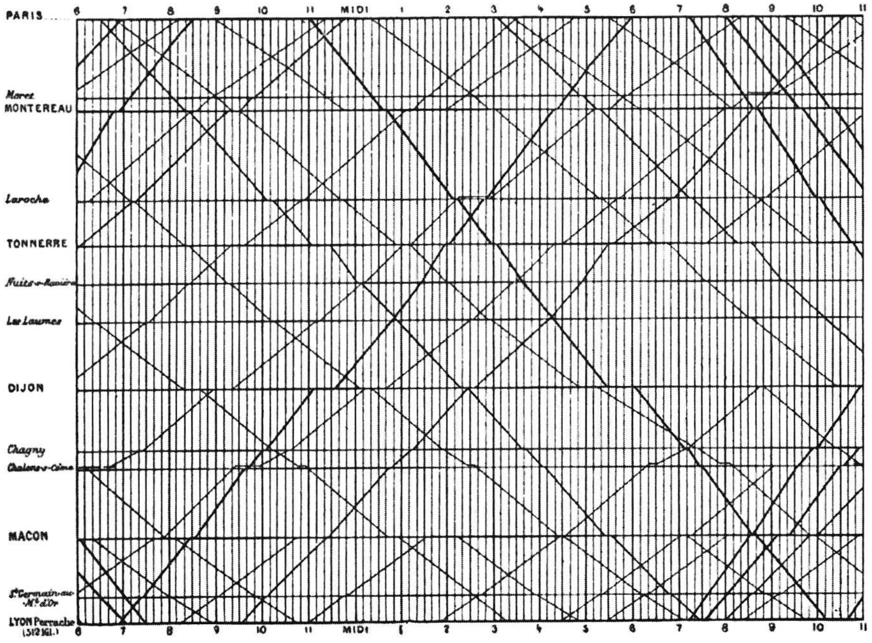


FIGURE 2-29: Section of a graphic timetable, with the route running vertically and time running from left to right. The diagonal lines represent trains traveling from Paris to Lyon (↘) and from Lyon to Paris (↗). The density of the diagonal lines corresponds to the frequency of trains. The slope of the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

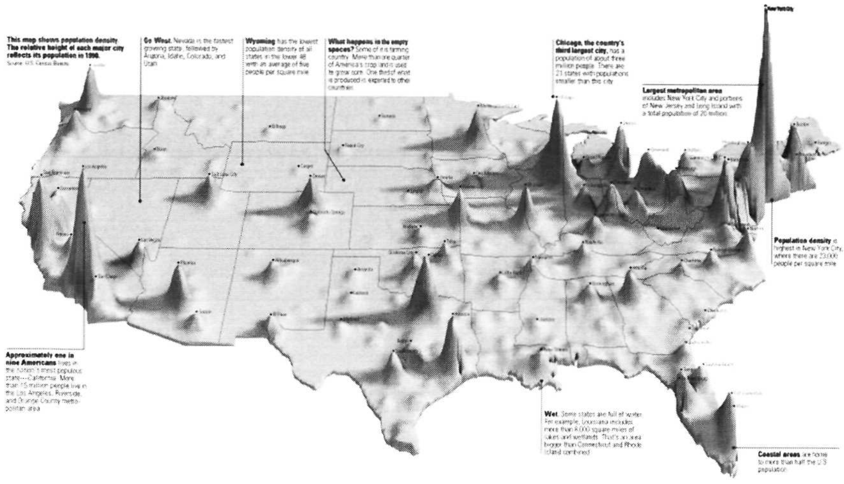


FIGURE 2-30: U.S. population density. SOURCE: By Agnew Moyer Smith 2000, http://www.understandingusa.com

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.*

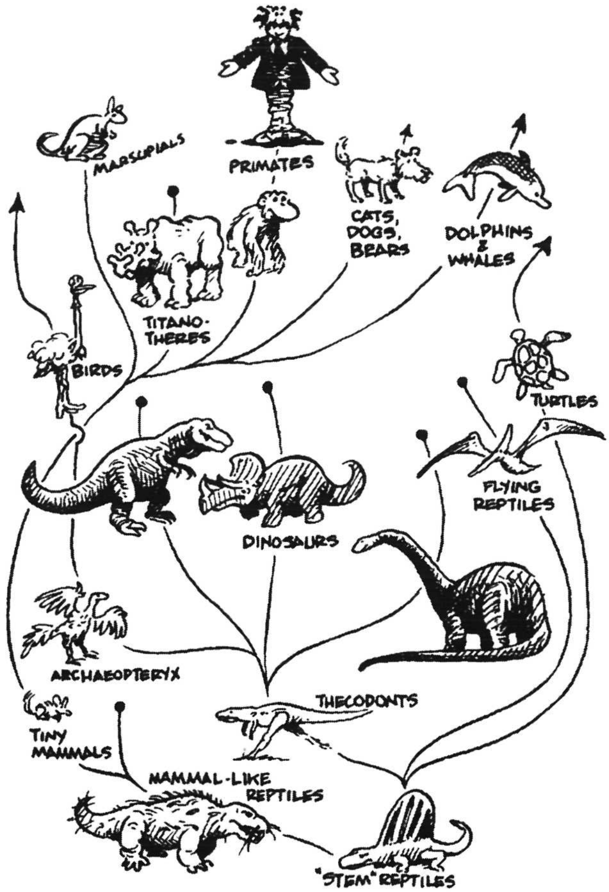


FIGURE 2-31: Evolution. SOURCE: L. Gonick 1990, part of drawing on p. 20.

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*).

FIGURE 2-32: London Underground diagram. SOURCE: London Transport.

COMMENT: This figure serves to illustrate a *distorted integral metric space*. A part of this subway map was shown earlier (as figure 2-15) to illustrate *linking* by *connectors*.

SYNTAX OF SPATIAL STRUCTURE (2.5): A *distorted integral metric space* with *line locators* that are also *connectors* between *labeled nodes*. There are two *insets* (a logo and a legend). 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 *linking* of the stations involves *literal* correspondence, while their positioning involves *distorted literal* correspondence. 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*).

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.

FIGURE **2-33**: A world map, in the standard Mercator projection.

COMMENT: This figure serves to illustrate the fact that, strictly speaking, all maps are *distorted* integral metric spaces. This is due to the problem of having to project the curved surface of the earth onto the flat surface of the map. In reality, the surface of South America is almost *nine* times the surface of Greenland. However, in the standard Mercator projection shown here, South America seems even slightly smaller than Greenland.

SYNTAX OF SPATIAL STRUCTURE (2.5): A *distorted integral metric space* with *surface locators* (marking the continents) and a single *grid line* (marking the equator).

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The distorted integral metric space involves a distorted, though basically *literal* correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A *map*.

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.

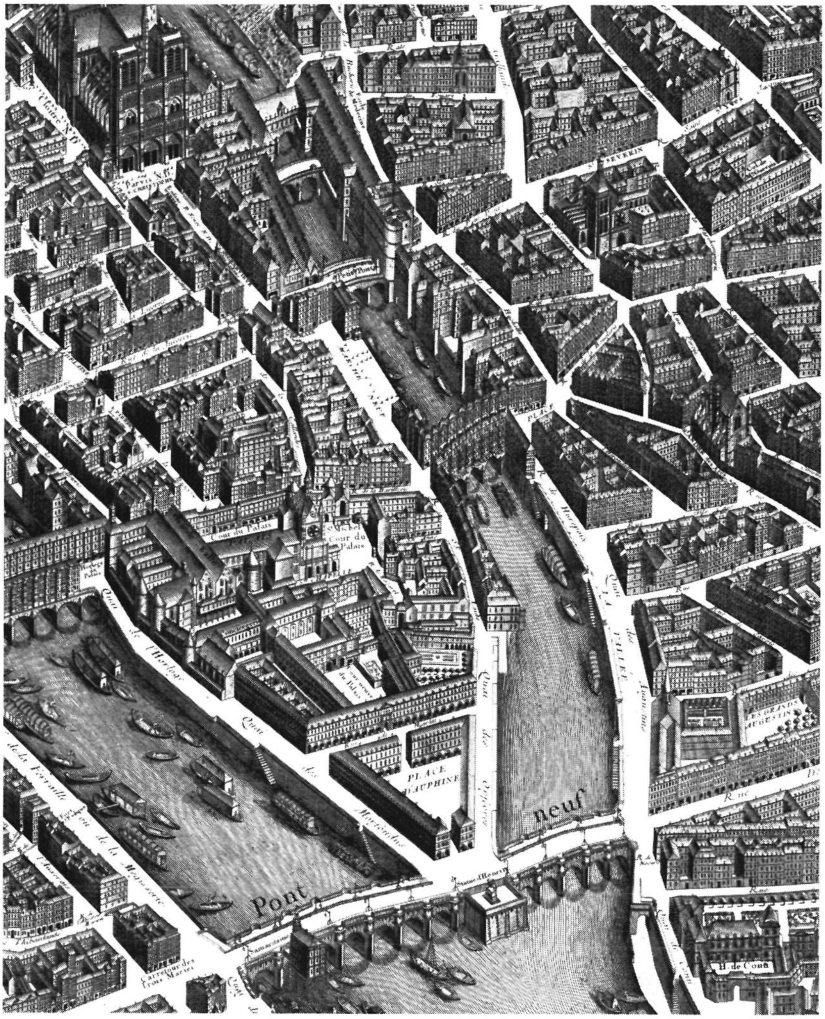


FIGURE 2-34: The center of Paris, with the Pont Neuf and the Notre Dame (upper left). SOURCE: Turgot and Bretez 1739 (reproduced in Tufte 1990, p. 36).

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.

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

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.

A LOOK AT THE LITERATURE CONCERNING MEANINGFUL SPACES

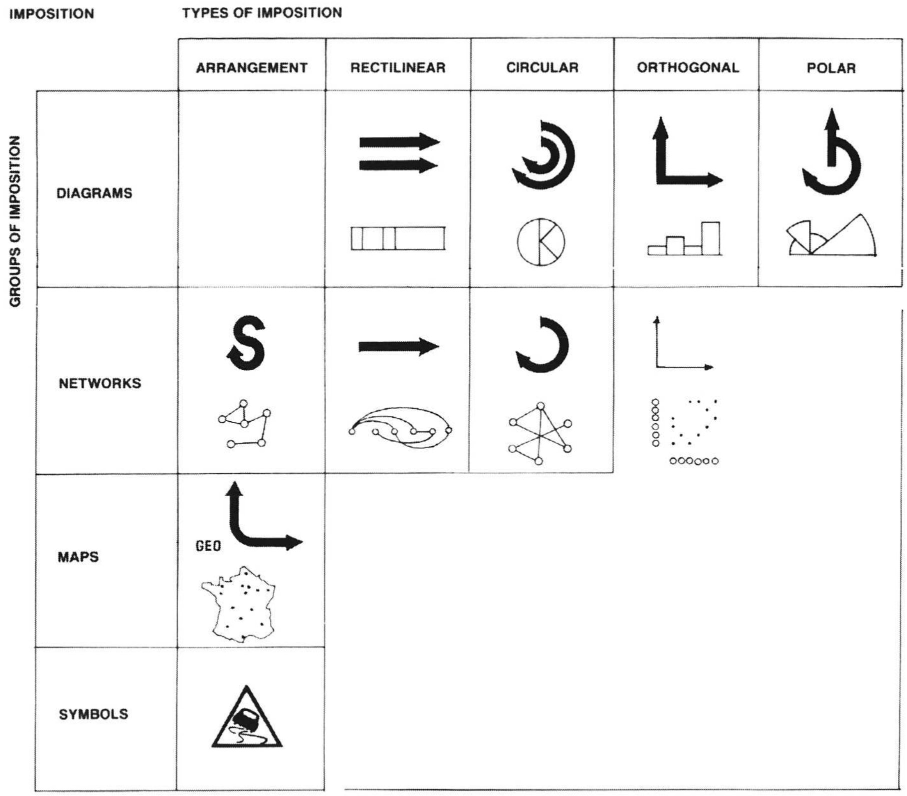


FIGURE **2-36**: Bertin's classification of spatial structures ("impositions").
SOURCE: Bertin 1967/1983, p. 52.

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 orthogonal 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.

Wexelblat 1991 Semantic dimensions:	Tversky 1995 Spatial pictorial devices:	Engelhardt et al. 1996 Represen-tational uses of space:	Card et al. 1999 Types of axes:	This thesis Spatial structures:
-	-	*nominal:* random arrangement	*unstructured* axis	arbitrary spatial structure
nominal dimension	conveying *categorical* relations	*categorical:* unordered slotting	*nominal* axis	unordered separation
ordinal dimension	conveying *ordinal* relations	*ordinal:* ordered slotting	*ordinal* axis	ordered separation
linear dimension	conveying *interval* relations	*quantitative:* sliding	*quantitative* axis	metric axis
-	-	*spatial:* spatial mapping	-	integral metric space

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 specified 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 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.)

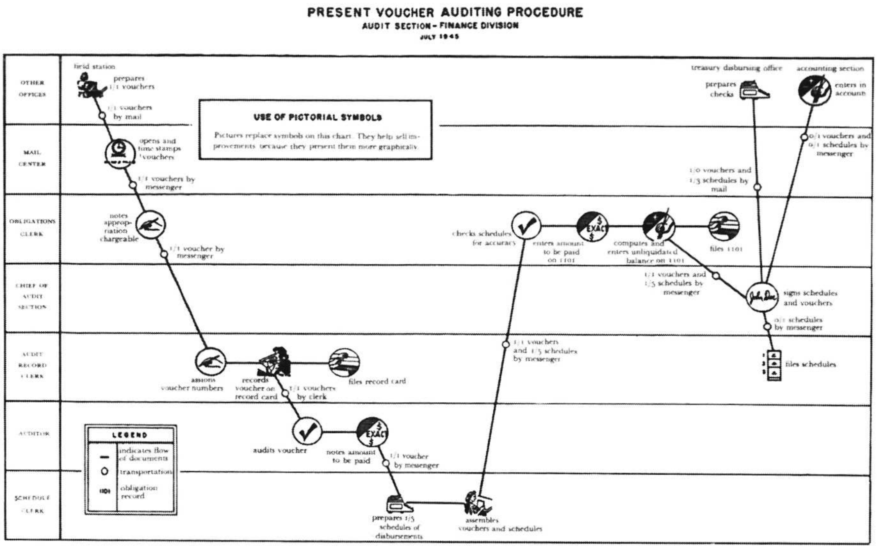


FIGURE 2-38: Document flow procedure along different offices and clerks, 1945. SOURCE: N.N. Barish 1951 (reproduced in de Bruijn 1967, p. 93).

COMMENT: This figure serves to illustrate the fact that a group of graphic objects may simultaneously participate in several basic spatial structures, in this case arrangement along a horizontal *metric axis*, arrangement by *vertical separations*, and *linking* by *connectors*.

SYNTAX OF SPATIAL STRUCTURE (2.5): A *simultaneous combination* of *linking*, vertical *separation*, and a horizontal (probably distorted) *metric axis* (representing time). The representation contains *labeled nodes* that are separated by *separators* and linked by *connectors*. There are two superimposed *insets*.

TYPE OF CORRESPONDENCE (3.1): The vertical separation, the horizontal time axis, and the linking all involve *metaphoric* correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A *chronological link diagram* (= both a *link diagram* and a *time chart*).

Note 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.

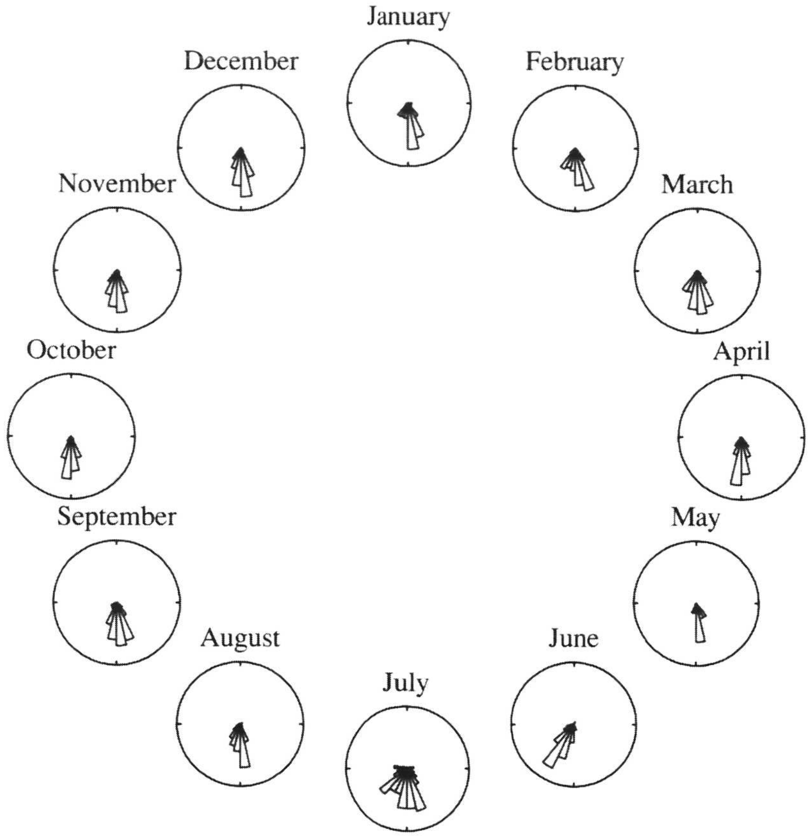


FIGURE 2-39: Representation of a year of wind data.
SOURCE: Wilkinson 1999, p. 323.

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*.

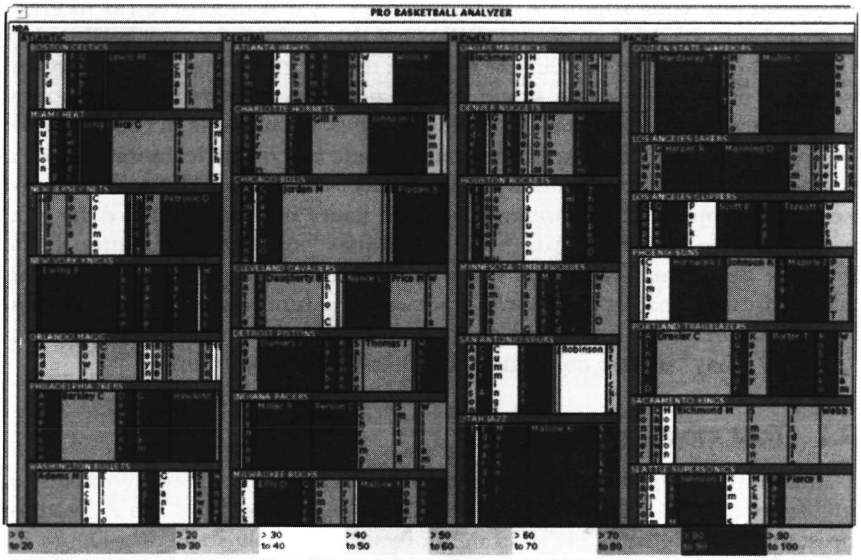


FIGURE 2-40: Representation of baseball data (a 'tree map').
SOURCE: B. Shneiderman (reproduced in Spence 2001, p. 152).
COMMENT: This figure shows a recursive application of proportional division.
SYNTAX OF SPATIAL STRUCTURE (2.5): *Nested proportional divisions*, involving three levels of division (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.

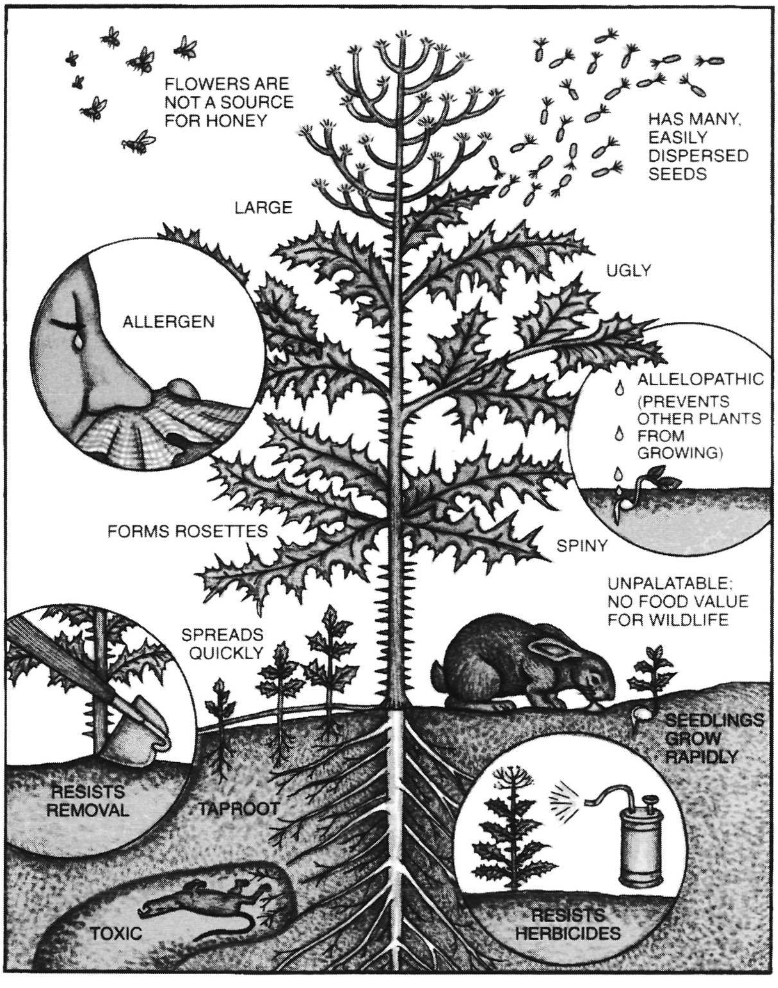


FIGURE 2-41: Characteristics of the ultimate weed.
SOURCE: By P. Wynne, in Tufte 1997, p. 126.

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*.

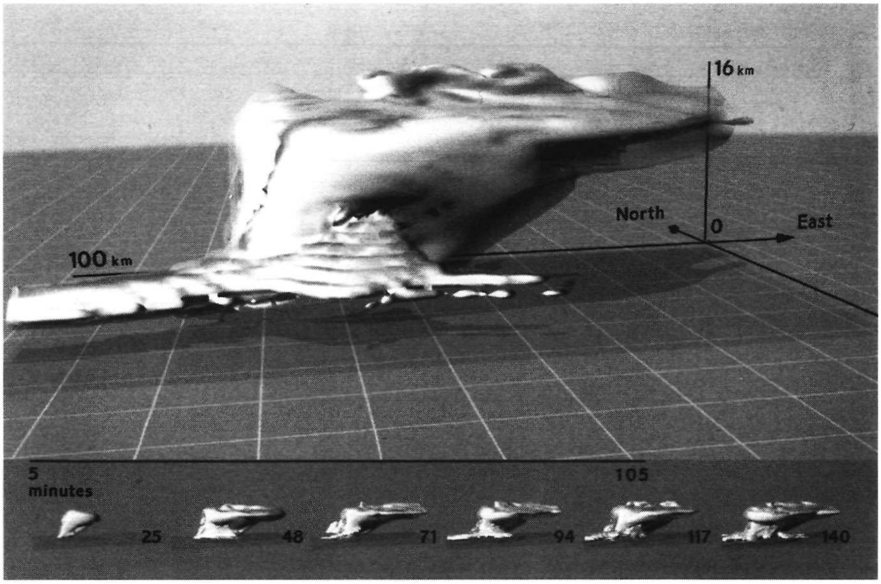


FIGURE **2-42**: From an animation of a numerical model simulating a thunderstorm. The lower part displays 'stills' from the animation along a timeline. SOURCE: Tufte 1997, p. 21.

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).

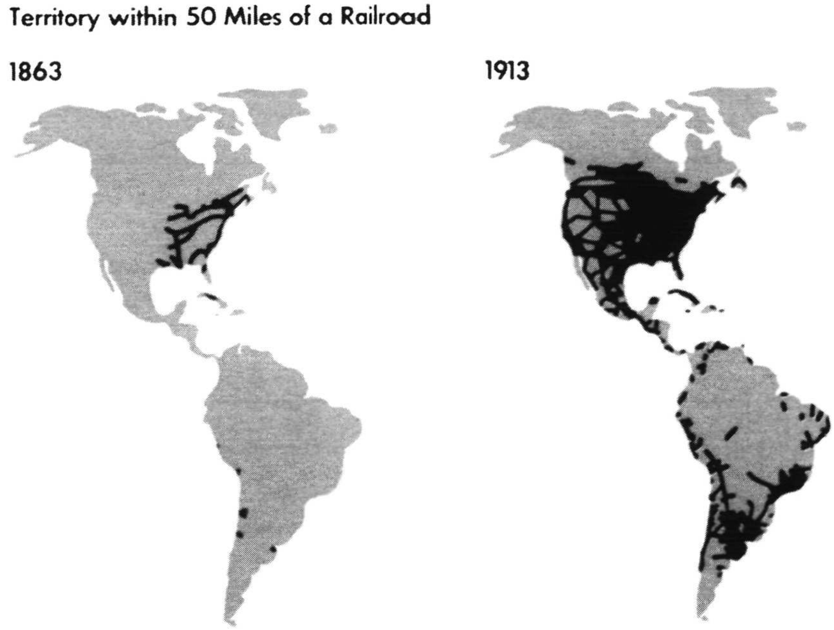


FIGURE **2-43**: The spreading of the railroad system. SOURCE: 'Modern man in making', Otto Neurath, 1939 (reproduced in Houkes 1993, p. 49.)

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.

TYPE OF GRAPHIC REPRESENTATION (4): *Maps*.

