IN DETAIL

Galton's gleam Visual thinking and graphic discoveries

Michael Friendly and **Howard Wainer** recount the tale of Francis Galton and his discovery of weather patterns, which led to modern weather maps – providing a glimpse into the history of visual thinking and graphic communication, the subject of their new book

Imagine a scene from a recent restaurant meal with family or friends (most likely from a time before large parts of the world went on lockdown due to the coronavirus pandemic). Close your eyes. How vividly can you imagine the table, the restaurant setting, the faces of your dining companions? What was your server wearing? Do you have images of the sequence of dishes? For some people, this is easy and natural to do; others can remember many details, but they cannot replay the scene in mental images.

Discussions of the ability to construct, remember and convey such images are sometimes categorised under such headings as "inner vision", "visual insight" or "graphic communication". More evocatively, in the context of scientific discovery, such images might be called "a gleam in the mind's eye", something that Einstein evoked when he said: "If I can't picture it, I can't understand it." Some phenomena are better understood visually than in tables or words.

In this account, we focus on some particularly interesting "gleams" that originate with Francis Galton. Specifically, we highlight Galton's initial contributions to the modern science of mental imagery, followed by some of the notable discoveries he made using his own visualisation abilities.

A polymath, Galton was among the most dominant scientific and intellectual figures in Victorian England. In recent times, his advocacy of eugenics, and the racist underpinnings of ideas that sought to evolve and preserve "high races of men", have been the subject of vociferous criticism.[1] But Galton made important contributions in many areas: biology and genetics (studies of inheritance, twin studies), forensic science (fingerprints), geography (exploration of Africa), meteorology (weather maps), and psychology and cognitive science (word

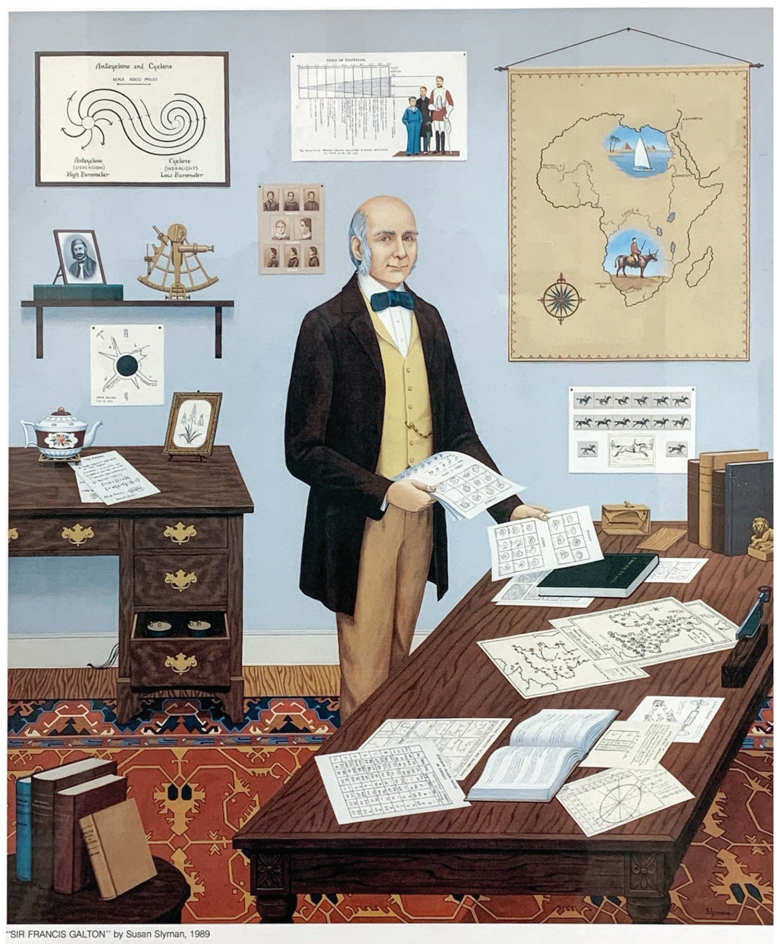

FIGURE 1 A portrait of Francis Galton in his study by the noted folk artist Susan Slyman. In her rendition, Galton is surrounded by some of his visually based discoveries. It appeared as the frontispiece in Wainer's 2005 book, *Graphic Discovery*,[2] and provides a suitable overview of some of the topics we discuss in this article. Galton's first scatter diagram, outlining the theory of regression, is at the front right of his desk; the middle of the desk displays some of his weather charts that led to his discovery of the anticyclonic pattern of winds around a low pressure zone, a diagram of which appears on the wall at upper left. The figure is reprinted with permission of the artist; the image is courtesy of Stephen Stigler.

