Chapter 1
Introduction to Visual Representations

Let's stop for a moment and consider just how much information we have to take in every day as part of our routine activities. E-mails arrive on our computers, credit card statements arrive from the bank every month, and last-minute holiday offers, stock market index variations, and advertising leaflets fill the mailbox. Not to mention work. Perhaps you work in a large department store and have to decide the discount policies to be applied to sale items: Which items should we put on sale in the coming months? Summer is arriving—should we perhaps put the beach umbrellas on sale? What percentage discount should we apply? How did the sales of the previous month's promotional items go?

In all of these situations, the common recurring theme is the enormous quantity of information that we have to deal with on a daily basis. Each of the previously described situations almost always involves making a decision: Which e-mail or advertising flyer can we throw out because it doesn't interest us? How much did we charge to the credit card last month? Will we perhaps need to limit our spending in the future? Where can we spend the next holiday without it costing us a fortune? Would it be worthwhile to invest our savings in a particular stock? What discount can we put on the beach umbrellas in the coming months?

Perhaps we haven't even realized, but in the last decade, the quantity of information that we all have to process has increased enormously. The globalization of economy and communication, but above all the rapid advances in technology (and not only communication and information technology), have brought us in, recent years, to what some noted scholars define as *information pollution*. Anyway, if we really think about it, what we are witnessing in reality is not an explosion of information, but rather an explosion of *data*, which we are continuously pressed to observe, process, and develop, for our family or work activities. We are *informed* by the data that we continually receive from numerous sources. The information, very valuable and important for our lives, is built and elaborated on starting from this continuous and constant influx of data that we are passively or actively subjected to. Therefore, we need effective methods that allow us to go through this information and, for example, help us make decisions.

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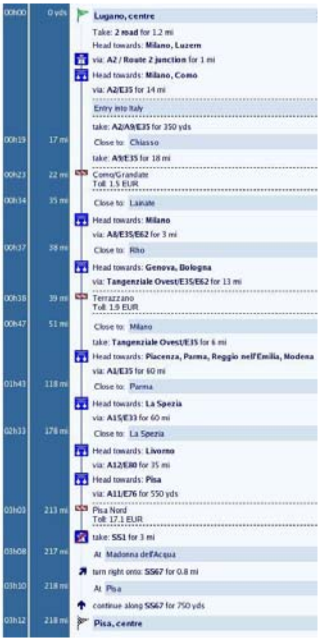

00h00	0 yds	**Lugano, centre**
		Take: **2 road** for 1.2 mi
		Head towards: **Milano, Luzern**
		via: **A2 / Route 2 junction** for 1 mi
		Head towards: **Milano, Como**
		via: **A2/E35** for 14 mi
		Entry into Italy
		take: **A2/A9/E35** for 350 yds
00h19	17 mi	Close to: Chiasso
		take: **A9/E35** for 18 mi
00h23	22 mi	Como/Grandate Toll: 1.5 EUR
00h34	35 mi	Close to: Lainate
		Head towards: **Milano**
		via: **A8/E35/E62** for 3 mi
00h37	38 mi	Close to: Rho
		Head towards: **Genova, Bologna**
		via: **Tangenziale Ovest/E35/E62** for 13 mi
00h38	39 mi	Terrazzano Toll: 1.9 EUR
00h47	51 mi	Close to: Milano
		take: **Tangenziale Ovest/E35** for 6 mi
		Head towards: **Piacenza, Parma, Reggio nell'Emilia, Modena**
		via: **A1/E35** for 60 mi
01h43	118 mi	Close to: Parma
		Head towards: **La Spezia**
		via: **A15/E33** for 60 mi
02h33	178 mi	Close to: La Spezia
		Head towards: **Livorno**
		via: **A12/E80** for 35 mi
		Head towards: **Pisa**
		via: **A11/E76** for 550 yds
03h03	213 mi	Pisa Nord Toll: 17.1 EUR
		take: **SS1** for 3 mi
03h08	217 mi	At: Madonna dell'Acqua
		turn right onto: **SS67** for 0.8 mi
03h10	218 mi	At: Pisa
		continue along **SS67** for 750 yds
03h12	218 mi	**Pisa, centre**

Fig. 1.1 Road map for the Lugano–Pisa route, provided in a textual version (left) and a visual version (right). Image from http://www.viamichelin.com; reproduced with the permission of Via-Michelin.

