Galton's Gleam: Visual Thinking & Graphic Discoveries

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If I can't picture it, I can't understand it. --- Albert Einstein

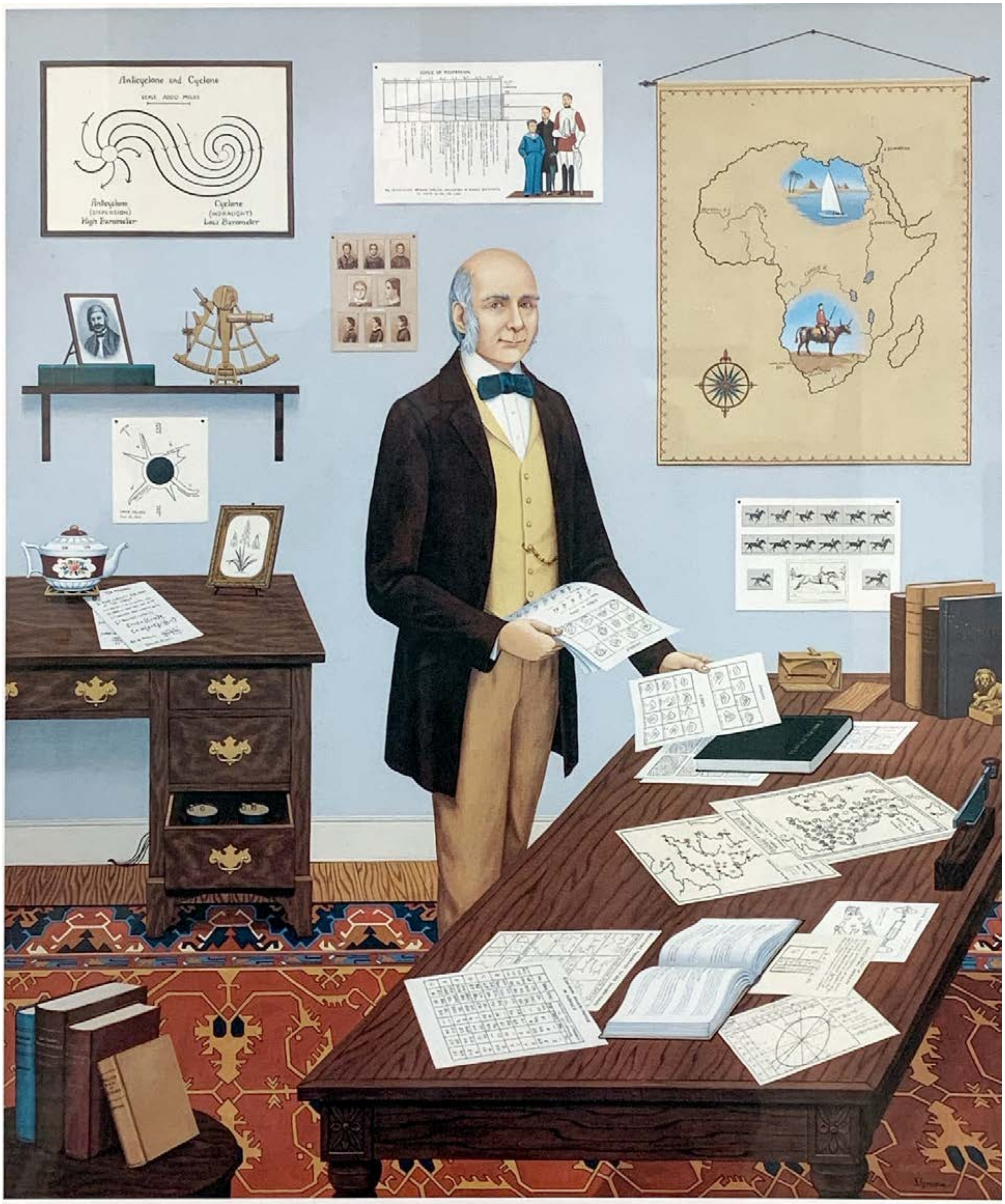
Imagine a scene at a recent restaurant meal with family and friends. Close your eyes. How vividly can you see the table, the restaurant setting in your mind's eye? What was your server wearing? Do you have images of the sequence of dishes? For some people, this is easy and natural; others can remember many details, but they can't replay the scene in mental images.