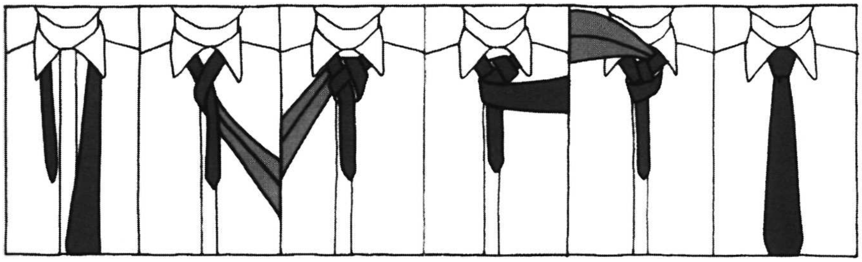


FIGURE **2-44**: How to tie a tie. SOURCE: Mijksenaar and Westendorp 1999, p. 49.
COMMENT: This figure is a *graphic multiple* of a picture.
SYNTAX OF SPATIAL STRUCTURE (2.5): A *graphic multiple* of an *integral metric space,* arranged in an *ordered horizontal lineup.*
TYPE OF CORRESPONDENCE (3.1): While the pictures themselves involve *literal* correspondence, their ordered horizontal lineup involves *metaphoric* correspondence (order in *space* stands metaphorically for order in *time*).
TYPE OF GRAPHIC REPRESENTATION (4): *Pictures.*

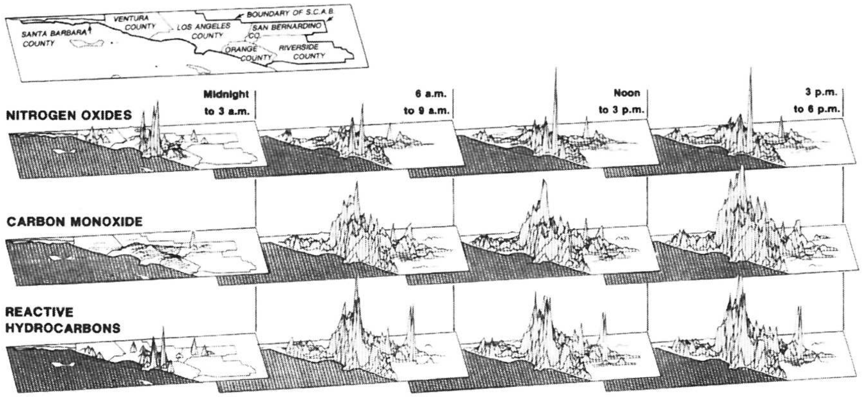


FIGURE **2-45**: Varying intensity of air pollution in the Los Angeles area in the course of the day, concerning three different pollutants.

SOURCE: Los Angeles Times, July 22, 1979 (reproduced in Tufte 1983, p. 42).

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.*)

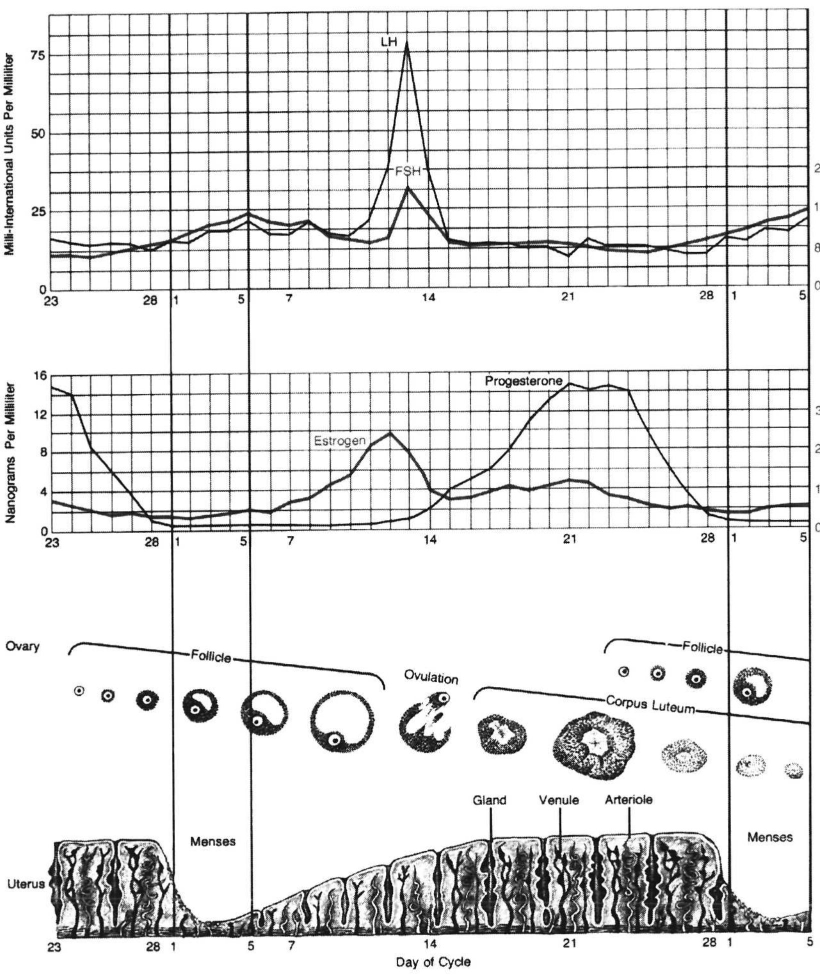


FIGURE 2-46: The relationship of female reproductive hormones and the events in the ovary and uterus during the menstrual cycle.
SOURCE: Wallace 1978, p. 172.

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 contains *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*.)

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.

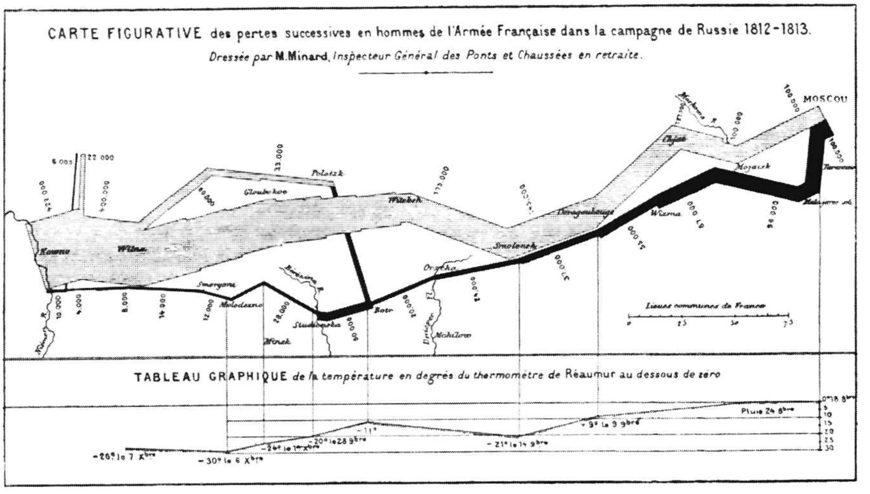


FIGURE 2-47: The dramatically diminishing number of Napoleon's surviving soldiers during their march to Moscow (lighter path) and their retreat (black path). The chart at the bottom shows the temperatures during the retreat.
SOURCE: M. Minard 1861 (reproduced in Tufte 1983, p. 41).

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.)

CHAPTER 3

Interpretation of Graphic Representations

In Chapter 2 we have examined the *syntax* of graphic representations. We have regarded a composite graphic object as consisting 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. In addition, we have already made several statements about the *interpretation* of graphic representations (section 2.1). Let us recall these:

> 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).

There is a large amount of literature on the interpretation of graphic representations, mostly consisting of semiotically-tinted proposals to distinguish different types of graphic symbols. Taken together, the existing literature consists of a thick jungle of confusing and often contradictory terminology (see the 'terminology comparison tables' towards the end of both section 3.1 and section 3.2). In this chapter, in order to 'sort things out', we will develop a systematic and consistent approach to the main aspects of graphic interpretation, and apply this approach to numerous example figures. In addition we will, at the appropriate points in the text, use this approach to compare the existing literature on graphic interpretation, and to discuss specific shortcomings in that literature.

Let me give a brief overview here of the four sections of this chapter. In the first section (3.1), we will discuss **type of correspondence**. Type of correspondence is a core aspect of the interpretation of *elementary graphic objects* as well as of the interpretation of *graphic relations* between graphic objects. We will define type of correspondence as the relationship between *what is shown* and *what is meant*. The main types of correspondence that we will distinguish are *literal, metaphoric, metonymic, rebus-based,* and *arbitrary-conventional.* In the two remaining, shorter sections of this chapter we will briefly discuss two additional aspects that are involved in the interpretation of graphic objects: *mode of expression* and *informational role*. The **mode of expression** of graphic objects (section 3.2) concerns the classification of graphic objects into *pictorial* objects (in a spectrum from realistic to schematic pictures) and *non-pictorial* objects (abstract shapes, words and numbers). Sorting out a confusing issue in the literature, we will discuss the non-trivial relationship between *type of correspondence* and *mode of expression*. Concerning the **informational roles** of graphic objects (section 3.3) we will propose to classify graphic sub-objects of a composite graphic object either as *information objects* (which have to be adjusted if the information changes), or as *reference objects* (e.g. legends, labeled axes, grid lines), or as *decoration objects*. Finally we will make a few brief remarks about different **types of represented information** (section 3.4). First however, we will turn our attention to different *types of correspondence* that may be involved in graphic representations.

3.1 Type of Correspondence

> "Signs are either literal or metaphorical. They are called literal when used to signify the things for which they were invented [...] They are metaphorical when the actual things which we signify by the particular words are used to signify something else [...]" (Book Two, p. 71).
>
> [Letters, sounds and syllables have] "meaning not by nature but by agreement and convention [...] People did not agree to use them because they were already meaningful; rather they became meaningful because people agreed to use them." (Book Two, p. 101)
>
> *Saint Augustine (A.D. 397/1995)*

In the quotes above, from more than 1600 years ago, Saint Augustine discusses the interpretation of signs, using three main terms that we will use in this section - 'literal', 'metaphorical', and 'convention'. However, while Saint Augustine uses these terms with regard to *text*, we will here propose corresponding notions that apply to *graphics*. In other words, we will focus specifically on notions of *visual* literalness, *visual* metaphor, and *visual* convention. Graphic representations differ from text in that they can 'depict' or 'show' things that we recognize.

> In a *graphic* representations we define **type of correspondence** as the type of relationship between *what is shown* and *what is meant*.

To give an example of a *textual* metaphor, one might say: "man is a wolf", where the use of the word 'wolf' would be regarded as involving a metaphor. In the context of this framework, such a (visual) metaphor would involve a *picture* of a wolf. Here we will *not* regard the written word 'wolf' as a (visual) metaphor, because we will be looking at the relationship between what is *shown* and what is meant. See the definitions of the various possible types of correspondences that are given below. What a written word or text *shows*, consists merely of strings of letters from the Latin alphabet. Consequently, in this framework such *textual* graphic objects will always be regarded as involving *arbitrary-conventional* correspondence (to interpret them, we need to be familiar with more or less arbitrary conventions).

The notion of 'what is shown' in a graphic representation is not a trivial matter. Goodman (1976) has taken the extreme point of view that recognizing depictions is not based on such a thing as 'natural resemblance' between the depiction and the depicted, but always on arbitrary conventions. Richards has devoted a chapter to this issue (Richards 1984, fourth chapter). Taking up these issues is beyond the aims of this thesis. Here we will assume that, regardless of the involved phenomena, people are somehow able to have the experience of 'recognizing' things in representations, and we will regard these things as 'what is shown' in a representation.

	what is shown the display the representation	what is meant the information the represented
Saussure:	signifier	signified
Eco:	expression	content
Peirce:	representamen	interpretant and object
MacEachren:	sign-vehicle	interpretant and referent

FIGURE **3-01**: Terminology for talking about representation.

Type of correspondence is the territory of *semiotics* - the study of 'representation'. See the table in figure 3-01 for an overview of terminology that has been used in the semiotic literature for talking about representation. Ferdinand de Saussure and Charles Sanders Peirce are usually regarded as the founding fathers of semiotics. While Saussure's 'dyadic' approach involves two elements (signifier and signified), Peirce's 'triadic' approach involves three elements (representamen, interpretant and object). The 'interpretant' is *not* the 'interpreter', as it is misunderstood by some authors (e.g. by Mullet and Sano, 1995, p. 171). What Peirce *does* seem to mean with the term 'interpretant' is the *mental concept* that is activated in the mind of somebody who encounters the concerned representamen. As an example of the three elements of Peirce's 'semiotic triangle', a process of representation may involve relationships between the three-letter word "dog" (the representamen), the mental concept of a dog in somebody's mind (the interpretant), and a real-world dog (the object).

In the context of this framework we will prefer the dyadic approach followed by Saussure above the triadic one followed by Peirce. As already noted above, we will make the distinction between *what is shown* (for example the three letters "dog", or a drawing of a dog), and *what is meant* (for example, a specific real-world dog, or our mental concept of a dog, or the set of all dogs). *What is shown* in a graphic representation consists of elementary graphic objects and graphic relations, which we have analyzed in various ways in Chapter 2. *What is meant* by a graphic representation is derived by a viewer from *what is shown*. Different aspects of this derivation are the subject of the current chapter.

Concerning the nature of the relationship between *what is shown* and *what is meant*, it seems that a limited set of general possibilities can be identified. We will refer to these as **types of correspondence**. *Elementary graphic objects* as well as *visual attributes* as well as *spatial structures* may involve **literal**, **metaphoric** or **arbitrary-conventional** correspondence. See the table in figure 3-02 for some examples. For *elementary graphic objects*, there are two additional possible types of correspondence which we will refer to as **metonymic** correspondence and **rebus-based** correspondence. See figure 3-03 for examples of the proposed types of correspondence as they appear in Egyptian hieroglyphs. Many more examples of the different types of correspondence are described in the figure captions throughout this thesis. The following subsections consist of separate discussions for each of the types of correspondence. For now we will limit ourselves to brief definitions:

- **literal**: what is shown is based on *similarity* to the physical object or physical structure that is meant, or on similarity to a prototypical example of the kind of physical object that is meant.
- **metaphoric**: based on a (supposed) *analogy* between what is shown and what is meant, this may concern either a shared functional characteristic or a structural analogy.
- **arbitrary-conventional**: what is shown seems to stand for what is meant by *pure convention*, although in many cases the current users of the concerned representation may simply not be aware of the fact that the representation originated involving one of the other types of correspondence.
- **rebus-based**: based on the fact that (part of) the spoken word for what is shown *sounds* like (part of) the spoken word for what is meant.
- **metonymic**: based on a mental association due to the fact that there is (or used to be) a relationship of *physical involvement* between what is shown and what is meant (e.g. what is shown 'is a part of' or 'is a possible result of' what is meant, or in some other way it 'plays a role in' what is meant).

	Type of Correspondence		
	literal	metaphoric	arbitrary-conventional
elementary graphic object	'wine glass' icon standing for 'wine glass'	'wine glass' icon standing for 'fragile'	'elephant' icon standing for 'Republican party'
visual attribute	yellow desert versus green forest on a map	relative sizes of bars in a bar chart	color coding of electrical wires
spatial structure	the arrangement on a map, the connections in a wiring diagram	the arrangement on an x/y chart, the connections in a family tree	the arrangement of red above green on a traffic light

FIGURE **3-02**: *Literal*, *metaphoric* and *arbitrary-conventional* correspondence apply to *elementary graphic objects* as well as to *graphic relations* (concerning *visual attributes* and *spatial structure)*. For *elementary graphic objects* there are two additional possible types of correspondence: *rebus-based* correspondence and *metonymic* correspondence.

See the figures throughout this thesis for many more examples. Each example figure has a figure caption that includes an assessment of the involved type(s) of correspondence.

Type of correspondence should not be confused with certain other aspects of pictorial objects: All pictorial objects, regardless of the type of correspondence that they are involved in,

- may vary in their degree of *pictorial abstraction*, involving a spectrum from very realistic to very schematic (see section 3.2),
- may show an archaic example of the concerned object, i.e. an object 'like it used to look'. For example, the postal horn displayed in figure 3-07 is an archaic object.

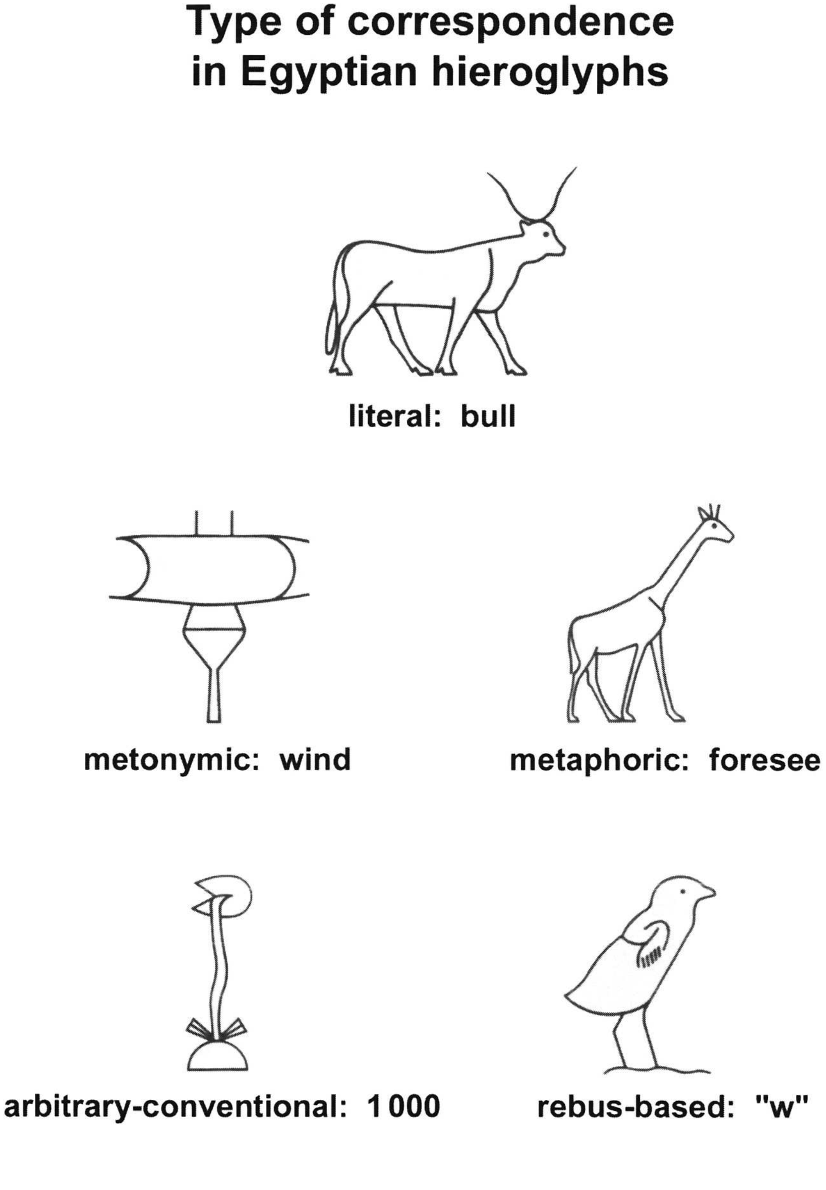


FIGURE 3-03: The five types of correspondence distinguished in this thesis can also be identified in Egyptian hieroglyphs. SOURCE: Composed by the author, individual hieroglyphs reproduced from Betrò 1995.

In this thesis, whenever we talk about the type of correspondence of an *elementary graphic object*, we will mean the type of correspondence of the *shape* of the elementary graphic object. In other words, regarding type of correspondence, an elementary object is equated with its *shape* (see also section 2.4 on *visual attributes*). After all, it is usually the *shape* of an elementary object that determines 'what we see in it'. Meanwhile, the elementary object's other visual attributes, such as *size* and *color*, and the object's anchoring(s) in *spatial structure(s)* may involve *other* types of correspondence than the type of correspondence that is involved in its shape. In this way an elementary object may be simultaneously involved in different types of correspondence. For example, a pictorial object may simultaneously involve a *literal* shape, an *arbitrary-conventional* color-coding, a *metaphoric* size in relation to the sizes of other objects, and a *metaphoric* spatial positioning along a time line.

In an analysis that our framework is definitely related to, Richards (1984) uses the term 'mode of correspondence', distinguishing 'literal' and 'non-literal' correspondence. Richards also includes the possibility of 'semi-literal' correspondence, partly because he does not allow an object to simultaneously be involved in different types of correspondence. He does not distinguish between the type of correspondence involved in an *object itself* (regarding its shape) and the type(s) of correspondence involved in its anchoring(s) in *syntactic structure(s)*, or the type(s) of correspondence involved in its other *visual attributes*.

In addition to its *intended referent* (the concept that it stands for), a *metaphoric*, *metonymic* or *rebus-based* graphic object involves an *intermediary referent* (its *literal* interpretation). This applies to some *arbitrary-conventional* objects as well, for example to the elephant as a symbol of the Republican Party. In this sense, such objects involve a *literal* correspondence that serves as a basis for their *metaphoric, metonymic, rebus-based* or *arbitrary-conventional* correspondence.

In some cases the intended meaning of a graphic object involves *several intermediary referents*, where each step between referents has its own type of correspondence. For example, an interface button in a word processing program depicts a pair of scissors (first intermediary referent), the pair of scissors stands *metonymically* for the act of physically cutting into a paper document (second intermediary referent), and the act of physically cutting into a paper document in turn stands *metaphorically* for the act of removing selected text from the electronic document (intended referent). This phenomenon can be referred to as *multi-step semiosis*.

In the following subsections we will discuss the types of correspondence distinguished here, starting with *literal* correspondence.

3.1.1 Literal correspondence

> Correspondence is **literal** what is shown is based on *similarity* to the physical object or physical structure that is meant, or on similarity to a prototypical example of the kind of physical object that is meant.

A literal *elementary object* depicts the kind of physical object that it stands for. Literal *visual attributes* express physical (spatial and visual) attributes of the represented objects. Literal *graphic relations* may represent a physical arrangement, physical links, physical separation or physical containment. In the context of this thesis the term 'physical' may refer both to physical things in the real world and to physical things that exist only in the imagination (e.g. a planned building, a fantasy creature). Possible synonyms for the term 'literal' correspondence include 'physical' correspondence and 'direct' correspondence.

FIGURE 3-04: A pictogram used in the catalogue of a company that rents party glasses. This pictogram involves *literal* correspondence: what is shown is a prototypical example of what is meant.

PHYSICAL STRUCTURES AND CONCEPTUAL STRUCTURES

Since our definition of *literal* correspondence uses the notion of a 'physical structure', let me make a few remarks about physical versus conceptual structures. Any 'structure' that is not a *physical* structure can be referred to as a *conceptual* structure. Likewise, any 'space' that is not a *physical* space can be referred to as a *conceptual* space.

Concerning their 'literalness', *spatial structures* that are displayed in graphic representations can be divided into three groups:

- Spatial structures that represent **physical** structures, involving *literal* correspondence. These are found for example in:
  - maps and pictorial diagrams (representing physical spaces), or in
  - wiring diagrams (representing physical links).

- Spatial structures that represent **conceptual** structures, involving *metaphoric* correspondence. These are found for example in:
  - statistical charts and time charts (representing conceptual spaces), or in
  - family trees and organization charts (representing conceptual links).
- Spatial structures that represent **hybrid** structures, involving both *literal* and *metaphoric* correspondence. See for example the graphic timetable in figure 2-29, and the 'U.S. population landscapes' on the front cover and in figure 2-30.

Note that some representations of physical spaces (e.g. subway maps) are *distorted* (subsection 2.5.2) and can be regarded as involving *distorted* literal correspondence. We will now turn to the discussion of *metaphoric* correspondence.

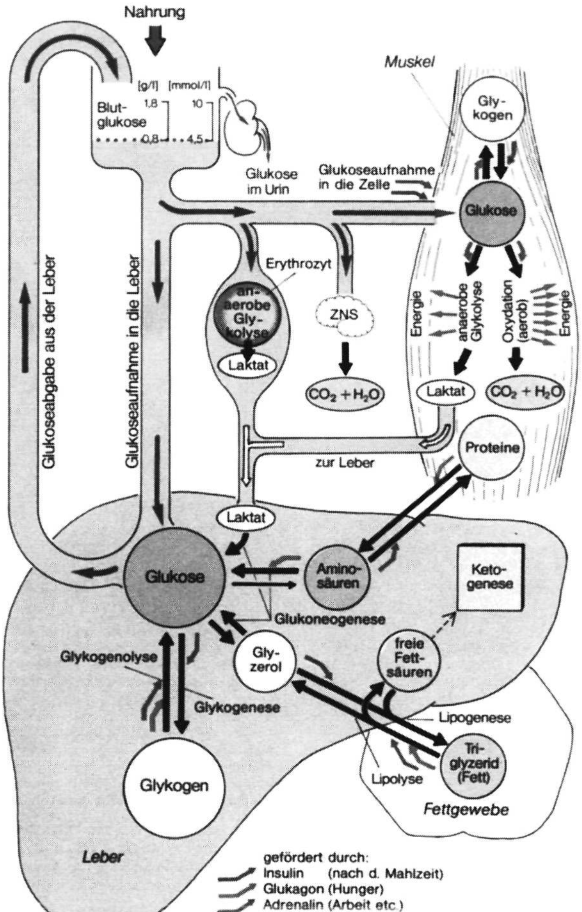


FIGURE 3-05: The pathways of glucose in the human body.
SOURCE: Silbernagel and Despopoulos 1983, p. 247.

COMMENT: The *containments* of certain substances in organs such as in the liver in the lower half of the figure, represent *physical* containments, involving *literal* correspondence. In contrast, the circles of Venn diagrams (e.g. figure 2-18) represent *conceptual* containments, involving *metaphoric* correspondence.