associations, mental imagery, standardised questionnaires). He is best known in statistics for his discovery of the idea of regression towards the mean and the concentric ellipses that characterised the bivariate normal distribution, published in 1886, which led to the theory of correlation by Karl Pearson, published in 1896. A three-volume biography of Galton by Pearson gives details of his life, and nearly all of his papers are available at galton.org. Figure 1 gives a visual overview of his work.

Mental imagery and visual imagination

> The real voyage of discovery consists, not in seeking new landscapes, but in seeing with new eyes. (Marcel Proust, *La Prisonnière*, vol. 5 of *Remembrance of Things Past*)

"Mental imagery" and "visual imagination" are closely related terms. In literature, some great fiction writers, such as Marcel Proust and Charles Dickens, provide compelling examples of their ability to imagine scenes and translate them into words that convey the rich detail of setting, and the thoughts and emotions of the characters, so that the reader can see these too and connect with their own experience. Underlying this is the cognitive capability of mental imagery, a capacity to imagine scenes and memories in rich, vivid detail.

But although Proust achieved literary immortality with his ability to evoke rich visual images in words – his "remembrance of things past"[3] – it was Galton who chose to study this topic scientifically as a mental ability that people possess to a greater or lesser degree.[4,5] He stated this most clearly as:

> great differences in the power of forming pictures of objects in the mind's eye; in other words, of visualizing them. In some persons the faculty of perceiving these images is so feeble that they hardly visualise at all .... Other persons perceive past scenes with a distinctiveness and an appearance of reality that differ little from actual vision. Between these wide extremes I have met with a mass of intermediate cases extending in an unbroken series.[5]

In a groundbreaking experiment, Galton devised a questionnaire that he distributed to 100 male acquaintances, either "distinguished in science or in other fields of intellectual work".[4] The questionnaire began by asking the subjects to "think of some definite object – suppose it is your breakfast-table as you sat down to it this morning – and consider carefully the picture that rises before your mind's eye". He asked them to record aspects of the quality of their mental image – for example, "Illumination – Is the image dim or fairly clear? Is its brightness comparable to that of the actual scene?". Other questions were asked about the degree of definition of the image, colour, the field of view, and so forth.

Although Galton himself was highly gifted in visual thinking, he concluded, surprisingly, (among other things) that his sample of 19 Fellows of the Royal Statistical Society showed little inclination to rich visualisation. In part, this reflected Galton's view that there is a wide distribution in the ability or inclination to visual thinking that could be related to gender, class and age. But his explanation reflects a gender and class bias of the Victorian age and an egregious extrapolation beyond his data. Scientific men, he said, might confess to feeble powers of visualisation because "an over-readiness to perceive clear mental pictures" is "antagonistic to … habits of highly-generalised and abstract thought". On the other hand, "women and intelligent children" have vivid mental imagery and can report this in detail, he said. Galton's claims about differences in mental imagery among *general* groups (scientists and non-scientists; men and women) have largely been refuted by later research,[6] but he established the idea that subjective experience of mental imagery could be studied scientifically, and his work spurred many follow-up studies of individual differences.

In extreme form, some people have been claimed to have eidetic or photographic memory: a brief glance at a page of text is sufficient to recite it, forwards or even backwards. The best-known documented case is that of a young man referred to as "S." by the Russian psychologist Alexander Luria in his 1968 text, *The Mind of the Mnemonist*. "S." (real name Solomon Shereshevsky) was a young reporter for a Moscow newspaper who later became a professional mnemonist, demonstrating nearly limitless ability to remember random words, numbers, poems in a foreign language – almost anything the audience could supply. His secret was that he translated everything into rich, immutable sensory images containing tastes, smells and visual images, something now called *synaesthesia*. (For more on the story of Shereshevsky, see bit.ly/3emYCDf.)

