the functional art
an introduction to information graphics and visualization

alberto cairo

“Welcome to Alberto’s world. Cairo has done it all in The Functional Art: theory, practice, examples. And he’s done it brilliantly. It is the most comprehensive and sensible book yet on real-world information graphics; we won’t need another one for a long time.”

Nigel Holmes, former graphics director for Time magazine and founder of Explanation Graphics

Includes a complete introductory information graphics video course
Contents

Introduction xiv

PART I foundations

1 Why Visualize: From Information to Wisdom 5
   Rational Optimism 6
   Low-Tech Visualization to the Rescue 8
   Drowning in Data? Only If You Don’t Know How to Swim 14
   From Information to Wisdom 15
   Making Reality Visible 17
   Visualization as a Technology 19

2 Forms and Functions: Visualization as a Technology 25
   An Information Graphic on Defense 26
   What Shape Should My Data Have? 28
   The Origins of “Form Follows Function” 32
   More about Functions in Nature 33
   Functions Constrain Forms 36
   The Bubble Plague 39
   More Flexible Than It Seems 43

3 The Beauty Paradox: Art and Communication 45
   Building a Narrative Structure 46
   An Unexpectedly Controversial Chart 47
   The Visualization Wheel 50
   Abstraction-Figuration 52
   Functionality-Decoration 53
   Density-Lightness 54
   Multidimensionality-Unidimensionality 54
   Originality-Familiarity 54
   Novelty-Redundancy 57
   Identifying your audience 59
   Engineers vs. Designers: Edward Tufte and Nigel Holmes 61
   Minimalism and Efficiency 63
Is All “Chartjunk” Junk?  64
Fun and Functionality  68
Otto Neurath and the Visual Education of the Masses  70

4  The Complexity Challenge:
Presentation and Exploration  73
It’s Not the Style, It’s the Content  74
Seek Depth  76
Graphics Don’t “Simplify” Information  78
Finding Balance: Density and Multidimensionality  80
Functionality and Abstraction  81
Fun-tionality  85
The “Boom” Effect  86

PART II  cognition

5  The Eye and the Visual Brain  97
The Unexplained Eye  98
Let There Be Light  99
Light and Photoreceptors  100
Foveal, Peripheral Vision, and Animated Infographics  102
The Lying Brain  105
The Efficient Brain  108
A New Diagram For Vision  110

6  Visualizing for the Mind  111
The Brain Loves a Difference  111
The Gestalt School of Thought and Pattern Recognition  114
Choosing Graphic Forms Based on How Vision Works  118
The Perceptual Tasks Scale as a Guide for Graphics  123
Other Preattentive Features: Seeing in Depth  128

7  Images in the Head  133
How to Open an Airplane Door  134
Recognizing by Remembering  136
The Comparing Brain  139
The Mental Imagery Debate  141
How Do We Really Know that a Face is a Face?  142
Applying Object Recognition to Information Graphics  144
Looking Ahead  146
PART III  practice

8  Creating Information Graphics  153
    Brazilian Saints  154
    The Changing Face of Brazil’s Population  160
    Inequality and the Economy  167
      A Word on Structure, Color, and Type  171

9  The Rise of Interactive Graphics  185
    Early Lessons on Interaction Design  188
      Visibility  189
      Feedback  190
      Constraints  192
      Consistency  192
    Structuring Interactive and Animated Infographics  195
    Different Kinds of Interaction  200
      Instruction  200
      Conversation  200
      Manipulation  203
      Exploration  204
    How to Plan For Interactive Infographics  204

PART IV  profiles

1  The Infographics Gentleman  212
    John Grimwade (Condé Nast Traveler magazine)

2  Information Art  231
    Juan Velasco and Fernando Baptista
    (National Geographic magazine)

3  All the Infographics That Are Fit to Print  250

4  Capital Infographics  264
    Hannah Fairfield (The Washington Post)

5  Germanic Precision  279
    Jan Schwochow (Golden Section Graphics)
6 Visualization in Academia 293
Geoff McGhee (Stanford University)

7 Quantitative Humanism 306
Hans Rosling (Gapminder Foundation)

8 Truth and Beauty Operator 314
Moritz Stefaner (http://moritz.stefaner.eu)

9 The Rising Stars 326
Gregor Aisch (driven-by-data.net) and
Jan Willem Tulp (TULP interactive)

10 Visualizing Literature 342
Stefanie Posavec (itsbeenreal.co.uk)

Bibliography 351
Index 354
Why Visualize: From Information to Wisdom

My expertise has always been my ignorance, my admission and acceptance of not knowing....When you can admit that you don’t know, you are more likely to ask the questions that will enable you to learn.