SYNTAX OF SPATIAL STRUCTURE (2.5): A composite graphic object that involves *nodes, labels, linking* by *connectors*, and *containment* by *containers.*

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The containment in organs involves *literal* correspondence, see the comment above. The linking by arrows involves *metaphoric* correspondence. VISUAL ATTRIBUTES: Some shapes (e.g. the kidney, muscle, brain, liver) involve *literal* correspondence, the remaining shapes involve *arbitrary-conventional* correspondence.

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

3.1.2 Metaphoric correspondence

Correspondence is **metaphoric** if it is based on a (supposed) *analogy* between what is shown and what is meant. This may concern a structural analogy, a comparable function, or a shared characteristic.

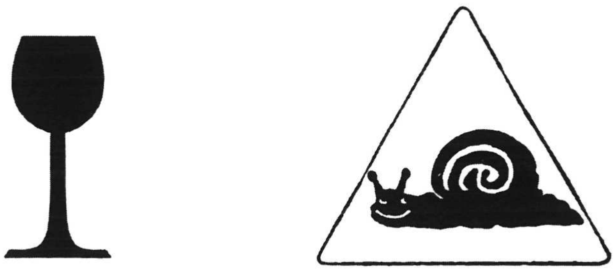


FIGURE **3-06**: Two examples of graphic objects that involve *metaphoric* correspondence. In both cases, what is shown (wine glass, snail) 'shares a characteristic' with what is meant:

Left: A pictogram on a cardboard box, indicating a fragile content.

Right: 'Go slow.' This is one of the earliest pictographic suggestions for a traffic sign, from 1923. If this sign was interpreted as involving *literal* correspondence, it could be understood as a warning that there are snails ahead, crossing the street. SOURCE: Krampen 1965, p. 12.

We have noted earlier that metaphoric correspondence may be involved in *graphic objects* as well as in *graphic relations* between graphic objects. Examples of metaphoric *graphic objects* can be found on many computer screens, such as the pictogram of a trash can, and the pictogram of a house standing for 'My Homepage' in an Internet browser. Some examples of metaphoric *graphic relations* are the arrangement of objects along a timeline (where distances stand for time intervals), the proportional sizes of bars in a bar chart (where heights stand for quantities), the linking of names in a family tree (where links stand for descent), and the containment in Venn diagram circles (where containment stands for set membership). In musical notation, both the horizontal and the vertical arrangement of the marks on the score involve spatial relations that are metaphoric: the 'higher' the mark, the 'higher' the pitch, and the further on the score, the further in time.

3.1.3 Metonymic correspondence

> Correspondence is **metonymic** if it is based on a mental association due to the fact that there is (or used to be) a relationship of *physical involvement* between what is shown and what is meant. For example, what is shown 'is a part of' or 'is a possible result of' what is meant, or in some other way it 'plays a role in' what is meant.

Note that with the definition of metonymy that I am giving above, I am including what traditional rhetoricians refer to as 'synecdoche', where a part stands for the whole. I regard a synecdoche as a special case of metonymy. There are other authors who do the same (e.g. Lakoff and Johnson, 1980, p. 36). According to many scholars, both metaphor and metonymy play crucial roles in human cognition.

> "Metonymy is one of the basic characteristics of cognition. It is extremely common for people to take one well-understood or easy-to-perceive aspect of something and use it to stand either for the thing as a whole or for some other aspect or part of it." *Lakoff (1987, p. 77)*

For examples of metonymic graphic objects see the various pictograms in figure 3-07. The Cross as a symbol of Christianity is another example that could be regarded as a metonymic graphic object. Tversky discusses pictorial metonymy and mentions that in the pictorial language of the Dakota Indians, 'famine' was conveyed by portraying empty racks for drying buffalo meat (Tversky 1995, p. 34, referring to Mallery 1893/1972).

Let me add a few remarks about the difference between *metaphoric* symbols and *metonymic* symbols. Both metaphor and metonymy in graphic representations can be regarded as 'figures of depiction' (a term from Tversky, 1995, corresponding to 'figures of speech'), and they may sometimes *seem* confusingly related. However, the distinction between the two is quite clear.

- In the case of a **metaphoric** symbol, what is meant is *compared* to something that is *neither* part of it *nor* otherwise physically involved in it, and an *analogy* between the two is suggested.
- In the case of a **metonymic** symbol, *no comparison* is involved and *no analogy* is suggested. Instead, what is shown is either *part of* what is meant or otherwise *physically involved* in it.

FIGURE 3-07: Eight examples of graphic objects that involve *metonymic* correspondence. What is shown 'plays a role in' what is meant (or used to play a role), except for the skull at the lower right, in which case what is shown 'is a possible result'. The first four pictograms are from signage indicating a bar, a restaurant, bathrooms, and a hairdresser. The third row shows two different pictograms indicating a post office. The last row shows pictograms for a mine and for danger.

3.1.4 Rebus-based correspondence

> Correspondence is **rebus-based** if it is based on the fact that (part of) the spoken word for what is shown *sounds* like (part of) the spoken word for what is meant.

Goldwasser refers to a rebus as a 'phonetic metaphor'. She argues that, while "metaphor is built on the discovery of similarities, or on the creation and revelation of such between two *signifieds*", a rebus "is based not on any similarity of *signifieds*, but on similarity between *signifiers*", the signifiers being spoken words in this case (Goldwasser 1995, pp. 71-72).

Rebus-based graphic objects have been involved in the early stages of the development of many writing systems. Figures 3-08 and 3-09 show rebus-based Egyptian hieroglyphs. In the course of their development, most writing systems came to be regarded as *arbitrary-conventional*. Arbitrary-conventional correspondence is discussed in the next subsection.

FIGURE 3-08: *Rebus-based* Egyptian hieroglyphs.

FIGURE 3-09: Egyptian hieroglyphs from the 'White Chapel' of Sesostris I, around 2000 B.C. SOURCE: Reproduced from Sandison 1997.

COMMENT: When they were fully developed as a writing system, about two thirds of the Egyptian hieroglyphs had a *rebus-based*, phonetic function.

SYNTAX OF SPATIAL STRUCTURE (2.5): A *horizontal separation*, achieved by *vertical separators*, containing a *segmented vertical lineup* of graphic objects. The upper part of the second column shows objects that are contained by an elliptical *container* (indicating a Royal name).

TYPE OF CORRESPONDENCE (3.1): VISUAL ATTRIBUTES: The shapes of the majority of the displayed hieroglyphs involve *rebus-based* correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A *written text*.

3.1.5 Arbitrary-conventional correspondence

> Correspondence is **arbitrary-conventional** if what is shown seems to stand for what is meant by *pure convention*. Concerning many representations that are regarded as arbitrary-conventional, the current users may simply not be aware of the fact that the representation originated involving one of the other types of correspondence.

Many arbitrary-conventional graphic objects actually do have a motivated origin, involving a *metaphor*, a *metonymy* or a *rebus*. However, when such an origin is forgotten, the graphic object will be perceived as being *arbitrary-conventional*. Thus an arbitrary-conventional representation is one that, while the original choice for it seems arbitrary, receives meaning through consistent use.

Examples of arbitrary-conventional *graphic objects* are written words, the elephant as the symbol for the Republican Party in the United States, and the Swastika as the symbol of the Nazi regime. Examples of arbitrary-conventional *visual attributes* can be found in many color-coding systems (e.g. of electrical wires, of subway lines). Arbitrary-conventional correspondence may involve either

- **external** convention, which is an established convention *outside* the representation at hand, or
- **internal** convention, which is not an established convention but an encoding that is consistent and carries meaning *within* the representation at hand, and is usually explained by some kind of *legend*.

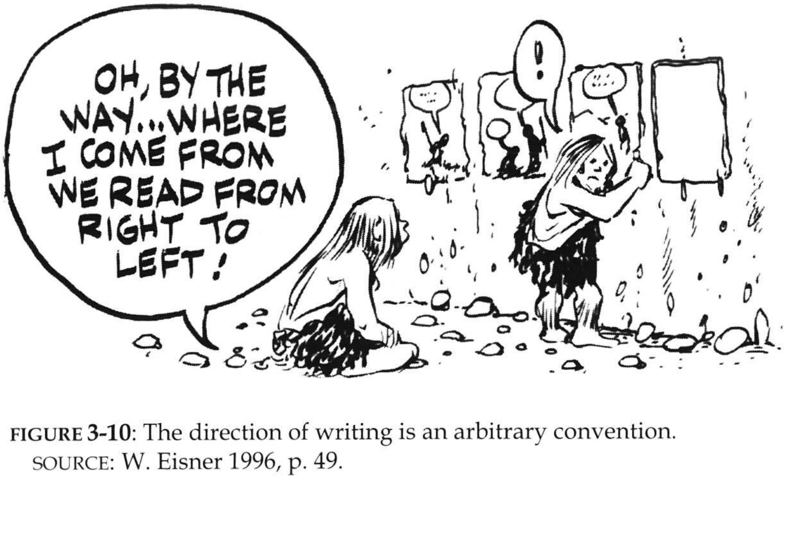


FIGURE **3-10**: The direction of writing is an arbitrary convention.
SOURCE: W. Eisner 1996, p. 49.

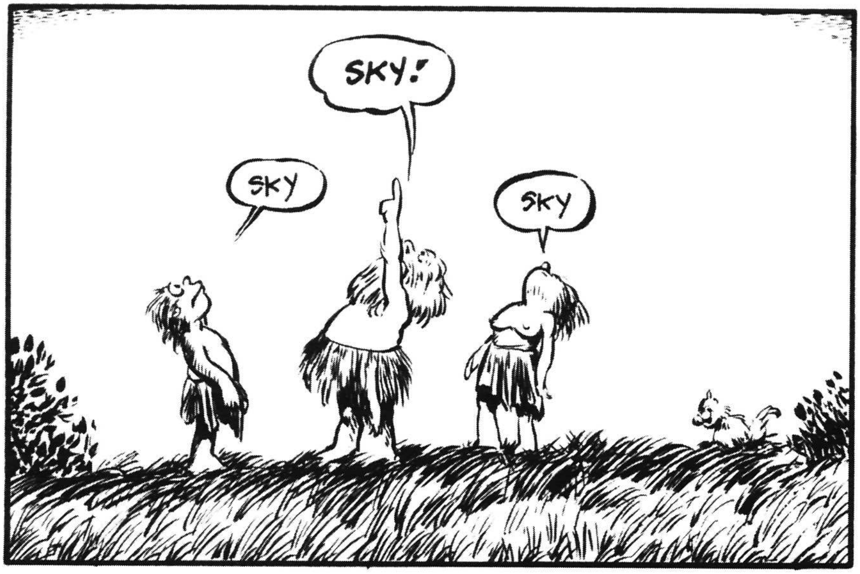


FIGURE 3-11: Words involve arbitrary conventions. SOURCE: Gonick 1990, p. 66.

COMMENT: Written words involve *two* steps of *arbitrary-conventional* correspondence: one from meaning to sound, and one from sound to letters.

SYNTAX OF SPATIAL STRUCTURE (2.5): An *integral metric space* with graphic objects, three of which (the human figures) are *labeled* with *containers* (the word balloons) containing further *graphic objects* (three times the word 'sky').

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The integral metric space involves *literal* correspondence (spatial relations in the picture stand for spatial relations in an imagined physical world). VISUAL ATTRIBUTES: Like the integral metric space, the shapes that stand for physical objects involve *literal* correspondence (what is shown is what is meant). The word balloons on the other hand (both the shapes of the containers and the shapes of the contained word) involve *arbitrary-conventional* correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A *picture*.

The standard traffic light arrangement of positioning the red light above the green light is an example of a spatial structure that is arbitrary-conventional. This type of spatial structure should not be confused with spatial structures that are simply *arbitrary* but *not* conventional, such as a random scattering of graphic objects on a page. While an *arbitrary* spatial structure encodes no information, an *arbitrary-conventional* spatial structure encodes information through (arbitrary) convention. Relying on the information that is provided by the *arbitrary-conventional* arrangement of the traffic lights, color-blind drivers stop for the 'top light' and go with the 'bottom light'.

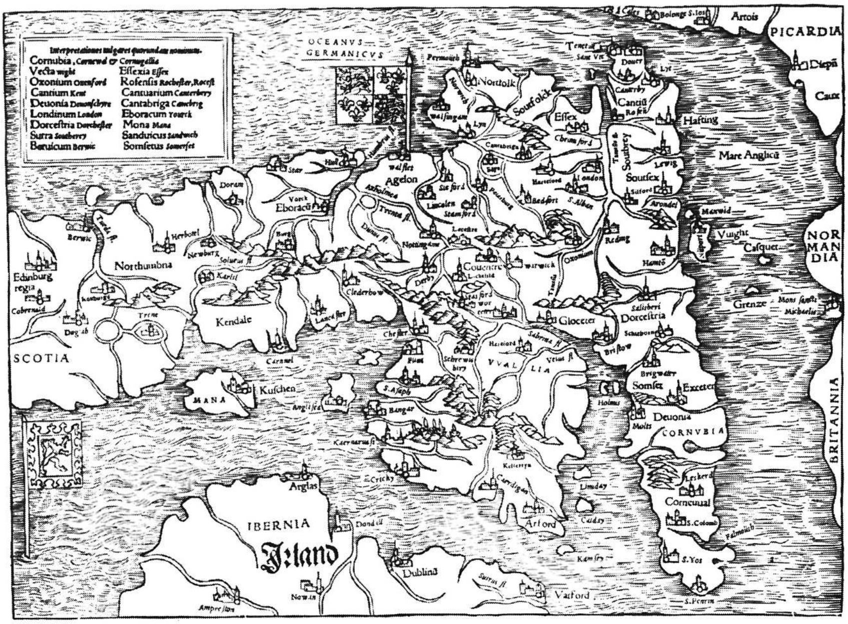


FIGURE **3-12**: The first printed map of Britain. SOURCE: 1540 edition of *Geographia* (reproduced in Holmes 1991, p. 32).

COMMENT: The orientation ('orient'-ation) of maps is an arbitrary convention.

SYNTAX OF SPATIAL STRUCTURE (2.5): An *integral metric space* (the map) containing *surface locators* (marking land masses), *line locators* (marking rivers), *point locators* (little drawings of buildings, marking cities), *labels*, and a *superimposed inset*.

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The relative distances and relative directions within the map involve *literal* correspondence, while the orientation of the map involves *arbitrary-conventional* correspondence.

TYPE OF GRAPHIC REPRESENTATION (4): A *map*.

Spatial arrangement may be *partly* arbitrary-conventional. We can make a distinction between two aspects of spatial arrangement:

- *relative spatial arrangement* (internal to the representation), e.g. spatial distances and *relative* directions within the representation, and
- *directionality* (how the representation is oriented), e.g. the cartographic convention of orienting maps with North at the top.

Often the relative spatial arrangement of objects in a graphic representation involves *literal* or *metaphoric* correspondence, while the involved directionality may involve culturally determined, *arbitrary-conventional* correspondence (see also Tversky 1995, 2001). See figure 3-10 (on reading from right to left), figure 3-12 ('orient'-ation of a map) and figure 3-13 (a 'counterclockwise' clock).

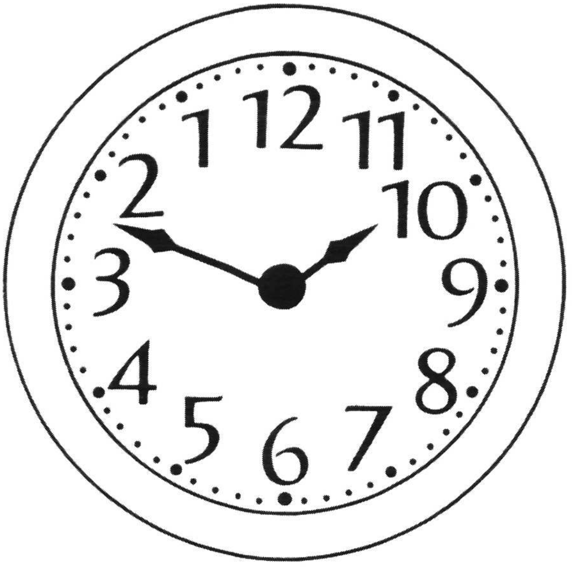


FIGURE 3-13: The clock face could also have developed to look like this.
SOURCE: Norman 1990.

COMMENT: The direction of advancement of the clock is an arbitrary convention.

SYNTAX OF SPATIAL STRUCTURE (2.5): A *metric space* involving a circular *metric axis*, two *point locators* (the two arms), and a *labeled* circular *grid line* (a circle of tick marks with numerals).

TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The proportional distances along the circular time axis involve *metaphoric* correspondence, while the direction of advancement ('clockwise' or 'counterclockwise') involves *arbitrary-conventional* correspondence. VISUAL ATTRIBUTES: The lengths of the two arms involve *arbitrary-conventional* correspondence.

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

3.1.6 A look at the literature concerning type of correspondence

Various authors have discussed issues related to type of correspondence, see the table in figure 3.14 for an overview of commonly mentioned concepts.

Metaphor and metonymy in graphic representations can be referred to as 'figures of depiction', a term from Tversky (1995, p. 32) that corresponds to the 'figures of speech' or 'tropes' in spoken language. Horton (1994) uses the somewhat less elegant term 'figures of image'.

<table>
<tr><th rowspan="3"></th><th colspan="4">Type of Correspondence</th></tr>
<tr><th rowspan="2">literal</th><th colspan="2">using a 'figure of depiction'</th><th rowspan="2">arbitrary-conventional</th></tr>
<tr><th>metaphoric</th><th>metonymic</th></tr>
<tr><td>Knowlton 1966</td><td>iconic</td><td>analogical</td><td rowspan="3">-</td><td>arbitrary</td></tr>
<tr><td>Arnheim 1969</td><td>picture</td><td>symbol</td><td>sign</td></tr>
<tr><td>Many authors</td><td>icon</td><td>-</td><td>symbol</td></tr>
<tr><td>Rogers 1989</td><td>resemblance</td><td>symbolic</td><td>exemplar</td><td>arbitrary</td></tr>
<tr><td>Barthes 1965</td><td>iconic</td><td colspan="2">motivated</td><td>arbitrary</td></tr>
<tr><td>Horton 1994</td><td>subject directly</td><td colspan="2">analogy, 'figure of image'</td><td>conventions</td></tr>
<tr><td>Tversky 1995</td><td>straightforward</td><td colspan="2">'figure of depiction'</td><td>arbitrary</td></tr>
<tr><td>Peirce 1897</td><td colspan="2">icon</td><td>index*</td><td>symbol</td></tr>
<tr><td>Richards 1984</td><td>literal</td><td colspan="3">non-literal</td></tr>
</table>

* At least a subset of the signs that Peirce calls "indices" seems to be related to the concept of *metonymy*. See the discussion in the text.

FIGURE **3-14**: Comparison of notions in the literature that are related to type of correspondence.

On the following pages, we will discuss several of the distinctions from the literature as summarized in the table in figure 3-14.

According to **Peirce**, a sign may be an 'icon', an 'index', or a 'symbol'. In the following I will briefly explore these three much-quoted categories. For each category I will reproduce relevant quotes from Peirce and then match his category to the concepts proposed here.

'Icon'

Peirce's notion of an a 'icon' concerns what other authors may call 'isomorphism':

- [An icon] "exhibits a similarity or analogy to the subject of discourse" (Peirce 1885 vol. 5, p. 243).
- "Icons comprehend all pictures, imitations, diagrams, and examples." (Peirce 1886 vol. 5, p. 380).
- Peirce subdivides iconic signs into three categories:
  "Those which partake of simple qualities [...] are *images;* those which represent the relations [...] of the parts of one thing by analogous relations in their own parts, are *diagrams;* those which represent the representative character of a representamen by representing a parallelism in something else, are *metaphors*." (Peirce 1902/1998, p. 157.)

Translated into our terminology, Peirce's 'icons' include:

- *literal* graphic objects (Peirce's 'images'),
- *metaphoric* graphic objects (Peirce's 'metaphors'), and
- graphic objects that involve *metaphoric graphic relations* (Peirce's 'diagrams').

'Index'

- "Indices are signs which stand for their objects in consequence of a real relation to them. [...] Of this sort are all natural signs and physical symptoms." (Peirce 1886, vol. 5, p. 379).
- One of the examples that Peirce gives for an 'index' is "a piece of mould with a bullet-hole in it as sign of a shot" (Peirce 1895/1998, p. 170).
- "The index is physically connected with its object" (Peirce 1895/1998, p. 168).
- "Psychologically, the action of indices depends upon association by contiguity" (Peirce 1895/1998, p. 172).

Although it is not clear whether Peirce's notion of an 'index' would at all be applicable to intentional graphic representation, it does seem to have aspects in common with our definition of *metonymic*, which I recall here: "Correspondence is *metonymic* if it is based on a mental association due to the fact that there is (or used to be) a relationship of *physical involvement* between what is shown and what is meant. For example, what is shown 'is a part of' or 'is a possible result of' what is meant, or in some other way it 'plays a role in' what is meant (see subsection 3.1.3).

'Symbol'

In some of his early work Peirce refers to as a 'token' what he later calls a 'symbol'.

- "The token represents its object in consequence of a mental association, and depends upon a habit. Such signs are abstract and general, because habits are general rules to which the organism has become subjected. They are, for the most part, conventional and arbitrary." (Peirce 1886, vol. 5, p. 379.)

Peirce's 'symbol' corresponds to our *arbitrary-conventional* graphic object.

Many other authors have adopted the term 'symbol' for *arbitrary-conventional* representations, contrasting it with the term 'icon' for *literal* representations, which is a narrower use of the term 'icon' than in Peirce's writings.

Arnheim (1969, pp. 135-142) distinguishes three possible functions of images: an image may function as a 'picture', as a 'symbol', or as a 'sign'.

As examples of '**pictures**', Arnheim mentions a photograph, a painting of a Dutch landscape from the seventeenth century, and a simply drawn cartoon or caricature. Other examples he gives of pictures are a triangle as a picture of a mountain, and a drawing of two overlapping circles as a ground-plan for a two-ring circus. Arnheim's 'pictures' seem to correspond to our *literal* representations.

As examples of '**symbols**', Arnheim mentions how musical notation "represents the pitch level of sounds by the structurally analogous location of the notes on the staff". Other examples he gives of symbols are arrows, a triangle as a symbol of hierarchy, and a drawing of two overlapping circles "that may be meant to show the logical relation of any two overlapping concepts". Arnheim's 'symbols' seem to correspond to our *metaphoric* representations. Note that Arnheim's use of the term 'symbol' is very different from Peirce's use of the same term.

As examples of '**signs**', Arnheim mentions letters and words in verbal languages, and a triangle as a sign for danger. Arnheim's 'signs' seem to correspond to our *arbitrary-conventional* representations.

Rogers (1989, p.110) proposes a classification of icons, illustrated in figure 3-15. She distinguishes 'resemblance' icons, 'exemplar' icons, 'symbolic' icons, and 'arbitrary' icons. 'Resemblance' icons seem to correspond to our *literal* icons. It is not immediately clear what Rogers means with 'exemplar' icons. From her definition "An exemplar icon serves as a typical example for a general class of objects.", one might expect her to mean our *literal* graphic objects, which often show a prototypical example of what is meant (see subsection 3.1.1). However, from the example that Rogers gives of an 'exemplar' icon - the knife and fork used on a sign that indicates a restaurant - and from her explanation that this sign "shows the most salient attributes associated with what one does in a restaurant, i.e. eating", I conclude her 'exemplar' icons correspond to what we refer to as *metonymic* graphic objects. Her 'symbolic' icons seem to correspond to our *metaphoric* graphic objects, and her 'arbitrary' icons to our *arbitrary-conventional* graphic objects.

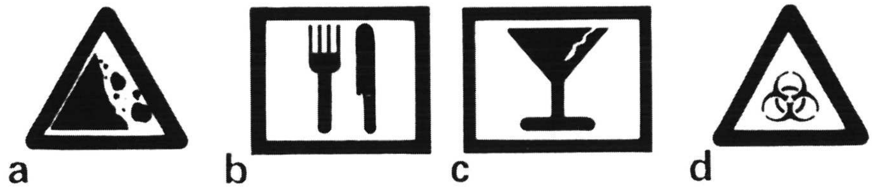


FIGURE 3-15: Classification of icons proposed by Rogers (1989): a) 'resemblance icons', b) 'exemplar icons', c) 'symbolic icons', and d) 'arbitrary icons'.
In our terminology these involve: a) *literal*, b) *metonymic*, c) *metaphoric*, and d) *arbitrary-conventional* correspondence (this sign stands for 'biohazard').
SOURCE: Rogers 1989, p 110.

Richards (1984, 2002) distinguishes between 'literal' and 'non-literal' correspondence. He also includes the possibility of 'semi-literal', partly because he does not distinguish between the type of correspondence of a *graphic object itself* (regarding its shape) and the type(s) of correspondence involved in the graphic object's *graphic relations*. See section 5.2 for a discussion of Richards' distinctions.

Recall that a graphic object may be simultaneously involved in different types of correspondence. For example, a pictorial object may simultaneously involve a *literal* shape, an *arbitrary-conventional* color-coding, a *metaphoric* size in relation to the sizes of other objects, and a *metaphoric* spatial positioning along a time line. None of the frameworks that can be found in the literature mentions or examines such a simultaneous involvement of different types of correspondence.

In this section we have discussed *type of correspondence*, which is concerned with the type of relationship between *what is shown* and *what is meant*. Type of correspondence is a core aspect of the interpretation of graphic representations, and is involved in the interpretation of *elementary graphic objects* as well as in the interpretation of *graphic relations* between graphic objects. We have identified a basic set of possibilities for type of correspondence, and we have discussed these possibilities, examining various examples. In the remaining sections of this chapter we will provide a brief discussion of *modes of expression* (section 3.2), the *informational role* that graphic objects may play within a representation (section 3.3), and the *types of information* that may be represented graphically (section 3.4).