Discussions of the ability to construct and remember such images are sometimes categorized under such headings as "inner vision", "graphic communication", or "visual insight". More evocatively, in the context of scientific discovery, such images might be called "a gleam in the mind's eye," something that Einstein evokes in our opening quote: visual understanding of some phenomenon better understood 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 remarkable discoveries he made using his own visualization abilities.

Galton's contributions to science

The Victorian polymath Sir Francis Galton was among the most dominant scientific and intellectual figures in Victorian England (Brookes, 2004; Bulmer, 2003). He made important contributions in many areas: biology and genetics (studies of inheritance, twin studies), forensic science (fingerprints), geography (exploration of Africa), meteorology (weather maps), psychology and cognitive science (word associations, mental imagery, standardized questionnaires). He is best known in statistics for his discovery of the idea of regression toward the mean and the concentric ellipses that characterized the bivariate normal distribution (Galton, 1886) and led to the theory of correlation by Karl Pearson (1896). A three-volume biography of Galton (Pearson 1914/1924/1930) gives details of his remarkable life, and nearly all of his papers are available at http://galton.org. Figure 1 gives a visual overview of his work.



"SIR FRANCIS GALTON" by Susan Slyman, 1989

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) Graphic Discoveries and provides a suitable overview of some of the topics we discuss here. His 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 courtesy of Stephen Stigler.

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*, v. 5 of *Remembrance of Things Past*

"Mental imagery" and "visual imagination" are closely related terms. In literature, some great fiction writers, such as Proust or Dickens, provide compelling examples of their ability to imagine scenes and translate these into words conveying the rich detail of setting, 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 ability to evoke rich visual images in words -- his remembrance of things past – it awaited the genius of Sir Francis Galton to study this topic scientifically as a mental ability that people possess to more or less degree (Galton, 1880a, 1880b). He stated this most clearly as:

"There are great differences in the power of forming pictures of objects in the mind's eye; in other words, of visualizing them. In some people, the faculty of perceiving these images is so feeble that they hardly visualize at all …. Other persons perceive past scenes with a distinctiveness and 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". [Galton, 1880b, p. 312]

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" (Galton, 1880a, p. 304) . 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, e.g., "1. 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, color, 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 visualization. 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 visualization because "an over-readiness to perceive clear mental pictures" is "antagonistic to … habits of highly generalized and abstract thought." On the other hand, "women and intelligent children" have vivid mental imagery and can report this in detail. Galton's claims about differences in mental imagery among *general* groups (scientists vs. non-scientists;

men vs. women) have largely been refuted by later research (Brewer & Schommer-Atkins, 2006), but he established the idea that subjective experience of mental imagery could be studied scientifically.

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, forward or even backward. The most well-known documented case is that of a young man, called "S.", reported by the Russian psychologist, Alexander Luria in *The Mind of the Mnemonist* (Luria, 1987). S (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,[1] something now called synesthesia.

In the modern history of statistics, scientific discovery and visual thinking, John von Neumann is perhaps the best exemplar of eidetic memory. Herman Goldstine (1980) reported asking him to say how *A Tale of Two Cities* began. Von Neuman immediately began to recite the entire first chapter word for word, and continued until asked to stop 10 or 15 minutes later.

Galton's work spurred many follow-up studies of individual differences in mental imagery. 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.

With the advent of functional magnetic resonance imaging a new cohort in cognitive neuroscience has tried to tie these differences more 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 (Picasso's Guernica) or an emotional data visualization (Minard's graphical portrayal of Napoleon's failed 1815 campaign). In their 2016 account MacKisak and his colleagues provided a detailed history of the philosophical and empirical roots of what is now called "imagery science", but this new science can be traced to Galton.

Visually-based discoveries

There are many stories that constitute the origins of data visualization that we reported elsewhere[2] and to which we refer the interested reader. Many are classic, but deserve re-telling from a modern perspective: Michael Florent van Langren and the first statistical graph, André-Michel Guerry and the birth of modern social science, John Snow and cholera, and so forth.