—Richard Saul Wurman, from Information Anxiety 2

Recently someone asked me what personality trait best characterizes those interested in a career in visualization and infographics. My answer: “An insatiable, childish curiosity.”

Curiosity, combined with a tendency to try to explain everything using reason, led me to a career in journalism and, later, to specialize in information graphics. It is not possible to be a good communicator if you have not developed a keen interest in almost everything as well as an urge to learn as much as you can about the strangest, most varied, unrelated topics. The life of a visual communicator should be one of systematic and exciting intellectual chaos. In my case, it consists of regular shifts between journalism, cognitive psychology, international
politics, and history. In your case, it might be sports, music, architecture, or just about anything else.

Let me give you an example of how far healthy curiosity can take you.

**Rational Optimism**

My original plan for this chapter was to open it with a few formal definitions for information visualization, information design, and infographics. But something changed my mind. While randomly navigating *The New York Times* website, I stumbled on a review of a book called *The Rational Optimist: How Prosperity Evolves*, by British science essayist Matt Ridley (2010).

The review was mostly critical, but the hypotheses Ridley proposed sounded intriguing. The book honored its title, making a case for optimism about our future as a species. I had read other Ridley books in the past and had loved his *Genome: The Autobiography of a Species in 23 Chapters* (2006), so I was positively biased.

My curiosity ignited, I grabbed my Kindle and purchased the book. One minute later, it had finished downloading. For the rest of the day, I traded book writing for reading. (Note to my editor: I did it to make this chapter better, I promise!) The book is so well written that it was difficult to put down before the end.

One chapter about the fertility rate, or the average number of children born to women in each country, caught my eye. You may have heard or read the stories of Malthusian doomsayers who claim that rising fertility in poor regions is the reason the Earth has to support 7 billion people, with a forecast of 9 billion two decades from now, and even more in the far future.

Other doomsayers focus on the aging populations of developed countries where fertility rates are below 2.1 children per woman, a number that is known as the “replacement rate.” If the replacement rate in a country is significantly below 2.1, the population will shrink over time. If it’s much higher than 2.1, you’ll have a much younger population down the road, which can cause problems. Younger populations, for example, show greater rates of violence and crime.

Ridley contradicts both kinds of apocalyptic thinking by discussing two interesting trends. On average, fertility in rich countries is very low, but in the past few years it has trended slightly upward. On the other hand, poor countries show a decrease in average fertility. Contrary to conventional wisdom, in many countries

---

that verge on becoming first-world economies, such as Brazil, the drop is dra-
matic: the fertility rate has trended from more than six children per woman in
1950 to less than two in 2010.

Ridley suggests that, due to these two complementary trends, fertility rates ev-
erywhere will converge around 2.1 in a few decades, and the world population
will stabilize at 9 billion people. It’s counterintuitive, isn’t it?

Ridley’s case is compelling and supported by prospective data from reliable
sources, such as the United Nations (UN) and The World Bank. But something
made me uncomfortable as I read his arguments. It took me a while to figure out
what it was. Ridley writes about curves and lines and trends, but the chapter on
fertility and population includes just one graphic, similar to the one in Figure 1.1.

![Figure 1.1](image)

**Figure 1.1** How much world population increases compared with the previous year.

The graphic is simple and clear, but also insufficient to support the claims Ridley
makes. All it shows is that when you plot population change as a time-series chart,
the trend is negative. The closer we get to the present, the lower the worldwide
population growth. **The fact that the graphic is an aggregate of the data of all
countries in the world impedes our ability to see the multiple patterns**

---

Ridley discusses. Where are those rich countries whose fertility rate is slowly recovering? Where is the evidence for the assertion that developing countries such as Brazil, China, and India are stabilizing their populations?

I told you before that I am curious. I didn’t just take a day off to read The Rational Optimist. I also looked for the data Ridley used for the chapter on population. With that data, would I be able to prove his hypotheses?