3.2 Mode of Expression

Concerning its **mode of expression**, an elementary graphic object may be:

- a **pictorial** object: in a spectrum from a **realistic picture** to a **schematic picture**, or
- a **non-pictorial** object: an **abstract shape**, a **word** or a **number**.

Mode of expression is an aspect of graphic objects that is related to their *type of correspondence*. In section 3.1 we have pointed out that in addition to its *intended* referent (the concept that it stands for), a *metaphoric, metonymic* or *rebus-based* graphic object involves an *intermediary* referent (its *literal* interpretation). This applies to some *arbitrary-conventional* objects as well, for example to the elephant as a symbol of the Republican Party. In the latter case, the elephant is the intermediary, *literal* referent, while the Republican Party is the intended, *arbitrary-conventional* referent. In this sense there is a relation between type of correspondence and mode of expression: An elementary graphic object is regarded as a **pictorial** graphic object (a *picture*) if it involves a *literal* correspondence - either to its *intended* or to its *intermediate* referent. In other words, a *pictorial* graphic object functions as a depiction of a physical object or scene, which may be either its intended or its intermediary referent. A *pictorial* object can be situated on a continuum from *realistic* rendering to *schematic* rendering.

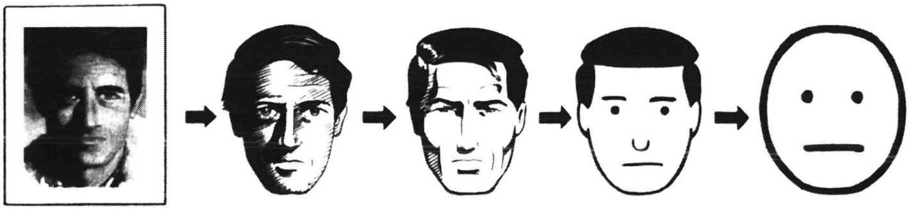


FIGURE **3-16**: An example of the spectrum from *realistic* picture to *schematic* picture. SOURCE: Scott McCloud 1993, p. 45.

An elementary graphic object is regarded as a **non-pictorial** object if it involves no literal correspondence - neither to its intended referent nor to its intermediary referent. In other words, a non-pictorial object does *not* function as a depiction of a physical object or scene. It may be an *abstract shape*, a *word* or a *number*.

It follows from the above that a graphic object (e.g. a circle) may be *pictorial* in one context (e.g. as the head of a human figure), and *non-pictorial* in another context (e.g. in a Venn diagram).

WRITTEN TEXT

In the discussion above, we have listed *words* as a category of non-pictorial graphic objects. Words are the constituent objects of written texts like this one. In this framework, **written text** is regarded as a special case of graphic representation. Recall that we have defined a graphic representation as a visible artifact on a more or less flat surface, that was created in order to express information.

Written text is the *special case* of graphic representation in which:

- the *syntactic structure* of the representation is a *lineup* (long texts in Western languages are often vertical lineups of horizontal lineups),
- the *graphic objects* represent expressions in an existing human language, and
- the *linear ordering* within the lineup is determined by the sentential grammar of that language.

This definition of written text includes text in which the graphic objects are *words* that are composed with letters from the Latin alphabet, such as the written text you are reading right now. However, this definition of written text also includes text in which the graphic objects are *pictorial* symbols, such as Egyptian hieroglyphs and (ancient) Chinese characters. The lineup of graphic objects in written texts is often a *segmented lineup*, which was described in subsection 2.5.1 as a lineup that is broken up into several parallel shorter lineups, usually all running in the same direction (e.g. *this* line of text continues here).

Written text is a special case of graphic representation.

FIGURE 3-17: A sentence. SOURCE: Engelhardt 2002.
COMMENT: This figure serves to illustrate our view of written text as a special case of graphic representation.
SYNTAX OF SPATIAL STRUCTURE (2.5): A *horizontal lineup* of graphic objects.
TYPE OF CORRESPONDENCE (3.1): SPATIAL STRUCTURE: The linear order of the words involves *arbitrary-conventional* correspondence, following the grammatical conventions of the English language. VISUAL ATTRIBUTES: The shapes of the letters involve *arbitrary-conventional* correspondence, with the choice of letter combinations involving the more or less phonetic conventions of English spelling.
TYPE OF GRAPHIC REPRESENTATION (4): A *written text*.

Textual graphic objects, such as textual labels, are contained in many graphic representations. Different authors take different approaches to text within graphics. Richards for example explicitly chooses to omit textual labels from his analysis of graphic representations (Richards 1984, pp. 9/9). Horn on the other hand emphasizes the special and crucial role that words play in graphic representations (Horn 1998, pp. 57-58), and maintains that "tight integration of verbal and visual elements is the unique identifying feature of visual language" (ibid, p. 101). This notion of 'visual language' seems to imply that all graphic representations that do *not* contain textual objects (e.g. figures 2-08, 2-17, 2-20, 2-44, 3-06, 3-07) have to be regarded as not involving visual language. Concerning the treatment of textual objects, I agree with neither Richards nor Horn. In the syntactic analysis proposed in Chapter 2 of this thesis, textual objects are treated like all other graphic objects.

A LOOK AT THE LITERATURE CONCERNING MODE OF EXPRESSION

	Mode of Expression			
	pictorial		non-pictorial	
	realistic picture	schematic picture	abstract shape	word or number
Arnheim 1969	realistic	stylized	non-mimetic	
Bowman 1968	objective	associative	conventional	-
Richards 1984	figurative	semi-figurative	non-figurative	
Bertin 2001	figurative image		non-fig. image	word
Horn 1998	image		shape	word
Twyman 1979	pictorial		schematic	ver-bal/numerical
Krampen 1965	pictograph		diagram	phonogram
MacEachren 1995	mimetic		arbitrary	
Various authors	iconic		symbolic	
Tufte 1983	picture			word, number

FIGURE **3-18**: A comparison of terminology used in the literature to describe mode of expression.

Let us take a brief look at several of the distinctions that are summarized in the table in figure 3-18.

Bowman (1968 pp. 30-33) distinguishes 'objective' figures (*realistic pictures*), 'associative' figures (*schematic pictures*), and 'conventional' figures (*abstract shapes*). He offers a fourth category - 'abstract' figures - which, he says, represent information "in terms of pure visual logic". From the examples that Bowman shows, we can conclude that his 'abstract' figures are graphic representations that express *conceptual structures* (see section 3.1.1) through the *graphic relations* between several *graphic objects*.

Richards' 'mode of depiction' is concerned with the degree of schematization that is involved in the depiction of an object (Richards 1984, p. 7/6). Mode of depiction may be 'figurative, semi-figurative or non-figurative'. A *figurative* element is high in pictorial detail, a *semi-figurative* element is schematized to a certain degree, and a *non-figurative* element is highly schematized (Richards 2002, p. 93). Without the aid of captions, context or conventions, we are unlikely to recognize what is represented by a non-figurative element (Richards 1984, p. 10/8).

Horn (1998) uses the appealing simple terms 'image', 'shape' and 'word', see figure 3-19.

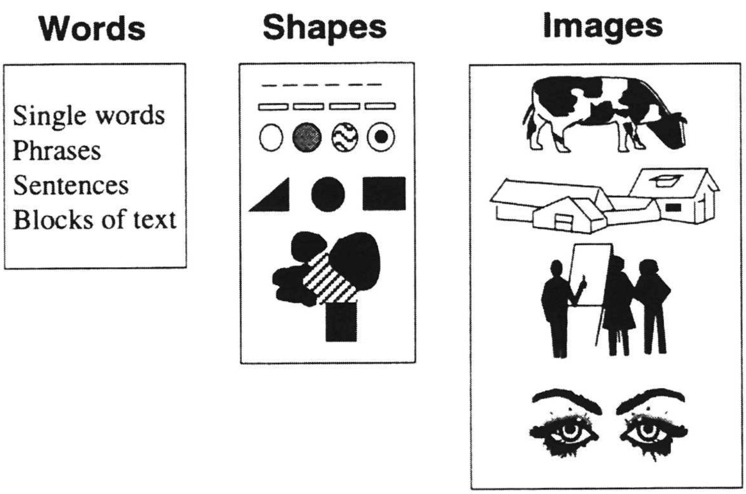


FIGURE 3-19: Horn's division into 'image', 'shape', and 'word'.
SOURCE: Horn 1998, p.91.

Twyman (1979) offers a "schema for the study of graphic language" in the form of a matrix. He refers to our mode of expression as 'modes of symbolization', distinguishing four possibilities: *pictorial, schematic, verbal/numerical,* and combinations of pictorial *and* verbal/numerical.

Tufte distinguishes *words, numbers,* and *pictures,* where 'pictures' includes abstract shapes (Tufte 1983, pp. 10, 180).

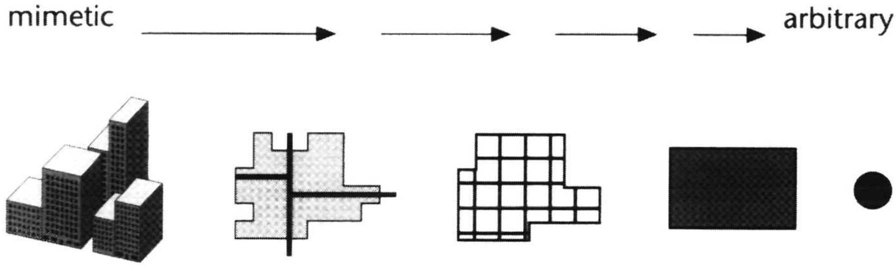


FIGURE 3-20: Continuum from 'mimetic' to 'arbitrary'. SOURCE: MacEachren 1995, p. 259, adapted from Robinson and Petchenik 1976.

MacEachren (1995, pp. 257-269) discusses 'iconicity' as a continuum from 'mimetic' to 'arbitrary' signs (see figure 3-20). This continuum corresponds to our continuum of *pictorial schematization* from *realistic pictures* to *schematic pictures*, extended at the schematic end to include our *non-pictorial, abstract shapes*. However, MacEachren notices the shortcomings of such a one-dimensional approach to 'iconicity' and struggles with problems such as "Where does metaphorical or metonymic correspondence fit in?" (MacEachren 1995, p. 262), and the related question of how to compare the 'iconicity' of a schematically rendered 'direct sign' with a realistically rendered 'indirect sign' (MacEachren 1995, p. 263), where 'direct' versus 'indirect' seems to refer to our *literal* versus our *non-literal*. These issues can be sorted out and clarified by *distinguishing* between what we are calling the *mode of expression* of a graphic object on one hand, and what we are calling the *type of correspondence* that the graphic object is involved in, on the other hand. We will now examine the relationship between these two.

RELATIONSHIP BETWEEN MODE OF EXPRESSION AND TYPE OF CORRESPONDENCE

In the previous subsection, we have discussed type of correspondence. We will now examine the relationship between a graphic object's mode of expression and its type of correspondence.

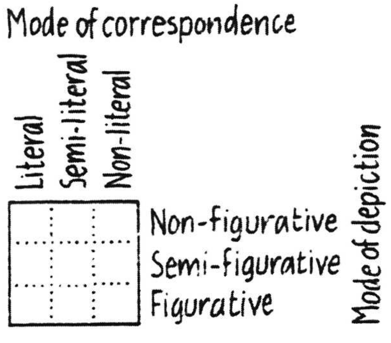


FIGURE **3-21**: According to Richards, type of correspondence on one hand and mode of expression on the other hand are two independent phenomena (referred to by Richards as 'mode of correspondence and 'mode of depiction'). I believe that the category in the upper left corner (literal and non-figurative) is contradictory. See below for a discussion of this issue.
SOURCE: Richards 1984, p. 8/1.

According to Richards (1984) mode of expression and type of correspondence are two independent phenomena (see figure 3-21). Assessing the literalness of a *pictorial* graphic object ('figurative' in Richards' terminology, e.g. a little drawing of a machine), he judges the object *by itself*, disregarding the arrangement of several of these objects with regard to each other. This is indeed what we would expect for the assessment of the literalness of objects. However, when trying to assess the literalness of a *non-pictorial* object ('non-figurative' in Richards' terminology, e.g. a single station marker in the London Underground diagram), Richards runs into a problem: There is no resemblance to any obvious primary physical referent. Without making this explicit, Richards then basically disregards the object itself. Instead, he looks at the literalness of the *arrangement* of several of these objects with regard to each other, in order to come up with a 'literalness-judgment' for that object. This aspect of Richards' approach seems to be inconsistent.

As opposed to Richards, I would claim that the concept of graphic objects that are literal and at the same time non-pictorial (Richards: 'literal and non-figurative'), is contradictory: As soon as a graphic object (e.g. a circle or a triangle) is interpreted as involving *literal* correspondence - in other words if it is interpreted as depicting a physical object (e.g. the circle as depicting the moon, or the triangle as depicting a mountain peak) - it is *pictorial*. See the table in figure 3-22 for an overview of the relationship between mode of expression and type of correspondence.

Mode of Expression:	**Type of Correspondence:**	
	literal	**non-literal**
pictorial	**literal pictures** (what is shown is what is meant) - Richards: literal and figurative - Robinson et al.: pictorial - Strothotte: presentational - Commonly used term: **iconic**	**metaphoric, metonymic, rebus-based and arbitrary-conventional pictures** - Richards: non-literal and figurative - Robinson et al.: associative
non-pictorial	(a contradictory category) - Richards: literal and non-figurative	**abstract shapes** (also words, numbers) - Richards: non-literal and non-figurative - Robinson et al.: geometric - Strothotte: abstract-graphical - Commonly used term: **symbolic**

FIGURE 3-22: Relationship between a graphic object's type of correspondence and its mode of expression. For examples, see figure 3-23.

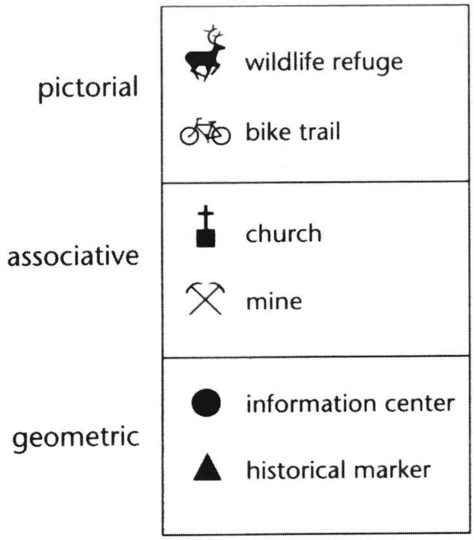


FIGURE 3-23: Robinson et al.'s three categories of symbols correspond to three of the four quadrants in our table on the previous page - figure 3-22: 'pictorial' to our upper left quadrant, 'associative' to our upper right quadrant, and 'geometric' to our lower right quadrant.
SOURCE: MacEachren 1995, p. 258, derived from Robinson et al. 1984.

'ICONIC VERSUS SYMBOLIC' DISTINCTION IGNORES NON-LITERAL PICTORIAL GRAPHIC OBJECTS

While Richards proclaims type of correspondence and mode of expression as *two independent dimensions,* other approaches do exactly the opposite by treating the two as *one single dimension,* often using the terms 'iconic' and 'symbolic' for the two poles of such a dimension.

A commonly made distinction divides visual signs into 'iconic' signs and 'symbolic' signs. This distinction probably originates from Peirce's 'icon-index-symbol' trichotomy, although it does not follow Peirce's original broad concept of 'iconic'. Peirce used the term 'iconic' in the sense of 'isomorphic', which includes structural analogy (see subsection 3.1.6). Many authors use the term 'iconic' in the narrower sense of 'showing the visual appearance of what is represented'. In our terminology such 'iconic' signs are *pictorial, literal* graphic objects. On the other hand, signs that are commonly referred to as 'symbolic' are usually defined in the sense of 'abstract and based on convention'. In our terminology such 'symbolic' signs are *non-pictorial, arbitrary-conventional* graphic objects. An application of this dichotomy is the classification by Strothotte and Strothotte (1997) into "presentational" pictures and "abstract-graphical" pictures. According to Strothotte and Strothotte, "presentational" pictures are "dominated by iconic signs", where an "iconic sign" is "a sign that resembles what it stands for" (Strothotte and Strothotte, 1997 p. 51). "Abstract-graphical" pictures on the other hand are "dominated by symbolic signs", where "symbolic signs" are "geometric primitives, arrows, lines, or text labels", or mappings of "invisible properties onto visible attributes" (Strothotte and Strothotte 1997, p. 46). This simple dichotomy between 'iconic' and 'symbolic' would work well if pictorial signs would always stand for what they depict, and if arbitrary-conventional signs would always be non-pictorial. The fact is however, that many pictorial signs do *not* stand for what they depict. In addition, arbitrary-conventional signs may be non-pictorial as well as pictorial. As we have seen, many pictorial graphic objects are based on *metaphor, metonymy,* or *arbitrary convention*. Think for example of a pictogram of a wine glass standing for 'fragile object' (metaphor), of the pictograms of human figures on signs for bathrooms (metonymy), or of the elephant standing for the Republican Party (arbitrary convention). All these symbols fall *outside* the 'iconic' versus 'symbolic' distinction. They are not 'iconic' because they do not stand for the object that they show, and they are not 'symbolic' because they are pictorial.

Finally let me note that a *non-pictorial* symbol (which is always non-literal, see the table in figure in 3-22) usually involves *arbitrary-conventional* correspondence. Sometimes however, *metaphoric* connotations of an abstract shape may play a role, such as a round shape standing for harmony (described by both Arnheim and Horton). Some *color*-coding systems could possibly be regarded as involving both metaphoric and a metonymic correspondence. For example, one might argue that *red* as a color for warning and danger involves a *metaphoric* correspondence between a dangerous object or situation on one hand, and glowing fire or blood on the other hand. Representing these objects (glowing fire or blood) by their red color could be regarded as involving *metonymic* correspondence.

3.3 Informational Roles of Graphic Objects

In Chapter 2 we noted that, regarding the *structure* of a graphic representation, the graphic sub-objects of a composite graphic object can play different *syntactic* roles. In this section we will look at the fact that, regarding the *interpretation* of a graphic representation, the graphic sub-objects of a composite graphic object can play different *informational* roles. Concerning such **informational roles** of graphic objects, we propose to divide graphic objects into *information objects*, *reference objects* (e.g. legends, labeled axes, grid lines), and *decoration objects.*

Information objects are the graphic objects that would have to be adjusted if the *information* (data) that one intends to represent would change. Examples of information objects are the bars in a bar chart or the shaded areas on a weather map that show the regions where it is expected to rain the next day.

Reference objects are the graphic objects that a) serve to enable the interpretation of information objects, and that b) would not necessarily have to be adjusted if the represented information (data) would change. Reference objects clarify the specific language or representation 'schema' (section 1.1) of the representation that they are part of. We can divide reference objects into *spatial reference objects* and *legend objects*:

- The function of **spatial reference objects** is to mark a *meaningful space.* Examples: Axes and their annotations, grid lines, familiar landmark features on thematic maps (e.g. towns and coastlines on a rainfall map). In the graphic multiple in figure 2-45, showing Los Angeles air pollution, the labeled map at the top is a spatial reference object.
- The function of **legend objects** is to explain symbols and/or visual attributes that are used in a graphic representation. Most legend objects are composite graphic objects, structured as a table with one column displaying (some of) the used symbols and/or visual attributes, and another column displaying a verbal or numerical explanation of their meaning. Example: The boxed composite graphic object in the lower right corner of the subway map in figure 2-32 is a legend object.

Decoration objects are graphic objects that serve neither as information objects nor as reference objects, and that could be erased without affecting the intended representation of data (information). They serve as embellishment, and may or may not be related to the context and theme of the represented information. In some cases a graphic object that seems to be a decoration object at first glance, may actually be regarded as an information object or a reference object, because it provides important contextual information.

As an illustration of informational roles note that in a standard classic clock face there are only two *information* objects: the two arms of the clock. The remaining objects such as tick marks (for hours and possibly minutes) and numerals are all *reference* objects.

The informational roles described above apply to graphic objects in their entirety. Separate *visual attributes* of graphic objects (e.g. shape, texture, color) can also be classified concerning their informational roles, as either **informative** or **decorative** visual attributes.

A LOOK AT THE LITERATURE: EMPHASIS ON INFORMATION OBJECTS

> "A warning seems justifiable that the background of a chart should not be made any more prominent than actually necessary. Many charts have such heavy co-ordinate ruling and such relatively narrow lines for curves or other data that the real facts the chart is intended to portray do not stand out clearly from the background. No more co-ordinate lines should be used than are absolutely necessary to guide the eye of the reader and to permit an easy reading of the curves."
>
> *Willard C. Brinton (1914, p. 346)*

> "Since the grid is simply a frame of reference, it should be visually subordinated so that the trend curve can be clearly distinguished". *Bowman (1968 p. 49)*

A 'curve' as mentioned in these quotes is an information object, while a 'coordinate ruling' or 'grid' is a reference object. Most authors advise to *minimize* spatial reference objects and decorative objects.

Bertin: Subject matter versus reference elements
Concerning the visible marks in a graphic, Bertin makes the distinction between what he calls *subject matter* and *reference elements* (Bertin 1983, pp.175, 180-181, 190). The *subject matter* consists of the elements "which constitute the information", also referred to by Bertin as the "content" of the graphic or the "meaningful marks". The *reference elements* or *reference components* on the other hand are the "background", also referred to by Bertin as the "meaningless marks". The subject matter is "figure" while the reference elements are "ground".

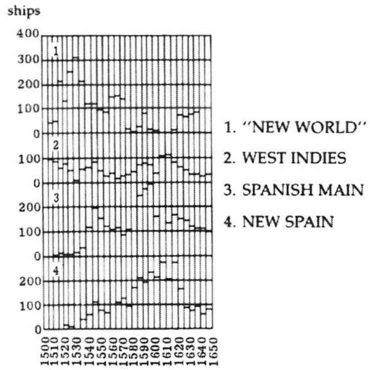
Bertin notes the importance of separating the subject matter from the background. In this context Bertin talks about the "total amount of black" in a graphic, and about the "portion of black" that is devoted to reference elements rather than to subject matter. To increase legibility, Bertin calls for "a reduction in the visibility of the background" (the reference elements) and "an increase in the visibility of the subject matter" (Bertin 1983, p.181). See Bertin's illustration that is reproduced here as figure 3-24. To demonstrate his point, Bertin first separates a graphic (first row of the figure) into reference objects and information objects (second row). He then *reduces* the amount of black (visibility) of the reference objects, and *increases* the amount of black (visibility) of the information objects (third row). He finally rejoins reference elements and subject matter (fourth row).

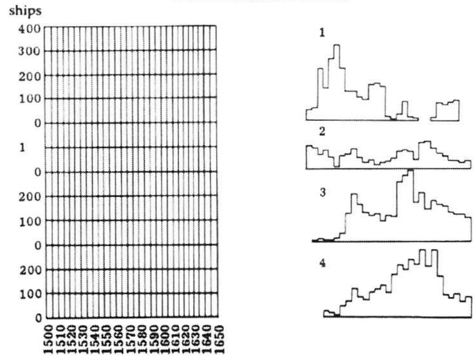
Tufte's 'data-ink ratio'

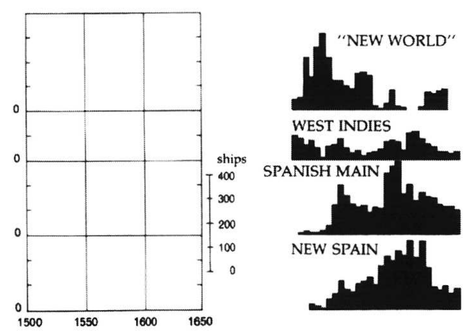
Tufte (1983, 1990) makes beautiful books in which he propagates the use of more ink for what we call *information objects*, and less ink for what we call *reference objects* and *decoration objects*, resulting in a high 'data-ink ratio'. He basically says the same as Bertin, but uses other words.

Tufte divides the total ink used in a graphic into *data*-ink and *non-data*-ink. Data-ink is the portion of the graphic's ink that displays the actual data. For example in a scatter plot, the axes and the grid are *non-data*-ink, while the dots marking the measurements are *data*-ink. The *data-ink ratio* is the ratio of data-ink to total ink. Tufte's design principle of increasing the data-ink ratio basically means reducing the amount of non-data-ink. In the course of striving for high data-ink ratios, Tufte introduces several related concepts:

- *De-gridding* - making reference grids less prominent - is one way to increase the data-ink ratio.
- In more general terms, a way to increase the data-ink ratio is to emphasize the figure and to de-emphasize the ground.
- *Chartjunk* is Tufte's term for the presence of a lot of non-data-ink, such as decoration objects and heavy grids. Chartjunk has a low data-ink ratio.







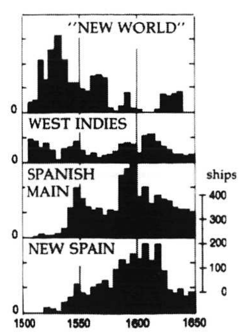


FIGURE 3-24: From top to bottom: A redesign as proposed by Bertin, reducing the visibility of the background (left side), and increasing the visibility of the subject matter (right side). SOURCE: Bertin 1967/1983, p. 181.

	Informational Roles			
	information object	reference object		decoration object
		spatial reference object	legend object	
Bertin 1967	subject matter	background	-	-
Wilkinson 1999	-	guides		-
Tufte 1983	data-ink	non-data ink		

FIGURE 3-25: A comparison of terminology that is used in the literature, and in this thesis, to describe different *informational roles* of graphic objects.