In the modern history of statistics, scientific discovery and visual thinking, John von Neumann is perhaps the best exemplar of eidetic memory. Herman Goldstine reported asking him to say how *A Tale of Two Cities* began. Von Neumann immediately began to recite the entire first chapter, word for word, and continued until asked to stop 10 or 15 minutes later.[7]

Luria's account of an individual so possessed by eidetic imagery that he could barely function in normal life, and only found work as a professional memory performer, excited modern cognitive scientists to study this topic in far more detail. More recently, with the advent of functional magnetic resonance imaging, a new cohort in cognitive neuroscience has tried to tie individual differences in mental imagery more

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FIGURE 2 Galton's isochronic chart of travel time to different parts of the world. Isolevel contours of equal travel time from London are depicted by shading. Original source: Royal Geographical Society, London, image number: S0011891; now public domain: bit.ly/34F7yiF.

directly to what could be observed in a human brain: what brain areas light up when presented with a verbal joke, an emotional art work (e.g., Picasso's *Guernica*) or an emotional data visualisation (e.g., Minard's graphical portrayal of Napoleon's failed 1812 Russian campaign; bit.ly/2XDqv3F).

In their 2016 account, Matthew MacKisack and colleagues provide a detailed history of the philosophical and empirical roots of what is now called "imagery science",[8] but this new science can be traced to Galton.

Time travel: isochronic chart

As well as studying visual thinking, Galton made many visual discoveries of his own. His most significant will be described later, but first it is useful to see another example of the artistry and imagination that he applied to many other topics. Figure 2 is an "isochronic passage chart", published in 1881, showing how long it would take to travel anywhere in the world from London, using iso-contours depicted by shading colour.

We can see that in Galton's time, one could get to almost anywhere in Europe within 10 days. The outer edge of North Africa took 10–20 days; somewhat surprising is his estimation that large chunks of North America, as far as Denver, could be reached in the same time.

But how could he map travel time for the entire known world? How could he render this in a way that is visually immediate and useful to travellers – for the "convenience of tourists", as he says in his conclusion?

For his data, Galton used many sources: timetables of the principal ocean-sailing companies; the UK postal guide, giving average times for mail delivery to various places, and so forth. But perhaps most ingenious was a crowd-sourced experiment to obtain real data: he sent dated letters to various correspondents and asked that they reply indicating when the letters arrived. Of this process he said:

> In this way the skeleton of the chart was formed, which I filled up by means of measurements based on the average length of a day's journey in the country under consideration. I think there is no estimate in the chart that does not admit of defence, but I freely acknowledge that judgments may greatly differ … as to whether a different estimate might not have been preferable.[9]

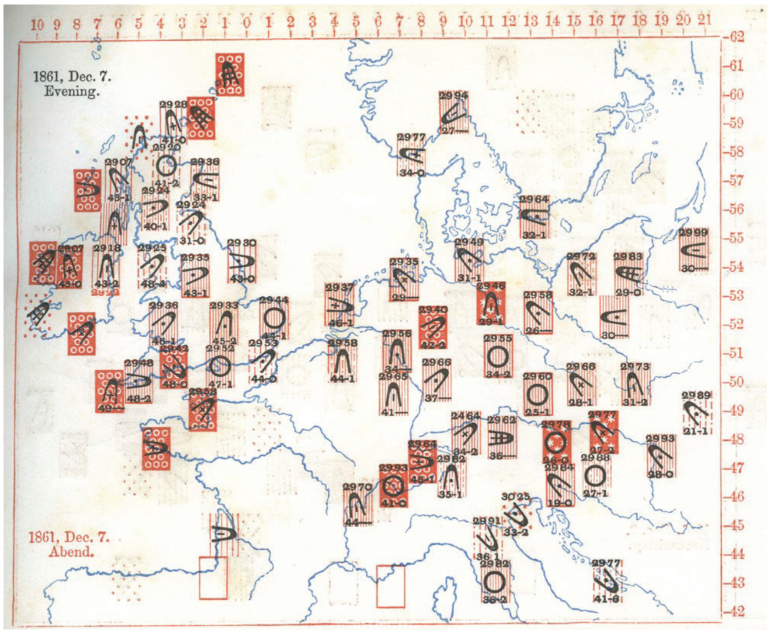

FIGURE 3 Galton's multivariate glyph map of wind direction, strength, cloud cover and rain for one of 93 time points: 7 December 1861, 9pm. The U-shaped icons open in the direction of the wind and are filled in relation to its strength. Stippled and hatched backgrounds range from clear to degrees of cloud, rain and snow. From *Meteorographica*;[10] image courtesy of Stephen Stigler, private collection.