Low-Tech Visualization to the Rescue

The first thing I did was go to the United Nations website. If you search for “UN data,” you will quickly find http://data.un.org/, which is a kind of paradise if you like to dig into huge databases on population, education, economics, and social development. Within the UN site, I searched for the fertility rate data. The UN’s figures begin in 1950; the projections extend as far as 2100.

I decided to exclude the years after 2010, playing with actual data (at that time) rather than forecasts. Using the filters the site offers, I asked for a table that included the more than 150 countries on which the UN has complete research. Figure 1.2 shows a screenshot of what I obtained.

![Figure 1.2 UN data table.](image)

I downloaded the table and decided to try a low-tech visualization exercise to show my students—mostly journalists with no technology background—that learning to create information graphics is not all that difficult.
Using OpenOffice (an open source software suite that includes a spreadsheet program), I reorganized the data and cleaned up the table a little. Some cells were missing, so the process involved a bit of manual tweaking—no big deal. Figure 1.3 shows an excerpt of the result.

Still with me? Now the fun begins. We have the table in the computer. Is it possible to make sense of it? Hardly. Extracting meaning from a table is tough. Can you see any interesting trends just by reading the figures? If you can, congratulations. You have an extraordinary memory. Most of us mortals have brains that didn’t evolve to deal with large amounts of data. Let me prove it to you: Look at Figure 1.3 again and tell me in what years between 1950 and 1975 did the difference between the fertility rates of Spain and Sweden grow, and in what years did it drop? This apparently simple task forces you to do something extremely difficult: look up a number, memorize it, read another one, memorize it and compare it with the previous one, and so forth until you get to the end of the series. I wouldn’t bother.

But what if I designed a simple chart with the data in the spreadsheet? The result (Figure 1.4) is a visual tool that helps answer my question. The message in that graphic is clear: Spain started 1950 with an average number of children per woman higher than Sweden’s. But then fertility in Spain fell drastically after 1970 and only recovered partially in the last five years of the series. On the other hand, Sweden’s fertility rate has remained pretty stable over the last 60 years, although it is well below the replacement level of 2.1 children per woman.

By giving numbers a proper shape, by visually encoding them, the graphic has saved you time and energy that you would otherwise waste if you had to use a table that was not designed to aid your mind. The first and main goal of any
A Comparison of Spain’s and Sweden’s Fertility Rates

Average number of children per woman over her lifetime

Source: UN

Figure 1.4 So much for Spanish pride.

graphic and visualization is to be a tool for your eyes and brain to perceive what lies beyond their natural reach.

However, presenting data for two countries is far simpler than presenting data for one hundred of them, which is what we may need to do in order to put some of Matt Ridley’s ideas to the test. Once we represent the lines for all countries in our data set, we get something similar to Figure 1.5. This colorful spaghetti dish may look interesting, but it’s totally useless for our purposes. This is what you get when you let a software program do the hard work for you.

Remember, what we want to reveal is the projected confluence of the lines of rich countries (trending slightly up in recent years) and those of poor countries (trending down) around the 2.1 children per woman line. If you look at Figure 1.5 long enough, you may be able to tell the lines apart, but it’s more likely you will just give up.

The way to solve this problem is to add some visual hierarchy to the mix. Obviously it makes no sense for all lines to be equally visible. In information graphics, what you show can be as important as what you hide. I put the chart generated in OpenOffice into Adobe Illustrator, where I highlighted a few rich countries and a few developing and poor countries.

I made other countries’ lines light gray, so they remain on the scene but don’t obscure the message. Why not get rid of them? Because they provide context to

---

This idea has inspired some of the best books out there, including those of Edward Tufte, William Cleveland, Stephen Few, and Stephen Kosslyn, among others. See the Bibliography for references.
**Fertility Rate**

Average number of children per woman over her lifetime

Showing all countries for which complete data is available

Figure 1.5 Too many lines obscure the message.

the cases that I highlight. While changing all the background lines to one color makes it impossible to see them as independent entities, collectively they show an overall downward trend in the data—you can see that many lines begin between the 6.0 and 8.0 children per woman point in 1950, but just a handful of them remain at that height in the vertical axis when they reach 2010. The final sketch in Figure 1.6 looks much more user-friendly than the previous one.