3.4 Type of Represented Information

The various graphic means that we have discussed in Chapter 2 tend to be used in certain typical ways. For example, different *quantities* of something are often expressed by different *sizes* (such as in a bar chart), while different *categories* of something are often expressed by different *colors* (often explained in a legend). Quantities and categories are different types of information. Types of information and the appropriate graphic means for representing them have been extensively examined and discussed in the existing literature. These aspects of graphic representation are *not* a focus of this thesis, so the few general remarks in this very brief section serve merely as pointers to these issues, included for the sake of completeness.

The most-cited author regarding types of information and their matching to appropriate graphic means is Jacques Bertin (1967/1983, 1977/1981, 2000/2001). Many authors who write about the use of visual attributes in graphic representations explicitly refer to Bertin's work as their basis (e.g. Richards 1984, p. 8/5; MacEachren 1995, p. 270; Card, Mackinlay and Shneiderman 1999, pp. 26-30; Wilkinson 1999, p. 118). The common main distinction that is made concerning types of information is into *nominal, ordinal* and *quantitative* information (quantitative information is also referred to as 'numerical', 'interval' or 'ratio'). A nominal attribute concerns *categories*, an ordinal attribute concerns a *ranking*, and a quantitative attribute concerns *quantities.* The table in figure 3-26 shows which visual attributes are generally considered appropriate for representing which types of information. For a brief discussion of visual attributes see section 2.4 of this thesis.

In the existing literature most attention concerning the matching of information to graphic means has concentrated on the use of *attribute-based relations* such as variations in size or color. Concerning the use of *spatial relations,* such as separation by a separator or arrangement along a metric axis, some considerations can be found in Tversky's work (1995, 2001). The table in figure 2-35 of this thesis gives an overview of which kinds of spatial structures express which types of information. For example, separation by a separator usually expresses *nominal* information, while arrangement along a metric axis expresses *quantitative* information.

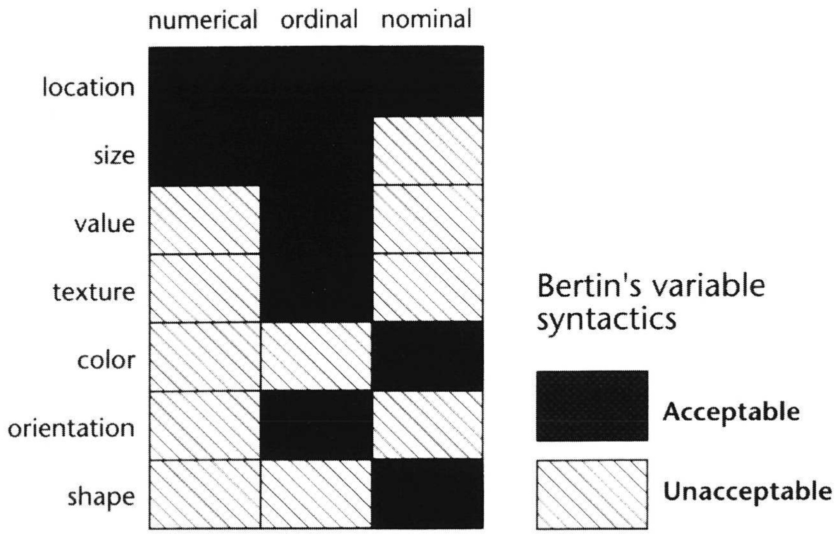


FIGURE 3-26: This table shows which visual attributes (shown at the left) are generally considered appropriate for representing which types of information (shown at the top). SOURCE: MacEachren 1995, p. 272, derived from Bertin 1967/1983.

Two additional kinds of distinctions that can be made regarding type of represented information are the distinction of concept-to-*attribute* relationships versus concept-to-*concept* relationships, and the distinction of *physical* structures versus *conceptual* structures:

- Nominal, ordinal and quantitative information involves concept-to-*attribute* relationships. Concept-to-*concept* relationships are relationships that can be expressed graphically through linking by connectors.
- The distinction between the representation of *physical* structures and the representation of *conceptual* structures is discussed in subsection 3.1.1.

This very brief summary concerning types of information that can be expressed in graphic representations brings us to the end of this chapter. In the next chapter we will discuss the classification of graphic representations.

CHAPTER 4

Classification of Graphic Representations

Various proposals can be found in the literature concerning **classifications** of graphic representations. Although both the exact way of categorizing as well as the terminology that is used are always different, it is nevertheless possible to identify certain distinctions that tend to be made when graphic representations are divided into different types.

The main criteria in most existing classifications of graphic representations seem to be based on combinations of:

- the type of *syntactic structure* that is involved in the representation, and
- the type of *information* that is expressed in the representation.

The concepts proposed in this thesis can serve to give a principled description of commonly distinguished types of graphic representation. The full list of types of graphic representation that we are proposing here consists of:

- ten **primary** types: *map, picture, statistical chart, time chart, link diagram, grouping diagram, table, (composite) symbol, written text,* and
- six **hybrid** types: *statistical map, path map, statistical path map, statistical time chart, statistical link diagram,* and *chronological link diagram.*

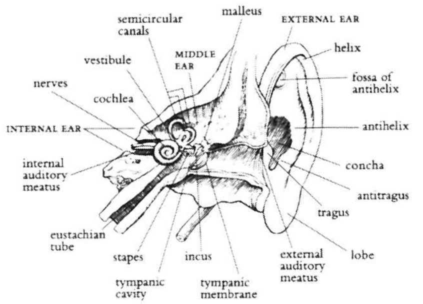
The figure captions of all example figures contained in this thesis (the boxed figures) include, as their last item, a classification of the concerned figure regarding these types of graphic representations. In this chapter we will first give brief descriptions of the proposed *primary* types, then discuss the proposed *hybrid* types, and finally examine and compare classifications of graphic representations that can be found in the literature.

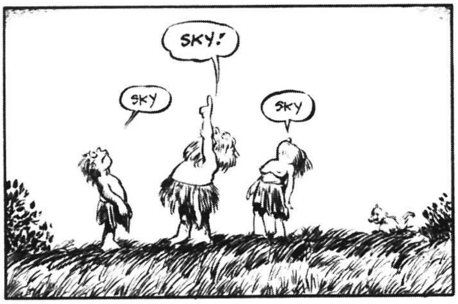
PRIMARY TYPES OF GRAPHIC REPRESENTATION

We will now look at the characteristics of each of the proposed *primary* types of graphic representation.

A **map** is a graphic representation in which the syntactic structure is based on an *integral metric space* (see subsection 2.5.2) that serves to represent a physical arrangement on a geographical surface. This integral metric space may be *distorted*, involving a more or less *literal* correspondence to the represented physical arrangement. The graphic objects that a map consists of are usually free in their *mode of expression*: they may be *non-pictorial* - such as abstract shapes as symbols for cities, and words or numbers as labels - or *pictorial* - such as pictorial symbols. Examples of maps (figures 3-12 and 2-28):

A **picture** is a graphic representation in which the syntactic structure is based on an *integral metric space* (see subsection 2.5.2) that serves to represent the physical structure of physical objects. Like in a map, the integral metric space of a picture may be *distorted*, involving a more or less *literal* correspondence to the represented physical structure. While the graphic objects that a map consists of are usually free in their mode of expression, the main graphic objects that a picture consists of involve a *pictorial mode of expression* (*realistic* or *schematic*). However, a picture may also include *labels*, which are free in their mode of expression. Examples of pictures (figures 2-16 and 3-11):

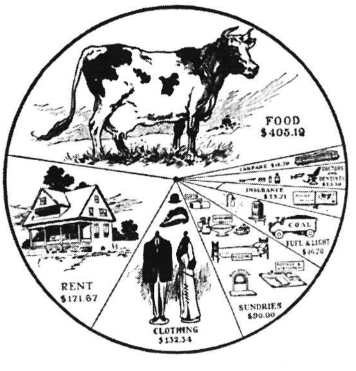


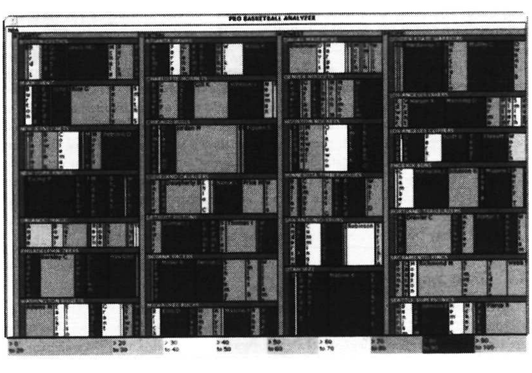


A **statistical chart** is a graphic representation in which the syntactic structure serves to show (and allows to compare) quantities. In order to do this, such a syntactic structure uses:

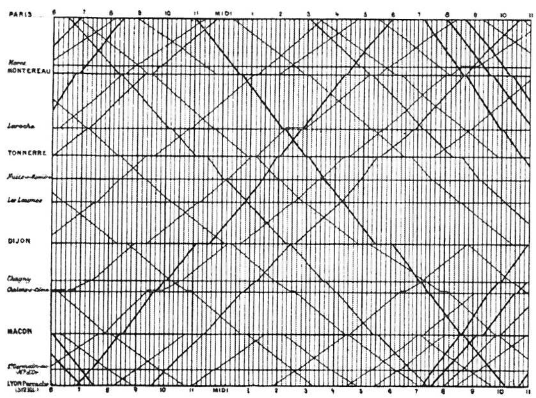
- *metric axes* (see subsection 2.5.2), such as in a two-axis chart, and/or
- *proportional division* of graphic objects (see section 2.4), such as in a pie chart, and/or
- variations in *visual attributes* (see section 2.4), such as variations of *size* or - much less precise in their interpretation - variations of *brightness*.

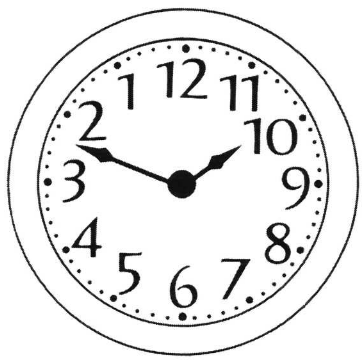
A statistical chart usually involves *metaphoric* correspondence.
Examples of statistical charts (figures 2-06 and 2-40):



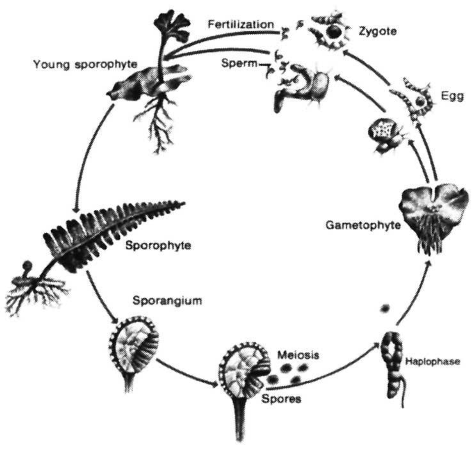


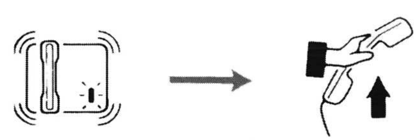
A **time chart** is a graphic representation in which the syntactic structure serves to show the passing of *time*. Such a syntactic structure may be an *ordered lineup* (subsection 2.5.1) or it may be based on a *metric axis* (subsection 2.5.2). A time chart involves *metaphoric* correspondence (order/length in graphic space stands metaphorically for order/length in time). According to Tufte, time charts are the most frequently used type of graphic representations (Tufte 1983, p. 28). Examples of time charts (figures 2-29 and 3-13):



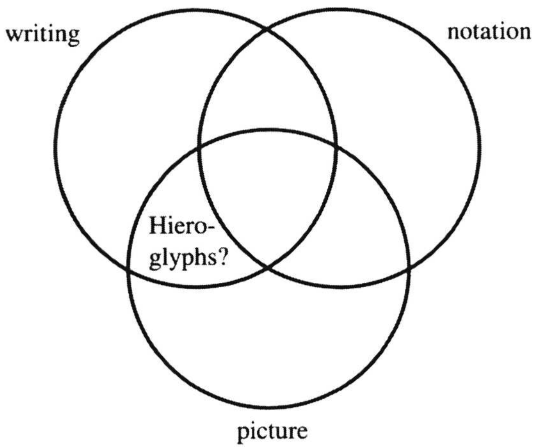


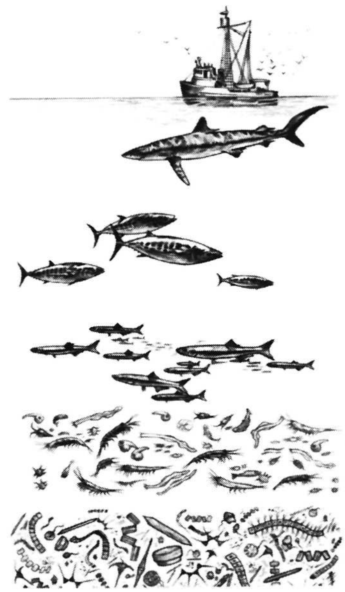
A **link diagram** is a graphic representation in which the syntactic structure consists of *linking*. Syntactic structures that consist of linking can be divided into *linear chains, circular chains, trees,* and *networks* (see subsection 2.5.1). Examples of link diagrams (figures 2-14 and 2-17):





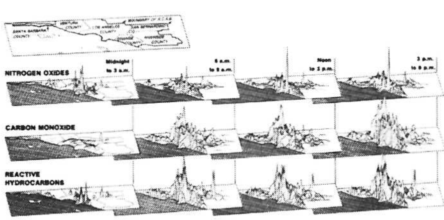
A **grouping diagram** is a graphic representation in which the syntactic structure serves to express the categorization of a set of elements. The syntactic structure of a grouping diagram may consist of a *spatial clustering*, of *separations by separators*, or of (overlapping) *containers* (all discussed in subsection 2.5.1). This type of representation involves 'grouping' in the sense proposed by Richards (1984). Examples of grouping diagrams (figures 2-18 and 2-08):



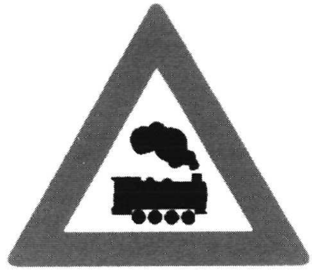


A **table** is a graphic representation in which the syntactic structure consists of a *simultaneous combination* of *horizontal separations* and *vertical separations* and/or of a *simultaneous combination* of *horizontal lineups* and *vertical lineups* (subsection 2.5.1). Examples of tables (figures 2-10 and 2-45):

Train No.	3701	XM 3301	3801	A 67	3 3803	3 3201	A3 51	3 3703	3 3807	3 3203	A3 61	3 3809	A3 47	3 3901
	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M	A M
New York, N.Y.	12 10	12 40	1 30	3 52	4 50	6 10	6 25	6 35	6 50	7 10	7 30	7 33	7 45	7 50
Newark, N.J. P	12 24	12 55	1 44	4 07	5 04	6 24	6 38	6 49	7 04	7 24	7 45	7 47	7 59	8 04
North Elizabeth										7 30				8 10
Elizabeth	12 31	1 03	1 51		5 11	6 31		6 56	7 11	7 32		7 54		8 13
Linden	12 36		1 56		5 16	6 36		7 01	7 15	7 37		7 59		8 18
North Rahway								7 03		7 39				8 20
Rahway	12 40	1 11	2 00		5 20	6 40		7 06	7 20	7 42		8 03		8 24
Metro Park (Iselin)	12 44		2 04	4 26	5 24		6 56	7 10	7 25		8 04	8 07	8 15	
Metuchen	12 48		2 08		5 28			7 14	7 29			8 11		
Edison	12 51		2 11					7 17	7 32			8 14		
New Brunswick	12 55		2 15		5 35		7 05	7 21	7 35			8 18	8 25	
Jersey Avenue	1 02		2 18					7 28				8 21		
Princeton Jct. S			2 31		5 50		7 19		7 50			8 34	8 41	
Trenton, N.J.			2 42	4 58	6 03		7 28		8 01		8 31	8 44	8 52	



A **symbol** is a graphic representation that is either an *elementary graphic object* (section 2.3) or a *composite symbol* (subsection 2.5.1). Examples of symbols (figure 3-04 and an outdated traffic sign):



A **written text** is a graphic representation in which:

- the *syntactic structure* of the representation is a *lineup,*
- the *graphic objects* represent expressions in an existing human language, and
- the *linear ordering* within the lineup is determined by the sentential grammar of that language.

See section 3.2 for a discussion of written text. An example of a written text is what you are reading right now.

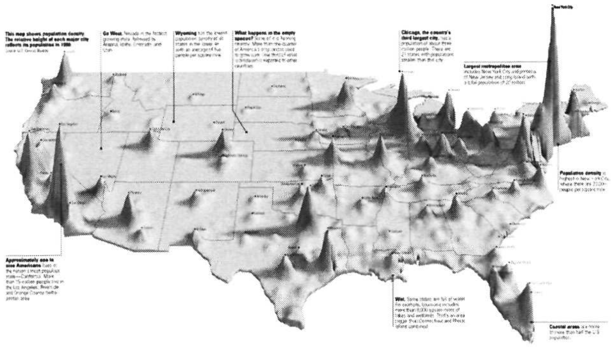
HYBRID TYPES OF GRAPHIC REPRESENTATION

Some types of graphic representation are *simultaneous combinations* of the primary types described above. See the table in figure 4-01.

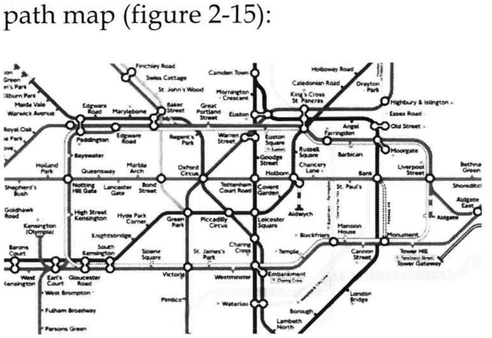
	statistical chart	link diagram
map	statistical map	path map
time chart	statistical time chart	chronological link diagram

FIGURE **4-01**: Some combinations of primary types of graphic representation, resulting in hybrid types.

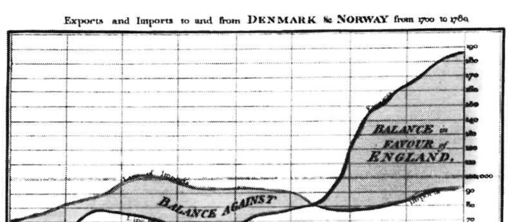
A **statistical map** is a representation that qualifies both as a *statistical chart* and as a *map* (a *map* that displays *quantities*). Example of a statistical map (figure 2-30):

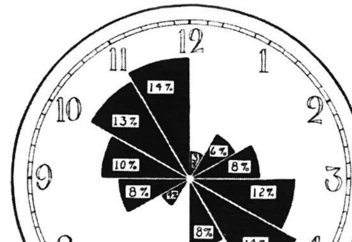


A **path map** is a representation that qualifies both as a *link diagram* and as a *map*. Example of a path map (figure 2-15):

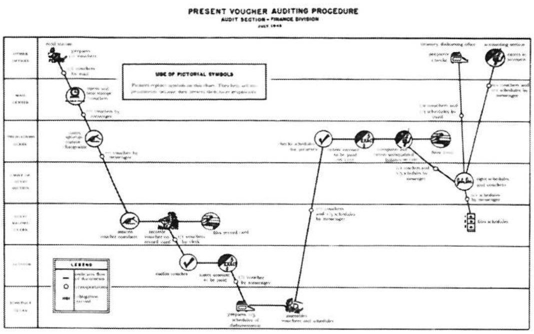


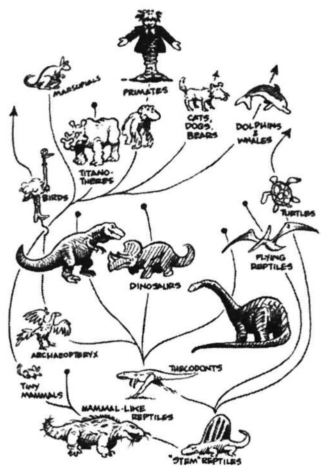
A **statistical time chart** is a representation that qualifies both as a *statistical chart* and as a *time chart*. Examples of statistical time charts (figures 2-25 and 2- 27):



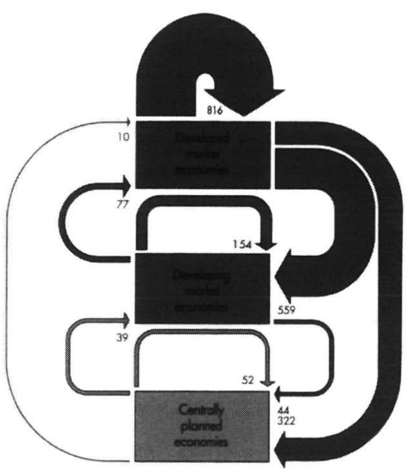


A **chronological link diagram** is a representation that qualifies both as a *link diagram* and as a *time chart* (e.g. family tree). Examples of chronological link diagrams (figures 2-38 and 2-31):

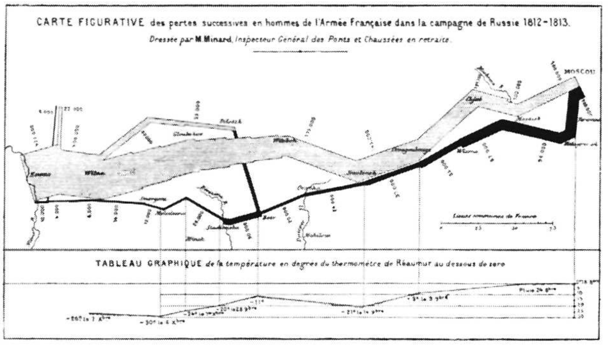




A **statistical link diagram** is a representation that qualifies both as a *statistical chart* and a *link diagram* (e.g. quantitative flows are represented by the thickness of lines). Example of a statistical link diagram (source: Bounford 2000, p.111):



A **statistical path map** finally is a representation that qualifies both as a *path map* and as a *statistical link diagram*. Example of a statistical path map (figure 2-47):



A complex graphic representation may involve a *nesting* of one or more of the above listed types of graphic representation into each other. The nesting of graphic representations into a *multipanel display* - usually arranged as a *lineup* or a *table* - is quite common. Two special cases of such a nesting are the *shared-axis lineup* and the *graphic multiple* (see subsection 2.5.4).

A LOOK AT THE LITERATURE CONCERNING CLASSIFICATIONS OF GRAPHIC REPRESENTATIONS

<table>
<tr><th>Categories proposed here:</th><th>Richards 1984 (3 categories)</th><th>Holmes 1993 (3 categories)</th><th>Kosslyn 1994 (4 categories)</th><th>Bertin 1967 (4 categories)</th></tr>
<tr><td>symbol</td><td>symbol</td><td>-</td><td>-</td><td>symbol</td></tr>
<tr><td>picture</td><td>pictorial illustration</td><td>diagram</td><td>diagram</td><td>-</td></tr>
<tr><td>map</td><td rowspan="6">diagram</td><td rowspan="2">map</td><td rowspan="2">map</td><td rowspan="2">map</td></tr>
<tr><td>statistical map</td></tr>
<tr><td>link diagram</td><td rowspan="3">chart</td><td>chart</td><td>network</td></tr>
<tr><td>statistical chart</td><td>graph</td><td rowspan="3">diagram</td></tr>
<tr><td>time chart</td><td rowspan="2">-</td></tr>
<tr><td>table</td><td>-</td></tr>
</table>

FIGURE 4-02-A: Some existing classifications of graphic representations. Continued on next page.

Categories proposed here:	Tufte 1983 (5 categories)	Bounford 2000 (8 categories)	Lohse et al 1994 (11 categories)
symbol		symbol	icon
picture	-	pictorial diagram	picture, structure diagram, process diagr.
map			map
statistical map	data map	relational diagram	cartogram
link diagram	-	organizational diagram	network chart
statistical chart	relational graphic	graph, chart	graph
time chart	time series, narrative of space and time	time diagram	time chart
table	table	table	table, graphic table

FIGURE 4-02-B: Some existing classifications of graphic representations. Continued from previous page.

The table in figure 4-02 (split in figure 4-02-A and 4-02-B) shows that eight of the sixteen types of graphic representations that are proposed here can serve as a common denominator for existing classification systems. In addition, the classification proposed here offers discrete categories of very common representations for which most existing classifications have overlapping categories. *Statistical time charts* for example - the most common type of quantitative graphics - have to be classified *either* as 'statistical charts' *or* as 'time charts' in most existing classification systems, probably depending on whether their quantitative aspect or their chronological aspect appears more dominant. Likewise, *chronological link diagrams* - such as family trees and work flow diagrams - have to be classified *either* as 'networks' (*link diagrams*) *or* as 'time charts' in most existing classification systems, ignoring their dual nature.

We will conclude this section by taking a brief look at the classifications proposed by Bertin, by Tufte, and by Richards.

Bertin's classification of graphic representations is shown in figure 2-36 of this thesis. First of all, Bertin makes a distinction between *graphics* and *pictography* (Bertin 1981, p.176). Pictography is concerned with the design of *symbols*. The aim of a symbol is to "*define a set* or a concept". The aim of *graphics* on the other hand is to make "*relationships* among previously defined sets appear".

Concerning *graphics*, Bertin distinguishes between *diagrams*, *networks*, and *maps*. This classification depends on the nature of the correspondences that are expressed on the plane. When the correspondences on the plane can be established:

- between all the elements of one information component and all the elements of *another* information component, the construction is a *diagram*. In other words, a diagram transcribes the relationships between two sets of elements. (Bertin 1981, pp. 192, 230; Bertin 1983, pp. 8, 50, 193.)
- among all the elements of the same information component, the construction is a *network*. In other words, a network transcribes the relationships within a single set of elements. (Bertin 1981, pp. 192, 232; Bertin 1983, pp. 8, 50, 269.)
- among all the elements of the same information component, arranged according to the actual arrangement of elements in physical space, the construction is a *map* (sometimes referred to by Bertin as a *topography*). (Bertin 1981, pp.192, 232; Bertin 1983, pp. 8, 51, 285.)

