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ONWARD
SENSATIONAL
METAPHORICAL
MATHEMAGICAL
ORIGIN
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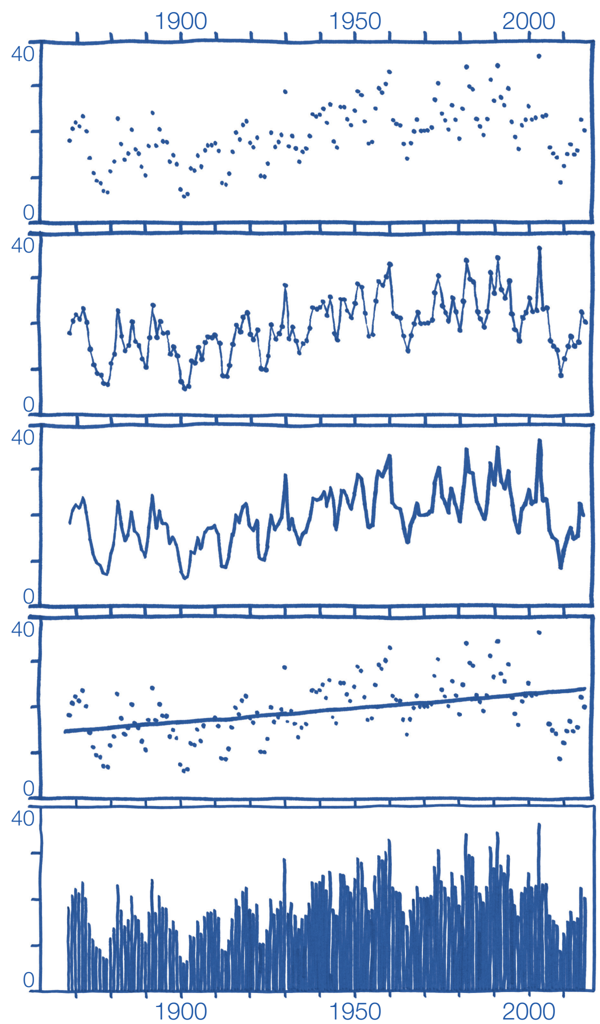
The archetypal display of time is the x-axis time-series chart. It tracks a value as it fluctuates up and down through time. There is a practical limit to how quickly data is sampled. We do not actually measure anything continuously. Smaller divisions of time can always be measured. So we choose a data-collection frequency that is precise enough. Showing a phenomenon with a continuous line mirrors our own uninterrupted experience of time, even though we record actual data at discrete moments. We see time-series data as an uninterrupted flow that proceeds to the right, just as we imagine the adventures of a storybook hero like Alice, whose journey progresses to the right as we turn the pages. Time-series charts consider the data's temporal density, value variability, and completeness. We must match the qualities of our data to the way we already perceive time. Visualization expert William Cleveland categorized ways of showing time by how each helps better show the data:



SYMBOL GRAPH
Shows long-term trend of low-frequency data

CONNECTED SYMBOL GRAPH
See data points and their ordering through time

CONNECTED GRAPH
Smooth series for when perceiving individual values is not important

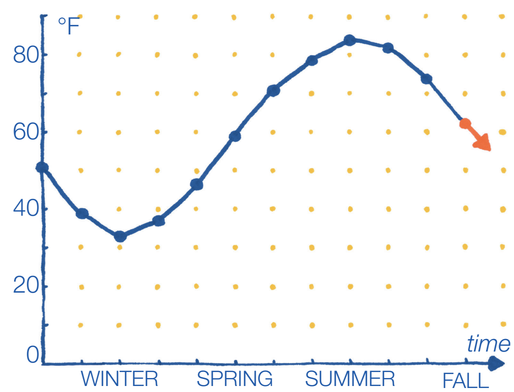
SYMBOL GRAPH WITH TREND
Helps assess a long-term linear trend

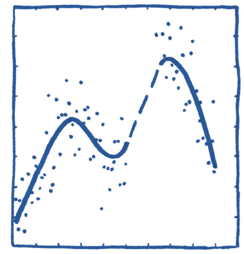
VERTICAL LINE GRAPH
Highlights max and min extremes while still showing individual values.

This data shows a measure of the disturbance level of the Earth's magnetic field. Learn its backstory in the endnotes.