Excited by what I was revealing, I explored other assertions made in *The Rational Optimist*. Ridley argues that a sudden drop in a country’s fertility rate is usually precipitated by several factors: an increase in average per capita income, women getting better access to education, and the shrinking of infant mortality figures. The facts that more children survive their first years of life and that women are spending more time in school are positively correlated to better family planning.

On the economic side, Ridley explains that in rich countries, leisure options are everywhere, and they are cheap and accessible; the distractions of the modern world free us, albeit partially, of our primary impulse to reproduce with no control. We can explain this phenomenon in bogus academic jargon: the average number
Figure 1.6 Highlighting the relevant, keeping the secondary in the background.
of children per couple is inversely proportional to the average amount of hours each member of that couple spends in front of any kind of screen. No kidding.

To prove the correlation between fertility, income, and women’s schooling, I designed two small scatter-plots in the same spreadsheet software I used before. In Figure 1.7, each little circle represents a country. The position of each country on the horizontal axis is proportional to its fertility rate. The position on the vertical axis equals average income per person (first chart) and the percentage of students in middle school who are female (second chart).

![Per capita income and fertility rate](image1)

![Percentage of middle school students who are women and fertility rate](image2)

**Figure 1.7** The more educated and rich you are, the fewer children you’ll have.

The black line running between the dots is called a trend line or regression line: the closer the dots are to this line, the stronger the correlation between the two variables represented. You can see that the dots are pretty close to the line, so the variables are related. On average, the richer people are, the fewer children they tend to have; and the fewer girls who attend middle school, the more children on average they have in that particular country.

Here’s the lesson I learned from this exercise: In just three or four hours of work, I completed a personal project that allowed me to see the evidence supporting Matt Ridley’s discussion on the evolution of fertility. His hypotheses seem to have some basis after all. **But if you don’t present your data to readers so they can see it, read it, explore it, and analyze it, why would they trust you?** This is a question many journalists, particularly those who write opinion columns, should ask themselves more often.
Drowning in Data? Only If You Don’t Know How to Swim

The example I just gave you was not chosen randomly. It helps us delve into topics that are essential to understanding the present state of graphics as a form of communication. Isn’t it amazing that we can read graphics at all, and use them to discover realities otherwise invisible to the bare eye? In the past two or three decades, psychology has unveiled many of the brain mechanisms involved in this kind of understanding. Another thought: Did you notice that the data I manipulated is available on the Internet for free? And isn’t it wonderful that the tools I used to prove Matt Ridley’s assertions are also broadly available to anyone and can be learned in a matter of hours?

Those three trends have converged to put visualization in the mainstream. The design of graphics is not just more democratic than it was a decade ago, when data was sparse and software expensive and difficult to use. We also have the potential to use graphics more intelligently because the principles informing their design have never been clearer.

Embracing graphics and visualization is no trivial endeavor. Citing research by International Data Corp (IDC), The Economist reported that the information generated in 2010 alone reached 1,200 exabytes,4 an amount equivalent to thousands of billions of issues of the venerable British magazine. The story added that the total amount of extant digital information totals several zettabytes. Here’s a simple explanation to help you grasp the challenge we’re dealing with:

1 bit, or binary digit, is the basic unit of information in computing. It represents either 0 or 1.

1 byte (the amount of information necessary to encode a letter or a number) = 8 bits

1 kilobyte = 1,000 bytes

1 megabyte = 1,000 kilobytes or 1,000,000 bytes (10^6)

1 gigabyte = 1,000 megabytes or 1,000,000,000 bytes (10^9)

1 terabyte = 1,000 gigabytes or 1,000,000,000,000 bytes (10^12)

1 petabyte = 1,000 terabytes or 1,000,000,000,000,000 bytes (10^15)

1 exabyte = 1,000 petabytes or 1,000,000,000,000,000,000 bytes (10^18)

1 zettabyte = 1,000 exabytes or 1,000,000,000,000,000,000,000 bytes (10^21)

1 yottabyte = 1,000 zettabytes or 1,000,000,000,000,000,000,000,000 bytes (10^24)

---

Confused? Don’t worry. You’re not alone. A yottabyte of information is such a huge number that it is impossible to imagine. In August 2010, Erich Schmidt, former CEO of Google, announced in a conference that between the beginning of time and 2003, humanity generated roughly five exabytes of data, whereas we now produce the same volume of bits every two days.