In summary, Bertin divides graphic representations into four groups: diagrams, networks, maps, and symbols. See figure 4-02-A.

Tufte distinguishes four 'fundamental graphical designs': *data maps, time series, narratives of space and time,* and *relational graphics* (Tufte 1983, pp. 15-50). Tufte does not mention this explicitly, but this classification seems to be based on whether or not graphic space is used to represent *physical space* and whether or not graphic space is used to represent *time*. If this is true, then the four possible combinations would be: space, time, both space and time, and neither space nor time (see table in figure 4-03). These four possibilities match with Tufte's classification. In addition to these four fundamental graphic designs, Tufte discusses tables, which he does not regard as graphics (1983, pp. 178-181 and 1990, pp. 104-105).

		graphic space represents **physical space**	
		yes	no
graphic space represents **time**	yes	narrative of space and time	time series
	no	data map	relational graphic

FIGURE **4-03**: Our arrangement of Tufte's four 'fundamental graphical designs' into a table.

Richards makes a distinction between *pictorial illustrations, symbols* and *diagrams* (Richards 1984, pp. 1/1, 10/1, and 2002, pp. 85-86). *Pictorial illustrations* "show physical appearances". *Symbols* "indicate a presence or act as pointers". *Diagrams* "exhibit relationships". See figure 4-02-A.

This rounds up our discussion of the classification of graphic representations. The next chapter will provide a brief overview of the various concepts from existing graphic theories, and describe how these concepts fit into the framework that is proposed in this thesis.

CHAPTER 5

Analyzing Graphic Representations and Graphic Theories

5.1 Analysis of Graphic Representations

Now that we have completed the discussion of the proposed framework, we can apply it by 'trying it out' on example specimen of graphics. We claim that we can provide any graphic representation with an analysis in terms of the framework. Instead of grouping such example analyses here in this section, we have decided to distribute these throughout the thesis. In other words, all 'boxed' example figures in the thesis have been provided with a figure caption that follows a standardized analysis scheme, applying the proposed framework. A visual overview of the figures is given in the Figure Index towards the end of the thesis.

The standardized figure caption starts with a brief description of **What is shown** by the figure, followed by a note on the **Source** of the figure, and a **Comment**, which serves to point out some specific aspect of the figure. This is followed by a standardized analysis scheme, which includes three main items:

- **Syntax of spatial structure**: a brief analysis of the figure in terms of the concepts presented in the section on 'Syntactic structures' (2.5).
- **Type of correspondence**: a brief analysis of the figure, usually split into 'Spatial structure' and 'Visual attributes', in terms of the concepts presented in the section on 'Type of correspondence' (3.1).

- **Type of graphic representation**: an assessment of the figure in terms of the general categories presented in the chapter on 'Classification of graphic representations' (4).

Most of the specific terms that are used in the figure captions can be looked up in the Glossary at the very end of this thesis.

5.2 Analysis of Graphic Theories

The framework that is developed in this thesis does not only enable the analysis of graphic representations, but it also enables the analysis and comparison of existing graphic theories.

In this section, 'terminology translations' are provided for various existing graphic theories, sorted alphabetically by author. The terms used by the concerned author are given between single quotes, and are translated into the corresponding terms from the framework developed in this thesis, which are given in *italics*. The latter terms can be looked up in three places in this thesis: in the Glossary, in the Subject Index, and in the (sub)sections that are given in parentheses after each 'translation'.

For most of the mentioned authors, brief discussions of their concepts can be found throughout the preceding chapters; see the separate Author Index towards the end of the thesis.

Some of the summaries below include a brief note concerning one or more concepts that seem to be missing in the context of the analysis proposed by the concerned author.

Arnheim (1969) makes a distinction between three possible functions that an image may have. It may be a 'picture', a 'symbol', or a 'sign':

- 'picture' ≈ a *literal* graphic object (3.1.1).
- 'symbol' ≈ a *metaphoric* graphic object (3.1.2).
- 'sign' ≈ an *arbitrary-conventional* graphic object (3.1.5).

Missing concept in this context: a *metonymic* (3.13) graphic object.

Arnheim also discusses the 'abstraction level of the image':

- 'realistic' ≈ *realistic* (3.2).
- 'stylized' ≈ *schematic* (3.2).
- 'non-mimetic' ≈ *abstract* (3.2).

Barthes (1965) distinguishes between 'iconic', 'motivated', and 'arbitrary' signs:

- 'iconic' signs ≈ *literal* (3.1.1) graphic objects.
- 'motivated' signs ≈ *metaphoric* (3.1.2), *metonymic* (3.1.3), and *rebus-based* (3.1.4) graphic objects.
- 'arbitrary' signs ≈ *arbitrary-conventional* (3.1.5) graphic objects.

Bertin (1967, 1977) is best known for his inventory and study of:
- 'visual variables' ≈ *visual attributes* (2.4).

Bertin divides graphic representations into four 'groups of imposition':
- 'map' ≈ *map* (4).
- 'diagram' ≈ *statistical chart* and/or *time chart* (4).
- 'network' ≈ *link diagram* (4).
- 'symbol' ≈ *symbol* (4).

Concerning the 'amount of black' in a graphic, Bertin makes a distinction between 'subject matter' and 'background':
- 'subject matter' ≈ *information objects* (3.3).
- 'background' ≈ *spatial reference objects* (3.3).

To show complex collections of data, Bertin promotes using a:
- 'collection of images' = a *graphic multiple* (2.5.4).

Bowman (1968) distinguishes different types of 'visual translation':
- 'objective' ≈ *realistic* (3.2).
- 'associative' ≈ *schematic* (3.2).
- 'conventional' ≈ *abstract* (3.2).
- 'abstract' ≈ a graphic representation that expresses a conceptual structure through *metaphoric* (3.1.2) *graphic relations* (2.1) between graphic objects.

Bowman also introduces the concept of:
- 'multi-plane space' ≈ a *graphic space* with several *visual layers* (2.2).

Card, Mackinlay and Shneiderman (1999) approach 'visual structures' as consisting of:
- 'spatial substrate' ≈ *graphic space* (2.2).
- 'marks' ≈ *elementary graphic objects* (2.3).
- 'graphical properties' ≈ *visual attributes* (2.4).

They distinguish four different 'types of axes':
- 'unstructured axis' ≈ an *unstructured dimension* (2.5.2).
- 'nominal axis' ≈ an *unordered lineup* or an *unordered separation* (2.5.1).
- 'ordinal axis' ≈ an *ordered lineup* or an *ordered separation* (2.5.1).
- 'quantitative axis' ≈ a *metric dimension* (2.5.2).

Concerning 'topological structure', Card et al. note two possibilities:
- 'connection' ≈ *linking* (2.5.1).
- 'enclosure' ≈ *containment* (2.5.1).

As special techniques for spatial encoding they briefly mention:
- 'composition' ≈ *simultaneous combination* (2.5.4) of orthogonal dimensions.
- 'alignment' ≈ *shared-axis multipanel* (2.5.4).
- 'recursion ' ≈ *nesting* (2.5.4) into a *separation* or a *lineup* (2.5.1).
- 'overloading' ≈ *nesting* (2.5.4) into a *metric space* (2.5.2).

Missing concepts in this context: *proportional division* (2.4), *proportional repetition* (2.5.1), *integral* versus *composite metric space* (2.5.2), *graphic multiples* (2.5.4).

Horn (1998) distinguishes three types of 'morphological elements of visual language':

- 'image' ≈ *pictorial object* (3.2).
- 'shape' ≈ *abstract shape* (3.2).
- 'word' ≈ *word* (3.2).

Concerning the arrangement of elements, Horn lists six types of 'topologies' or 'syntactical structures':

- 'proximity grouping' ≈ *spatial clustering* (2.5.1).
- 'network' ≈ *linking* (2.5.1).
- 'boundary' ≈ *separation by a separator* (2.5.1).
- 'concentric' ≈ *meaningful space* with a *radial* dimension (2.5.2).
- 'level' ≈ *horizontal separation* or *horizontal lineup* (2.5.1).
- 'matrix' ≈ *simultaneous combination* (2.5.4) of a *horizontal separation* and a *vertical separation* (2.5.1).

Missing concepts in this context: *metric axes* (2.5.2), *metric spaces* (2.5.2), *nesting* (2.5.4) and the possible *recursive nature* (2.1) of syntactic structures.

Knowlton (1966) distinguishes three 'parts' of a graphic representation - 'elements', their 'pattern of arrangement', and their 'order of connection':

- 'elements' ≈ *elementary graphic objects* (2.3).
- 'pattern of arrangement' ≈ positioning in *graphic space* (2.2 and 2.5).
- 'order of connection' ≈ *linking* (2.5.1).

Missing concepts in this context: other types of object-to-object relations such as *containment* (2.5.1).

According to Knowlton, each of the 'parts' mentioned above may be 'iconic', 'analogical', or 'arbitrary':

- 'iconic' ≈ *literal* (3.1.1).
- 'analogical' ≈ *metaphoric* (3.1.2).
- 'arbitrary' ≈ *arbitrary-conventional* (3.1.5, for graphic objects) or *arbitrary* (2.5, for graphic relations).

Missing concepts in this context: *metonymic* graphic objects (3.1.3).

Kosslyn (1994) divides graphic representations into four types:

- 'diagrams' ≈ *pictures* (4).
- 'maps' ≈ *maps* (4).
- 'charts' ≈ *link diagrams* (4).
- 'graphs' ≈ *statistical charts* (4).

He distinguishes two types of multipanel displays:

- 'pure multipanel display' = *graphic multiple* (2.5.4).
- 'mixed multipanel display' = *multipanel display* (2.5.4).

Krampen (1965) distinguishes three 'kinds of graphic signs':
- 'pictograph' ≈ *picture* (3.2).
- 'diagram' ≈ *abstract shape* (3.2).
- 'phonogram' ≈ *word* (3.2).

Lakoff (1987) proposes 'image schemata' which he believes play a crucial role in human cognition. These include:
- 'linear order schema' ≈ *lineup* (2.5.1).
- 'link schema' ≈ *linking by a connector* (2.5.1).
- 'container schema' ≈ *containment by a container* (2.5.1).
- 'front-back schema' ≈ *superimposition* (2.5.1).

Lohse et al. offer a classification of graphic representations into:
- 'graphs' ≈ *statistical charts* (4).
- 'time charts' ≈ *time charts* (4).
- 'network charts' ≈ *link diagrams* (4).
- 'maps' ≈ *maps* (4).
- 'cartograms' ≈ *statistical maps* (4).
- '(graphic) tables' ≈ *tables* (4).
- 'pictures', 'structure diagrams', and 'process diagrams' ≈ *pictures* (4).
- 'icons' ≈ *symbols* (4).

Missing concepts in this context: *grouping diagrams*, and *hybrids* of the listed types (e.g. *chronological link diagram, statistical time chart*) (4).

Peirce (1885, 1886, 1902), distinguishes different types of signs:
- 'icon', subdivided by Peirce into:
  - 'image' ≈ a *literal* graphic object (3.1.1).
  - 'metaphor' ≈ a *metaphoric* graphic object (3.1.2).
  - 'diagram' ≈ a representation that involves *metaphoric* (3.1.1) *graphic relations*.
- 'index' seems to be related to *metonymic* correspondence (3.1.3), but is possibly not applicable to intentional graphic representation.
- 'symbol' ≈ an *arbitrary-conventional* graphic object (3.1.3).

Richards (1984, 2000, 2002) approaches graphic representations as consisting of 'significant elements' and their 'relational features':

- 'significant element' ≈ *elementary graphic object* (2.3).
- 'relational feature' ≈ *graphic relation* (2.1).

Missing concepts in this context: *composite graphic objects* (2.1), *nesting* (2.5.4) and the possible *recursive nature* (2.1) of syntactic structures.

Richards analyzes graphic representations with regard to three 'modes of interpretation':

- 'mode of depiction' ≈ *mode of expression* (3.2).
- 'mode of organization' ≈ type of *graphic relations* (2.1).
- 'mode of correspondence' ≈ *type of correspondence* (3.1).

In Richards' approach, 'mode of depiction' and 'mode of correspondence' apply to 'significant elements', while 'mode of organization' applies to their 'relational features'.

Concerning possible **modes of depiction** for significant elements, Richards distinguishes:

- 'figurative' ≈ *realistic picture* (3.2).
- 'semi-figurative' ≈ *schematic picture* (3.2).
- 'non-figurative' ≈ *abstract shape* (3.2).

Concerning possible **modes of organization** for relational features of significant elements, Richards distinguishes:

- 'variation' ≈ *graphic relations* (2.1) that express *order* or *quantities* (3.4).
- 'linking' ≈ *linking* (2.5.1). Linking expresses *concept-to-concept relationships* (3.4).
- 'grouping' ≈ *graphic relations* (2.1) that express *categories* (3.4), e.g. relations of spatial *containment* (2.5.1).

Missing concept in this context: types of *metric spaces* (e.g. *integral* versus *composite metric spaces, graphic multiples, shared-axis multipanels*) (2.5.2, 2.5.4).

Concerning possible **modes of correspondence** for significant elements, Richards distinguishes:

- 'literal' ≈ *literal* (3.1.1).
- 'semi-literal' ≈ involving both 'literal' and 'non-literal' correspondence.
- 'non-literal' ≈ *metaphoric* (3.1.2), *metonymic* (3.1.3), *rebus-based* (3.14) or *arbitrary-conventional* (3.1.5).

Missing concept in this context: application of type of correspondence to *graphic relations* (not only 'significant elements', but also the 'grouping, linking, or variation' that is achieved by their 'relational features', can be 'literal' or 'non-literal').

Rogers (1989) distinguishes four types of 'icons':

- 'resemblance icon' ≈ *literal* graphic object (3.1.1).
- 'symbolic icon' ≈ *metaphoric* graphic object (3.1.2).
- 'exemplar icon' ≈ *metonymic* graphic object (3.1.3).
- 'arbitrary icon' ≈ *arbitrary-conventional* graphic object (3.1.5).

Strothotte and Strothotte (1997) (and many other authors) distinguish between 'iconic' signs (which 'resemble what they stand for'), and 'symbolic' signs (such as 'geometric primitives, arrows, lines, and text labels'):

- 'iconic' sign ≈ a *pictorial* (3.2), *literal* (3.1.1) graphic object.
- 'symbolic' sign ≈ a *non-pictorial* (3.2), *arbitrary-conventional* (3.1.5) graphic object.

Missing concept in this context: *pictorial* graphic objects (3.2) that involve *other* than literal correspondences (3.1.2- 3.1.5). The elephant for example that stands for the Republican Party - is it an 'iconic' sign or a 'symbolic' sign? See the discussion in section 3.2.

Tufte (1983, 1990, 1997) makes the distinction between 'data ink' and 'non-data ink':

- 'data ink' ≈ the ink used for *information objects* (3.3).
- 'non-data ink' ≈ the ink used for *reference objects* and *decorative objects* (3.3).

Tufte promotes 'layering and separation' and the use of 'small multiples':

- 'layering and separation' ≈ the use of *visual levels* (2.2).
- 'small multiples' ≈ *graphic multiple* (2.5.4).

Tversky (1995, 2001) approaches graphic representations as consisting of 'elements' and their 'spatial relations':

- 'elements' ≈ *elementary graphic objects* (2.3).
- 'spatial relations' ≈ *spatial relations* (2.5).

Concerning 'elements', Tversky lists 'general principles' of pictographs and symbols:

- 'straightforward' depictions ≈ *literal* graphic objects (3.1.1).
- 'synecdoche' or 'metonymy' ≈ *metonymic* graphic objects (3.1.3).
- 'rebus principle' ≈ *rebus-based* graphic objects (3.1.4).
- 'schematic' icons ≈ *schematic* graphic objects (3.2).
- 'conventionalized', 'arbitrary' depictions ≈ *arbitrary-conventional* graphic objects (3.1.2).

Missing concept in this context: *metaphoric* graphic objects (3.1.2).

Concerning 'spatial relations', Tversky examines 'spatial metaphors':

- 'spatial metaphor' ≈ *metaphoric* (3.1.1) *spatial relation* (2.5.1 and 2.5.2).

Missing concepts in this context: types of *metric spaces* (e.g. *integral* versus *composite metric spaces, graphic multiples, shared-axis multipanels*) (2.5.2 and 2.5.4), and, in general, *nesting* (2.5.4) and the possible *recursive nature* (2.1) of syntactic structures.

Twyman's (1979) 'schema for the study of graphic language' (1979) is a matrix that sets out two phenomena against each other:

- 'mode of symbolization' ≈ *mode of expression* (3.2)
- 'method of configuration' ≈ *syntactic structure* (2.5).

Concerning **mode of symbolization**, Twyman distinguishes:

- 'pictorial' ≈ *pictorial* (3.2).
- 'schematic' ≈ *abstract* (3.2).
- 'verbal/numerical' ≈ *word* and/or *number* (3.2).
- 'pictorial and verbal/numerical' ≈ *pictorial* combined with *word* and/or *number* (3.2).

Concerning **method of configuration**, Twyman distinguishes:

- 'pure linear' ≈ *lineups* (2.5.1).
- 'linear interrupted' ≈ *segmented lineups* (2.5.1).
- 'list' ≈ Twyman's examples for this category include simple *vertical lineups, lineups* of *lineups*, and simple *tables* (2.5.1).
- 'linear branching' ≈ *tree* structures of *linking* (2.5.1).
- 'matrix' ≈ *tables* (2.5.1), *bar charts* (2.5.2), and metric spaces that are composed of two orthogonal *metric axes* (2.5.4).
- 'non-linear directed' and 'non-linear open'≈ *arbitrary spatial structures* (2.5) and *integral metric spaces* (2.5.2).

Missing concepts in this context: *containment* (2.5.1), types of *composite metric spaces* (e.g. *graphic multiples, shared-axis multipanels*) (2.5.4), and, in general, *nesting* (2.5.4) and the possible *recursive nature* (2.1) of syntactic structures.

Wilkinson (1999) uses some non-standard terms:

- 'aesthetic attributes' ≈ *visual attributes* (2.4).
- 'guides' ≈ *reference objects* (3.3).
- 'facets' ≈ *graphic multiple* (2.5.4).

CHAPTER 6

Conclusions

In this thesis we have proposed a framework for parsing the syntactic structure of simple as well as complex information graphics (Chapter 2). In addition, this framework includes an examination of graphic interpretation (Chapter 3) and classification (Chapter 4), and can be used to analyze existing graphic theories (section 5.2). We have applied this framework to all example figures in the thesis, providing standardized analyses in the figure captions. The terminology of the proposed framework is summarized in the Glossary at the very end of this thesis.

We now briefly return to the aims and claims that we discussed in Chapter 1. These concerned the proposal of a *syntactic* approach, which is intended to be *comprehensive* and *unifying*, and which may apply in different *cultural contexts*.

A SYNTACTIC FRAMEWORK

We have offered a proposal for the syntactic decomposition of graphic representations that can be applied *recursively*. We gave an example of a nesting of four levels of decomposition, when describing the syntactic structure of figure 2-03. Different types of nested syntactic structures were discussed in subsection 2.5.4. We have proposed the notion of different *syntactic roles* that graphic objects may play within a syntactic structure - these syntactic roles were discussed in section 2.5.3. The notion of *meaningful space* was introduced, and distinctions were made between *integral metric spaces*, *composite metric spaces*, and *distorted metric spaces*. We have compared our approach to the related approaches that were proposed by Richards (1984) and Horn (1998), which are both more limited in their set of syntactic structures that they describe, and which neither discuss recursive nesting, nor the possible structures of metric spaces.

Coming up with a set of basic syntactic structures, from which composite syntactic structures can be constructed, did involve certain choices that had to be made. An example of such a choice is our approach to 'partitioned graphic spaces', which was discussed at the beginning of subsection 2.5.2.

A COMPREHENSIVE FRAMEWORK

The example figures that were analyzed cover a wide range of different types of graphics (see the Figure Index towards the end of this thesis for an overview). We have not yet come across an example of a graphic representation that could not be analyzed in terms of the proposed framework. This does not, of course, mean that we will not find such an example in the future.

A UNIFYING FRAMEWORK

So far it seems that nobody has mapped out in detail how the various terminologies of different graphic theories can be related to each other. We have taken up this challenge in the 'term comparison tables' and in the literature discussion at the end of most (sub-) sections, using the proposed framework as a 'common denominator' for the numerous concepts that have been proposed in the literature. In section 5.2, we have provided a brief overview of how many existing approaches to graphic theory can be 'translated' into the concepts of this framework. By 'translating' them into the terms of this framework, any two of the existing graphic theories can be compared to each other. One of the conclusions of this exercise is that many approaches offer subsets of the same superset of relevant concepts (the superset that we have tried to present here), but that many authors have used terms in different, sometimes opposite ways, in order to describe these concepts. In the end, it is of course not the terms that are important, but the concepts that are involved.

CULTURE DEPENDENCE

I have claimed in Chapter 1 that the framework proposed in this thesis is concerned with possible 'universal' principles of graphic representation, not only applicable to a broad spectrum of different types of graphic representations, but probably also extending across different cultures. We have done no research to confirm these claims, so most things we say in this regard will be based on speculation. The principles that were discussed in this thesis seem to be applicable to various non-Western graphic representations, such as Egyptian hieroglyphs (discussed in subsection 3.1.4) and graphic representations used by American Indians (discussed by Tversky 1995, 2001). Most of the proposed types of object-to-object relations are based on Gestalt principles of human perception, which also seem to hold across different cultures. Maps in all cultures make similar uses of integral metric spaces, point locators, surface locators, and labels. Examples from various cultures are known concerning phenomena of metaphor, metonymy and rebus. An example of culture dependence in graphic structures is *directionality*, which is discussed by Tversky (1995, 2001), and in subsection 3.1.5 of this thesis.

WHAT IS IT ALL GOOD FOR?

The primary value of this work lies in the theoretical domain of the systematic analysis of various aspects of graphic representation. We have shown in this thesis that the proposed framework can be successfully applied to the analysis of a broad range of example graphics, as well as to the analysis and comparison of a large number of existing graphic theories. In addition, we hope that the development of the proposed concepts can form a basis for more practical work with graphic representations. Possible practical applications might include the analysis of design problems with specific graphics. Prescription of 'rules of good design' was not an aim of this thesis. Nevertheless, the thesis does provide a language that may be useful when discussing the phenomena that are involved in good and bad design. The proposed concepts concerning the composition and decomposition of syntactic structures could be used to generate and discuss different design alternatives for a given graphic representation problem.

Another possible area of application is in document analysis and data mining research that aims at information retrieval through automatic parsing of graphic representations. Parsing requires a syntactic framework. Research in computer science is developing in both directions, concerning automatic parsing as well as automatic generation. Continuing the work presented here, the proposed framework could be integrated into a computer-based design tool for generating graphic representations, possibly in combination with existing systems for static or interactive visualizations. Such software has the potential to serve as a cognitive tool, allowing people to create and explore different visual representations of the information that they are working with. These are exciting challenges for future research.

Abstract

In this thesis we propose a framework for the analysis of graphic representations of information. Graphic representations seem to play an increasingly important role in our lives. While our common sources of information (e.g. books, newspapers) used to be almost completely textual, we are now seeing more and more diagrams, pictograms, maps and charts. We see such graphic representations on paper as well as on signage and on screen. Some types of graphic representations have developed due to recent advances in computer technology, while others can already be found on archeological objects from ancient cultures. In this thesis, 'graphic representations' are taken to include prehistoric maps and Egyptian hieroglyphs as well as family tree diagrams, pictorial statistical charts, and modern 3-D computer visualizations. In the context of this investigation we will limit ourselves to static representations.

Graphic representations can be regarded as expressions of visual languages. The primary aim of the thesis is to examine the main principles of these visual languages, regarding both their graphic syntax and their interpretation.

In Chapter 1 we lay out the context of this work, discussing the notions of *graphic representation* and of *visual language*, and we elaborate on the aims of this thesis.

In Chapter 2 we examine the *syntax* ('grammar') of graphic representations. Section 2.1 provides an overview of our approach to graphic syntax and its recursive nature. A graphic representation may be elementary or composite. We regard a composite graphic representation as consisting of a *graphic space*, a set of *graphic objects* and a set of *graphic relations* that these graphic objects are involved in. A graphic object may itself be a composite graphic representation, so this approach can be applied recursively. Graphic relations may concern either *spatial structure* or variations of *visual attributes*. On a subway map for example, the colored lines, the station markers, and their textual labels are all *graphic objects*. Some of the *graphic relations* between the colored lines involve variations of a *visual attribute*, in this case color. Some of the *graphic relations* between station markers involve *spatial structure*, in this case their spatial positioning, and their connectedness by the colored lines. In section 2.2 we briefly explore *graphic space*, which is the substrate of all spatial relations within graphic representations. In sections 2.3 and 2.4 we take a brief look at *elementary graphic objects* and their *visual attributes*.

By far the longest section is section 2.5, in which we explore the various types of basic and composite *syntactic structures* into which graphic objects can be arranged within a graphic space. We regard the syntactic structure of a graphic representation as a set of graphic relations. These graphic relations

may be object-to-*object* relations or object-to-*space* relations. An object-to-*object* relation is a relation between objects (subsection 2.5.1), while an object-to-*space* relation is a relation between an object and one or more points in a *meaningful space* (subsection 2.5.2). For example, the labeling of a city on a map of a country involves an object-to-*object* relation between two objects: the name of the city (a textual label), and the 'city-dot' that marks the city's location. The name of the city will usually be placed close to the 'city-dot', either above or below it, or to its left or right. The spatial positioning of the 'city-dot' itself however, involves an object-to-*space* relation between the 'city-dot' and a specific point in the meaningful space of the map. Similarly, a line that connects two boxes in a flow chart involves object-to-*object* relations between the line and the two boxes, while a curve in a two-axis chart involves object-to-*space* relations between the curve and a set of specific points in the meaningful space of the chart.