Another way to achieve continuous flow is to use a summary curve. They are generally constructed with some type of moving average. In this way, they differ from a mathematical trend, which uses a formula to fit a single straight line to the data. A smoothing summary curve may benefit data that is too noisy. However, not showing the noise of all the data points can suggest a cleaner story than is actually there. Also, be careful that the summary line does not conceal significant gaps in the data. If you connect sparse points you might suggest more data than is actually available. It is better to leave gaps empty or straddle them with a dashed line.

Even seemingly simple line charts can confuse or, in very poor designs, lead to faulty decoding. Data journalist Dona Wong advocates that axis scales should be segmented into the familiar multiples people already use when thinking about numbers. We often count in fives or tens, but elections sometimes come in four-year cycles. Time should be in days, weeks, months, or years. Line charts do not need to have a baseline at zero, but their baseline should not confuse. Extend axes to zero rather than stopping at a baseline that is *close to zero*. A zero baseline may be emphasized as heavier, a non-zero baseline should have the same weight as other grid lines.





The dashed line gives us a way to express the idea that something is not concrete. Something impermanent. It may be temporary; it may not currently exist (it will in the future or it did in the past); or it may be invisible or hidden. One way or the other, it represents what it is—not solid.
CONNIE MALAMED, 2012

Ratio scales... have a meaningful zero point. Weight, height, speed, and so on, are examples of ratio variables. If one car is traveling at 100 mph and another one is at 50, you can say that the first one is going 50 miles faster than the second, and you can also say that it's going twice as fast.
ALBERTO CAIRO, 2016

100°F is not twice as hot as 50°F because temperature zero points are arbitrary. 0°F was originally keyed to the temperature of brine by the inventor of the first modern thermometer, Daniel Gabriel Fahrenheit.

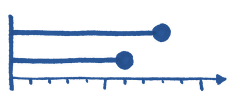
Sizing Up

We already had a glimpse of the power of size. Recall that *big things are important* because a bigger object takes up more of your visual field. Bigger things demand notice. When objects are collected into groups, the largest group commands more attention. A taller pile of things has more things in it. More products, more land, more people, more money, and even more time: We can convey all flavors of *more* with larger size.

The *International System Of Typographic Picture Education*, or Isotype, is a method of pictorial statistics developed by Otto and Marie Neurath. It used a single symbol to represent a fixed quantity. Greater quantities are shown by the repetition of that symbol, rather than scaling the size of a single symbol.

The basic metaphorical linkage between physical size and numeric magnitude seems easy enough. However, the way you actually make shapes bigger with data in order to show more is trickier than meets the eye. We are pretty good at decoding linear position along the number line; four looks twice as far from zero as two does. However, decoding the same numbers in two dimensions, with sized areas, is fraught with pitfalls.

When we encode values in spatial dimensions, we must admit and reconcile the dimensionality of our data. A single column of number values is one-dimensional, no matter what the data is a measurement of in the real world. If our only task is to show values, then we can locate each one on the one-dimensional number line and call it quits.



Points on a line are, of course, just positions. Each point has the same size, no matter how large the value it represents. Mere position misses the opportunity to distinguish values using the visual weight of more ink, or more pixels. Harness the visual importance of size by connecting each point back to its baseline. Now, value is also represented by length. If we increase the connector's thickness, then we increase the visual impact of each value's length. The steadfast bar chart appears. *Voila.*

In order for each bar length to encode the value it represents, it must encompass the *entirety* of the value, all the way from zero. Truncate a bar with a non-zero baseline and its size ceases to have meaning. It is perfectly fine to leave the data as points if you want to focus on a narrow range of positions, but, once you introduce the physicality of length, you have to show it all. Otherwise, the length is worse than meaningless; it is misleading.

Bar charts can have horizontal or vertical orientations. The dominant horizontal metaphor is that of progress towards a goal, often a target of 100% completion. Horizontal bars, like the number line, convey travel away from an origin baseline. They are like runners on a straight dash or miners cutting tunnels into the sheer side of a mountain. Horizontal progress bars are one of the most often experienced data visualizations. Horizontal bars also make great companions to the horizontal text of category titles. However you lay your bar, remember that its journey, how far it has come, is more meaningful if you can see where it began.

