Counting But Losing Count: *the legacy of Otto Neurath's Isotype charts*

Pino Trogu

Since its invention by Otto Neurath in 1920s Vienna, the Isotype system of statistical visualization hasn't gone out of fashion. Isotype charts with their rows of aligned pictograms are common today but were a novelty one hundred years ago. Some praise Isotype charts for their accessible style of repeated pictorial symbols. Others correctly believe that this figurative characteristic often gets in the way of the data-message being presented. This paper questions the soundness of requiring the viewer to engage in such a cumbersome strategy to extract information from a typical Isotype chart: counting the symbols in each row and multiplying by the given scale to get the totals. Recent psychological findings on the limitations of working memory reveal why this strategy is inefficient, and renders Isotype ineffective for displaying data greater than the number seven plus or minus two – the famous finding of George A. Miller on the limitations of human working memory. The effectiveness of the Isotype method is therefore higher and its disadvantages less noticeable when small quantities are involved, and when other refinements can be added to the charts to aid the viewer. This paper notes that Isotype charts are subject not only to the limitation of working memory but also to the inherent ambiguity of words and images. Being culturally constituted, both words and images elude universality and are always in need of disambiguation. It suggests that Neurath was unaware of how deeply his pictograms are culturally constituted – not universal. The paper shows how these mental and cultural limitations can be mitigated or even eliminated by the use of means that are less ambiguous because more widely dispersed globally in almost every modern culture – namely by written arabic numerals showing absolute quantities and fractions. In many cases, written numbers are the best pictures. In today's world, they are pictures that are transcultural and psychologically immediate. By viewers throughout the world, they are so familiar that they require little mental processing time or effort. A picture is worth a thousand words. The picture of a number is worth almost any number of Isotype pictures.

Keywords

Isotype, Neurath, chunk, working memory, counting, arabic numerals, design history, information design, data visualization

1. Psychology

Chunking and the bottleneck of working memory

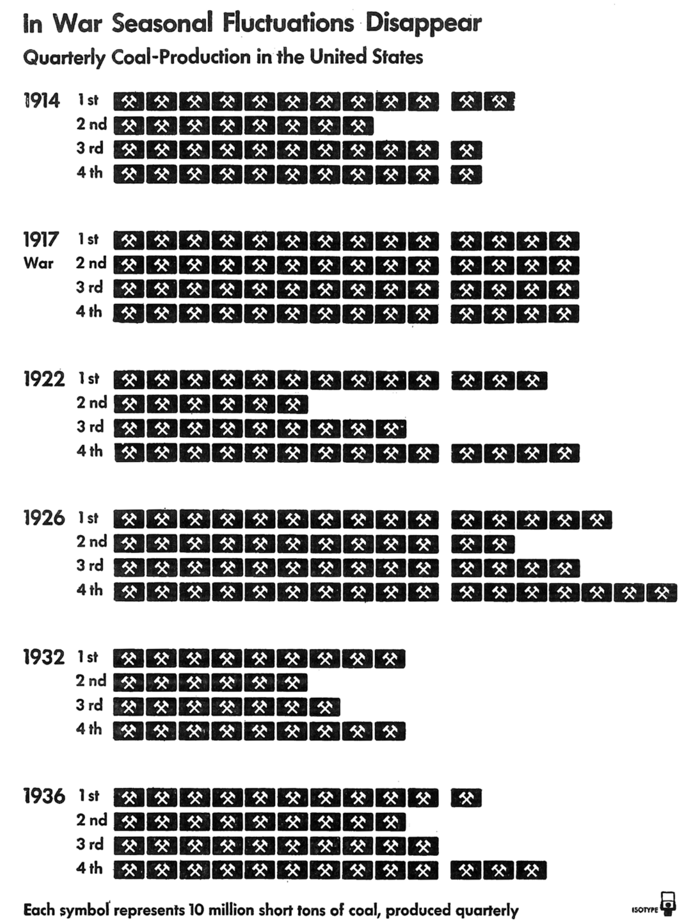
While the Isotype[1] system developed by Otto Neurath (1882–1945) and Marie (Reidemeister) Neurath (1898–1986) was highly innovative, its authors could not have anticipated the adverse effects on working memory by the breaking up of the solid bar – found in traditional bar charts – into repeated smaller parts. For these small parts go squarely against a basic coping mechanism the brain employs when dealing with large numbers of things. But it would be decades before this conflict could be tested empirically. That mechanism, one of the seminal findings of modern psychology, was termed "chunking" by its discoverer, a young Harvard professor named George Miller. His 1956 paper, titled "The magical number seven, plus or minus two: Some limits on our capacity for processing information" began with the memorable sentence: "My problem is that I have been persecuted by an integer (Miller, 1956)." Miller explained that although one can never keep more than about seven chunks of information in immediate memory, if one can chunk the items, then one is able to handle them more efficiently. For example, social security, telephone, and credit card numbers are chunked into groups to aid memorization. Thus the number 185–96–3217 has nine digits but only three chunks, making it much easier to handle and recall than 1-8-5-9-6-3-2-1-7. Many pictograms in a row, discrete items such as "iiiiiiiiii", inadvertently un-chunk what could be represented by a single chunk, an item such as "———" (Trogu, 2015a).

Isotype does sometimes chunk long strings of pictorial symbols into groups of five or ten elements – as shown in several charts from *Modern Man in the Making* (Neurath (1939), 79, 87). Yet it's still difficult to read these charts because of the sheer number of total elements, which, according to Isotype's model, could be handled by simply *counting* them. For example, a chart of coal production in the United States from 1914 to 1936 shows the symbols grouped in sets of ten; it helps, but there is still a lot of counting and multiplying left to do (*figure 1*).

1 The word Isotype, usually set in all-caps, comes from "…the initials of 'I-nternational S-ystem O-f TY-pographic P-icture E-ducation'; the word is based on Greek roots and may be translated 'always using the same types' (Neurath (2010), 102)." The acronym was suggested to Neurath by Marie Reidemeister in 1937 in The Hague, Netherlands, to describe the "picture-text style" they would use in his 1939 book *Modern Man in the Making* (Neurath, M. (1973), 63–64).

Figure 1.

This chart of coal production in the US from 1914 to 1936 shows that seasonal fluctuations are a typical feature of the economy, only to disappear during what Neurath named a *war economy* (Neurath, P. (1973), 39, 81). In 1917 during World War I, "fluctuation was reduced to a minimum (Neurath (1939), 86)." But, except for that year, reading this chart still requires a lot of counting. Original chart from page 87 of *Modern Man in the Making*, 1939.



As in all typical Isotype charts, a scale or key indicates the value of each item; in this case "Each symbol represents 10 million short tons of coal, produced quarterly." Thus, the viewer is required to count the pictograms and multiply them by the scale to get the totals.

It will be shown that if simple numerical labels were added to the horizontal axis in the chart, this process of counting would be much easier, maybe even unnecessary.