There are numerous situations in which we use visual representations to understand the various data. This could involve anything from last week's stock market trends to a travel itinerary or even the weather forecast for various geographical areas. Thanks to our visual perception ability, a visual representation is often more effective than written text.

Let's take, for instance, the case of a person who has to travel by car from Lugano to Pisa and needs to find out which route to take. It is possible to represent this information in a textual form by providing, for example, a meticulous description of the roads to follow and the junctions to take. It is, however, also possible to represent this information in a visual form, through a map that visually highlights the entire route to follow. A route generated by a very popular website is represented in Fig. 1.1.

The website in Fig. 1.1 provides a very useful service. We can set a departure point and a destination, and the website will indicate the route to follow. Among the various configurable options, we can request an itinerary that favors the highway or the toll-free roads. The website creates the best route possible, according to our requirements. The route, as we can see in Fig. 1.1, is presented in two forms: One is a textual table that reports the distances, the names of the roads to follow, and the junctions to note, and the other is a visual version in the form of a road map.

The website provides two complementary versions that can be used for different purposes. For example, a truck driver transporting goods will want to know exactly which roads to take and their relative distances; in this case, the textual version can be very useful. There are, however, some aspects that can be interesting when we plan an itinerary for a recreational journey, such as the possibility of finding an alternative route or places close to the route that might be of interest to the tourist. Although useless for the truck driver, these aspects could indeed be indispensable for a family wishing to program the route for their next holiday and can be effectively revealed through the use of the visual version of the route.

The visual version has the advantage of using some graphical properties that are very quickly and efficiently processed by visual perception. The visual attributes like color, size, proximity, and movement are immediately taken in and processed by the perceptual ability of vision, even before the complex cognitive processes of the human mind come into play.

Let's clarify this concept with an example. Figure 1.2 shows a sequence of numerical data and a visual representation, constructed by horizontal lines of length proportional to the values on the left that they represent.

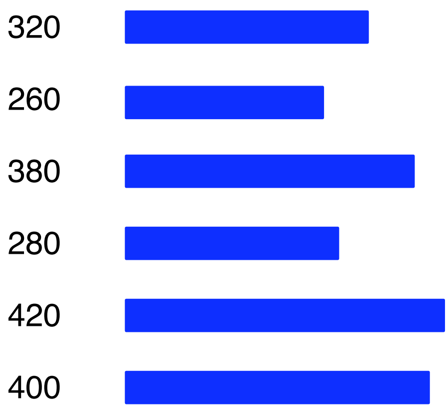

Fig. 1.2 Mapping numerical values to the lengths of bars.

Let's suppose that we have to determine the maximum and minimum numerical values indicated on the left. If we didn't have the lines at our disposal, we would have to perform the following procedure: Read each of the numerical values, keeping in mind the extreme values (the maximum and the minimum) that we come across while reading them, right through to the end. In one sense this is a cognitive exercise, since it is necessary to compare the pairs of numerical values each time to decide if one value is higher or lower than the other.

We'll repeat the same exercise, this time with the aid of the lines on the right. The length of the lines shows us at a glance the maximum and minimum values. This information is processed by our visual perception, which immediately recognizes the lengths of the lines and arranges them in relationship to the values represented.

Since humans perceive *visual attributes* very well, like the extension of the lines in the previous case, we can represent a great deal of different data by "mapping" them to different visual attributes. For instance, we could represent the lines of the previous figure with different colors, or different widths, to codify further data. In this case, the visual representations, if well constructed, can be useful not only for perceiving information more quickly but also for processing several items of information at the same time. Let's not forget that the human brain is a "machine" that constantly processes a huge amount of data and information simultaneously. In this way we can easily single out, in one or more collections of data, the maximum and minimum values, the existence of relationships between the data, grouping, trends, gaps, or interesting values. As a result, the visual representations allow us to understand complex systems, make decisions, and find information that otherwise might remain hidden in the data.

