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Do you see it this way? Visualising as a tool of sense-making

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> 'Observing business cycles' is a figurative expression. What we actually see are tables of figures or charts that purport to show in standardized symbols one among several species of changes found in time series, which are themselves bleak numerical records of certain mass activities. These series give many glimpses of our cycles, but none of them gives a well rounded view. The changes on which we focus attention never occur by themselves in the way our symbols suggest. […] Like other scientific concepts, ours is a man-made entity, created by pulling apart items of experience that can be observed directly; then putting like parts together into a new whole that cannot be seen by the eye or touched by the fingers. (Mitchell 1951, p. 29)

1. Introduction

How do scientists make sense of what appears (in their community) to be a new phenomenon? That is, how do they get to grips with its evidence; figure out its elements and their relationships; conceptualise it in ways that provide resources to think with; place it with respect to other phenomena in their field; and create representations of it that will enable them to investigate it in various ways? The activity of initial sense-making: making sense of something new, or reconceptualising a phenomenon in new ways, might include visualising it into some form, categorizing it under some labels, or narrative-making about how its elements fit together.[1] This paper considers the importance of visualisation as a sense-making project along the lines and roles recently suggested for narrative-making in the sciences.

This paper written in warm memory of Margie Morrison's ideas and work is inspired by an important and relevant insight we shared with her since we worked together in the Models as Mediators project. *Models as Mediators* (Morgan and Morrison 1999) argued that models are not a derivative of either theory or data, but a representation chosen to mediate between these to help us understand and think about both. In reporting that project, while Marcel Boumans focussed on the choice of ingredients and how to integrate them, and Mary Morgan on a choice of analogy that could represent elements of both sides, Margie Morrison pointed to the role of *constraints* induced not only by what we already know about the phenomenon to be modelled, but then also by the materials of which the model will be built. Here we focus on that choice problem again – how to make sense of the bits we do know to create such representations and how those choices about how we 'see' a phenomenon constrain what we see about them, and frame how we think about them. In this paper we will investigate the nature of the constraints that play a role in creating and then using visualisations to make sense of a new phenomenon.

If we start with evidence about a new phenomenon, such records or traces do not make sense by themselves, therefore they need to be organised together and processed to see whether they show some patterns, or some inter-relations. This processing is usually done by translating the relevant information or data into a common medium (such as a mathematical model, a narrative, or a diagram) where they can be examined for patterns, compared directly, and meaningful relations can be established between them. While there is an extensive literature on the translation of data into statistical media to support statistical inference, the broader study of this translation in terms of sense-making has just started. An important step in this direction can be found in Morgan's (2022) account of narrative as a sense-making technology for science.

According to Morgan (2017), the quintessential feature of narrative is that it shows how things relate together, so that constructing a narrative account of a phenomenon in science involves figuring out how the supposed elements of a phenomenon can be related to each other to form a coherent account of that phenomenon. 'Narrativising serves to join things up, glue them together, express them in conjunction, triangulate, splice/integrate them together (and so forth)' (2022, pp. 10–11). As such, narrative-making can be understood as a colligating process. William Whewell used the term colligation for the binding of a number of isolated facts by a general notion or hypothesis. 'Colligation of Facts' is a term which may be applied 'to every case in which, by an act of the

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[1] We thank Roger Backhouse for suggesting that there might be several basic ways of 'sense-making': category making and narrative making, to which we add here, visualising.

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intellect, we establish a precise connexion among the phenomena which are presented to our senses' (Whewell 1858, p. 60). In the narrative sense-making account, colligating is interpreted more broadly to include the binding together of a wider set of materials, not just of facts or evidence, but of hypotheses and ideas about a phenomenon.

But to invoke the notion of colligation does not determine how colligating gets done. Different modes of sense making will involve different strategies, that is the active process of colligating will rely on different basic strategies or recipes appropriate for that broader mode of sense making. For example, category-making uses two different recipes/strategies, one that heaps up elements to 'define' the categories by their similarities, and the other that 'divides' or draws lines between things to separate the categories by their differences. (Müller-Wille 2007; Bowker and Star 2000). Heaping up involves pulling together all the elements that seem to relate to a particular category in order to define that category; while the alternative strategy involves arraying all the possible elements and drawing dividing lines between them, throwing irrelevant elements out to create a class by establishing its boundaries.