Closely related to the above is the notion of *syntactic roles*. Somewhat comparable to the different syntactic roles that words can play within the syntactic structure of a sentence (e.g. the role of noun phrase or verb phrase), graphic objects can play different syntactic roles within the syntactic structure of a graphic representation. We examine these different syntactic roles (subsection 2.5.3), and discuss how they differ with regard to the spatial 'anchoring' that they involve. A 'city-dot' on a map for example functions as a *point locator* (anchored to a point in a meaningful space), a word underneath a bar in a bar chart functions as a *label* (anchored to the object that it labels), and an arrow in a flow chart functions as a *connector* (anchored between the objects that it connects). Other possible syntactic roles of graphic objects include *separators* (e.g. dividing lines), *containers* (e.g. a framing box), *line locators* (e.g. a curve in a two-axis chart), *surface locators* (e.g. a lake on a map), and *metric bars* (e.g. the bars in a bar chart).

We round up section 2.5 with a discussion of different types of *composite* syntactic structures (subsection 2.5.4). We examine the *graphic multiple* for example, which consists of two or more variations of a graphic representation. Other types of composite syntactic structure include the *multipanel* with a *shared axis*, and the *background-inset display*.

In Chapter 3 we deal with various aspects of the *interpretation* of graphic representations. First we discuss *type of correspondence* (section 3.1), which we define as the relationship between what is *shown* and what is *meant*. The main types of correspondence that we distinguish are *literal, metaphoric, metonymic, rebus-based,* and *arbitrary-conventional*. For example, a pictogram that indicates a restaurant by showing a knife and fork, is a *metonymic* graphic object, while the relative spatial positioning of graphic objects along a time line involves a *metaphoric* use of graphic space. After type of correspondence we discuss *mode of expression* (section 3.2), which concerns the classification of graphic objects into *pictorial* objects (in a spectrum from realistic to schematic pictures) and *non-pictorial* objects (abstract shapes, words and numbers). Sorting out a confusing issue in the literature, we discuss the non-trivial relationship between *type of correspondence* and *mode of expression*. We then discuss the *informational roles* (section 3.3) that graphic objects may play within a graphic representation, distinguishing between *reference objects* (e.g. legends, labeled axes, grid lines), the actual *information objects* (which would have to be adjusted if the represented information would change, e.g. a curve plotted in a two-axis chart), and *decoration* objects. We conclude Chapter 3 with some very brief remarks on the *types of represented information* that may be involved in graphic representations (section 3.4).

In Chapter 4 we offer a *classification* system of graphic representations, giving principled descriptions of the proposed types of graphic representations, and discussing existing classification systems.

In Chapter 5 we examine how the framework developed in this thesis can be applied to the analysis and discussion of real-world graphic representations, as well as to the analysis of graphic theories from the existing literature. Concerning the application to real-world graphic representations, we briefly discuss the standardized analyses in the captions of the numerous example figures throughout the thesis. Concerning the literature, we show for a large number of existing graphic theories how they can be 'translated' into the terms of this framework.

Finally, in the Conclusions (Chapter 6), we make an attempt to assess the value and the possible applications of this work.

Samenvatting

In dit proefschrift worden een systeem en een begrippenkader ontwikkeld voor de analyse van grafische representaties van informatie. Grafische representaties lijken steeds belangrijker te worden in ons leven. Terwijl in het verleden de gebruikelijkste bronnen van informatie (bijvoorbeeld boeken, kranten) bijna volledig tekstueel waren, zien we tegenwoordig steeds meer diagrammen, pictogrammen, kaarten en grafieken. We zien zulke grafische representaties zowel op papier en op borden, als op beeldschermen. Sommige vormen van grafische representatie zijn ontstaan door recente ontwikkelingen in de computertechnologie. Andere vormen zijn al te vinden op archeologische objecten uit de oudheid. In dit proefschrift omvat de term 'grafische representatie' zowel prehistorische kaarten en Egyptische hiërogliefen als familiestambomen, beeldstatistieken en moderne 3-D computer-visualisaties. In het kader van dit onderzoek beperken we ons tot statische representaties.

Grafische representaties kunnen worden beschouwd als uitdrukkingen in visuele talen. Het hoofddoel van dit proefschrift is het onderzoeken van de basisprincipes van deze visuele talen, zowel voor wat betreft hun grafische syntaxis als voor wat betreft hun interpretatie.

In hoofdstuk 1 zetten we de context van het onderzoek uiteen. We bespreken de noties van *grafische representatie* en van *visuele taal*. Verder wordt aandacht besteed aan de doelstellingen van dit proefschrift.

In hoofdstuk 2 wordt de *syntaxis* ('grammatica') van grafische representaties behandeld. Sectie 2.1 geeft een overzicht van onze benadering van grafische syntaxis en syntactische recursiviteit. Een grafische representatie kan elementair zijn of samengesteld. We vatten een samengestelde grafische representatie op als bestaande uit een *grafische ruimte*, uit een verzameling van *grafische objecten*, en uit een verzameling van *grafische relaties* tussen deze grafische objecten. Een grafisch object kan zelf ook weer een samengestelde grafische representatie zijn; deze decompositie kan dus recursief worden toegepast. Grafische relaties hebben betrekking op *ruimtelijke structuur* of op *visuele attributen*. Op een metro-plattegrond bijvoorbeeld zijn zowel de gekleurde lijnen, de markeringen van de haltes, als de tekstuele labels *grafische objecten*. Sommige van de *grafische relaties* tussen de gekleurde lijnen bestaan uit variaties van een *visueel attribuut*, in dit geval kleur. Sommige van de *grafische relaties* tussen de markeringen van de haltes hebben betrekking op *ruimtelijke structuur*, in dit geval ruimtelijke positionering en verbinding door gekleurde lijnen. In sectie 2.2 gaan we kort in op *grafische ruimte* - het substraat van alle ruimtelijke relaties in grafische representaties. Secties 2.3 en 2.4 bevatten korte beschouwingen over *elementaire grafische objecten* en hun *visuele attributen*.

In sectie 2.5 onderzoeken we de verschillende soorten van elementaire en samengestelde *syntactische structuren* waarin grafische objecten kunnen worden gerangschikt in een grafische ruimte. We beschouwen de syntactische structuur van een grafische representatie als een verzameling van grafische relaties. Hierbij maken we een verschil tussen object-*object* relaties en object-*ruimte* relaties. Een object-*object* relatie is een relatie tussen objecten (subsectie 2.5.1), terwijl een object-*ruimte* relatie een relatie is tussen een object en één of meerdere punten in een *betekenisvolle ruimte* (subsectie 2.5.2). Het labelen van een dorp op een kaart bijvoorbeeld, houdt een object-*object* relatie in tussen twee objecten: een dorpsnaam (een tekstueel label) en de stip die de positie van het dorp aangeeft. De positie van de naam is doorgaans boven of onder die stip. De ruimtelijke positionering van de stip zelf houdt een object-*ruimte* relatie in, namelijk die tussen de stip en een specifiek punt in de betekenisvolle ruimte van de kaart. Op een soortgelijke manier houdt een pijl in een stroomdiagram een object-*object* relatie in, tussen de lijn en de twee objecten die verbonden worden door die lijn. Een curve in een assenstelsel daartegen houdt een object-*ruimte* relatie in, tussen de curve en een verzameling specifieke punten in de betekenisvolle ruimte van het assenstelsel.

Nauw gerelateerd hieraan is de notie van *syntactische rollen*. Zoals woorden verschillende rollen kunnen spelen in de syntactische structuur van een zin (bijvoorbeeld de rol van onderwerp, gezegde, of lijdend voorwerp), zo kunnen grafische objecten verschillende syntactische rollen spelen in de syntactische structuur van een grafische representatie. We onderzoeken deze verschillende syntactische rollen (subsectie 2.5.3), en gaan in op verschillen wat betreft hun ruimtelijke 'verankering'. Een stip voor een dorp op een kaart bijvoorbeeld, fungeert als een *punt-markeerder* (verankerd in een punt in de betekenisvolle ruimte). Een woord onder een staaf in een staafdiagram fungeert als een *label* (verankerd aan het object dat wordt gelabeld). En een pijl in een stroomdiagram fungeert als een *connector* (verankerd tussen de objecten die worden verbonden). Andere mogelijke syntactische rollen van grafische objecten zijn die van *separator* (bijvoorbeeld een scheidslijn), *container* (bijvoorbeeld een omsluitend kader), *lijn-markeerder* (bijvoorbeeld een curve in een assenstelsel), *vlak-markeerder* (bijvoorbeeld een meer op een kaart) en *kwantitatieve staaf* (bijvoorbeeld de staven in een staafdiagram).

Sectie 2.5 wordt afgesloten met een bespreking van verschillende soorten *samengestelde* syntactische structuren (subsectie 2.5.4). We behandelen onder andere de *graphic multiple*, die in principe bestaat uit twee of meer variaties van een grafische representatie. Andere soorten samengestelde syntactische structuren zijn bijvoorbeeld de *multipanel* met een *gedeelde as*, en de *achtergrond* met *inzet*.

In hoofdstuk 3 gaan we in op verschillende aspecten van de *interpretatie* van grafische representaties. We bespreken eerst het *type correspondentie* (sectie 3.1), dat we definiëren als de relatie tussen dat wat wordt *getoond* en dat wat wordt *bedoeld*. De typen correspondentie die we onderscheiden zijn: *letterlijk*, *metaforisch*, *metonymisch*, *rebus-gebaseerd*, en *willekeurig-conventioneel*. Een pictogram bijvoorbeeld dat een restaurant aangeeft door middel van een mes en een vork is een *metonymisch* grafisch object, terwijl de grafische ruimte *metaforisch* wordt gebruikt als grafische objecten langs een tijdslijn worden geplaatst. Na het *type correspondentie* bespreken we de *manier van expressie* (sectie 3.2). Die heeft betrekking op de classificatie van grafische objecten in *afbeeldende* objecten (in een spectrum van realistisch tot schematisch) en *niet-afbeeldende* objecten (abstracte vormen, woorden en getallen). Ingaande op een verwarrend probleem in de bestaande literatuur, bespreken we ook het niet-triviale verband tussen *type correspondentie* en *manier van expressie*. Verder gaan we in op de *informatieve rollen* (sectie 3.3) die grafische objecten kunnen spelen in een grafische representatie. We maken onderscheid tussen *referentie-objecten* (bijvoorbeeld legenda's, gelabelde assen, rasterlijnen), daadwerkelijke *informatie-objecten* (die veranderd moeten worden als de informatie verandert, bijvoorbeeld een curve in een assenstelsel) en *decoratie-objecten*. We sluiten hoofdstuk 3 af met enkele opmerkingen over de verschillende *soorten van informatie* die grafisch kunnen worden gerepresenteerd (sectie 3.4).

Hoofdstuk 4 introduceert een *classificatiesysteem* voor grafische representaties. Gebaseerd op de in dit proefschrift ontwikkelde concepten, geven we een beschrijving van de te onderscheiden types van grafische representatie. Vervolgens vergelijken we dit systeem met reeds bestaande classificatiesystemen.

In hoofdstuk 5 geven we aan hoe de in dit proefschrift gestelde benadering kan worden toegepast op de analyse en discussie van grafische representaties in de praktijk, plus op de analyse van grafische theorieën in de bestaande literatuur. Wat betreft de toepassing van onze benadering op voorbeelden van grafische representaties in de praktijk, wijzen we de lezer op de talrijke voorbeelden van grafische representaties in dit proefschrift, die in hun onderschrift worden geanalyseerd en geclassificeerd. Wat betreft de literatuur laten we voor een groot aantal bestaande grafische theorieën zien hoe ze 'vertaald' kunnen worden naar de door ons voorgestelde begrippen.

In de conclusies tenslotte (hoofdstuk 6) doen we een poging om de waarde en de mogelijke toepassingen van dit werk te beoordelen.

ILLC Dissertation Series

ILLC DS-1996-01: **Lex Hendriks**. *Computations in Propositional Logic.*

ILLC DS-1996-02: **Angelo Montanari**. *Metric and Layered Temporal Logic for Time Granularity.*

ILLC DS-1996-03: **Martin H. van den Berg**. *Some Aspects of the Internal Structure of Discourse: the Dynamics of Nominal Anaphora.*

ILLC DS-1996-04: **Jeroen Bruggeman**. *Formalizing Organizational Ecology.*

ILLC DS-1997-01: **Ronald Cramer**. *Modular Design of Secure yet Practical Cryptographic Protocols.*

ILLC DS-1997-02: **Natasa Rakic**. *Common Sense Time and Special Relativity.*

ILLC DS-1997-03: **Arthur Nieuwendijk**. *On Logic. Inquiries into the Justification of Deduction.*

ILLC DS-1997-04: **Atocha Aliseda-LLera**. *Seeking Explanations: Abduction in Logic, Philosophy of Science and Artificial Intelligence.*

ILLC DS-1997-05: **Harry Stein**. *The Fiber and the Fabric: An Inquiry into Wittgenstein's Views on Rule-Following and Linguistic Normativity.*

ILLC DS-1997-06: **Leonie Bosveld - de Smet**. *On Mass and Plural Quantification. The Case of French 'des'/'du'-NP's.*

ILLC DS-1998-01: **Sebastiaan A. Terwijn**. *Computability and Measure.*

ILLC DS-1998-02: **Sjoerd D. Zwart**. *Approach to the Truth: Verisimilitude and Truthlikeness.*

ILLC DS-1998-03: **Peter Grunwald**. *The Minimum Description Length Principle and Reasoning under Uncertainty.*

ILLC DS-1998-04: **Giovanna d'Agostino**. *Modal Logic and Non-Well-Founded Set Theory: Translation, Bisimulation, Interpolation.*

ILLC DS-1998-05: **Mehdi Dastani**. *Languages of Perception.*

ILLC DS-1999-01: **Jelle Gerbrandy**. *Bisimulations on Planet Kripke.*

ILLC DS-1999-02: **Khalil Sima'an**. *Learning efficient disambiguation.*

ILLC DS-1999-03: **Jaap Maat**. *Philosophical Languages in the Seventeenth Century: Dalgarno, Wilkins, Leibniz.*

ILLC DS-1999-04: **Barbara Terhal**. *Quantum Algorithms and Quantum Entanglement.*

ILLC DS-2000-01: **Renata Wassermann**. *Resource Bounded Belief Revision.*

ILLC DS-2000-02: **Jaap Kamps**. *A Logical Approach to Computational Theory Building (with applications to sociology).*

ILLC DS-2000-03: **Marco Vervoort**. *Games, Walks and Grammars: Problems I've Worked On.*

ILLC DS-2000-04: **Paul van Ulsen**. *E.W. Beth als logicus.*

ILLC DS-2000-05: **Carlos Areces**. *Logic Engineering. The Case of Description and Hybrid Logics.*

ILLC DS-2000-06: **Hans van Ditmarsch**. *Knowledge Games.*

ILLC DS-2000-07: **Egbert L.J. Fortuin**. *Polysemy or monosemy: Interpretation of the imperative and the dative-infinitive construction in Russian.*

ILLC DS-2001-01: **Maria Aloni**. *Quantification under Conceptual Covers.*

ILLC DS-2001-02: **Alexander van den Bosch**. *Rationality in Discovery - a study of Logic, Cognition, Computation and Neuropharmacology.*

ILLC DS-2001-03: **Erik de Haas**. *Logics For OO Information Systems: a Semantic Study of Object Orientation from a Categorial Substructural Perspective.*

ILLC DS-2001-04: **Rosalie Iemhoff**. *Provability Logic and Admissible Rules.*

ILLC DS-2001-05: **Eva Hoogland**. *Definability and Interpolation: Model-theoretic investigations.*

ILLC DS-2001-06: **Ronald de Wolf**. *Quantum Computing and Communication Complexity.*

ILLC DS-2001-07: **Katsumi Sasaki**. *Logics and Provability.*

ILLC DS-2001-08: **Allard Tamminga**. *Belief Dynamics. (Epistemo)logical Investigations.*

ILLC DS-2001-09: **Gwen Kerdiles**. *Saying It with Pictures: a Logical Landscape of Conceptual Graphs.*

ILLC DS-2001-10: **Marc Pauly**. *Logic for Social Software.*

ILLC DS-2002-01: **Nikos Massios**. *Decision-Theoretic Robotic Surveillance.*

ILLC DS-2002-02: **Marco Aiello**. *Spatial Reasoning: Theory and Practice.*

ILLC DS-2002-03: **Yuri Engelhardt**. *The Language of Graphics.*

Bibliography

Arnheim, R. (1969). *Visual thinking*. University of California Press.

Augustine, Saint (397/1995). *De doctrina Christiana*. Edited and translated by R.P.H. Green. Oxford University Press. Originally written in A.D. 397.

Barthes, R. (1965). *Éléments de sémiologie.*

Bertin, J. (1967). *Sémiologie graphique*. Paris: Editions Gauthier-Villars. English translation by W.J. Berg (1983) as *Semiology of graphics*, Madison, WI: University of Wisconsin Press.

Bertin, J. (1977). *La graphique et le traitement graphique de l'information*. Paris: Flammarion. English translation by W.J. Berg and P. Scott (1981) as *Graphics and graphic information processing*, Berlin: Walter de Gruyter & Co.

Bertin, J. (2000/2001): Matrix theory of graphics. *Information Design Journal 10 (1)*, pp. 5-19.

Betrò, M.C. (1995). *Geroglifici*. Milano: Mondadori.

Blackwell, A., and Y. Engelhardt (1998). A taxonomy of diagram taxonomies. In: *Proceedings of Thinking with Diagrams 98: Is there a science of diagrams?*, August 22-23, 1998, Aberystwyth, pp. 60-70.

Blackwell, A., and Y. Engelhardt (2002). A meta-taxonomy for diagram research. In: M. Anderson, B. Meyer, and P. Olivier (Eds.), *Diagrammatic representation and reasoning*, Springer-Verlag, pp. 47-64.

Bounford, T. (2000). *Digital diagrams: Effective design and presentation of statistical information*. New York: Watson-Guptill Publications.

Bowman, W.J. (1968). *Graphic Communication*. New York: John Wiley.

Brinton, W.C. (1914). *Graphic methods for presenting facts*. New York: McGraw-Hill Book Company / The Engineering Magazine Company.

Bruijn, W.K. de (1967). *Schematechniek*. Alphen aan den Rijn / Brussel: N. Samson NV.

Card, S.K., J.D. Mackinlay, and B. Shneiderman (Eds.) (1999). *Readings in information visualization: Using vision to think*. San Francisco: Morgan Stanley Kaufmann Publishers.

Daru, M., 2000: Jacques Bertin and the graphic essence of data. *Information Design Journal 10 (1)*, pp. 20-25.

Degn, C., E. Eggert, and A. Kolb (1973). *Seydlitz für Gymnasien, Band 3B, Amerika - Ozeane - Polargebiete*. Verlag Ferdinand Hirt, Kiel, and Herman Schroedel Verlag KG, Hannover.

Dreyfuss, H. (1972). *Symbol sourcebook: An authoritative guide to international graphic symbols*. New York: Van Nostrand Reinhold.

Eco, U. (1985). Producing signs. In: M. Blonsky (Ed.), *On Signs*. Baltimore: John Hopkins University Press, pp. 176-183.

Eisner, W. (1985). *Comics and sequential art*. Tamarac, Florida: Poorhouse Press.

Eisner, W. (1996). *Graphic storytelling*. Tamarac, Florida: Poorhouse Press.

Elkins, J. (1999). *The domain of images*. Cornell University Press.

Engelhardt, Y., J. de Bruin, T. Janssen, and R. Scha (1996). The visual grammar of information graphics. In: N. H. Narayanan, and J. Damski (Eds.), *Proceedings of the AID '96 Workshop on Visual Representation, Reasoning and Interaction in Design*, Stanford University.

Engelhardt, Y. (1996). Towards a design theory for visualization. *Proceedings of Accolade 1996*, Dutch Research School in Logic, University of Amsterdam, The Netherlands, pp. 65-77.

Engelhardt, Y. (1997). Structure-preserving visualization (extended abstract). *Proceedings of the CODATA Euro-American Workshop on Visualization of Information and Data, 24-25 June 1997*, Paris, France.

Engelhardt, Y. (1998). Meaningful space: How graphics use space to convey information. In: *Proceedings of Vision Plus 4*, School of Design, Carnegie Mellon University, Pittsburgh, pp. 108-126.

Engelhardt, Y. (1999). Meaningful space. In: *If/Then: Design implications of new media*, Netherlands Design Institute, pp. 72-74.

Engelhardt, Y. (2001). Grundprinzipien grafischer Darstellungen. In: *Navigation durch Text, Bild und Raum*, Forum Typografie, Arbeitskreis Hamburg e.V. pp. 124-137.

Gamut, L.T.F. (1991). *Logic, language and meaning, Volume 2: Intensional logic and logical grammar*. University of Chicago Press.

Goldwasser, O. (1995). *From icon to metaphor: Studies in the semiotics of the hieroglyphs*. Fribourg, Switzerland: University Press.

Gonick, L. (1990). *The cartoon history of the universe, Volumes 1-7*. New York: Doubleday.

Goodman, N. (1976). *Languages of art*. Indianapolis: Hackett.

Holmes, N. (1991). *Pictorial maps: History, Design, Ideas, Sources*. New York: Watson-Guptill Publications.

Holmes, N. (1993). *The best in diagrammatic graphics*. Mies, Switzerland: Rotovision.

Holmes, N. (2000/2001). Pictograms: A view from the drawing board or, what I have learned from Otto Neurath and Gerd Arntz (and jazz). *Information Design Journal 10 (2)*, pp. 133-143.

Horn, R.E. (1998). *Visual language: Global communication for the 21st century*. Bainbridge Island, WA: MacroVU, Inc.

Horton, W.K. (1994). *The icon book: Visual symbols for computer systems and documentation*. John Wiley & Sons.

Houkes, R. (Ed.) (1993). *Information design and infographics*. Rotterdam: European Institute for Research and Development of Graphic Communication, H R & O.

Jean, G. (1992). *Writing: The story of alphabets and scripts*. New York: Harry N. Abrams.

Johnson, M. (1987). *The body in the mind: The bodily basis of meaning, imagination and reason*. Chicago: University of Chicago Press.

Kepes, G. (1944). *Language of vision*. Chicago: Paul Theobald.

Knowlton, J.Q. (1966). On the definition of "picture". *AV Communication Review, 14*, pp. 157-183.

Kosslyn, S.M. (1989). Understanding charts and graphs. *Applied Cognitive Psychology, 3*, pp. 185-225.

Kosslyn, S.M. (1994). *Elements of graph design*. New York: W.H. Freeman and Company.

Krampen, M. (1965). Signs and symbols in graphic communication. *Design Quarterly, 62*, pp. 1-31.

Lakin, F. (1987). Visual grammars for visual languages. In: *Proceedings of AAAI 87, Sixth National Conference on Artificial Intelligence*, Seattle, Washington, July 1987, pp. 683-688.

Lakoff, G. (1987). *Women, fire, and dangerous things: What categories reveal about the mind*. Chicago: University of Chicago Press.

Lakoff, G., and M. Johnson (1980). *Metaphors we live by*. Chicago: University of Chicago Press.

Lohse, G.L., K. Biolisi, N. Walker, and H.H. Rueter (1994). A classification of visual representations. *Communications of the ACM, 37 (12)*, pp. 36-49.

MacEachren, A.M. (1995). *How maps work: Representation, visualization, and design*. Guilford Press.

MacEachren, A.M. (2000). An evolving cognitive-semiotic approach to geographic visualization and knowledge construction. *Information Design Journal 10 (1)*, pp. 26-36.

Mackinlay, J.D. (1986). Automating the design of graphical presentations. *ACM Transactions on Graphics 5, 2*, pp. 110-141.

McCloud, S. (1993). *Understanding comics: The invisible art*. Northhampton, MA: Kitchen Sink Press.

Mijksenaar, P., and P. Westendorp (1999). *Open here: The art of instructional design*. New York: Joost Elffers Books.

Minsky, M. (1985). *The society of mind*. New York: Simon and Schuster.

Mullet, K., and D. Sano (1995). *Designing visual interfaces: Communication oriented techniques*. Englewood Cliffs: SunSoft Press - Prentice Hall PTR.

Norman, D.A. (1990). *The design of everyday things*. New York: Doubleday.

Peirce, C.S. (1873). On representations. In: C.J.W. Kloesel et al. (Eds.), *Writings of Charles S. Peirce: A chronological edition, Volume 3*, pp. 62-66. Bloomington: Indiana University Press.

Peirce, C.S. (1932). Elements of logic. In: C. Hartshorne, and P. Weiss (Eds.), *The collected papers of C.S. Peirce*. Cambridge, MA: Havard University Press.

Ratté, J. (1924). *Moderne loontechniek*. (No publisher given.)

Richards, C.J. (1984). *Diagrammatics: An investigation aimed at providing a theoretical framework for studying diagrams and for establishing a taxonomy of their fundamental modes of graphic organization*. Ph.D. thesis, Royal College of Art, London.

Richards, C.J. (2000). Getting the picture: diagram design and the information revolution. *Information Design Journal 9 (2/3)*, pp. 87-110.

Richards, C.J. (2002). The fundamental design variables of diagramming. In: M. Anderson, B. Meyer, and P. Olivier (Eds): *Diagrammatic representation and reasoning*. London: Springer, pp. 85-102.

Robinson, A.H., and B.B. Petchenik (1976). *The nature of maps*. Chicago: University of Chicago Press.