Geometric shapes or pictorial symbols?

Bar charts are often used to visualize data like population, money, and goods. Although height (or length) is the immediately perceived difference among the bars, a bar chart is actually an area graph like the pie chart[2] or the more granular tree-map (Shneiderman, 1992). To obtain the size and proportions of each area, the original data are "factorized", so for example the quantity 125 can be depicted as a bar measuring 5 units at the base and 25 units tall, while the quantity 75 would be a bar 5 units wide but only 15 units tall (*figure 2A*). Dividing everything by 5 yields the proportional units of 5 and 3. Shown sideways, each new unit now stands for 25 of the original units; a 5 x 5 unit is now 1 x 1 (*figure 2B*). Since what matters is overall length, we can safely eliminate the divisions (*figure 2C*).

Figure 2.

In these three bar charts, the two bars all depict the relative quantities of 5 and 3 units.

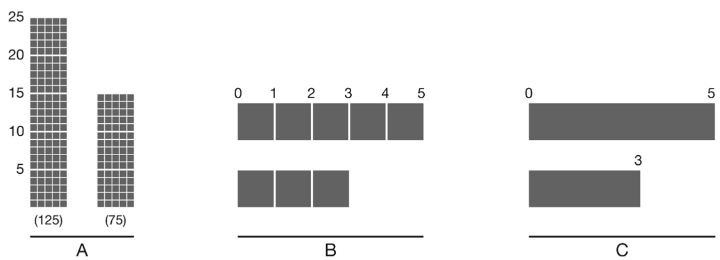
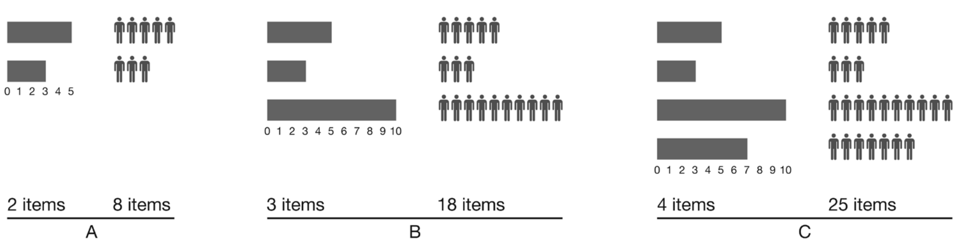


Figure 3.

In this comparison, the examples A, B, and C show the traditional bar chart (solid) on the left and the typical Isotype chart (pictograms) on the right. The continuous nature of the solid bars also allows for more precise data representation, while with pictograms "rounding off" is often necessary.

Now, if we substitute a pictogram for each unit we get the typical Isotype chart. In figure 3, to make the comparison easier, the solid bars have been shortened to match the length of the pictogram bars, but the relative lengths 5 and 3 are unchanged. Now compare the two solid bars with the rows of pictograms: we are comparing two items versus eight items (*figure 3A*). Eight items are still manageable, being within Miller's seven-plus-or-minus-two span of human working memory, but if we add another row of 10 units, the new comparison becomes three items versus eighteen (*figure 3B*); adding a fourth row of 7 units pushes the comparison to four versus twenty-five (*figure 3C*); and so forth.



Subvocalization and labeling

The current view on working memory is that a limited span of time, lasting less than a handful of seconds, rather than the number of items, is the true measure of this strict bottleneck of the mind. Building on Miller's findings, in 1974 Baddeley and Hitch proposed their multi-component model of working memory, which remains the standard reference on the subject in cognitive psychology today (Baddeley & Hitch, 1974). One of its components is the articulatory or *phonological loop*, which provides temporary verbal storage, even in the case of visually presented materials. Baddeley found that we unconsciously name objects as they are presented to us, in a process called "subvocalization", which is a kind of inner speech (Baddeley (2014), 49–66). Since the 1970s, it has been known that we subvocalize when viewing pictures (Noizet & Pynte, 1976).

Subvocalization helps the phonological loop with the temporary storage of verbal information, but the total span of this temporary storage, just a handful of seconds, cannot be directly modified. Thus subvocalization will be insufficient if the mental math required to read an Isotype chart exceeds this total span of time. In that case, to help the viewer move forward quickly, the designer should provide additional aids such as numerical labels, and also find a way to modify or organize the chart into more manageable visual chunks.

Typical Isotype charts could be improved by the simple insertion of a horizontal ruler with number labels, which would eliminate the work required to mentally add the pictograms and multiply them by the given scale. Why not read off a few labels instead of performing such cumbersome arithmetic? For the same reason that one stops counting with one's fingers as soon as one learns the multiplication table by heart. Reading off labels takes little effort; it's like automatically recalling number facts from one's long-term memory storage. One does not perform mental math when recalling simple number facts like 2 + 2 = 4.

Figure 4 is an adaptation of an early Isotype chart showing marriages in Germany in 1911–1926. This modified chart shows that inserting a horizontal axis with plain numerical labels provides fast and precise identification of the length of each row of pictograms, without the need to count and multiply the symbols. While the pictorial character is preserved, the statistical data are now precisely given and quickly grasped. The scale or key may be kept in Isotype charts, but if the numerical labels are missing, adding them will be a big improvement.

Labels on the horizontal axis add local detail to the overall display. While the notation "1 sign for 100,000 a year" gives the scale, the labels make the chart more complete. Labels have been a basic feature of data visualizations since William Playfair published the first bar chart in 1786, showing Scotland's imports and exports for the year 1781 (Playfair, 1786).

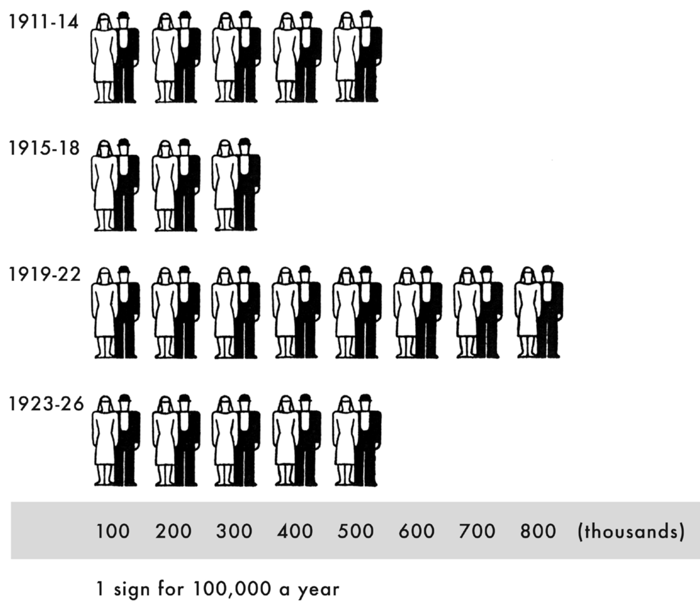
As noted by Christopher Burke, Neurath was probably aware of Playfair's work (Burke, Kindel & Walker (2013), 10–12), even though Neurath does not mention Playfair in his "visual autobiography" (Neurath, 2010). But Playfair's original labels were soon omitted in Isotype charts: in a thorough analysis of successive versions – from 1925 to 1929 – of an Isotype chart on births and deaths, Kinross documents the progressive simplification of

2 Wilkinson defines the pie chart as "…a stacked bar in polar coordinates (Wilkinson (2005), 35–36)."

Figure 4.