A different conceptual meaning is conveyed if the horizontal bar chart is rotated to create columns. The dominant visual metaphor for the vertical bar chart is a stack of stuff. Each column represents a total number of things, items that are often not actually stackable in the real world. A row of columns can show time progressing to the right. Like the horizontal bar chart, each vertical column must extend all the way to zero or it will lose its meaning. You would not be able to appreciate the height of a stack of stuff if you were only allowed to see its top.

As long as visual comparisons are of the *more-or-less* variety (e.g., 18 versus 13), not the multiplicative *x-times more* (e.g., 18 versus 1), we are pretty good at reading

Pierre E. Levasseur referred to vertical bar charts, in 1885, as *columns of stacked facts.*

Suppose the money received by a man in trade were all in guineas, and that every evening he made a single pile of all the guineas received during the day, each pile would represent a day ... so that by this plain operation, time, proportion, *and* amount, *would all be physically combined.*
WILLIAM PLAYFAIR, 1786

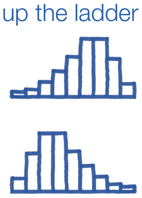
The square root is a good transformation, for this small dataset. But maybe a different warping effect would be better? Why, we could raise our data to a power (x^2, x^3, …) or take its inverse ($1/x$), or try some combination (like $1/\sqrt{x}$). You see, once we entertain the possibility of transforming our scales, the effort threatens to spiral into a multiverse of possibilities. How can we rein in this power before we lose control?

It is an unusual data set indeed that yields its secrets more readily when it is left untransformed.
HOWARD WAINER, 2005

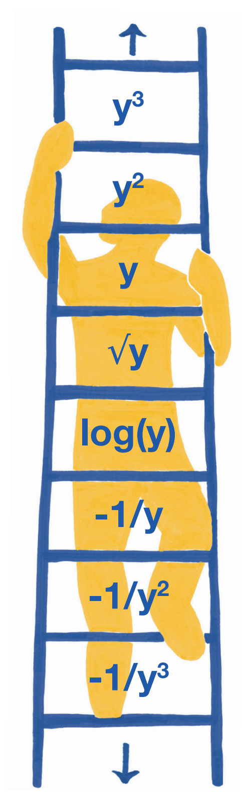
Overlapping marks, empty voids, and ratio comparisons can all hinder our ability to see the data before us. However ugly the data arrives, the *ladder of transformation* can help find better forms for visual exploration. If your data (y) has outliers on its lower end, a bottom-tail, then try walking the data up the ladder: $y \rightarrow y^2 \rightarrow y^3$. This sequence of powers impacts larger numbers more and helps pick apart clusters at the top end of your distribution. If the data has a top-tail, outliers like the 43 kg of oxygen, try walking the data down the ladder. The Procrustean ladder lets us warp the number line world in pursuit of seeing what the data is hiding.

If we want to learn more we must think more.
JOHN TUKEY, 1977

Left-skewed "negative" bottom-tails can be moved up the ladder

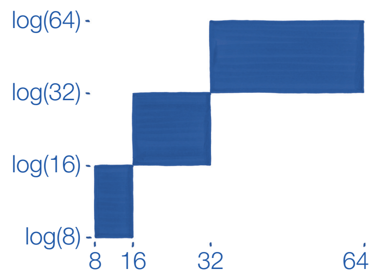


Right-skewed "positive" top-tails can be moved down.



If one of our biggest problems as humans is grappling with ratio comparisons, then what we need is a system of "ratio-numbers." This system would express ratios as differences, the kind of comparison we like. That way, we would be able to consume ratios in a more visually discernible way. Lucky for us, this "ratio-number" already exists. In fact, it has been helping us for over 400 years.

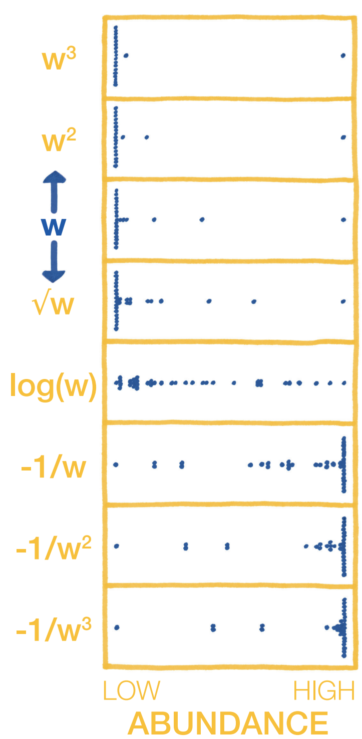
The ratio-number, or *logarithm*, has a tricky technical definition. How it works can prevent us from appreciating why it works: Logs were invented to transform ratios to differences. Too often, we throw a logarithm at a scale because we know it will compress a wide range of numbers to a narrower field. This may motivate you to try a log transformation, but it is only a partial victory if you miss the magic of what happens. For that, let's plot a short series of doubling numbers: 8, 16, 32, 64. Each step rises by 100 percent, a constant increase in ratio from one pair of numbers to the next. Above, the visual distance between these numbers is emphasized with filled boxes. Along the horizontal, the distance between each number doubles, because the number doubles. Along the vertical, we plot the logarithm of each number. The vertical visual difference is the same, because the ratio is the same. The world of the logarithm is built for comparing ratios. This is just what is needed to address troublesome comparisons that are so hard for our mind to make any sense of.



