Hertzsprung and Russell: The Minards of Astronomy

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Abstract

This article will explore the history of flow maps, the extent of their use and how astronomy has benefited from this illustrative way of communicating ideas. Flow maps are multidimensional infographics that tell a long story in one single image. In 1812 the French civil engineer Charles Joseph Minard created a flow map that is still dubbed "the mother of all flow maps", summarising Napoleon's Russian campaign (Figure 1). Almost 100 years later, in 1910, Ejnar Hertzsprung and Henry Norris Russell created a multidimensional flow map that arguably surpasses Minard's map in ingenuity — the Hertzprung–Russell diagram. The Hertzprung–Russell diagram represents a major step towards an understanding of stellar evolution, or "the lives of stars", and is still used in astronomy today.

Introduction

Charles Joseph Minard's map of Napoleon's disastrous Russian campaign of 1812 (Figure 1) is one of the best known infographics in history. Minard was a pioneer of the use of graphics in engineering and statistics. His *Carte figurative des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812–1813* was published in 1869 and according to infographic guru Edward Tufte it "*may well be the best statistical graphic ever drawn*" (Tufte, 1983). The graph — in fact a flow map — displays several variables in a single two-dimensional image:

1. The size of the army.
2. The geographical coordinates (latitude and longitude) of the army's route.
3. The direction in which the army was travelling, both as it advanced and retreated, showing where units split from and then later re-joined the main army.
4. The location of the army on certain dates.
5. The temperature along the path of the retreat.

According to Harris (1999), flow maps "*can be used to show movement of almost anything, including tangible things such as people, products, natural resources, weather, etc, as well as intangible things such as know-how, talent, credit of goodwill*"; that is, flow maps be used to indicate:

- What is flowing, moving or migrating etc.;
- The direction of flow and/or its source and destination;
- How much is flowing, being transferred, transported, etc;
- General information about what is flowing and how it is flowing.

A good flow map tells a long and complicated story in one single image. In this way it gives a perspective similar that of a journalist and must therefore answer the same questions as the journalist: Who? What? Where? Why? How? (Van den Broek *et al.*, 2012).

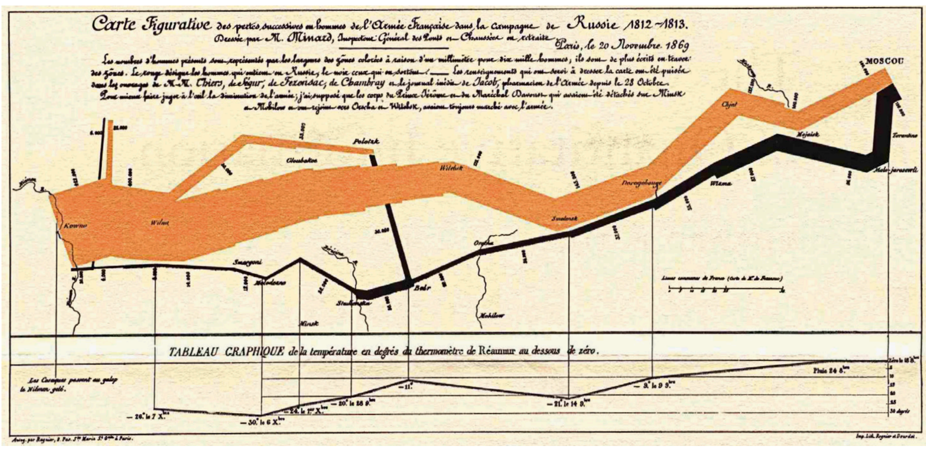

Figure 1. The hellish march of Napoleon's troops in the winter of 1812–1813, as illustrated by Minard. The weather is shown for the period of their retreat. Only a handful of the French troops made it home. Source: Wikimedia Commons.

The stellar Minard map

Astronomers have their own Minard map: the Hertzsprung–Russell diagram (HR diagram; Figure 2). This diagram was independently developed in the period 1911–1913 by the Danish astronomer Ejnar Hertzsprung and his American colleague Henry Norris Russell. Rather than a conventional map showing the locations of the stars it shows the relationship between the stars' absolute magnitudes or luminosities — on the vertical axis — versus their spectral types (or classifications) and effective temperatures — on the horizontal axis, with temperature increasing from right to left.

There are several forms of the HR diagram, but all share the same general layout: stars of greater luminosity lie toward the top of the diagram, and stars with higher surface temperature are toward the left side of the diagram. What makes the Hertzsprung–Russell diagram so brilliant is that it led astronomers to speculate that it might be used to demonstrate stellar evolution. You can see this demonstrated by the white evolutionary track of the Sun in Figure 3.