1.1 Presentation

When we want to communicate an idea, we sometimes use a picture. It could be a sketch on paper, a drawing on a blackboard, or images projected on a slide or transparency. The visual representations help us to illustrate concepts that, if expressed verbally, we would find difficult to explain clearly to a listener. Just imagine trying to explain to someone over the telephone how to fix a bathroom faucet. When we have data with which we need to illustrate concepts, ideas, and properties intrinsic to that data, the use of visual representation offers us a valid communication tool. The difficult part is in defining the representations that effectively achieve their goal. Edward Tufte, one of the major contemporary scholars of this discipline and Professor Emeritus of Political Science, Statistics, and Computer Science at Yale University, maintains that "excellence in statistical graphics consists of complex ideas communicated with clarity, precision, and efficiency" [58]. It is necessary for a picture to give the reader as much data as can be processed quickly, using as little space as possible.

Let's look at the visual representation illustrated in Fig. 1.3. It deals with a map created by Charles Joseph Minard, a French engineer, in 1869. The map was conceived to illustrate the number of losses suffered by Napoleon's army during the disastrous march toward Moscow in 1812. The thick band shows the route taken by the troupes, from the Polish border to Moscow, and the width of this track represents the number of soldiers present at each point of the journey. The number of losses suffered by the army is evident at a glance. Of the 422,000 soldiers who set off from the Polish border, only 100,000 arrived in Moscow. Napoleon's retreat during the freezing Russian winter is represented by the dark line, linked to a graph that reports the harsh temperatures that further decimated the already-exhausted army. Some rivers, in which numerous soldiers lost their lives attempting to cross, are also

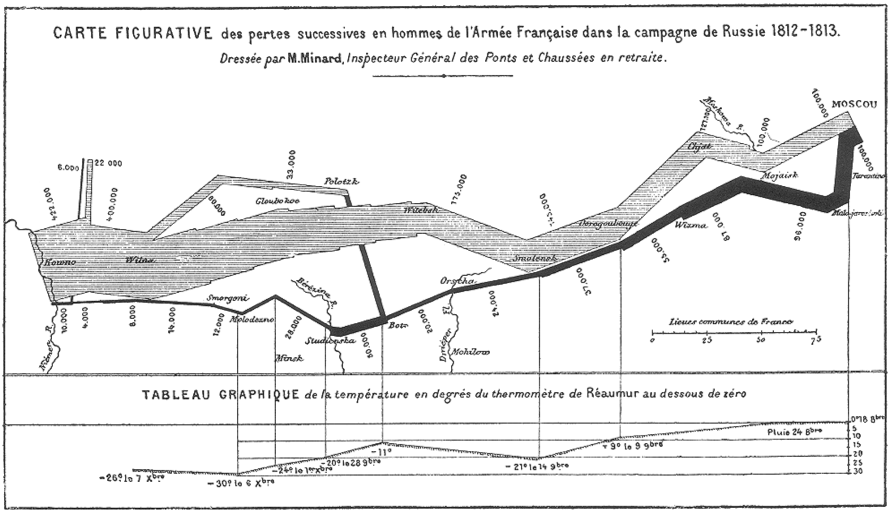

Fig. 1.3 Visual representation of the march of Napoleon's army in the Russian campaign of 1812, produced by Charles J. Minard.

indicated. This visual is a superb example of the concept of excellence expressed by Tufte, who, not without good reason, defined it as "the best statistical graphic ever drawn" [58].

1.2 Explorative Analysis

The explorative analysis of data is one of the applications that benefits the most from visual representations and the ability of analysis by visual perception and the human cognitive system. This has been used for years to identify properties, relationships, regularities, or patterns. Jacques Bertin (a French cartographer who, as early as 1967, wrote a work defining the basic elements of every visual representation) defines it as "the visual means of resolving logical problems" [5].

We'll illustrate the concept with an example. Figure 1.4 displays some statistical data on cancer-related mortality among men in the United States in the period from 1970 to 1994. In the picture, the counties are represented (3,055 in total) by a color scale ranging from blue to red, according to the percentage of cases found in each county. Thanks to the color, we can single out the geographical areas with an average (white), below-average (blue shades), and above-average (red shades), number of cases. It is noticeable how above average-cases are predominantly found in the counties along the East Coast and in the south east of the United States. The American National Cancer Institute produced this and many other images with the aim of identifying possible causes for the onset of tumors. In fact, it is by now almost certain that most cases of cancer are associated in some way with lifestyles that