Author's adaptation of an Isotype chart of "Men Getting Married in Germany in a Year". The shaded area with the numerical labels on the x-axis has been added to the original, which included only the key: "1 sign for 100,000 a year." The lack of numerical labels on the quantitative axis, opting instead for a general key or scale, is a consistent feature of Isotype charts. The chart is Picture 27 in *International Picture Language* (Neurath (1936), 77).

Men Getting Married in Germany in a Year



the visual elements and the shifting of the verbal elements (the labels) to the "periphery" (Neurath, M. & Kinross (2009), 81–84). In the first version of that chart, each pictogram bar is labeled with an exact number, while the last version features only a typical Isotype scale: "one baby = 1 million." But the scale forces the viewer to perform mental math – an unnecessary task if labels are provided. The psychologist Daniel Willingham points out that in general, our brain prefers not to think at all, especially about something to which we already know the answer, like that 2 + 2 = 4 (Willingham, 2009). Whenever possible, the brain skips thinking in favor of automatic behavior and recall: walking, driving a car, or adding two and two.

Closure

Breaking up the traditional solid bar into many smaller items is the opposite of chunking, and as Miller pointed out when more than 6–7 items are involved, our capacity for processing them diminishes quickly. Counting is time-consuming, and in real life we crave fast closure and are bound by working memory to "act fast", chunk, and move quickly to the next chunk. Only then we are able to keep up with the reading of a graphic, the reading of a text, or a conversation in progress.

While counting is possible, it's hard to keep lots of items in temporary memory storage, while also trying to understand the overall graphic. But since the overall comprehension depends on the prior successful "closure" of the smaller parts, these in turn must be grasped quickly or one's attention will shift to something else.

It's telling that this whole-and-parts conundrum applies not just to the visual, but to the verbal as well. In language, one also has to achieve semantic closure all the time – quickly disambiguating between the many possible meanings of a word or phrase – and understand each "clause" at every stage of a sentence. And yet the overall meaning of the clause or the sentence might not be clear until the very end, when the whole comes into focus (Cassirer (1953), 304–305). Because individual words only become meaningful when closure occurs, it's the clause, rather than single words, that should be considered the "primary perceptual unit of all languages (Hirsch (1977), 108–109)." Because it saves time, chunking the elements in a chart is a good strategy to quickly achieve closure. Thus, whether one is looking at a graph, reading a text, or listening to speech, closure always has to occur quickly. Allowing more time would seem reasonable but, alas, the opposite is true: even a perfectly formed sentence, if spoken with extremely long pauses between words, will be difficult to follow and to understand. In such a scenario, chunking and closure become impossible within the few seconds allowed by working memory: by the time the next word is spoken, the previous word will have been forgotten.

Broad overview and detailed reading

Although the familiar look of pictograms greatly contributed to the success of Isotype graphics in exhibits, books, and films, the repeated symbols often feel monotonous and endless. A recent study by Benus and Jansen analyzes the efforts by Peter Alma – an associate of Neurath in Vienna who later worked in Holland – to provide visual variety and avoid monotony in Isotype charts (Benus & Jansen, 2016). Interestingly, Alma's variations on typical pictograms, people for example, add the benefit of a more compact, almost abstract, overall shape. This approximation, to brick-like elements that almost blend together, helps to make the shapes of the pictorial bars more easily comparable.

Sometimes the bricks composing the shapes can also reveal fine details even as one is reading the broader story. John Tukey challenged the principle "…that nothing should be given both graphically and in tabular form" and showed with his *semi-graphic displays* that properly arranged digits could be pictorial and tabular at the same time (Tukey, 1972). Today, using multiple small marks to fill traditional solid bars can yield a densely packed, "dappled" bar made up of little squares that look like a solid surface. The chart of US congressional votes shown in figure 5 illustrates how grouping small elements into simple geometric shapes exploit several positive psychological principles, including the gestalt principle of closure.[3] Wolf-

3 In particular, see the gestalt principles of proximity (the spacing of the elements); similarity (the likeness of the elements); and closure (the meaningful whole), by which a field that is not continuous can appear solid because of a "…symmetrical brightness distribution […] in which the 'homogeneity' consists in a uniform dappled effect (Wertheimer (1938), 74–75, 83–88)." However, the symmetrical brightness distribution is broken "…each time our eyes are confronted with a sufficiently sharp break in luminosity, [and] we tend to see the edge or boundary of a surface (Krampen, 1965)."

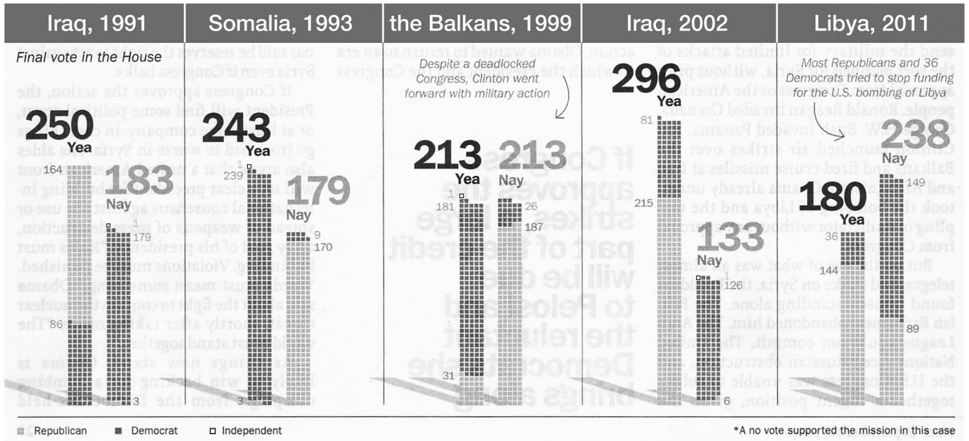


Figure 5.

"How congress voted on past military strikes" (detail). The five bar charts depict US congressional votes on striking foreign countries (Scherer & Altman (2013), 16). Original colors have been changed to: light gray dot = Republican (was red); dark gray dot = Democrat (was blue); outline dot = Independent (was green). Time magazine author's collection.

gang Köhler notes that "If the circumstances of a visual perception permit such a closure, the presented object is said to be a '*sinnvolle*' [meaningful and suitable] figure, organization, design, etc. (Köhler (1938), 393)." In the stacked-bar variant of figure 5, the little squares are very effective, each original red or blue square precisely showing a vote by a Republican or Democratic member of the United States Congress (Scherer & Altman, 2013). Here both the overall shape – the coarse overview – as well as the details are easily readable (Tukey, 1972).