Visually based discoveries

Stories of scientific discovery are useful if they can shed some light on the questions "What were they thinking?" and "How did they come to understand things in this way?". In our new book, *A History of Data Visualization and Graphic Communication*,[12] we trace the origins of graphical methods in relation to scientific problems whose solutions were facilitated by visual thinking and thus seeing lawful regularity in otherwise chaotic numbers.

The selections included in this article discuss what we call Galton's "gleam" and illustrate our theme of visual thinking with Galton's use of visual smoothing and interpolation of three (or more) dimensional data, often shown on a map or a two-dimensional plane.

To place this in historical context, the very idea of graphing data or showing places and other features on maps began with 1D representations, and progressed to 2D (maps, line graphs, scatterplots). The idea of showing something more than just two dimensions on a flat piece of paper was an important ingredient in Galton's gleam.

Winds across Europe: the modern weather map

Galton is best known in statistics for his 1886 discovery of regression towards the mean in problems of heritability. However, perhaps his most significant *visual* discovery occurred nearly 25 years earlier. In 1863, he published *Meteorographica, or Methods of Mapping the Weather*, a monumental work that established new laws of weather patterns connecting barometric pressure and wind direction, forming the essence of modern weather maps. It is not too great a stretch to claim this as a best example of a scientific discovery achieved almost entirely through graphical means; or, as the historian Stephen Stigler puts it, "something that was totally unexpected, and purely the product of his high-dimensional graphs".[2]

Galton began an interest in meteorology around 1858, after he was appointed a director of the observatory at Kew, London. This work suggested many scientific questions related to geodesy, astronomy and meteorology, but – in Galton's mind – any answers depended first on systematic and reliable data, and second on the ability to find coherent patterns in the data that could contribute to a general understanding of the forces at play.

In 1861, Galton began a crowd-sourced campaign to gather meteorological data from weather stations,

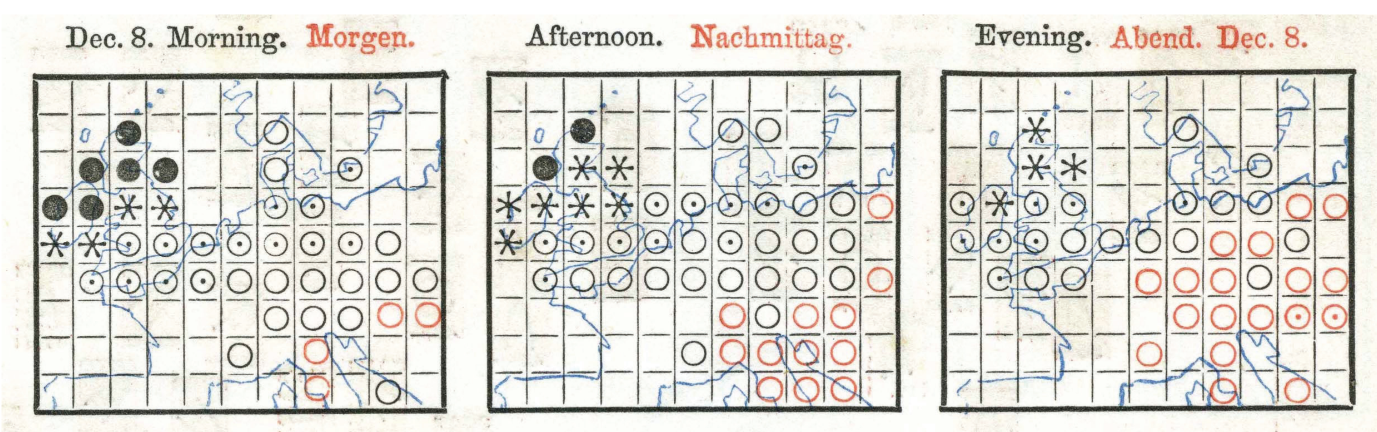

FIGURE 4 Iconic, grid-based maps of barometric pressure for 8 December 1861. Black and red symbols respectively represent lower and higher barometric pressure than average. The symbols are filled to show the deviation from average. Courtesy of Stephen Stigler, private collection.