“The information explosion is so profoundly larger than anyone ever thought,” said Schmidt. Five exabytes is more than 200,000 years of DVD-quality video.5

To be fair, not all that “information” is what you would call information in a colloquial conversation. Most of it is the product of automated processes and communications between computers, mobile phones, and other devices—nothing that a human brain can understand. But still.

Let’s catch our breath here and move on.

From Information to Wisdom

In the 1970s, years before access to the Internet was universal, Richard Saul Wurman, then a professor of architecture in North Carolina, predicted that the oncoming information explosion would require the intervention of a new breed of professionals trained in organizing data and making sense of it. According to Wurman, the biggest challenge our species was about to face was to learn how to navigate the upcoming tsunami of bits that was cresting the horizon.

Wurman called these people information architects. Their discipline, information architecture, has been defined by others as:

- The structural design of shared information environments;
- The combination of organization, labeling, search, and navigation systems within websites and intranets;
- The art and science of shaping information products and experiences to support usability and findability;
- An emerging discipline and community of practice focused on bringing principles of design and architecture to the digital landscape.

Wurman suggests that one of the main goals of information architecture is to help users avoid information anxiety, the “black hole between data and knowledge.”

People still have anxiety about how to assimilate a body of knowledge that is expanding by the nanosecond.... Information anxiety is produced by the

---

5 Google Atmosphere 2010 conference.
ever-widening gap between what we understand and what we think we should understand.6

The gap is better represented through the diagram in Figure 1.8, which shows the steps separating the two extremes of Wurman’s maxim. It is based on several models known as DIKW Hierarchies (Data, Information, Knowledge, Wisdom). Although the models have been criticized as simplistic and vague,7 they are useful for explaining what visualizations and graphics are about.

![Figure 1.8 From reality to people’s brains.](image)

In the diagram, **unstructured information** means **reality**, the world out there in all its glorious complexity. Every phenomenon that can be perceived or measured can be described as information.

**Data** are records of observations. Data can be encoded as symbols (numbers and words) that describe and represent reality. In between unstructured information and data, you can see a **first level of encoding**. Imagine a researcher studying the fertility rate. The data would be the records the researcher makes in a spreadsheet, for instance: 2, 5, 6, 2, 2, 1, 1, 4, 3, 3 (and so on) children per woman.

The **second level of encoding** takes us from data to **structured information**. This happens when a communicator (a researcher, a journalist, or whomever) represents data in a meaningful way, using text, visuals, or other means. We can also say that this communicator has given shape to data, so that relevant patterns become visible.

---

Information consumption can lead to higher **knowledge** on the part of the audience, if its members are able to perceive the patterns or meaning of data. It is not a passive process; our brains are not hard drives that store stuff uncritically. When people see, read, or listen, they assimilate content by relating it to their memories and experiences.

We reach **wisdom** when we achieve a deep understanding of acquired knowledge, when we not only “get it,” but when new information blends with prior experience so completely that it makes us better at knowing what to do in other situations, even if they are only loosely related to the information from which our original knowledge came. Just as not all the information we absorb leads to knowledge, not all of the knowledge we acquire leads to wisdom.

Every step in our diagram implies higher **order**. When we see the world, we unconsciously impose organization on the unstructured information that our eyes gather and transmit to the brain. We create hierarchies. We don’t perceive everything in front of us at once, as we’ll see later in this book. A moving entity, for instance, attracts our attention more than a static one, because movement may suggest an approaching threat. We therefore process the position and identity of the moving object before paying attention to anything else. Our brain gives **meaning** to the object, even if we are not aware of the reason why.

In the words of Kevin Kelly, a famous philosopher of technology, in his book *What Technology Wants* (2010):

> Minds are highly evolved ways of structuring the bits of information that form reality. That is what we mean when we say a mind understands; it generates order.

So, without conscious effort, the brain always tries to close the distance between observed phenomena and knowledge or wisdom that can help us survive. This is what cognition means. **The role of an information architect is to anticipate this process and generate order before people’s brains try to do it on their own.**

### Making Reality Visible

Today, **information architect** refers broadly to professions with very different sets of tools and theoretical traditions. Outside academic circles, an information architect can be someone who writes technical handbooks, a software engineer, a web developer, a wayfinding designer (yes, that’s a profession; who do you think creates public spaces that can be navigated with ease?), and that nerdy guy who makes charts on fertility just for the fun of it.