Figure 3 shows the strength of HR diagrams in illustrating stellar evolution, in this case that of the Sun. Stars can be big or small, hot or cool, young or old, low or high mass:

- On the vertical axis: on a logarithmic scale the brightness of a star (luminosity) with the current luminosity of the Sun standardised as 1.
- On the horizontal axis: from right to left on a logarithmic scale the temperature of a star.
- The temperature as a measure of the star's colour (red is "cold", blue is "hot").
- The size of a circle indicates the size of a star (from dwarfs to supergiants). The size can also be indicated by the lines in which the radius is compared with the current Solar radius.
- By adding evolutionary tracks the diagram can be used to illustrate stellar evolution. In Figure 3 the Sun's evolutionary track is indicated by the white trail.

The interactive website, Star in a Box, beautifully illustrates the evolution of stars with masses higher than, similar to, or lower than that of the Sun. Even the mass decrease during the life of a star can be followed. In Figure 4 the death of a star is mapped in detail. The image shows the evolution of Supernova 1987A, from 11 million BCE (when ape men emerged, lower left) until the outburst of the supernova in 1987. As a size comparison, the orbits of Earth as well as the planet Jupiter are indicated.

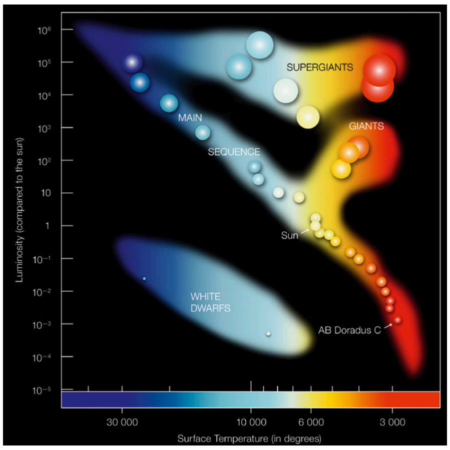

Figure 2. Hertzsprung–Russell diagram with a number of well-known stars including the Sun. Credit: ESO

Multidimensional infographics

The information contained in a chart is generally presented in two dimensions, indicated on the horizontal and the vertical axes. What makes an infographic more than a chart is the possibility of visualising information with more variables. A weather chart, for example, can be a multidimensional or multivariate infographic.

In *The Visual Display of Quantitative Information,* Edward Tufte is an advocate of multidimensional infographics (Tufte, 1983). At times he labours the point, but he is right: by making the best possible use of the different variables, we have the ability to achieve an enormous wealth of visual possibilities that viewers are likely to find pleasing, both visually and cerebrally. He calls this "visual abundance" as the antithesis to the "chart junk" that he deprecates.

Tufte regards as "chart junk" all the visual elements in maps and charts that are not necessary to understand the information being presented, or that distract the viewer from the information. There are many examples of redundant elements: heavy or black gridlines, glaring backgrounds, unhelpful text, strange fonts, images or icons in charts, shadows and unnecessary 3D simulations in line and bar charts. In fact, you could refer to anything that does not meet the criteria for why we make charts as chart junk: we make these charts to communicate numbers or events in such a way that we can compare the numbers or can follow the events by eye.

In Minard's flow map (Figure 1) time, temperature, place, direction, the number of troops, and the division of the troops are combined to form a fine and informative synthesis. Even without a caption, it is possible to read the story from the chart. You can almost feel the cold that the poorly clad soldiers endured — even the tin buttons of their uniform disintegrated as a result of the freezing temperatures.

A remarkable scatterplot

It is quite surprising that Edward Tufte never mentions Hertzsprung and Russell in one of his four highly acclaimed books on visual communication. Rudolf Kippenhahn calls their diagram without exaggeration, "*The astrophysicist's most important diagram*" (Kippenhahn, 1980). In their paper, *A Remarkable Scatterplot*, Ian Spence and Robert F. Garrison call the Hertzsprung–Russell diagram a shining example of the power of visual display (Spence & Garrison, 1993). Although the graph seems simple, it is far from trivial, and astronomers have exploited and extended this remarkable scatterplot in countless ways. The diagram has been described as "*one of the greatest*