Logarithm is from the Greek words *logos* (ratio) and *arithmos* (number, also the root for arithmetic: the art of counting). John Napier published a set of logarithms in 1614 and they evolved to Leonhard Euler's 1748 standard definition.

The log's quotient property states directly that the ratio of division becomes the difference of subtraction: $\log(x/y) = \log(x) - \log(y)$

The example transformation below expands the original set of elements of the human body to several dozen. Now, elements that have only a trace abundance, like lithium and arsenic, are included too. Each element is represented by a dot, which is enough detail to show a ladder full of transformations. The most abundant element, oxygen, is again in the rightmost position. It is kept fixed there at every rung of the ladder. The 37th least abundant element (molybdenum) is kept fixed at the leftmost position. See how oxygen causes most of the elements to overlap on the blue w-rung (I chose *w* to represent *weight*). Transformations reshape how the distribution appears. Different views reveal different aspects of the distribution. It appears the log(w) transform de-clusters best.

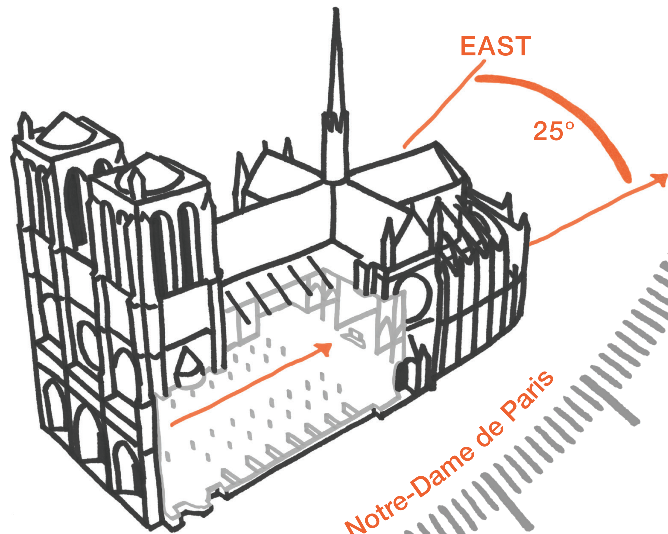


Praying Toward the Sun

French Gothic cathedrals face worshipers toward sunrise.