Narrativising also relies on two main sense-making strategies or recipes using processes that tie together or juxtapose materials along two 'formats' or 'grids' along which things are aligned, or colligated, to make sense (Morgan 2017). One such sense-making format or grid uses the possible network of relationships as the main device for 'ordering' varied materials and the other orders the elements along space or time-dimensions. Working with the relational grid creates a network depicting a set of relationships of various kinds: causal, mechanistic, or associational. The benefit of colligating using a network grid is that the resulting narrative can be 'opaque about the exact nature of those relations; it can allow knowledge to be uncertain; it can allow for multiple perspectives; it can enable complexity to be maintained; and it can embrace context where the cut between content and context is unclear' (Morgan 2022, p. 12). Colligating along time-lines and spatial relations may well involve, and offer, similar kinds of complexity. For example, the narrative may treat time going forward or backward; it might take time cut into different chunks (lunar or solar, millions of years or seconds), while the cultural-artifactual relative dating of archaeology can be contrasted with the absolute time-based divisions based on natural science dating methods in that same field. And narrative-making of power relations may use spatial ordering devices just as political maps use colours and border lines.

Visual sense-making uses the same kinds of strategies of causal/associational and time- or space-based grids as ways of depicting an understanding of phenomena. For example, the life-cycle accounts of developmental biology may use spatial visualisation of cycles to understand repeating events through time, while certain kinds of mechanical systems (e.g. pulley systems) may find spatial visualisation with lines and circles the most effective way of representing how pulleys work: both visualisations combine time and causal relations to make sense of certain phenomena – by depicting them with various forms and shapes. Topology and geometry are both mathematical theories of space, but one could say that while geometry describes a space in terms of quantities and therefore implies a metric, topology does so in terms of qualities. In considering colligating via visualising, we propose to privilege the notion of topology and its associated processes of colligation as the broad strategy for making visual sense of phenomena, though some examples may be better thought of with the narrower geometric notion (we return to this issue later).

These sense-making strategies: visualising, narrativising, and categorizing involve, in another sense, more than colligating. These sense-making strategies not only join things up, but sometimes the need to clarify relations between things means that scientists have first to sort things out so that the relationships can been seen more clearly before they can be 'bound together' as Whewell supposed. Sometimes the sorted-out things are joined in a different order or set of relations than they first appear. This sorting out and putting back together could involve a set of more heterogeneous observations, coming in different forms from different observers in different places, contributing diverse information in the empirical domain.

In this paper we will investigate the way in which visualisations can be sense-making, (and find some parallels with narrative sense-making). Here we find that, symptomatically, colligating evidence in visualising involves not only processes of composing, decomposing and recomposing, but also a process of, on the one hand, fixing the phenomena in some form of representation, and, on the other hand, fixing that visual representation into a space with a specific topology that enables a specific kind of reasoning (Morgan 2020). However, a word of warning – these two sets of processes: composing processes and fixing processes may be generic to our kinds of cases, but perhaps not be general for colligating in all kinds of visualising.[2]

It is surely important that sense-making in science is never something purely individual, it is not that something should only make sense to oneself. As Abraham Kaplan (1964, p. 128) emphasized, scientific knowledge is intersubjective, so one has to ask 'Do you see what I see?' to help decide whether what I see might be my own illusion or could be shared knowledge of the object. Scientific visualisation is a tool to reach this kind of intersubjectivity. But intersubjectivity does not include everyone, sense making is an activity that is related to a specific community. Moreover, visualisations, as for all representations operating within communities and sub-communities, are designed to see things in a particular way. It is not only 'do you see what I see?', but 'do you see it in the way I present it to you?' Visualisations, as sense-made representations, are designed to be seen by others in the same community of scientists who know to read them (cf. Morgan 2022, p. 9).

For the community who share a visualisation, each sense-making representation both opens up possibilities of reasoning, of manipulation, etc – and at the same time, constrains those activities. This is where the material possibilities of representations matter: time series representations offer different semantics and grammars from algebraic models, with different possibilities for usage and different constraints on what they can be used to do (Morrison 2015, see also Boumans 2012; Morgan 2020). Once things get conceptualised in a particular form, in a particular media, much else follows and much else is ruled out. We will see this in our three examples below, for while they all use time grids, each uses a different topology, and so they have very different possibilities in usage and for understanding their target phenomena.

2. Visualising a new phenomenon in three ways

'The business cycle problem' emerged in the early twentieth century to be the focus of attention as a conceptual problem, as a theoretical problem, and as an empirical problem. What was the business cycle? How should it be defined? How should it be characterised? And, how should it be made sense of? Whatever the business cycle was, it was understood as being a fundamentally new phenomenon and so requiring a rethink of existing concepts, theories, and accounts of how economic behaviour, at the aggregate level, changes over time. The flurry of both theoretical work and empirical work went along together, but were not well-linked. We focus here on the empirical work where visualising proved an important element of economists' sense-making technology, enabling us to discuss and compare three different visualisations of the business cycle, each developed in the first half of the twentieth century.