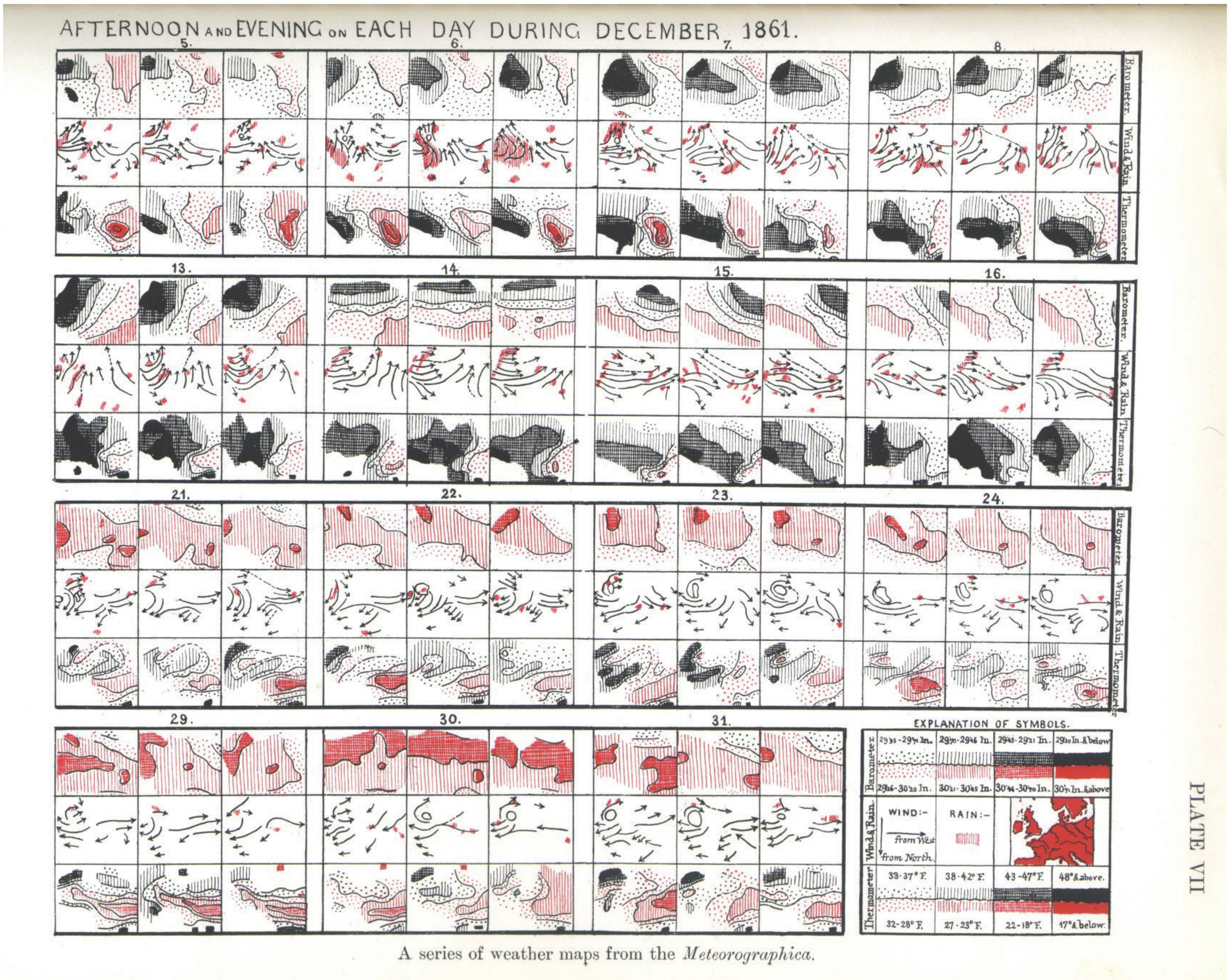

FIGURE 5 Galton's multivariate schematic mini-maps. Each daily panel is a 3 × 3 schematic display of barometric pressure, wind direction and rain, and temperature (rows) for observations at morning, afternoon and evening (columns). The top two rows show data for the initial portion of the month; the bottom two rows are for the end of the month. Courtesy of Stephen Stigler, private collection.

lighthouses and observatories across Europe, enlisting the aid of over 300 observers. His instructions included a data collection form to be filled out at 9am, 3pm and 9pm for the entire month of December 1861, recording barometric pressure, temperature, wind direction and speed, and so forth. It is no small measure of his success here that he designed his form to define the conditions of observation and standardise the scales on which seven weather variables were to be recorded.