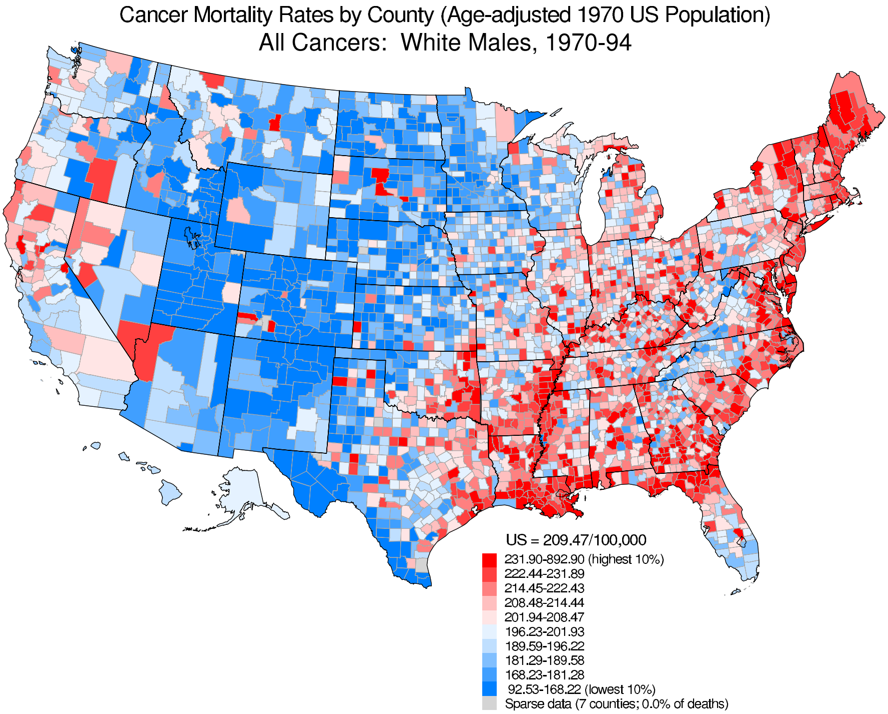

Fig. 1.4 A map of the United States showing the number of cancer related deaths in the male population from 1970 to 1994, subdivided into counties. Image from http://www3.cancer.gov/atlas/ and reproduced with permission.

people lead and other environmental factors. The representation in Fig. 1.4 does not provide an explanation as to why the incidence of death is higher in certain counties than in others but can suggest that researchers carry out epidemiological studies in determined regions, which may throw some light on factors that increase the risk of cancer. For instance, in the past, thanks to a visual representation of this type, a high number of cases of lung cancer were found in the coastal areas of Georgia, Virginia, north east Florida, and Louisiana. Researchers found that these cases were connected to asbestos powder, inhaled by workers in the shipyards during the Second World War.

1.3 Confirmative Analysis

Visual representation is also a visual means of carrying out confirmative analysis on structural relationships between series of data, to confirm or infirm hypotheses on the data. For example, stock market workers are well aware that the stock exchange of various nations is influenced by events. This can be illustrated by Fig.

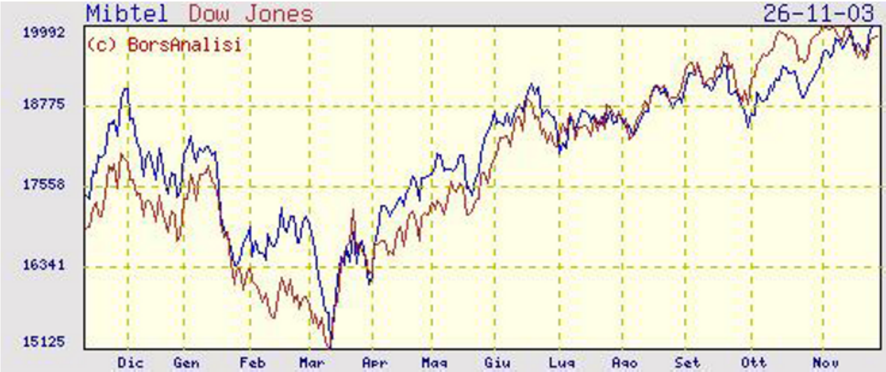

Fig. 1.5 A picture that compares the Italian MIBTEL stock market share index (in blue) to the U.S. Dow Jones shares index (in red). Image from http://www.borsanalisi.com and reproduced with permission.

1.5, where the values of the Italian stock market index MIBTEL and those of the American Dow Jones are represented over the course of a year. In the figure, it is easily noticeable how, when compared to one another, the rising and falling phases of the two stock markets follow a similar trend. This correlation between the two indexes, clearly represented by a picture, could be demonstrated through the use of complicated math formulas, which would certainly be less expressive and intuitive than a picture.