When economists of the early twentieth century began to formulate the notion of 'the business cycle', they understood it as a phenomenon rather different from the earlier designated 'trade cycle' (a somewhat irregular economic event in nineteenth-century experience of trading activity) and of the still earlier notion of 'crisis' (a more irregular happening, either a natural event such as a harvest failure or an

[2] In this sense, we share a 'deflationary' view with Morrison, that is: being sceptical about formulating philosophical accounts that will adequately cover all the diverse ways models function (see e.g. Morrison 2015, p. 121).

institutional failure like a banking crisis). The 'business cycle' (apparently named by Mitchell in 1913) was conceived as a phenomenon of the modern 'business' world, not obvious in its timing, not easily characterised nor explained by causal elements. A 'capitalist cycle' had been theorized in the Marxian tradition, but only at the beginning of the twentieth century did economists as a profession become obsessed with understanding this 'new' phenomenon of 'the business cycle.'

Part of this impetus surely came from the kind of data patterns that they had begun to chart, for by the end of the nineteenth century, economists had stopped relying on tables of numbers (in which it is very difficult to 'see' repeating cycles) and become used to creating and using time-series graphs of data series to understand the events in the economy. As argued in Maas and Morgan (2002, p. 98), they had learnt to use time-series graphing as 'a technique to reveal economic phenomena and as materials upon which to base explanations.' This had entailed 'repackaging' historical events as 'data', and the 'timing of history.' They had learnt not just to see standardized events plotted against time on a graph, but to see sets of such series plotted above each other in layers (as in Fig. 2), opening up the possibilities of sense-making in linking those series. This 'plate stacking' (as Jan Tinbergen called this method, which he employed himself till the late 1930s), not only revealed common time patterns, but in doing so suggested potential causal connections between the layers. William Stanley Jevons ([1862] 1995) for example plotted a variety of financial market series, one above the other, in his 'Study of periodic commercial fluctuations.' Such time-graphs paved the way for the kinds of visualisations we discuss here – the difference being that we are witnessing how economists did not just distinguish certain patterns in individual series but did so in order to conceptualise a complex conglomerate phenomenon, the business cycle. Rather as ecologists want to understand the ecology and meteorologists want to understand the weather, economists sought ways to conceptualise, to define in order to understand, the behaviour of the modern aggregate commercial economy. Visualising the business cycle, and especially creating its topological description, became the primary site for making sense of the evidence on this new phenomenon and in the process for defining the concept of the business cycle.

The first visualisation we look at is Henry Ludwell Moore's harmonic cycle of crops and rainfall, see Fig. 1.[3] The second visualisation is the *A-B-C* barometer developed at Harvard University under the supervision of Warren Persons, see Fig. 2. The third visualisation is an example of a 'reference cycle chart,' a graph (one of many) representing the shapes and salient characteristics of the US business cycles, see Fig. 3, developed at the National Bureau of Economic Research (NBER) under the supervision of Wesley C. Mitchell.

Fig. 1 shows Moore's harmonic cycles in the fluctuations of crops and in the mean effective monthly rainfall, over the period 1870–1918, with a longer harmonic cycle of 33 years and a short one of 8 years duration.

Fig. 2 shows a section of Warren Persons' 'business barometer': the bimonthly averages of cycles of groups *A*, *B*, and *C*, for the period 1903–1908, where group *A* represents 'yield of ten railroad bonds, price of industrial stocks, price of twenty railroad stocks, New York clearings'; group *B* 'pig-iron production, outside clearings, Bradstreet's prices, Bureau of Labor prices, reserves of New York banks'; and group *C* 'rate on four-to-six months paper, rate on sixty-to-ninety day paper, loans of New York banks, deposits of New York banks.'

Fig. 3 shows the visual behaviour of one series (this 'sample chart' is for coke production) with indications of variation at the top and bottom and with explanatory texts at both sides (not repeated in the other 174 charts that we counted). These charts were presented and discussed in Burns and Mitchell (1946); they will be explained in more detail in the next section.

The most striking initial difference between these three cycle visualisations is their different topologies, that is to say, the shapes and forms of the three visualisations. While the topology of the NBER reference charts (Fig. 3) is basic Euclidean, that is points and straight lines, the elements of the topology of Moore's figures (Fig. 1) are harmonic functions, and the topology of the Harvard barometer (Fig. 2) is complex (or even 'messy').