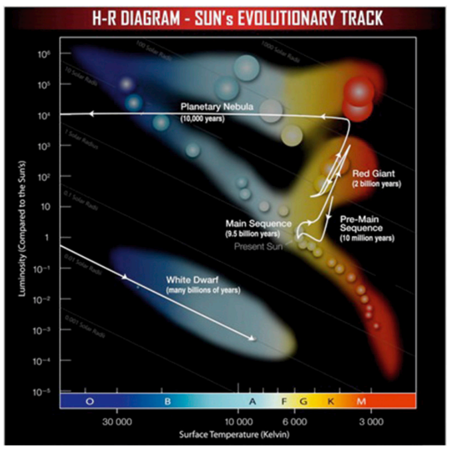

Figure 3. Hertzsprung–Russell diagram showing the evolutionary track of the Sun. Source: chandra.harvard.edu

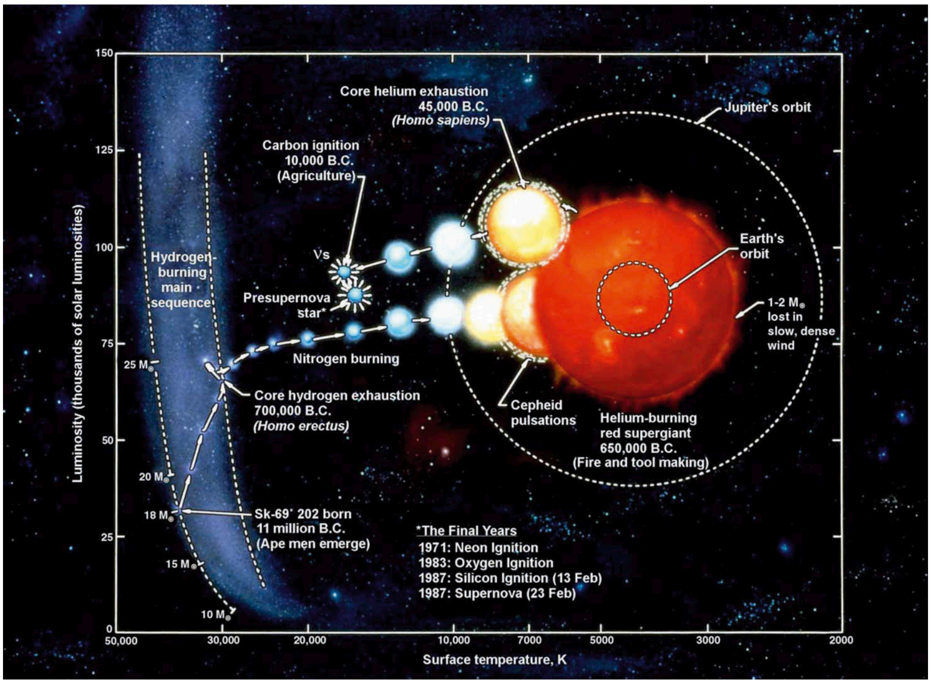

Figure 4. The Herzsprung–Russell diagram for the dying star that led to the famous Supernova 1987A explosion. Source: cococubed.asu.edu

Do's and don'ts for flow maps

Do:	Don't:
Integrate texts and images.	Create texts and images that are not integrated, leading to an insoluble jigsaw puzzle.
Let aesthetics serve content.	Let aesthetics overwhelm content.
Tell a story that can easily be followed.	Have no beginning and no end.
Be multidimensional.	Be "flat".
Answer questions like: who, what, where, in which direction, when, how, how much, how many, and why.	Leave the reader with unanswered questions.
Follow the *gestalt* laws, like the law of good continuation, the law of similarity and the law of proximity (Wikipedia, 2013).	Let it look like a Christmas tree.
Make it appropriate for the audience (contents and semiotics can be easily understood).	Make it unsuited to the audience (too simple, too complicated or with unclear semiotics).

observational syntheses in astronomy and astrophysics" (Smith & Jacobs,1973).

We even dare to go a step further in saying that the Hertzsprung–Russell diagram is a multidimensional flow map that almost surpasses Minard's multidimensional map in its ingenuity. It is a shining example of tinkering with dimensions in order to tell the most important story ever written: that of the evolution of the Sun and its fellow stars. We name Hertzsprung and Russell from now on "the Minards of astronomy".

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Biographies

Jos van den Broek is a Professor in Science Communication at the Department of Science Communication & Society, Faculty of Science, Leiden University.

Pedro Russo is the international project manager for the educational programme EU Universe Awareness. He was also formerly the global coordinator for the biggest ever celebration of science, the International Year of Astronomy 2009. For more information, please visit http://home.strw.leidenuniv.nl/~russo/cv.html