There are still additional stories of visual thinking and graphic discovery that found no place in our new book, *Data Visualization: A History of Visual Thinking and Graphic Communication* (Friendly & Wainer, 2020). The selections included here celebrate what we call Galton's Gleam and illustrate our theme of

[1] The story of the mnemonist told by Luria was revisited by Reed Johnson in a *New Yorker* article (August 12, 2017), https://www.newyorker.com/books/page-turner/the-mystery-of-s-the-man-with-an-impossible-memory . The true story of S. turns out to be more complicated than that told by Luria.

[2] See Friendly & Wainer (2020) and Wainer (2005)

visual thinking with Galton's use of visual smoothing and interpolation of 3+-dimensional data, often shown on a map or a 2D 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 to show something more than just two dimensions on a flat piece of paper was an important ingredient to Galton's Gleam.

Time travel: Isochronic chart

What was perhaps Galton's most significant visual discovery 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" (Galton, 1881) showing how long it would take to travel anywhere in the world from London, using iso-contours depicted by shading color.

We can see that in Galton's time, one could get 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 travelers, for the "convenience of tourists" as he says in his conclusion?

For his data, Galton used many sources: time-tables 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.

Figure 2: Galton's isochronic chart of time travel. Isolevel contours of equal travel time from London are depicted by sharding. Original source: Royal Geographical Society, London, Image number: S0011891; now public domain: https://commons.wikimedia.org/wiki/File:Isochronic_Passage_Chart_Francis_Galton_1881.jpg

Of this process he said:

In this way the skeleton of the chart was formed, which I filled up by means of 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 defense, but I freely acknowledge that judgments may greatly differ as to whether a different estimate might not have been preferable. (Galton, 1881, p. 657)

Winds across Europe: The modern weather map

You may be surprised that what we call Galton's most significant *visual* discovery happened 25 years before the discovery of regression that he is most known for. 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, "something that was totally unexpected, and purely the product of his high-dimensional graphs".[3]

Galton began an interest in meteorology around 1858, after he was appointed a director of the observatory at Kew. This work suggested many scientific questions related to geodesy, astronomy and meteorology; but in his 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 he began a crowed-sourced campaign to gather meteorological data from weather stations, 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 standardize the scales on which the seven weather variables were to be recorded (link to image here).

From the returns, he began a process of graphical abstraction that resulted in his 1863 *Meterographica*. Altogether, he made over 600 maps and diagrams, using lithography, photography and even hand-made rubber stamps in the process. Figure 3 shows one of his initial symbolic glyph maps, recording the data from Dec. 7, 1861 at 9 PM. The map of Europe and his observation stations provides the geographic context. This was Galton's first step to bring order to the weather, in a collection of $3 \times 31 = 93$ 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.'' (p. 4)

[3] Stephan Stigler, personal communication, quoted by Wainer (2005).