1.4 Information Visualization

Eminent authors often refer to visual or graphical representations by the term *visualization* (or *visualisation* in the less common British version of the term). In this text, we use the expression *visual representation* rather than other synonyms. Obviously, this is not a casual choice; we use the terminology that is most in keeping with the subject at hand.

Spence [54] has noted that there is a wide range of uses for the term *visualization*. A quick check in a dictionary reveals that "visualization" is an activity in which humans beings are engaged as an internal construction in the mind [54, 65]. It is something that cannot be printed on paper or displayed on a computer screen. Taking this into consideration, we can summarize that visualization is a cognitive activity, facilitated by external visual representations from which people build an internal mental representation of the world [54, 65]. Computers may facilitate the visualization process with some visualization tools. This has been especially true in recent years with the use of increasingly powerful, low-cost computers. However, the above definition is independent from computers: Although computers can facilitate visualization, it still remains an activity that occurs in the mind. Some authors use the term "visualization" to refer to both the printed visual representation and the cognitive process of understanding an image. In this book, we maintain the distinction between the creation of a pictorial representation of some data and the cognitive process that takes place when interpreting the pictorial representation.

In this text, we don't speak of generic visual representation, which could be a figure that explains how to calculate the length of a cathetus in a right triangle:

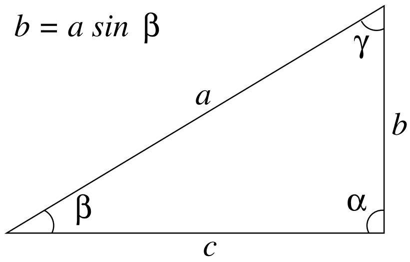

Fig. 1.6 Example of a visual representation that explains how to calculate the cathetus of a right triangle.

Instead, we are interested in visually representing data that can be generated, calculated, or found in many diverse ways, such as data from soccer matches in the last championship, data on the evolution of the population in various nations of the world, data revealed by instruments for environmental pollution tests, etc. The objective is to be informed by this data, or to put together information through the analysis (visual) of the data. The expression *information visualization* was coined by the researchers of Xerox PARC at the end of the 1980s to distinguish a new discipline concerned with the creation of visual artifacts aimed at amplifying cognition.

1.5 From Data to Wisdom

But just how is information created from the data that we represent in visual form? We have already mentioned that we are constantly solicited by a great amount of data arriving from numerous sources. In his essay in *Information Design* [29], Nathan Shedroff analyzes how the process of understanding data comes about, which we can outline in Fig. 1.7.

Shedroff defines this process as the "continuum of understanding" and describes it as a continuum that generates information from data. In addition, the information can be transformed into knowledge and finally into wisdom. Let's look at the principal features of the process:

- **Data** are entities that, of themselves, lack any meaning. They constitute the "bricks" with which we build information and our communicative processes. Let's take the example of data on the consumer price index (CPI) that are provided monthly by the national institute of statistics. These are a collection of numbers that taken singularly, are not much use to the general public. It is, how-

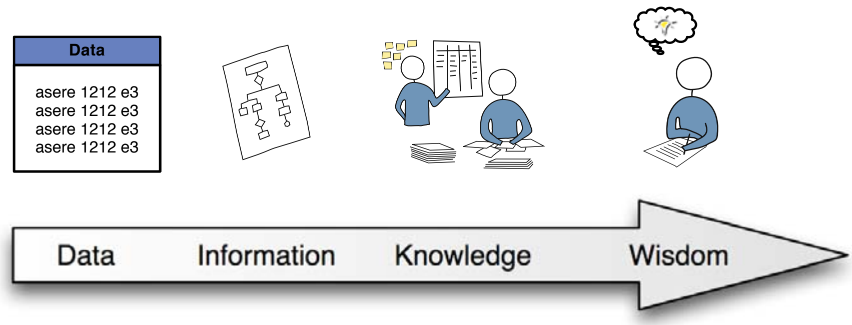

Fig. 1.7 The continuum of understanding, according to Nathan Shedroff.

ever, precisely these data on which the institute bases its annual report on the state of the economy and the nation's inflation.