A similar approach was actually used in an early bar chart designed by Neurath's team at the Museum for Society and Economy in Vienna around 1925 (Neurath, 1927). In it, stacked bars are formed by rows of dots representing housing units (1 dot = 100 units) built by the city between 1919 and 1925. Although the bars were drawn to resemble buildings, and the little dots to resemble windows, the overall effect is abstract and geometric if compared to later Isotype charts. The chart includes a numerical table with the data used for the visualization, but in later charts this device was also abandoned.[4]

Within the Isotype system, with few exceptions, abstract shapes were soon replaced by recognizable pictures. Compared to abstract shapes, pictograms appealed to Neurath because of their potential to be understood in any language. So he adhered to this strict notion, but at the perils, unknown for him at the time, of fragmenting the data representation beyond the processing capacity of the human brain, whose working memory cannot be modified or improved directly. Although brilliant, Neurath's Isotype system is not always optimal. When used with discretion, for example when small quantities are involved, it need not crowd out working memory, and it may work well. If Neurath, who was highly alert to the trends of philosophy and psychology, had lived in the era of cognitive psychology, he would have surely accommodated his ideas to it.

4 The reader will find this housing chart reprinted on page 28 of *Isotype: Design and contexts 1925–1971* (Burke, Kindel & Walker, 2013); also page 113 in reprint of original 1927 article (Neurath (1991), 99–117).

2. Culture

The legacy of Isotype

Through Isotype,[5] Otto and Marie Neurath attempted to create graphics that would be universally accessible and would educate citizens about the society they lived in. Their energetic, international attempt to foster social change through design ranks as a great and noble effort that has had lasting historical significance.

Otto Neurath was a polymath well known to philosophers as one of the founders of the Vienna Circle and its theory of logical empiricism (Neurath, 1973). But few philosophers know that his ideas about the graphical presentation of statistics, as applied in Isotype charts, are still very popular today. Interest in Neurath's work has continued in recent years with the publication of articles and books. Most notably, the volume *Isotype: Design and contexts 1925–1971* offers a broad overview covering biographical, historical, and cinematic topics (Burke, Kindel & Walker, 2013).

Though a fitting memorial to the vision of Otto and Marie Neurath, *Isotype: Design and contexts* leaves unanswered the question of whether the Isotype method was always the optimal solution to problems of statistical data display, especially if compared with other methods. Per Mollerup, in reviewing the book for *Visible Language*, laments this gap: "Isotype should itself be compared with competing data visualizing formats. How can we evaluate the virtues of airships without comparing airships with other airborne vessels (Mollerup (2014), 121)?"

The charts derived from Isotype endure and surround us with their aligned, repeated symbols. The method, like a great typeface such as Helvetica or Times, affects us whether we know it or not. But as with typeface variants, not all progeny of Isotype are as good as the original, especially in light of psychological findings that have come after Neurath's time.

Ambiguity in words and pictures

"Words make division, pictures make connection." These words, originally printed in all-caps in *International Picture Language*, are not as familiar as "a picture is worth a thousand words", but they can be just as dogmatic if not read in the proper context (Neurath (1936), 18). Although later in the text Neurath admits to the limitations of using pictures, the all-caps emphasis in

5 This article focuses on some limitations of Isotype when used as a statistical tool, mainly its variations of the traditional bar chart. Many other, very successful uses of Isotype, especially in museum exhibits, children's books and educational films, are well documented in *Isotype: Design and contexts 1925–1971* (Burke, Kindel & Walker, 2013). See also *Gesammelte bildpädagogische Schriften* (Collected writings on teaching by means of images). This 675-page volume also includes extensive photographic documentation (Neurath, 1991).

the original suggests a superiority and preference for pictures over words.[6] Such emphasis assigns pictures a trans-cultural immediacy that words presumably do not possess. We now know that this is a grave oversimplification.

It's understandable why Neurath's optimism and his idea of a unified science would, until the end, be consistent with a belief in the universal value of a "visual education" (Neurath, 1945). This type of education would bring together people of different socio-economic backgrounds by means also of a common visual language. In the foreword to *Modern Man in the Making*, Neurath warns that "The reader may not understand the contents by reading the text only; he must 'read' the pictures as carefully as the text. An international picture language is combined with a word language (Neurath, 1939)." Neurath's emphasis on "reading the pictures" is another example of his faith in the power of images.

But in many, if not most instances, pictures and pictograms are just as conventional as words and may imply similar ambiguities. Not only words, but pictures as well, need a sense of culture behind them, a sense of convention, and intention, that helps to disambiguate them. For example, the three pictograms in figure 6 all come from the map symbol set of the U.S. National Park System. But before you read the caption or the next paragraph, try to guess what the left and middle symbols represent. Both represent the same thing: the first is an old discontinued version; the second is the one currently used (National Park System, 2018).

After having guessed wrong, one might be forgiven for thinking that they have something to do with the internet, especially the first one, and especially seeing them next to the third, similar symbol on the right. The third is the now familiar Wi-Fi symbol, indicating the presence of a wireless connection to the internet, but the first two actually stand for "amphitheater." The old symbol on the left is probably a better representation of amphitheater than the current one in the middle. However, one can understand the need to update the old symbol to avoid the similarity and possible confusion with the more recent symbol for Wi-Fi. Luckily, while the current symbol for amphitheater could use another facelift, words can be used to disambiguate its vague appearance. Thus, whenever that symbol is used on a map, the same symbol will be repeated in the legend, accompanied by its corresponding written word: "amphitheater."

Figure 6.

Various map symbols used by the U.S. National Park System. Left: old, discontinued symbol for "amphitheater", as reproduced in Rudolf Modley's *Handbook of Pictorial Symbols* (Modley (1976), 89). Middle: current symbol for "amphitheater." Right: current symbol for "Wi-Fi" or wireless internet hot spot. Current set updated as of May 11, 2018 (National Park System, 2018).

This example shows that pictures, and pictograms, are not as universal as we might think. Neurath himself was well aware of the limitations of Isotype as a language.[7] He wrote about it in his visual autobiography (Neurath (2010), 104):

> *There are many reasons why Isotype cannot be developed as a "complete language" without destroying its force and simplicity. Our daily language, even in primitive societies, is to some extent richer than our Isotype representations can be, and one needs words added to the pictures. Whereas the pictures may remain identical in different countries, the explanations may be spoken or written in different languages.*

Just as words are often needed to disambiguate a particular image or pictogram, so additional words and sometimes images are needed to disambiguate a particular word or phrase. Universality would be a great thing, but images in themselves are no more or less universal than words are. Both always need context, and often they need each other to be correctly understood.