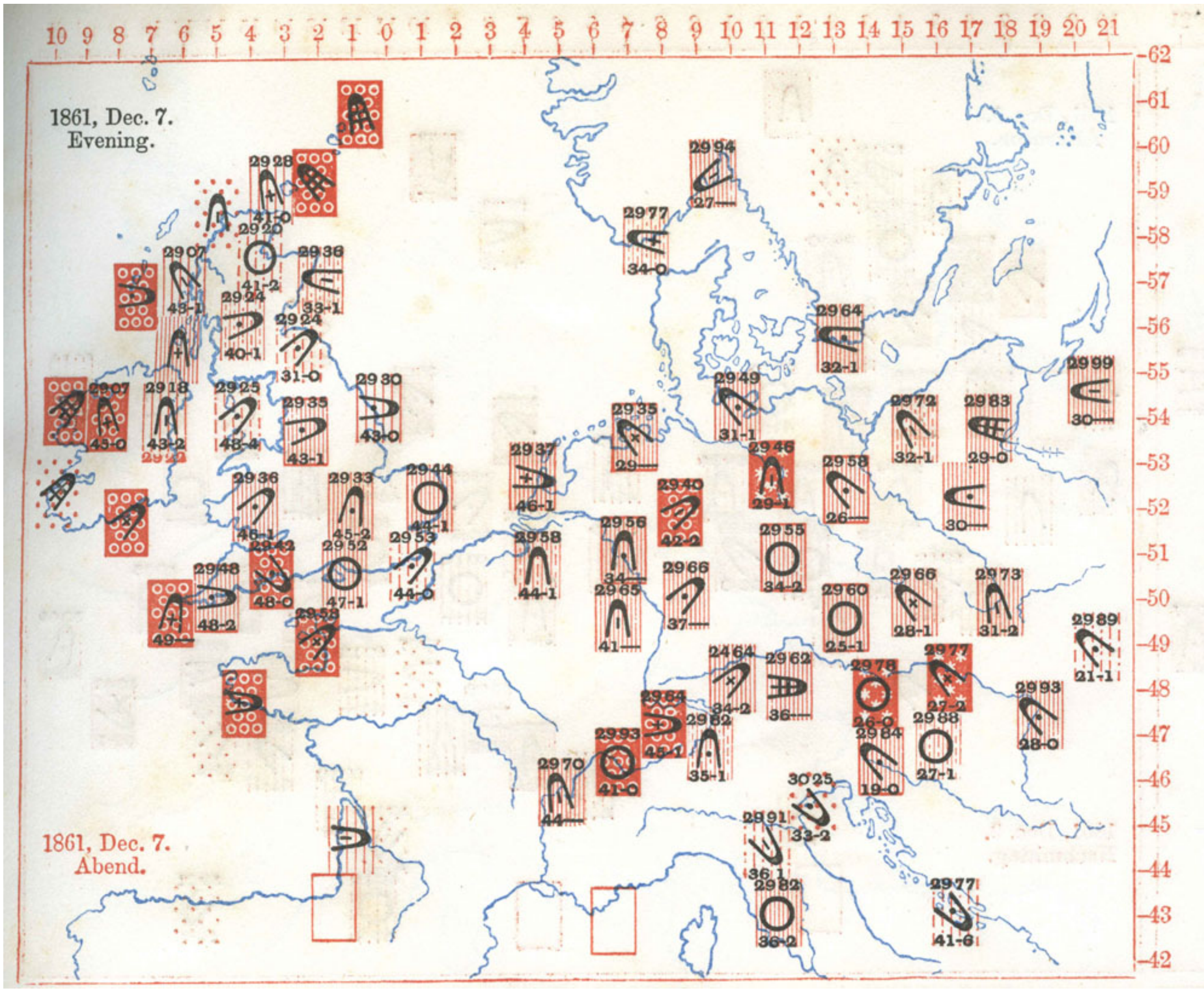


Figure 3: Galton's multivariate glyph map of wind direction, strength, cloud cover and rain for one of 93 time points: Dec. 7, 1861, 9PM. The U-shaped icons open in the direction of the wind, and are filled in relation to its strength. Stippled and hatched backgrounds range from clear through degrees of cloud, rain and snow. Source: Galton (1863); image courtesy of Stephen Stigler, private collection.

Although these maps showed all of the data visually, they gave far too much information to see general patterns, particularly when spread across 93 separate pages. He needed a way to compress and summarize 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). Today, we might call this a zoom-out operation or a graphic display using conditioning and small-multiples.

Figure 4: Iconic, grid-based maps of barometric pressure for Dec. 8. Red and black symbols represent respectively, lower and higher barometric pressure than average. The symbols are filled to show the deviation from average. Source: Courtesy of Stephen Stigler, private collection.