Robinson, A.H., R.D. Sale, J.L. Morrison, and P.C. Muehrcke (1984). *Elements of cartography* (5th ed.). New York: Wiley.

Rogers, Y. (1989). Icons at the interface: their usefulness. *Interacting with Computers, vol. 1 (1)*, pp. 105-117.

Sandison, D. (1997). *The art of Egyptian hieroglyphics*. London: Hamlyn.

Saussure, F. de. (1986). *Cours de linguistique générale, 25th ed.* (C. Bally, and A. Sechehaye, Eds.). Paris: Payot. Original work published in 1916.

Silbernagel, S., and A. Despopoulos (1983). *Taschenatlas der Physiologie, 2. Auflage*. New York: Georg Thieme Verlag; München: Deutscher Taschenbuch Verlag.

Spence, R. (2001). *Information visualization*. ACM Press and Addison-Wesley.

Strothotte, C., and T. Strothotte (1997). *Seeing between the pixels*. Springer Verlag.

Tufte, E.R. (1983). *The visual display of quantitative information*. Cheshire, CT: Graphics Press.

Tufte, E.R. (1990). *Envisioning information*. Cheshire, CT: Graphics Press.

Tufte, E.R. (1997). *Visual explanations*. Cheshire, CT: Graphics Press.

Tversky, B. (1995). Cognitive origins of graphic conventions. In: F.T. Marchese (Ed.), *Understanding images*. pp. 29-53. New York: Springer-Verlag.

Tversky, B. (2001). Spatial schemas in depictions. In: M. Gattis (Ed.), *Spatial schemas and abstract thought*. Cambridge: MIT Press.

Tversky, B. (in press). Some ways that graphics communicate. Chapter to appear in: *Working with words and images*, edited by Nancy Allen.

Twyman, M. (1979). A schema for the study of graphic language. In: P.A. Kolers, M.E. Wrolstad, H. Bouma (Eds.). *Processing of visible language. Vol. 1*. pp. 117-150. New York: Plenum Press.

Wallace, R.A. (1978). *Biology: The world of life*. Santa Monica: Goodyear Publishing Company.

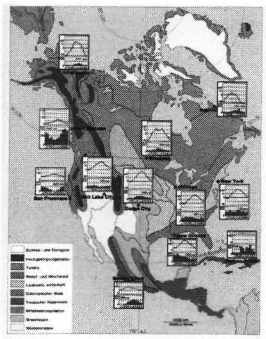
Wang, D., Y. Engelhardt, H. Zeevat (1997). Formal specification of a graphic design theory. In *Proceedings of TVL 97, International Workshop on Theory of Visual Languages*, September 1997, Capri, Italy, pp. 97-11

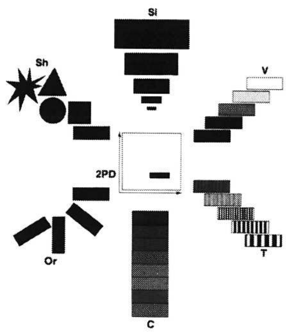
Wexelblat, A. (1991). Giving meaning to place: semantic spaces. In: M. Benedikt (Ed.), *Cyberspace: first steps*, pp. 255-271. Cambridge, MA: MIT Press.

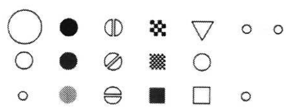
Wilkinson, L. (1999). *The grammar of graphics*. New York: Springer.

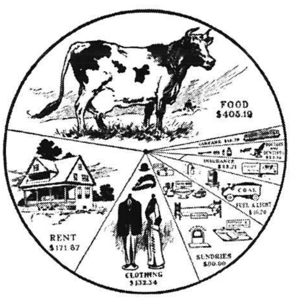
Figure Index

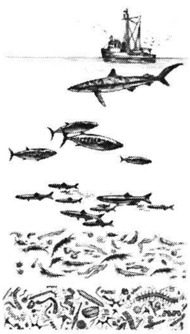
This figure index does not include tables and decomposition trees. Figures in parentheses ( ) are figures that serve to illustrate a specific point, and therefore have a caption that differs from the complete standardized analysis given for the other figures.

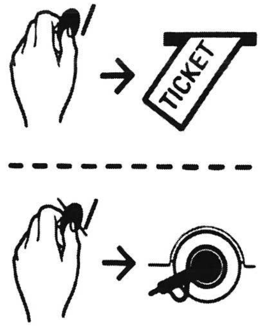


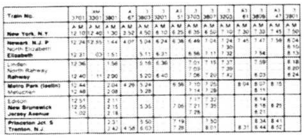






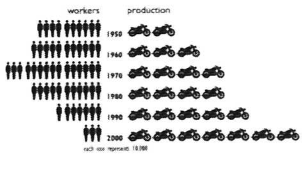




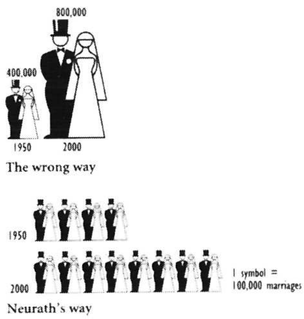


2-10, p. 36

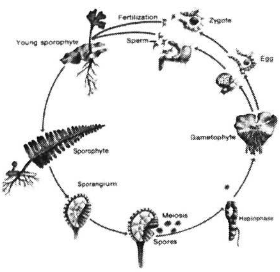
2-11, p. 37



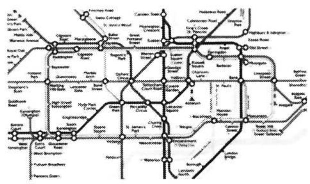
2-12, p. 38



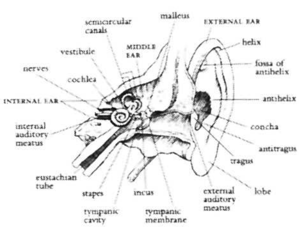
2-13, p. 39



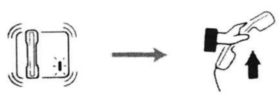
2-14, p. 41



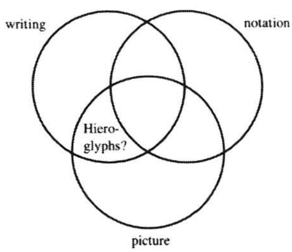
2-15, p. 42



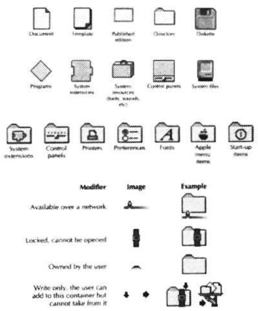
2-16, p. 43



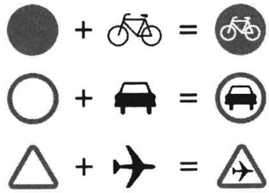
2-17, p. 44



2-18, p. 45

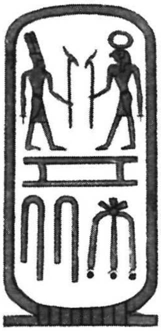


(2-19, p. 46)

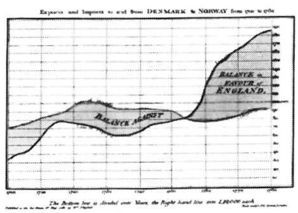


(2-20, p. 47)

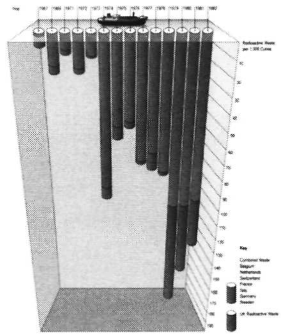
(2-21, p. 48)



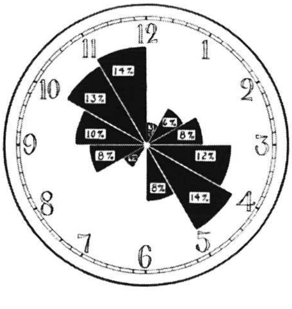
2-22, p. 49



2-25, p. 58

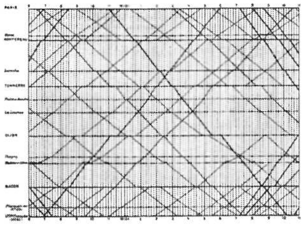


2-26, p. 59

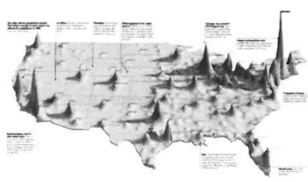


2-27, p. 61

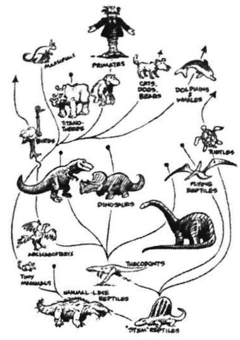
2-28, p. 62



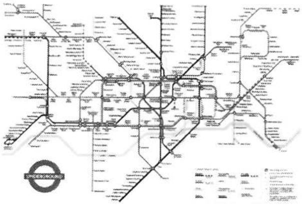
2-29, p. 63



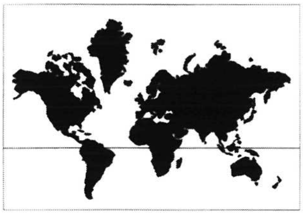
2-30, p. 64



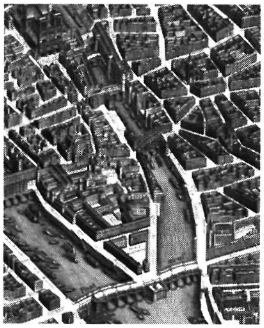
2-31, p. 66



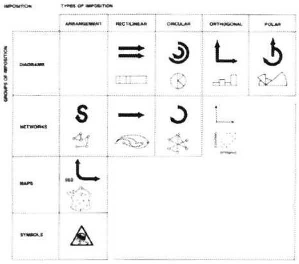
2-32, p. 67



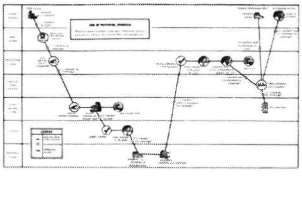
2-33, p. 68



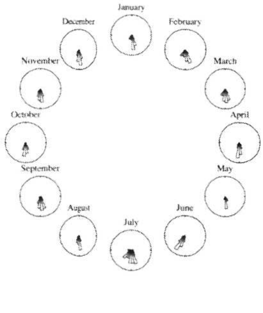
2-34, p. 69



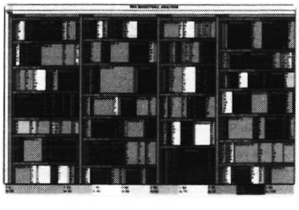
(2-36, p. 71)



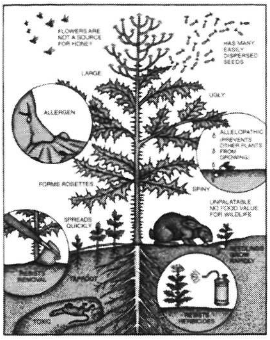
2-38, p. 80



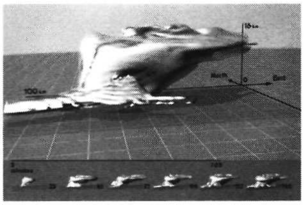
2-39, p. 82



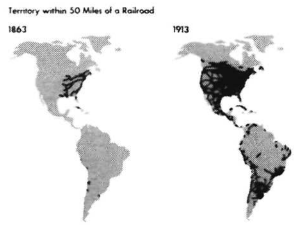
2-40, p. 83



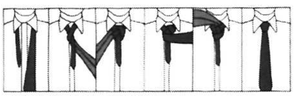
2-41, p. 85



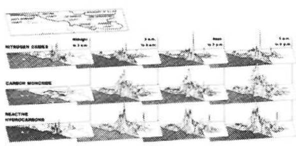
2-42, p. 86



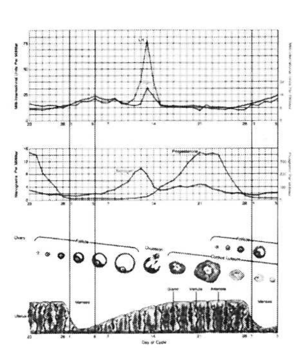
2-43, p. 88



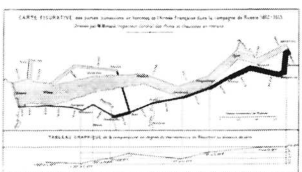
2-44, p. 89



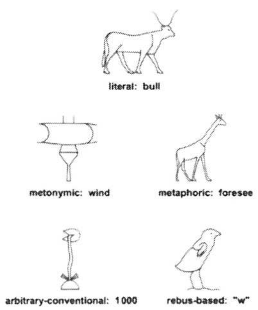
2-45, p. 90



2-46, p. 91

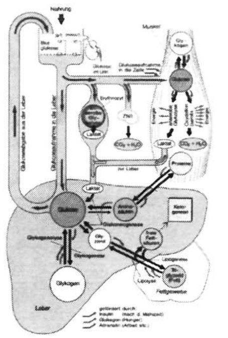


2-47, p. 93

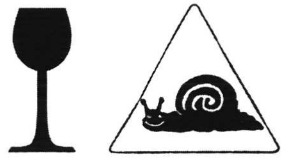


(3-03, p. 101)

(3-04, p. 103)

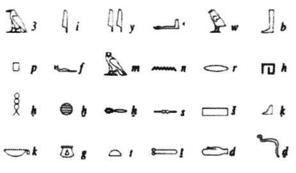


3-05, p. 105



(3-06, p. 106)

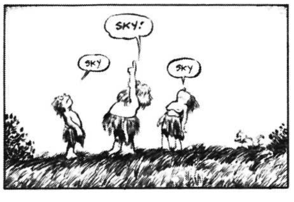
(3-07, p. 108)



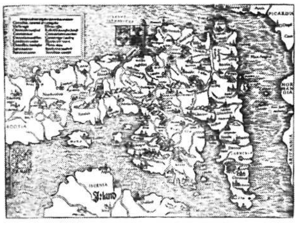
(3-08, p. 109)

3-09, p. 110

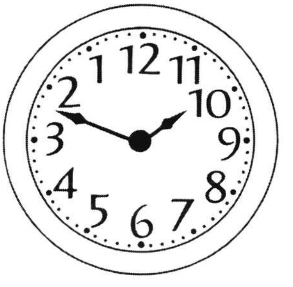
(3-10, p. 111)



3-11, p. 112

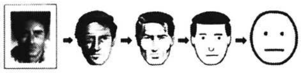


3-12, p. 113

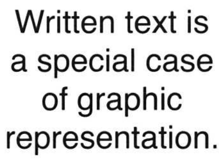


3-13, p. 114

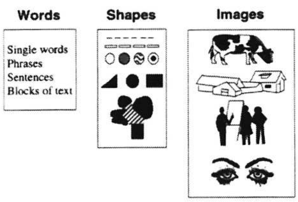
(3-15, p. 118)



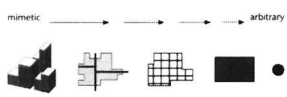
(3-16, p. 119)



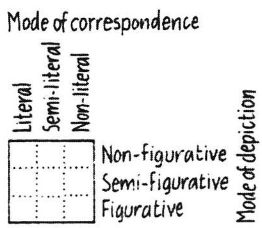
3-17, p. 120



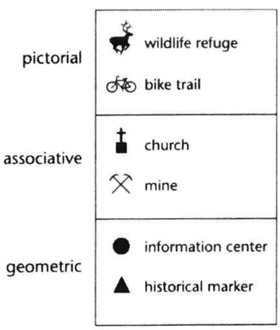
(3-19, p. 123)



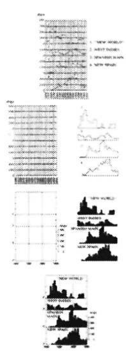
(3-20, p. 124)



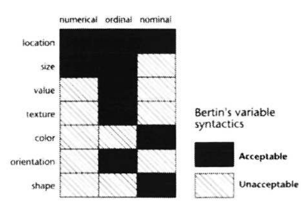
(3-21, p. 125)



(3-23, p. 127)



(3-24, p. 132)



(3-26, p. 135)

Author Index

Subject Index

Glossary

This is a glossary of key terms that are proposed and used in this thesis. Terms in *italics* are cross-references to other entries in the glossary. The numbers in parentheses at the end of each entry refer to the (sub-) section of the thesis in which the concerned concept is discussed.

arbitrary-conventional (a *type of correspondence*): Type of correspondence is arbitrary-conventional if it seems to be based on pure convention. Note that in many cases the current users of the concerned representation may simply not be aware of the fact that the representation originated involving one of the other types of correspondence (3.1.5).

background-inset display (a type of *composite syntactic structure*): A background-inset display is a *nested syntactic structure* that consists of a *superimposition* of one or more *composite graphic objects* on a background object (2.5.4).

basic syntactic structure: See *syntactic structure.* A basic syntactic structure may be a positioning in a *meaningful space,* a *spatial clustering,* a *separation* by a *separator,* a *lineup,* a *linking* by a *connector,* a *containment* by a *container,* or a *superimposition* (2.5).

cluster: See *spatial clustering.*

composite graphic object: 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. A graphic object may be either a composite graphic object itself, or it may be an *elementary graphic object* (2.1 and 2.3).

composite metric space (a type of *meaningful space*): A composite metric space is a *metric space* that is constructed by combining two or more *metric axes* and/or *integral metric spaces.* In a *composite* metric space, a ratio between two spatial distances is only perceived as meaningful if these two distances are measured in certain directions (2.5.2). Compare with: *integral metric space.*

composite syntactic structure: A composite syntactic structure is a *syntactic structure* that is constructed from two or more *basic syntactic structures,* through *simultaneous combination* and/or *nesting* (2.5.4).

connector (a *syntactic role*): 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 (2.5.1).

container (a *syntactic role*): A container is a *graphic object* that contains other graphic objects by visually surrounding them (2.5.1).

containment by a container: Containment is a basic *syntactic structure,* see *container* (2.5.1).

decoration object (an *informational role*): Decoration objects are *graphic objects* that serve neither as *information objects* nor as *reference objects*, and that could be erased without affecting the intended representation of information (data). They serve as embellishment, and may or may not be related to the context and theme of the represented information (3.3).

distorted metric space (a type of *meaningful space*): A distorted metric space is a meaningful 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 (2.5.2).

elementary graphic object: An elementary graphic object is a *graphic object* at the most detailed level of a syntactic decomposition. 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) (2.3).

graphic multiple (a type of *composite syntactic structure*): 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 (2.5.4).

graphic object: *Graphic representations*, as well as their graphic constituents, are graphic objects. A graphic object may be an *elementary graphic object* or a *composite graphic object* (2.1 and 2.3).

graphic relation: A graphic relation may be either an *object-to-object relation* or an *object-to-space relation* (2.1).

graphic representation: A graphic representation is a visible artifact on a more or less flat surface, that was created in order to express information (1).

graphic space: Graphic space is the two-dimensional or (virtual) three-dimensional space that is displayed within a *graphic object* (2.2).

graphic sub-object: A graphic sub-object is a *graphic object* that is part of a *composite graphic object* (2.1 and 2.3).

grid line (a *syntactic role*): A grid line is a line-shaped *graphic object* that serves to mark a *meaningful space* (2.5.3).

information object (an *informational role*): Information objects are those *graphic objects* within a *graphic representation* that would have to be adjusted if the information (data) that one intends to represent would change (3.3). Compare with: *reference object* and *decoration object*.

informational role: The informational role of a *graphic object* is the role that it plays within a *graphic representation* with regard to the conveying of information. We distinguish three main informational roles: *information object*, *reference object*, or *decoration object* (3.3).

integral metric space (a type of *meaningful space*): An integral metric space is a two- or three-dimensional *metric space* in which all geometric properties of Euclidian space are subject to interpretation. This means that in an integral metric space, a ratio between 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) (2.5.2). Compare with: *composite metric space.*

label (a *syntactic role*): A label is a *graphic object* that is anchored to another graphic object by *spatial clustering* (sometimes also involving *containment* or *superimposition*), or through *linking* by a *connector* (2.5.1).

legend object (an *informational role*): Legend objects are *graphic objects* that explain symbols and/or visual attributes that are used in a *graphic representation*. Most legend objects are *composite graphic objects*, structured as a table with one column displaying (some of) the used symbols and/or visual attributes, and another column displaying a verbal or numerical explanation of their meaning (3.3).

line locator (a *syntactic role*): A line locator is a *graphic object* that is anchored to a specific line in a *meaningful space* (2.5.3).

lineup: A lineup is a basic *syntactic structure* in which *graphic objects* are arranged in a 'string': Each object is perceived as having two neighboring objects, except for the two objects at either end of the lineup (2.5.1).

linking: Linking is a basic *syntactic structure* that involves *connectors* (2.5.1).

literal (a *type of correspondence*): Type of correspondence is literal if what is shown is based on similarity to the physical object or physical structure that is meant, or on similarity to a prototypical example of the kind of physical object that is meant (3.1.1).

meaningful space: 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 (2.5.2).

metaphoric (a *type of correspondence*): Type of correspondence is metaphoric if it is based on a (supposed) analogy between what is shown and what is meant. This may concern either a shared functional characteristic or a structural analogy (3.1.2).

metonymic (a *type of correspondence*): Type of correspondence is metonymic if it is based on a mental association due to the fact that there is (or used to be) a relationship of physical involvement between what is shown and what is meant. For example, what is shown 'is a part of' or 'is a possible result of' what is meant, or in some other way it 'plays a role in' what is meant (3.1.3).

metric axis: A metric axis is a spatial dimension along which the ratios of spatial distances are perceived as meaningful. A metric axis establishes a *metric space* (2.5.2).

metric bar (a *syntactic role*): 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). 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) (2.5.3).

metric space (a type of *meaningful space*): 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 *graphic objects* (e.g. 'the distance between A and B is twice the distance between B and C') (2.5.2).

multipanel display (a type of *composite syntactic structure*): 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 (2.5.4).

nested syntactic structure: A nested syntactic structure is a *syntactic structure* that involves *nesting* (2.5.4)

nesting (a way of constructing *composite syntactic structures*): In a nesting of *syntactic structures*, a *composite graphic object* serves as a single *graphic object* in a syntactic structure at a 'higher level' (2.5.4).

node (a *syntactic role*): 'Node' is the term that we use for the *syntactic role* that is played by a *graphic object* that does not play any of the other syntactic roles that we have defined (e.g. *label, connector, separator*) (2.5.1).

object-to-object relation: An object-to-object relation is a graphic relation between *graphic objects* (2.5.1). Compare with: *object-to-space relation.*

object-to-space relation: An object-to-space relation is a graphic relation between a *graphic object* and one or more points in a *meaningful space* (2.5.1). Compare with: *object-to-object relation.*

point locator (a *syntactic role*): A point locator is a *graphic object* that is anchored to a specific point in a *meaningful space* (2.5.3).

proportional division: 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 (2.4).

proportional repetition: 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 (2.5.1).

rebus-based (a *type of correspondence*): Type of correspondence is rebus-based if it is based on the fact that (part of) the spoken word for what is shown sounds like (part of) the spoken word for what is meant (3.1.4)

reference object (an *informational role*): Reference objects are those *graphic objects* within a *graphic representation* that a) serve to enable the interpretation of *information objects,* and that b) would not necessarily have to be adjusted if the represented information (data) would change. Reference objects can be divided into *spatial reference objects* and *legend objects* (3.3).

separation by a separator: Separation is a basic *syntactic structure*, see *separator* (2.5.1).

separator (a *syntactic role*): A separator is a line- or band-shaped *graphic object* that is anchored between other graphic objects, thereby separating them (2.5.1).

shared-axis multipanel (a type of *composite syntactic structure*): 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 (2.5.4).

simultaneous combination (a way of constructing *composite 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 (2.5.4). Compare with: *nesting*.

spatial clustering: Spatial clustering is a basic *syntactic structure* in which *graphic objects* are arranged into two or more groups through the use of within-group proximity versus between-group distance. The involved groups of graphic objects are referred to as 'clusters' (2.5.1).

spatial reference object (an *informational role*): Spatial reference objects are *reference objects* that mark a *meaningful space* (e.g. grid lines, axes and their annotations) (3.3).

superimposition: Superimposition is a basic *syntactic structure* 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 (2.5.1).

surface locator (a *syntactic role*): A surface locator is a *graphic object* that is anchored to a specific surface in a *meaningful space* (2.5.3).

syntactic role: A syntactic role is a role that a *graphic object* may play within a *syntactic structure*. We distinguish these syntactic roles: *node, label, connector, separator, container, point locator, line locator, surface locator, volume locator, metric bar,* and *grid line* (2.5.1 and 2.5.3).

syntactic structure: The syntactic structure of a *composite graphic object* is a set of *graphic relations* in which its constituent *graphic objects* are involved. A graphic relation may be either an *object-to-space relation* or an *object-to-object relation*. A syntactic structure may be either a *basic syntactic structure* or a *composite syntactic structure*. The graphic objects that are involved in a syntactic structure may play different *syntactic roles* (2.5).

type of correspondence: Type of correspondence is the type of relationship between what is shown and what is meant. Type of correspondence may be *literal, metonymic, metaphoric, rebus-based,* or *arbitrary-conventional* (3.1).

volume locator (a *syntactic role*): A volume locator is a *graphic object* that is anchored to a specific volume in a *meaningful space* (2.5.3).

This study presents a framework for the analysis of the visual language of graphic representations. Diagrams, maps, charts and symbols, from ancient inscriptions to computer visualizations, are examined with respect to visual grammar and principles of interpretation. The issues explored include the different roles that a graphic constituent may play within a representation, the nesting of graphic structures and the nature of meaningful space.

ISBN 90-5776-089-4