According to the most accurate models of human working memory, words and pictures are not separate in the human mind; they are complementary. For designers, who typically are trained in the visual tradition, the question: "How do I make data accessible, communicative, and engaging?" often involves some kind of translation from verbal or numerical content into some kind of visual representation with that semantic content. In information design, that visual translation often involves the use of pictorial symbols arranged in rows that recall a similar, familiar arrangement of bars in a traditional bar chart.

Pictograms and dots

In 2011, when I started teaching a new data visualization class at San Francisco State University, I decided to focus on good graph construction: pie, bar, line, scatterplot, etc. While a pie chart might seem quaint, such basic designs should not be hastily dismissed. Thus it seemed odd that when simple pie or bar charts would suffice, students would instead produce elaborate charts with repeated human figures, squares, or dots. Something was off and I made up the rule: "Do not use little dots for numbers." Urging them to reconsider such practice, I spelled out the rule in a small handbook (Trogu (2012), 9):

> *Do not use little dots for percentages. Do not visualize quantities by the endless repetition of single units like little dots or little squares. We don't use pebbles to count anymore, and we have invented a tool called "place value." It's better to write out the number or to visualize it using a single solid area, not many tiny areas in little rows. Do not use little people as units to show quantities, even if the quantities represent people. Think of those poor little guys whose limbs get mutilated when you have to represent a fraction: arms, legs, even heads get cut off without mercy!*

6 Despite his preference for pictures, Neurath was well aware of the limitations of the Isotype *visual language*, stating, after the all-caps salvo, that "The Isotype picture language is not a sign-for-sign parallel of a word language (Neurath (1936), 18)."

7 For a discussion on the use of the word language in the context of Isotype, see "The Graphic Formation of Isotype, 1925–40," in *Isotype: Design and contexts 1925–1971* (Burke, Kindel & Walker (2013), 107–77); in particular note 1 on page 107. See also: "The Linguistic Status of Isotype" (Burke, 2011).

But how sound is this advice? Why would population or currency data be better represented by single, contiguous surface areas, rather than by series of smaller, separate areas?

Although Isotype charts are typically used in lieu of more traditional pie charts and bar charts, all are based, as we saw earlier, on size or surface area difference. In a pie, this difference is the angle of each slice, while in a bar chart this difference is the height of each equal-width bar. "Size" is one of Bertin's seven "retinal variables", which include an object's position on the plane: the underlying variable. Bertin's own caption for the diagram illustrating the size variable captures these differences and includes the Isotype repetition variant: "– categories of SIZE: height of a column, area of a sign, number of equal signs (Bertin (2011), 60)."

"Number of equal signs" is key in Isotype, which prescribes using a larger number of the same symbol to represent a larger quantity. But usually what counts is the overall size, the total area covered by the smaller symbols arranged side by side. Neurath warned against the use of abstract geometric shapes: "…the square and the circle will have no place in the Isotype system (Neurath (1936), 92)." He reasoned, correctly, that unlike length differences, area differences would be harder to differentiate. In a 1974 article, Marie Neurath describes this difference (Neurath, M., 1974):

> *Otto Neurath found that the methods in use to represent statistics were of very different merit; some were all right, for example bars: the eye can compare lengths. But it is impossible to see whether a circle is twice the size of another circle, whatever care the draftsman has taken to be correct.*

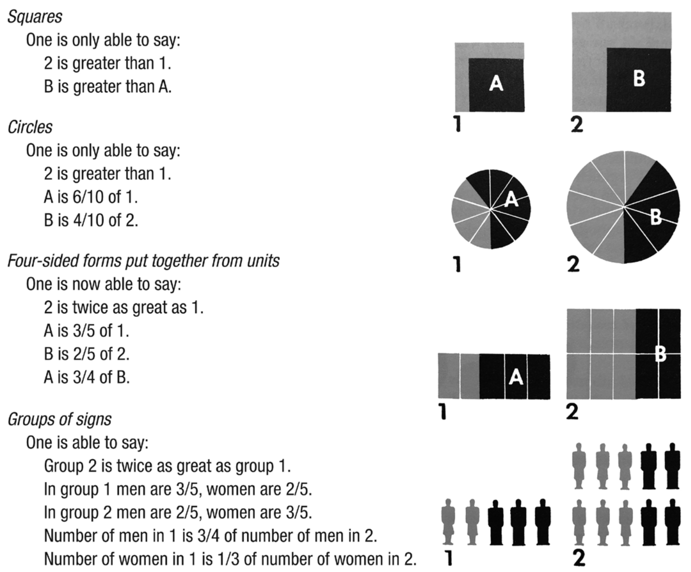
Neurath recognized that bars were an acceptable method to represent statistics – better than squares or circles – and included them, in somewhat veiled form, in a summary chart made for *International Picture Language* (*figure7*).

Equal areas of various geometric shapes are compared in this chart, with the goal to show that squares are inferior to sectioned circles; that both squares and circles are inferior to rectangles (another version of bars); and that all the above are inferior to groups of Isotype signs. This visual presentation is enhanced, with logical precision, by the captions explaining the uncertainty that the eye has already sensed. The last step, from rectangles to pictograms, adds the gender variable and reflects Neurath's belief that familiar pictorial shapes would represent and communicate statistical facts much better than abstract geometric shapes. And he had a point: anyone being asked will agree that the simplified shape of a human figure – especially if the data are about people – is more communicative than a generic rectangle; or not? The answer depends on the aim of the "communication" in the statistical chart.

Since Isotype signs represent not only the quantity (number of symbols) but also the specific quality of who or what the symbols represent,

Figure 7.

A summary chart of various equal area comparisons by means of different geometric shapes and pictorial symbols. Designed by Neurath and included as Picture 35 in *International Picture Language* (Neurath (1936), 96–97). As in original, captions for each method and their relative merits are given on the side of the chart. The colors in the figure have been adapted: gray was red in original; black is unchanged.



two birds are killed with one stone: (1) Data are visualized by the quantity of symbols and: (2) Data are made "concrete" and thus accessible to the layperson, who can recognize in the symbols a race, gender, profession, crop, or industrial good.

The next section describes how the noble aim of making the subject matter, the "what", more accessible by pictorial means, inadvertently resulted in making the data, the "how many", more difficult to grasp and absorb by visual means alone. As mentioned, the strategy proposed by Isotype, "counting", has proved to be inadequate.

Counting

In the Isotype chart shown in figure 8, also published in *International Picture Language*, a block of automobiles on the left (production in the US in 1929, one car = 100 thousand) is compared to production in Europe on the right (Neurath (1936), 93). But how much larger is the amount represented on the left (US) compared with the amount represented on the right (Europe)? The obvious answer is of course: "A lot!" – but a more precise answer will take longer than expected.