- Data alone are not enough to establish a communicative process. To give meaning to this data, they must first be processed, organized, and presented in a suitable format. This transformation and manipulation of the data produces **information** that "is accomplished by organizing it into a meaningful form, presenting it in meaningful and appropriate ways, and communicating the context around it" [29]. When the institute of statistics website provides us with data from the last five years, arranged into months and with comparisons and annual averages, we are able to establish the instances of inflation on the consumer price index of the past year and to understand how they compare to preceding years. This information is made possible through the organization (also in the form of tables and averages calculated at the end of the year) of the statistical data assembled. At this stage, the information is conceived.
- When information is integrated with experience, it creates **knowledge**. When we have experiences, we acquire the knowledge with which we are able to understand things. Think of a student, for example, who has to complete exercises on a topic that the teacher has explained. The exercises need to stimulate and challenge the student with problems to solve, so that the theoretical concepts can be applied and called upon in real-life situations. The development of knowledge should be the principal aim of any communication process.
- **Wisdom** is the highest level of comprehension. It can be defined as the stage in which a person has acquired such an advanced level of knowledge of processes and relationships (Shedroff calls it "meta-knowledge") that it is then possible to express qualified judgment on data. Wisdom is self-induced through contemplation, the study and interpretation of knowledge, but, unlike knowledge, it cannot be directly transmitted or taught.

Information visualization is located between data and information. It provides the methods and tools with which to organize and represent the data to finally produce information. Historically considered as a sector of the information discipline commonly known as "human–computer interaction," only in the past 10 years has it been considered a discipline in itself. In Card et al. [8] it is defined as "the use of computer-supported, interactive, visual representations of data to amplify cognition." Basically, the cognitive human processes create information taken from the data presented to us; we wish to improve the cognitive process precisely through visual representation of this data, making use of the perceptual ability of the human visual system. The widespread availability of increasingly powerful and less expensive computers, combined with advances in computer graphics, has made it possible for everyone to have access to systems with which to interact, manipulate visual representations in real time, and explore data that are displayed in various forms and representations.

1.6 Mental Models

Visual representations help us to understand data and therefore produce better information. But how does all of this come about? Robert Spence [54] stresses the fact that the process of visualizing data (meaning the activity of a person who observes a visual representation of content) is a cognitive activity with which people build *mental models* of data, or rather an internal representation of the world around them, from which they manage to expand on and understand such data. It's something that cannot be printed on a sheet of paper or visualized on a computer screen. Just what is a mental model then?

The term "mental model" was first used by Kenneth Craik in 1943 in his book *The Nature of Explanation* [15] and is mainly used by cognitive psychology scholars to describe how humans build knowledge from the world around them. Cognitive psychology defines it as a sort of "internal codification" to the brain of the outside world. The formation of an internal model is aided by visual properties that help us to build a "visual map" of the data that are shown. For example, if we often take the route described in Fig. 1.1, after the first time we no longer need to consult the map, because in our mind we have already created an internal model of the route to follow. This does not mean that we have memorized a copy of the map or the table in Fig. 1.1, but that we can recognize the main reference points (for example, the names of the cities, highways, and intersections) that we have associated with our mental model.

Card et al. [8] explained how visual representations can boost cognitive process, because they allow some inferences to be done very easily for humans. For instance, if, during a journey from Lugano to Pisa, we wish to stop twice to rest, at about one third and two thirds along the way, we can immediately identify two locations by consulting the visual representation of the route.

In their article "Why a diagram is (sometimes) worth ten thousand words" [38], Larkin and Simon carried out an empirical study comparing, in solving physics problems, diagrams versus the equivalent textual descriptions. The conclusion is that the diagrams are expressively more effective due to three properties:

1. **Locality**. In every visual representation, each element has its place in the physical space. In a well-designed representation, two pieces of data, which have to be processed simultaneously, can be represented by two different visual elements positioned in the immediate spatial vicinity. For example, in Fig. 1.5, the historical values of two different stock market indexes are placed together in a single diagram. This allows the reader to compare their fluctuations directly.
2. **Minimizing labeling**. This property is linked to the ability of human beings to recognize information represented in a visual format, without the need for a detailed description in textual form. It is better still if this information resembles, as much as possible, the actual world that it seeks to represent. The map shown in Fig. 1.1, for example, uses precise visual properties, such as the lines with the double red stripes at the edges and yellow at the center to denote the highway, while the suggested route is highlighted with the color purple and is superimposed on the highway to be followed. The junctions and exits to take (such as at Parma and La Spezia in the figure) are easily distinguished from the intersection of the two highways. The symbolic representations of the intersections that we find in the textual version, to the left of the map, are not necessary since they are already immediately understood from the visual version.
3. **Perceptual enhancement**. As previously cited, we can process a large amount of perceptual inference through visual representations, allowing us to single out relationships and dependence between data very naturally. For example, in Fig. 1.4, it is easy to single out groupings (known as *clusters*) of counties with a high rate of cancer. It is also easy to individualize some counties in the center and north of the United States showing an abnormal situation: a high number of cases in these counties, compared to a low number of cases in neighbouring counties.