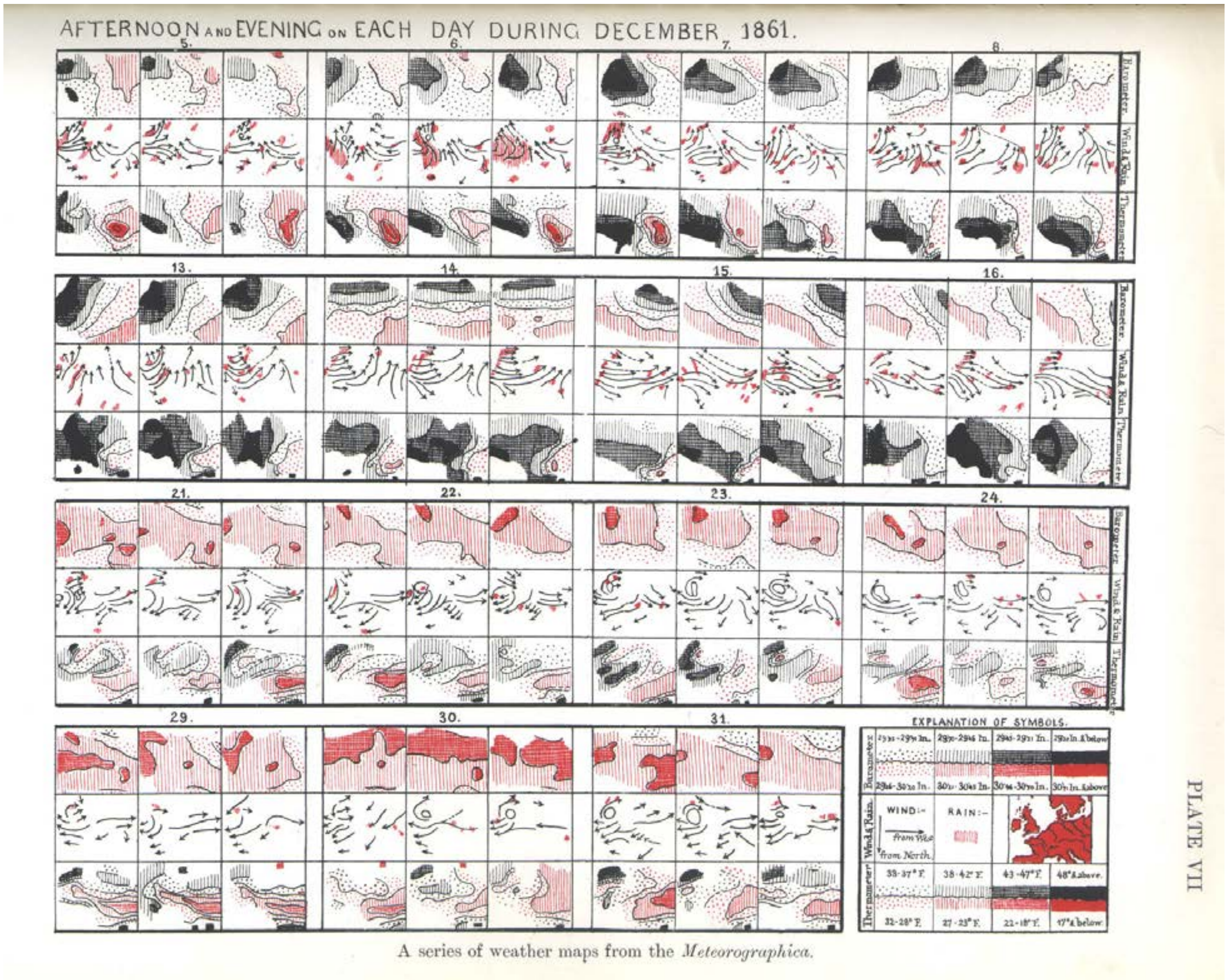
Visual Insight → Theory

In these, 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 x 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.

It is not clear at what point Galton had his OMG! 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 spiraled inward, rotating counter-clockwise. 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''. This observation would form the basis for a more general theory of weather patterns, linking barometric pressure to wind and other weather variables. Galton (1883) later 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 shortly confirmed.