From the returns, he began a process of graphical abstraction that resulted in *Meteorographica*. Altogether, he made over 600 maps and diagrams, using lithography, photography and even hand-made rubber stamps in the process. Figure 3 (page 31) shows one of his initial symbolic glyph maps, recording the data from 7 December 1861 at 9pm. The map of Europe and his observation stations provide the geographic context. This was Galton's first step to bring order to the weather, in a collection of 3 × 31 = 93 such maps. He explained that these visual symbols were just as precise as the letters N, NNW, NW, etc., to express wind direction, but the icons "have the advantage of telling their tale directly to the eye".[10]

Although these maps showed all of the data visually, they gave far too much information to see general patterns,

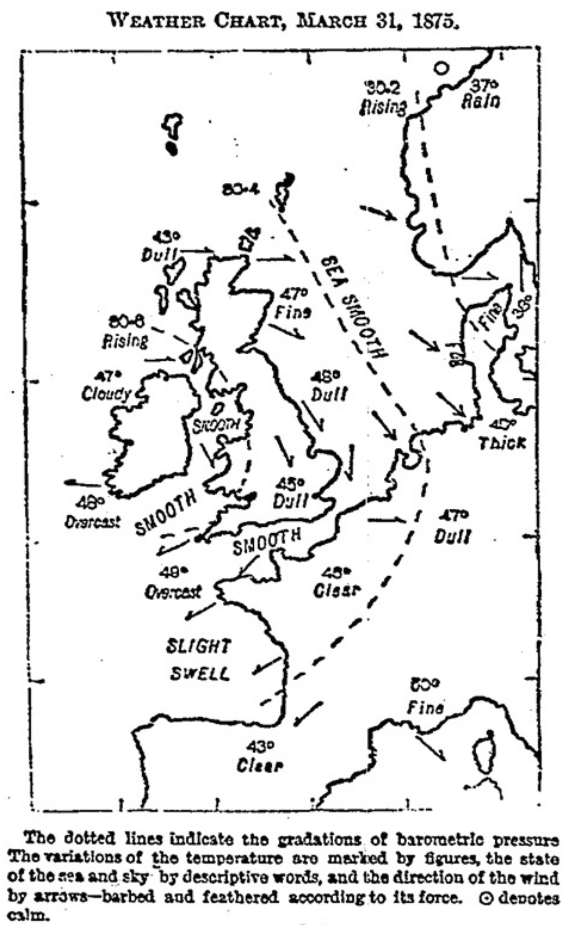

FIGURE 6 The first modern weather map, from *The Times* of London, 1 April 1875.

particularly when spread across 93 separate panels. Galton needed a way to compress and summarise the data to capture systematic variation over both time and space. He hit upon the idea of making iconic maps on a geographical grid to show barometric pressure (Figure 4, page 31). Today, we might call this a zoom-out operation or a graphic display using conditioning and small multiples.

Visual insight into theory; theory into practice

In these displays, Galton began to see something suggestive: barometric pressure seemed to shift throughout the day and over space in something of a coherent pattern. What was this related to? In a stroke of visual genius, he zoomed out to a higher level to show the combinations of wind direction, barometric pressure, rain and temperature in a collection of 3 × 3 schematic mini-maps, one for each day. Figure 5 is one of a two-page spread showing all the data for the month of December 1861.

It is not clear at what point Galton had his "eureka!" moment. Conveniently, it turned out that barometric pressure was generally low in the first half of the month, and high in the second half. At this time, a theory of cyclones suggested that in an area of low barometric pressure, winds spiralled inwards, rotating anticlockwise. Galton could confirm this from his charts, but he noticed something else. Across geographic space, areas of high barometric pressure also corresponded to an *outward* spiral of wind in the clockwise direction, and he called this relation an "anticyclone".[11] This observation would form the basis for a more general theory of weather patterns, linking barometric pressure to wind and other weather variables. Galton explained these results with reference to Dove's law of gyration. A prediction from this and Galton's cyclone–anticyclone theory was that a reversed pattern of wind flow should occur in the southern hemisphere. This prediction was confirmed shortly.

On 1 April 1875, *The Times* of London published a weather chart prepared by Galton; this was the first instance of the modern weather maps we see today in newspapers worldwide (Figure 6).

The story of Galton's "gleam", which ultimately led to this development, brings together some ideas of modern data science: gathering data through crowd-sourcing and standardised forms; organising the data in semi-graphic tables and maps; seeking regularities through visual smoothing and zooming to more abstract representation; and, finally, forming a general theory that could be tested. (It is hard to resist the comment that you *do* need a weatherman to know which way the wind blows.)

It is surely among the best stories of the rise of visual thinking – though there are many more to discover (see box, page 31).[12] ■

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