1.7 Scientific Visualization

When we have to visually represent data, we have to deal with the problem of their nature. Data themselves can have a wide variety of forms, but we can distinguish between data that have a physical correspondence and are closely related to mathematical structures and models (for example, the flow of air surrounding the wing of an airplane during flight or the density of a hole in the ozone layer that surrounds the earth), and data that have no correspondence with physical space and that we call *abstract*. We have seen some examples of abstract data in the visual representations described previously: the fluctuations in the stock market, the effect of the temperature on Napoleon's army during the retreat from Russia, the percentage of cancer cases in U.S. counties. Despite its name, abstract data always deal with concrete data, often resulting from some activity generated by humans, but don't correspond to a physical object positioned in any part of space.

In cases in which we must deal with data that have a correspondence in physical space, we speak of *scientific visualization*, while *information visualization* deals with visualization of abstract data that don't necessarily have a spatial dimension.

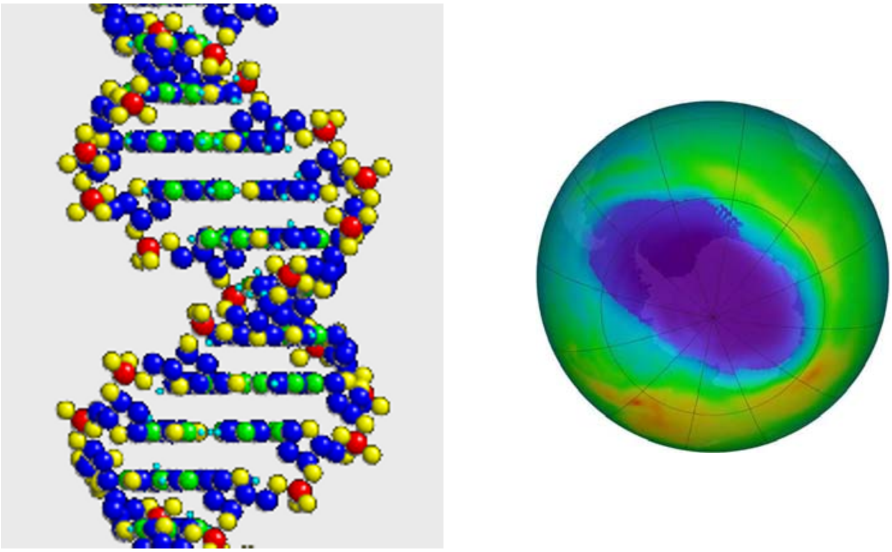

Fig. 1.8 Two examples of scientific visualization. To the left is a representation of a DNA structure, to the right the representation of the hole in the ozone layer over the South Pole on September 22, 2004. Images taken from the NASA Goddard Space Center archives and reproduced with permission.

Scientific visualization is a discipline that aims to visually represent the results of scientific experiments or natural phenomena (two examples are reported in Fig. 1.8). In this text, we deal predominantly with abstract data. For a complete treatment of scientific visualization, it is advisable to consult the *Visualization Handbook* by Hansen and Johnson [27].

1.8 Criteria for Good Visual Representations

What is it that distinguishes a good visual representation from a mediocre one? When can one speak of excellence in visual representation? Numerous scholars have set this challenge for themselves and have come up with the most disparate criteria. From a pragmatic standpoint, we can immediately say that visual representation is considered "good quality" when it fully satisfies the communication and analytic requirements of those for whom it was intended and created.