NORTH

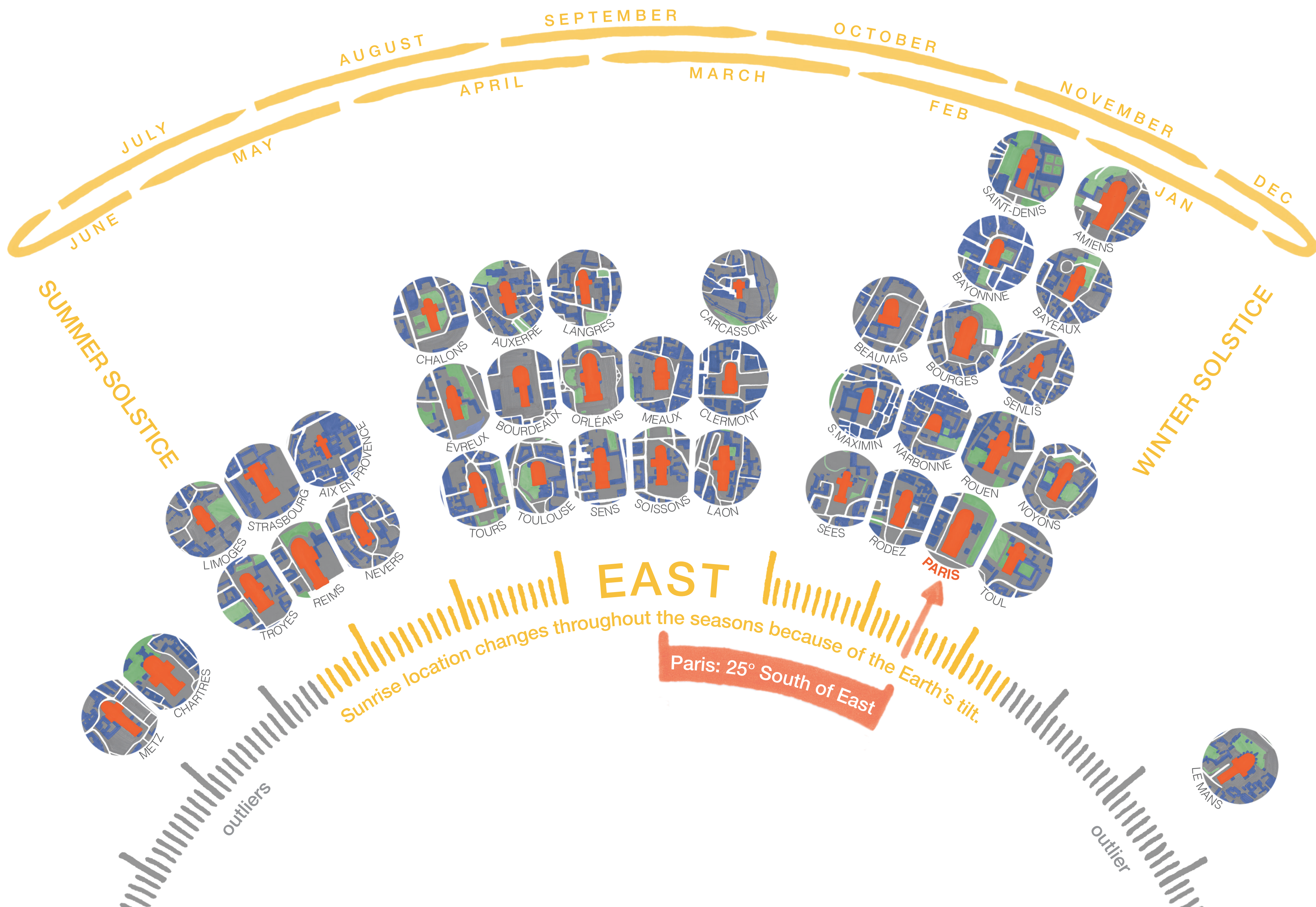
To-scale maps detail French Gothic cathedrals associated with the 1100s and 1200s. Each is positioned according to the long axis of its cathedral. For example, see how Notre-Dame de Paris faces worship 25° south of east. A pattern is revealed: All cathedrals are *oriented*, or face eastward. Most face worship toward the location of sunrise, seen in yellow, on a certain day of the year. Before building began, cathedral orientation was chosen by marking the location of sunrise from the construction site, often on a feast day associated with the cathedral. Three outliers do not face a sunrise. Each was built on the foundation of an ancient church whose orientation was set long before it became fashionable to orient worshiper prayers toward the sun.



SOUTH

WEST

Cathedral angles were measured using *OpenStreetMap*.


JUNE
JULY
MAY
AUGUST
APRIL
SEPTEMBER
MARCH
OCTOBER
FEB
NOVEMBER
JAN
DEC
SUMMER SOLSTICE
WINTER SOLSTICE
EAST
Sunrise location changes throughout the seasons because of the Earth's tilt.
Paris: 25° South of East
outliers
outlier
METZ
CHARTRES
LIMOGES
STRASBOURG
AIX EN PROVENCE
TROYES
REIMS
NEVERS
CHALONS
AUXERRE
LANGRES
CARCASSONNE
ÉVREUX
BOURDEAUX
ORLÉANS
MEAUX
CLERMONT
TOURS
TOULOUSE
SENS
SOISSONS
LAON
SAINT-DENIS
AMIENS
BAYONNNE
BAYEAUX
BEAUVAIS
BOURGES
SENLIS
S.MAXIMIN
NARBONNE
ROUEN
NOYONS
SÉES
RODEZ
PARIS
TOUL
LE MANS