Theory → Practice

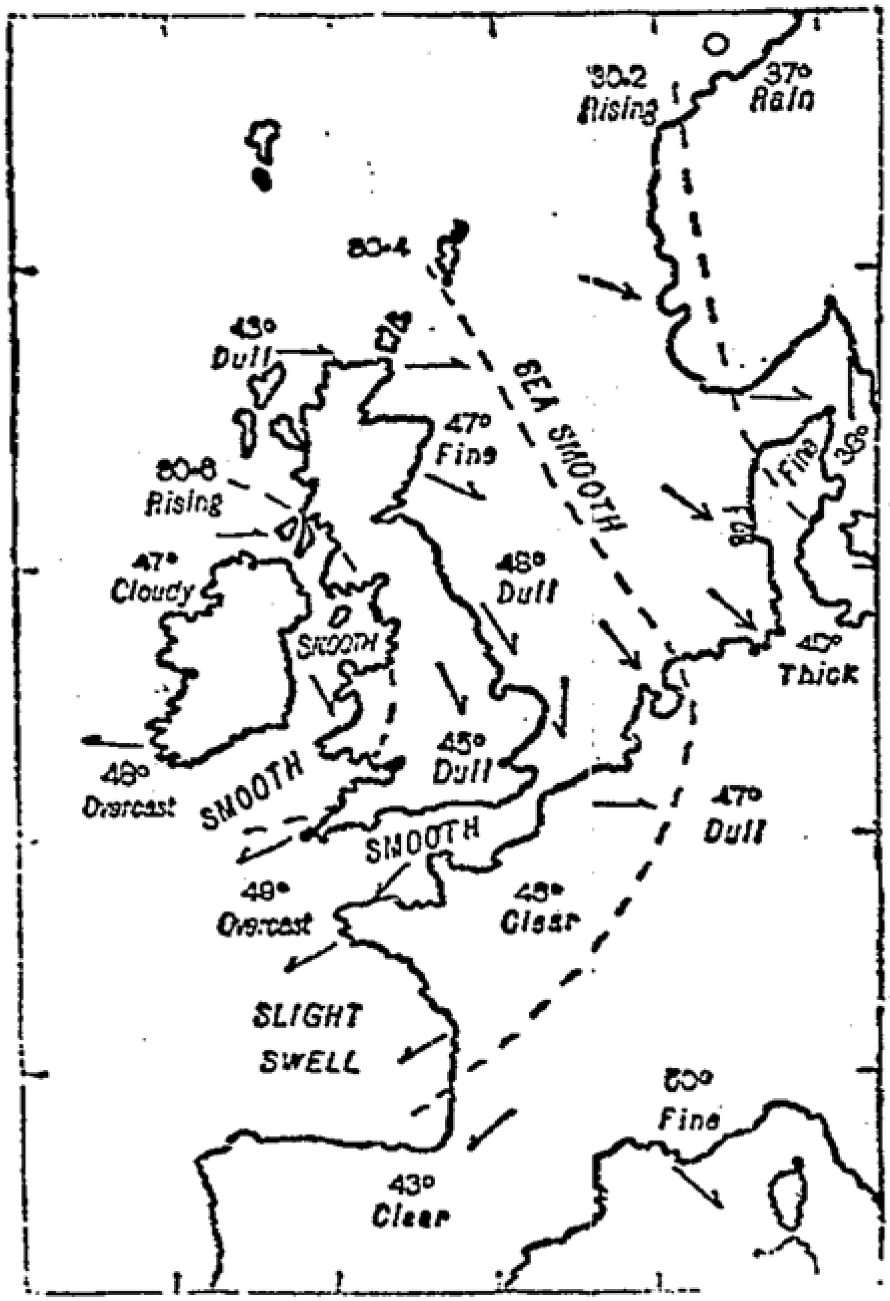
On April 1, 1875, *The London Times* published a weather chart prepared by Galton; this was the first instance of the modern weather maps we see today in newspapers worldwide. Galton's Gleam, combining systematic data collection, a belief that there must be something systematic to be discovered, and an inner vision that graphic displays were the key to insight is surely among the best stories of the rise of visual thinking. It is hard to resist the comment that you *do* need a weatherman to know which way the wind is blowing.



A series of weather maps from the *Meteorographica*.

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

WEATHER CHART, MARCH 31, 1875.



The dotted lines indicate the gradations of barometric pressure. The variations of the temperature are marked by figures, the state of the sea and sky by descriptive words, and the direction of the wind by arrows—barbed and feathered according to its force. ⊙ denotes calm.

Figure 6: The first modern weather map, from *The London Times*, April 1, 1875.

Conclusion

Stories of scientific discovery are useful if they can shed some light on the questions: "What were they thinking?" "How did they come to understand things in this way?" In our *History of Visual Thinking*, 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. John Snow's discovery of cholera as a water-born disease is surely the most well-known example, giving rise first to dot-maps of disease incidence and later to sophisticated models and graphical methods that smooth the data to help explain the pattern.

In this account we take the idea of visual thinking further: First with a more general description of these ideas and history; then with several lesser-known examples from the work of Francis Galton. Together they illustrate some ideas of modern data science: Gathering data through crowd sourcing and standardized forms; organizing the data in semi-graphic tables and maps; seeking regularities through visual smoothing and zooming to more abstract representation; finally, forming a general theory that could be tested. Galton had a remarkable mind, and apropos of our discussion today, its eye was brightly gleaming.

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