Does knowing the precise answer really matter? After all, Neurath clearly stated that "Very often it is preferable to remember rough pictures than to forget exact data (Neurath (1945), 246)." But let's try anyway: The group at left looks roughly ten times as large as the line at right. But can one check this assumption? Per Mollerup summarizes the counting technique: "In picture tables [Mollerup's definition], the reader must count the pictograms in different groups and multiply with the scaling factor to get the total amounts (Mollerup (2014), 111)." Counting is the official technique offered by the creators of Isotype. When Marie Neurath described another

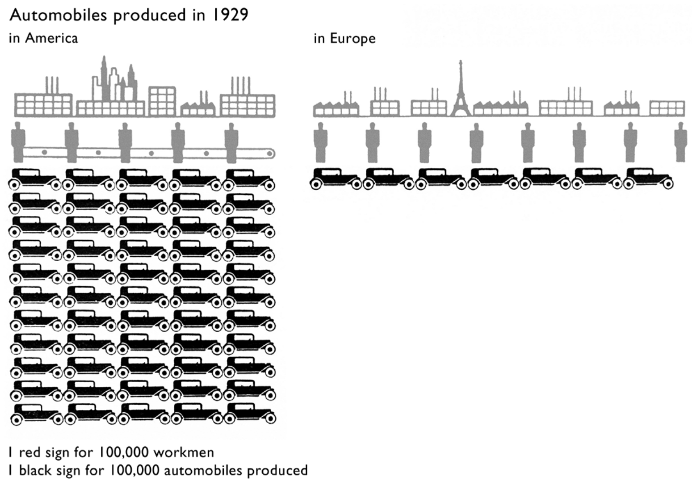


Figure 8.

Isotype chart showing car production in US and Europe in 1929. Picture 33 from *International Picture Language* (Neurath (1936), 93). The colors have been adapted: the buildings and the workmen, shown in gray, were red in original; the black cars are unchanged.

Isotype chart showing world population, she explicitly mentioned that counting provided a quick way to grasp the proportions of the various ethnic groups: "…how many they represent is stated alongside: [one figure =] 100 million. So each person can count how large the individual groups are, and do it faster than if they had a numerical table in front of them (Neurath (Reidemeister), M., 1928)."

While it's true that the relative proportions are grasped faster than if looking at a numerical table, the actual data – the magnitudes of the groups – are not grasped as quickly without some numerical notation. Counting is not very challenging per se, however, the span of time required to perform such counting is usually above the limits of our working memory.

In *Through the looking-glass* Lewis Carroll sets up Alice with this simple arithmetic problem: "Can you do Addition? the White Queen asked. "What's one and one and one and one and one and one and one and one and one and one?" "I don't know, said Alice. "I lost count." (Carroll (1872), 189). Try to solve the problem yourself. The answer would be easy if the question had been "What is five and five?", but then the tension in the text would disappear and with that the fun of the reader. But imagine yourself in Alice's place, with a similar, long line of identical widgets before you; imagine many such long lines of different lengths. In real life, if designers adhere strictly to the Isotype method, their visualizations all too often yield such serial presentations, with the result that the viewer is soon at a loss, much like Alice in front of the Queen. Thus, a concerned designer will not present the reader with "1+1+1+1+1+1+1+1+1+1" but will offer instead "5+5": one, at most two chunks, instead of ten units.

In Marie Neurath's example, *counting* sounds easy, but unless one gets out pencil and paper, it's a task that requires mental math: 100 million (in the world population chart described earlier) times the number of pictorial symbols presented. The visual comparison is indeed faster, but each total needs to be reckoned first.

So, let's count the signs shown in figure 8, where the scale reads: "1 black sign for 100,000 automobiles produced."

At left, 5 signs times 11 rows = 55 signs; 100,000 units times 55 = 5,500,000 automobile production in America in 1929. At right, 7 signs times 100,000 = 700,000 automobile production in Europe in 1929. Thus, in 1929 US automobile production was about eight times that of Europe. Most people, comparing two visual quantities side by side, will settle for an approximate rather than exact ratio between the two. And the aim of many data visualizations is just that, to give a general idea by a quick visual comparison which might be rounded off here and there if necessary. But psychologically, it's much easier to accept this approximation when we are physically prevented from checking the data by counting the visual units in the visualization. With many discrete units, we feel the need to "check" if all the units add up to our general estimation. Let's say you get a hundred dollars in a stack of one-dollar bills; do you trust, without counting, that such stack includes exactly one hundred notes? On the other hand, if five ten-dollar bills are placed side by side on a table before you, you can almost instantly see *fifty* dollars, without needing to count the bills. Why should this be the case?

A recent study by Haroz et al tested the memorability of Isotype charts versus traditional bar charts and it found Isotype charts to perform better (Haroz et al, 2015). But this may be true in a limited sense, as the study used test materials that displayed a 1:1 relationship between each unit in the data and each symbol representing that unit. In other words, one picture displayed in the chart – one parrot for example – represented exactly one parrot in the original data set; not ten or a hundred. This may be the biggest flaw of the study since Isotype charts typically assign a high value to each symbol: 1,000 or perhaps 100,000. Occasionally, Neurath's Isotype charts did display this 1:1 relationship, as in a chart of birth rates for married women in Paris and Vienna around 1900 (*figure 9*). Here, each newborn baby depicted in the chart directly represents a single newborn in real life, thus eliminating the need for a scale (Neurath (1939), 127). This chart can be read faster because of the direct correspondence between the quantity of symbols and the quantity in the data. Even if counting is involved, multiplication is not needed. Grouping the symbols in sets of ten is also quite helpful here.

Haroz et al also acknowledge another possible bias in their study: when the total number of items presented is small, such as five or less, the eye is able to quickly see the quantities without the need to count the individual items. In this process, termed *subitizing*, subjects are able to immediately and accurately identify the number of items if that number is 5–6 or less.[8] In displays of more than six items, subjects' accuracy quickly degrades and the process is then termed *estimating* (Kaufman et al, 1949). This apparent threshold received renewed attention in Miller's magical number

8 "Subitizing is the rapid, accurate, and confident judgment of numbers performed for small numbers of items. The term […] is derived from the Latin adjective *subitus* (meaning "sudden") and captures a feeling of immediately knowing how many items lie within the visual scene… (Wikipedia, 2018)."

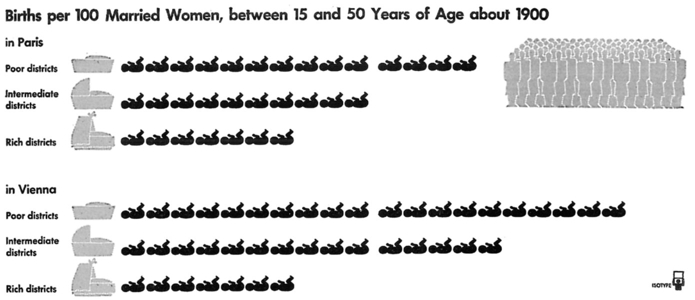


Figure 9.