But how can we go from a collection of abstract data to a visual representation that both is meaningful to the data it represents and, at the same time, can be useful for acquiring new knowledge from that data? There is no magic formula that, given a collection of data, shows us systematically which type of representation to use. It depends on the nature of the data, the type of information that it seeks to represent, and its intended users. But more importantly, it depends on the experience, creativity, and competence of whoever designs the representation. In literature, we find many innovative ideas and proposals that, even if their validity has been demonstrated through empirical studies with potential users, have remained unpractised and haven't found any following in the commercial world.

1.8.1 Graphical Excellence

Edward Tufte is certainly the most prominent expert in the world of statistical graphics for all that involves the excellence of visual representation. His works *The Visual Display of Quantitative Information* [58], *Envisioning Information* [59], *Visual Explanations* [60], and his latest work, *Beautiful Evidence* [61], are true milestones in the field of statistical graphics. Tufte points out some criteria to follow to ensure that a visual representation is effective. According to Tufte, a good picture is a well-built presentation of "interesting" data. It is something that brings together substance, statistic, and design. It aims to clearly, precisely, and efficiently present and communicate complex ideas. More generally, it aims to provide the viewer with "the greatest number of ideas, in the shortest time, using the least amount of ink, in the smallest space" [58]. In the numerous examples that Tufte reports in these texts, it is shown how very often whoever realizes the visual representation has artistic, rather than statistical, competence. This has led to the loss of power (and credibility) of visual representations, reducing them to simply being decorative tools.

Stephen Few has interpreted the teachings of Edward Tufte and has published two very interesting texts: *Show Me the Numbers* [19] and *Information Dashboard Design* [20]. The first is directed at visual statistics professionals, while the second is useful for anyone who has to realize visual dashboards. Few's books are written in a very pragmatic style, useful for those who want to find tips and best practices for building excellent visual representations.

1.8.2 Graphical Integrity

Tufte and Bertin [58, 5] report numerous cases of visual representation that, more or less intentionally, may lead to wrong interpretations. Tufte emphasizes what he defines with the term "visual integrity": The picture should not in any way distort or create false interpretations of the data. The representation of numerical data, just as they are physically designed on the surface of the graphic, should be directly proportional to the numerical quantity represented. The variations of the data should be shown, not the variations of the picture. Furthermore, the number of dimensions of the image must not exceed the number of dimensions of the data. Even the legends are to be used without distortion and ambiguity. Very often the visual representations are designed by artists without any statistical competence; at times this may produce artistic artifacts rather than clear, direct, and unambiguous visual representations of data.

1.8.3 Maximize the Data–Ink Ratio

One of the criteria to which, according to Tufte, it is necessary to pay close attention is the quantity of elements present in a visual representation. It is important not to overload the reader with too much elements, which could end up being unnecessary, if not positively damaging, to the final learning. The presence of some useless decoration (borders, insets, backgrounds, 3D effects, etc.) or of superfluous perspective doesn't make the visual itself more attractive; in fact, it does no more than draw attention away from what the image seeks to communicate. Therefore, these visuals should always be avoided, as instead of illustrating data, they are merely artistic compositions. Primary importance is given to the exhibition of data, not to the visual.

To avoid the representation of redundant and useless information in the image, Tufte defines a very simple criterion on making the most of useful ink. Basically, it's necessary to calculate how much ink is used to represent, unambiguously and relevantly, the real data and compare it with the quantity of ink used to visually enrich the pictures with decorations and other visual elements. The following equation is provided:

$$data - ink\ ratio = \frac{data - ink}{total\ ink\ used}.$$

The aim is to maximize the data–ink ratio, eliminating any non essential elements. One way to do this is to review and redesign the graphic, gradually eliminating the decorative elements, the insets, the borders, and all of the visual elements not pertaining to the data. This is how visually clear information is created, simple to understand and consequentially more beautiful and elegant.

1.8.4 Aesthetics

Elegance in visuals is attained, according to Tufte, when the complexity of the data matches the simplicity of the design. It's not by mere chance that Tufte mentions Napoleon's march in the Russian campaign, as represented by Minard (see Fig. 1.3), as an example of visual elegance. Elegant visuals are professionally designed with great attention to detail, avoiding decorations lacking in content and choosing an appropriate format and design. Complex details should be easily accessible and used to display data.

1.9 Conclusion

In this chapter, we have introduced the discipline of information visualization as a means of helping humans represent and understand abstract data that may have no relation to the physical space around us. We have also shown how the visual representation of data may help in communicating, analyzing data, and confirming hypotheses.