This chart of birth rates in Paris and Vienna around 1900, included on page 128 of *Modern Man in the Making*, shows much higher birth rates for the lower classes, with Neurath pointing out in the accompanying text that "birth-control [had already] started in the higher social classes (Neurath (1939), 127)."

seven article of 1956. It's no surprise that the earlier imaginary recipient of a hundred dollars was bound at first to *estimate* their loot, while the runner-up could *subitize*, and instantly see their fifty-dollar total.

Thus, it appears to be the case that Isotype charts work best when the number of elements in the visualization is rather small and falls within the lower range of Miller's original limit: seven items; but five or fewer will even be better.

Pictures and dots or written numbers as pictures?

Today's infographics often use small, repeated geometric shapes derived from the repeated pictogram motif, but when the number of items passes seven or thereabouts, often confusion ensues, sometimes made worse by the arbitrary value assigned to each shape. To explain this confusion, let's take a look at an infographic titled "Power revolution", about energy consumption, from Time magazine (Walsch, 2013). The graphic on the right in figure 10 shows that in the US in 2010, the government subsidy for biofuel was about $6.6 billion, which is visualized with 29 small, repeated squares aligned along the larger outer circle. Using a calculator reveals that each small square corresponds roughly to $230 million. What kind of scale is that?

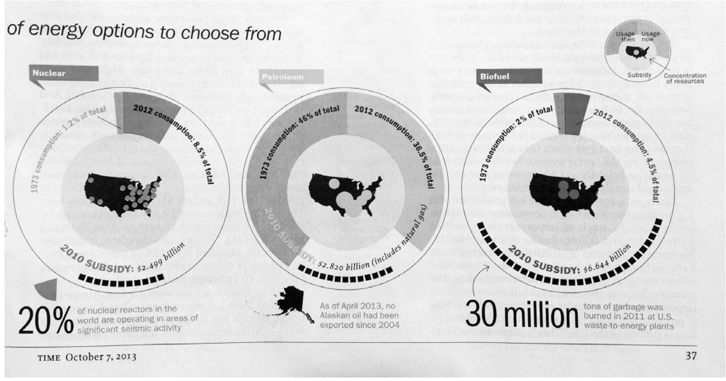


Figure 10.

"Power revolution" infographic, detail. The misleading large label "30 million" refers, despite the arrow, to the tons of garbage burned, mentioned next to it, and not to the $6.6 billion biofuel subsidy visualized by the row of small squares. The confusion is compounded by mixing the consumption data with the subsidy data as if they were slices of the same pie. Original appeared in Time magazine on October 7, 2013 (Walsch (2013), 36–37). Author's collection.

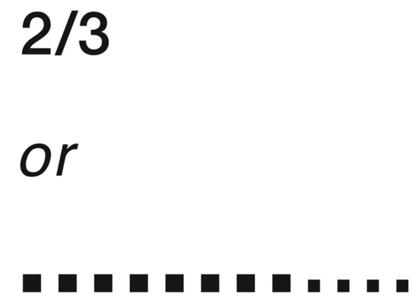
While Neurath and his Isotype associates would be too skilled to design such a confusing graphic today, such representations are typical of current data visualizations. Magazines like Time continue to offer this type of

representation derived from Isotype, while discerning newspapers like the *New York Times* very rarely do so anymore. While the Neuraths should not be blamed for these distortions, the general historical source cannot, for better or for worse be denied.

Today, data visualization software offers the design student multiple data construction tools, but how does one distinguish good infographics from bad infographics such as the one published in Time magazine? For example, which of the two visual representations of quantity shown in figure 11 will be processed faster by the viewer?

Figure 11.

Which symbol better represents "two thirds?" A numerical fraction or a series of dots? (Trogu, 2015b). Author's illustration.



Are the three marks in the numerical notation "2/3" more universally recognized and understood than the twelve marks in the graphic notation "**........**...."? Which will more quickly trigger in the mind of the viewer the concept of "two thirds?"

It's a mistake to assume that graphic elements, because they are visual, will be processed faster by the viewer. It's possible that sometimes, as Marie Neurath wrote, "…picture script is more rapidly readable than numerals and letters (Neurath (Reidemeister), M., 1928). But the opposite is probably more common. Cultural norm and psychology contradict the idea that pictures are faster to take in than numbers, and arabic numerals especially, have the advantage that their shape remains unchanged from one language to another. Thus in mathematics, the cultural emergence of the decimal system combined with the adoption of arabic numerals is a happy historical circumstance. While it took hundreds of years of convincing, when the use of arabic numerals and place value eventually took hold in Europe at the turn of the 14th century, their advantages became obvious when compared to other systems (Kaplan (2000), 106–115).

In figure 11, the symbol "2/3" will be processed faster because the verbal marks trigger two short words in the mind of the viewer: "two thirds", whether these are spoken or subvocalized. Thus, brevity is one advantage of the chunked "2/3" over the un-chunked "**........**....".

The other important advantage of such numerical notations is that their linguistic expression has already been established over many centuries.

Culturally, through literacy, number words have acquired very precise and unequivocal meanings. Unlike dots, written numerals are quickly named with their corresponding number words.

Arabic numerals are culturally constituted symbols that are the same in multiple modern cultures – making them more universal in many cases than pictures. Our minds are limited by working memory, and our symbols are inherently ambiguous and need a shared culture to disambiguate. Arabic numerals solve the problem of that double drawback: the time limitation of working memory and the ambiguities of language. Because culturally universal in the modern world, they are the pictures that in many cases are the most immediate, universal, fast and unambiguous.

Arabic numerals have found their way into many other languages and have become part of those other cultures. But, unlike general vocabulary, written numerals are truly international, so that in English one will read "2/3" as "two thirds" while in Italian one will read the same notation as "due terzi." So, regardless of the written language in which they appear, the mark and the concept remain the same and nothing gets lost in translation.

Test your language when reading the numerals in the window sign shown in figure 12:

Figure 12.

A "sale" sign in a storefront in Chinatown, San Francisco. The sign 最后20天 reads "the last 20 days" (direct translation), so if there's a sale, it means "20 days left." The sign 结业 reads "close out" which means "store closing", as in "out of business." Translation by Judy Chu. Author's photo.

Even without speaking Chinese, a tourist walking the streets of Chinatown in San Francisco will immediately recognize the price of many items for sale in the windows. Arabic numerals don't need a dictionary.

Place value, by making numerical notation standard and generally shorter, is another reason why arabic numerals are often intermingled with Chinese characters: "[Most numbers above 20] up to 99 would require 3 characters [in Chinese] rather than 2 numbers and at 100 [above 110], you're potentially dealing with 5 characters: 一百三十四 versus 134 (Edwards, 2014)." But the main reason Chinese people use arabic numerals may be that, as my neighborhood dry cleaner lady put it: "Everybody in the world uses them." – and this simple fact makes them a truly universal language.

Every picture is a word

In a culture saturated with images, are pictures better than words for conveying concepts and visualizing data? Pictures and words are not opposites. If subvocalization is always at work, even in the context of visually presented items, then the aural/verbal "naming" is the first immediate linguistic step in any meaningful perception. An image triggers a word – its corresponding sound or "sound-image" – then the word is associated with the actual meaning of that word, and with any secondary or implicit meanings (Saussure (1959), 66). And as mentioned, words are often needed to disambiguate pictures. "A photograph always better have a caption under it!" was the stern admonition of my favorite art school teacher. While evaluating the "communication potential of pictorial illustrations" of a literacy program in Latin America in the early 1950s, Seth Spaulding made this observation (Spaulding (1956), 44):

> *Pictures help put meaning into the words used, but the illustrations can not take the place of the words. The words, being abstractions, have skimmed off something common from thousands of concrete experiences and are therefore much more efficient communication units, especially if illustrative material assists the reader to relate the word value to his own experiential background.*

Neurath knew that the "pictures vs words and/or numbers" opposition is a rigid oversimplification. For example, he noted that while "…visualization may provide more impressive pictures than a formula […], on the other hand, one is much more limited by visual representation than by algebraic (Neurath (2010), 95)." This observation gives another hint of Neurath's effort to bridge the contrasts between his mathematical, his philosophical, and his visual education interests.

3. Conclusion

Memorable pictures; less memorable data

This paper has proposed that had Neurath been able to witness the advances of psycholinguistics and psychology in the decades after World War II, he surely would have made adjustments to his own prescriptions. Based on his own experience with Isotype, he surely would have reviewed and fixed its shortcomings by whatever means available: "Like sailors are we, who have to rebuild their ship on the open sea, without its ever being able to be laid up in dry dock and be newly rebuilt from the best materials."[9]

In Neurath's original text this quote is preceded by "There is no *tabula rasa*." and followed by "Only metaphysics can disappear without trace (Neurath (1932), 206)." Like his philosophy, Neurath's Isotype project took into account historical precedent as well as changing cultural conditions. In "The Linguistic Status of Isotype", Burke points to separate letters by Neurath to a fellow philosopher, a visual educator, and a psychologist, documenting his interest to conduct psychological studies on Isotype, and publish the results in a book (Burke (2011), 45). Macdonald-Ross notes that "In the early days of the Isotype Institute charts were informally tested on groups of schoolchildren, but these trials were never reported in journals (Macdonald-Ross (1977), 65)." Neurath also describes these studies in his visual autobiography (Neurath, (2010), 114–117). Although these studies were never published, their record likely survives in the Otto and Marie Neurath Isotype Collection at the University of Reading in the UK (Isotype, 2018a).[10]

Neurath was first a mathematician and a philosopher, but also a practical person seeking results. If he could see today some of the distortions that his picture language involuntarily spawned, would he jettison or shift some of his ship's ballast to keep it steady? He certainly would, as his repeated questioning of Isotype orthodoxy shows. Burke again documents Neurath's observation that "picture scripts" were not in themselves superior to alphabetic scripts, especially in scientific notation, and his strong scepticism that a "visual language" would be richer and more "dimensional" than a verbal language (Burke (2011), 40–44). Neurath knew that words can encompass far more meanings than is possible with pictures alone.

Internationally, pictograms now live happily alone or coexist with written words. Thus, on an airport sign, a woman and a man might, in fact, be smiling at Neurath and his followers who saw the utility of such symbols in a connected world (AIGA, 1974, 1979). At the same time, perhaps just above their faceless heads, another set of pictograms – an airplane, a suitcase, a car – might be sighing with relief to be wearing their written name tags: *departures, baggage claim, taxi*.

But when similar pictograms get cloned endlessly for visualizations that chase a pictorial, iconographic look, the result is instead a numbing of the senses; the anaesthetic stronger with each additional pictogram.

9 Neurath's metaphor of the "ship on the open sea" was made famous by the American philosopher Willard Van Orman Quine, who reprinted the original German quote in the opening of his book *Word and Object* (Quine, 1960).

10 Various documents and texts from the Isotype Collection can be found on the *Isotype revisited* website: isotyperevisited.org (Isotype, 2018b)

In statistical visualizations, all quantitative representations are abstractions, even when they depict concrete events such as deaths. An abstract scatterplot might show death rates from lung cancer in various countries in 1950 (Tufte (2001), 47). A more pictorial, Isotype-inspired animation might show the 70 million fatalities of World War II (Halloran, 2015). But while these graphs, by themselves, cannot fully render the cruelty of disease and the horror of war, one should still discriminate them based on the knowledge they can transmit and deposit in our long-term memory.

More empirical research is needed to buttress or refute the soundness of Isotype charts. Neurath was a promoter of pluralism and he was against authoritarian thinking. Were he alive today, he would heartily embrace a debate about the longevity and merits of his theory. But are the information designers and historians of data visualization of today open to an alternative view of Neurath's legacy? Designers today cannot accept Isotype's axioms without reservations or questioning, simply because they originated in the teachings of a revered historical figure.

Questions and considerations

This paper has asked and considered the following:

Given the limitations of human working memory, *counting* is not an effective strategy for reading an Isotype chart. Is it not better to include and "read off" numerical labels placed along a quantitative axis instead?

Written words and written numerals such as "2/3" can be more universal than pictures. In particular, arabic numerals are now used even in non-alphabetic writing like Chinese or Japanese. By their fast comprehension in any language, these numerals help to get around the bottleneck of working memory and solve the need to disambiguate. Thus, a picture might be worth a thousand words, but the picture of a number is worth almost any number of Isotype pictures.

Is using a pictorial symbol to represent data, better than using a solid abstract shape? Which wins the tradeoff between accessible, memorable pictorial symbols, and more easily remembered data by means of less memorable shapes?

Isotype charts that depict small quantities can function well due to our capacity to "subitize", to quickly report quantities without counting the items, when the number of items is below seven.

Small repeated symbols can sometimes coalesce into a larger overall pattern by proximity and similar color or shape. Thus, the "dappled" area of a large abstract shape made of small individual items can provide both overview and detail in a single image.

These questions and considerations invite designers and historians to re-evaluate the popular but uneven Isotype system. More studies are needed to test the validity of Isotype charts. But two issues listed above and at the core of this paper take precedence: (1) The graphic construction must mitigate the limitations of human working memory, which unfortunately are not helped by the cumbersome strategy of *counting*, and provide the reader with a more chunkable image than is afforded by the long strings of Isotype pictograms; and (2) The graphic construction must disambiguate by using both verbal and visual elements – by using written words, such as labels and numerical notations, as well as pictures. For designers, taking stock of these two constraints of memory and ambiguity, and taking advantage of established universals like arabic numerals, is a good place to start.

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