Beside the clear difference in topologies, there are other distinctions which can be observed at first glance. While the NBER chart shows the business cycle over one cycle period in 'relative time,' the Harvard graph and Moore's figure show the course of the cycles in 'absolute time' across a longer period. This distinction between relative and absolute time is borrowed from Judy Klein (1997, p. 104), which she defines as follows: 'With absolute time, every data point is associated with a unique date – e.g. January 1998. With relative time, every data point is associated with a place in a sequence.' But there are more distinctions to be observed: While the NBER chart shows a comparison with a reference cycle to make sense of business cycle elements as somewhat standardised objects, there are no such references or benchmarks in the Harvard graph. The sense-making aspect presented by the latter graph is based on the interrelationship of the relative *movements* of three curves, while Moore's cycle visualisation makes sense in harmonic representations, which have a topology of their own that facilitates a different kind of analysis of causal relationships between the two displayed cycles.

The difference between these three topological visualisations of the business cycle are not only the result of three different 'ideas' about the nature of the business cycle which led to three different representations. The difference is also the result of different views about how to make sense of the evidence on the business cycle, and what kind of sense that should be. While the sense-making grid in each case is a time-line, the time-domain ordering in each case is associated with a quite different topology, with the result that each visualisation makes sense of the data in a different way. We will explore these three visualisations to gain a better understanding of how visualisation involving different kinds of topologies not only frames the conceptualisation of the visualised phenomenon but also the kind of sense it makes. The intersection of the visualised phenomenon, the chosen topology, and kind of sense-making are inseparable.

Although we use Morgan's narrative account as a framework for understanding sense-making technologies, sense-making via visualisation differs from sense-making with narratives even though the formats or grids may have some similarities.[4] Visualising involves a kind of colligating process that Whewell called the 'Method of Curves.' This method was, according to Whewell particularly useful to detect and recognize order and regularity 'more readily and clearly' than if the observations were 'presented to the mind in any other manner' (Whewell 1858, p. 204). The outcome colligation is the perceived pattern which gives meaning to the observations. In vision science and in machine learning, pattern recognition, whether by human visual perception or by algorithms, is an interpretive process which give meaning to visual input and data (Palmer 1999, p. 9).[5] Most important, we need to distinguish between the outcome *colligation* (the visualisation), and the processes of *colligating* to that outcome (the visualising processes that go into creating that outcome).

These three visualisations are sense-making in a literal sense, they rely on a two-dimensional visual account, which enables an epistemological role. But the sense-making information that the graphs on these

[3] These three visualisations were not the only ones that were developed at the end of the nineteenth and beginning of the twentieth century. See Armatte (2003) for a broader survey of cycle visualisations and barometers.

[4] A graphic novel is, however, a nice example of a hybrid type, that merges visualisations with a narrative in such a way that it is even hard to distinguish them.

[5] Note that when a visualisation makes sense does not mean that the visualised phenomenon is real. When seeing patterns there is always the chance of a case of pareidolia, 'the tendency to perceive a specific, often meaningful image in a random or ambiguous visual pattern' (Leng and Leng 2020, p. 107).

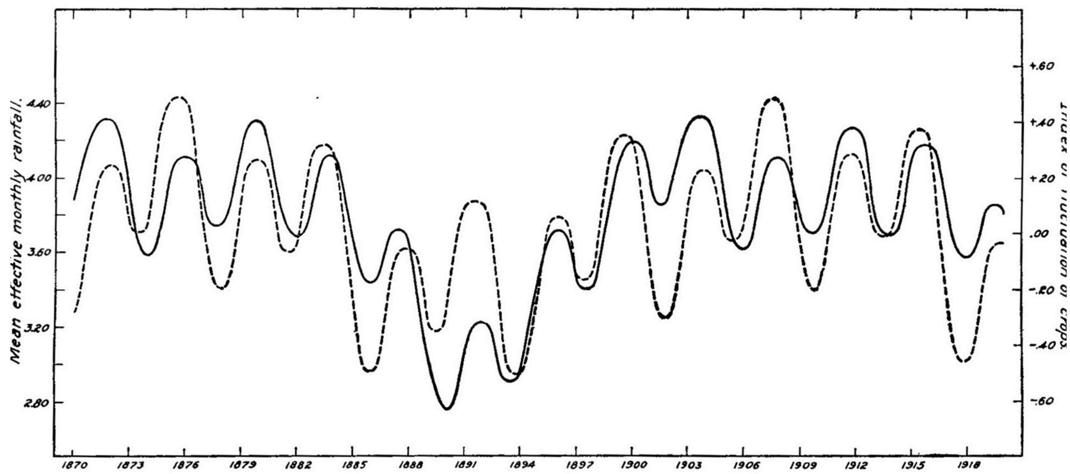

Fig. 1. Harmonic cycles of crops and rainfall.
Source: Moore 1914, p. 54, Figure 14

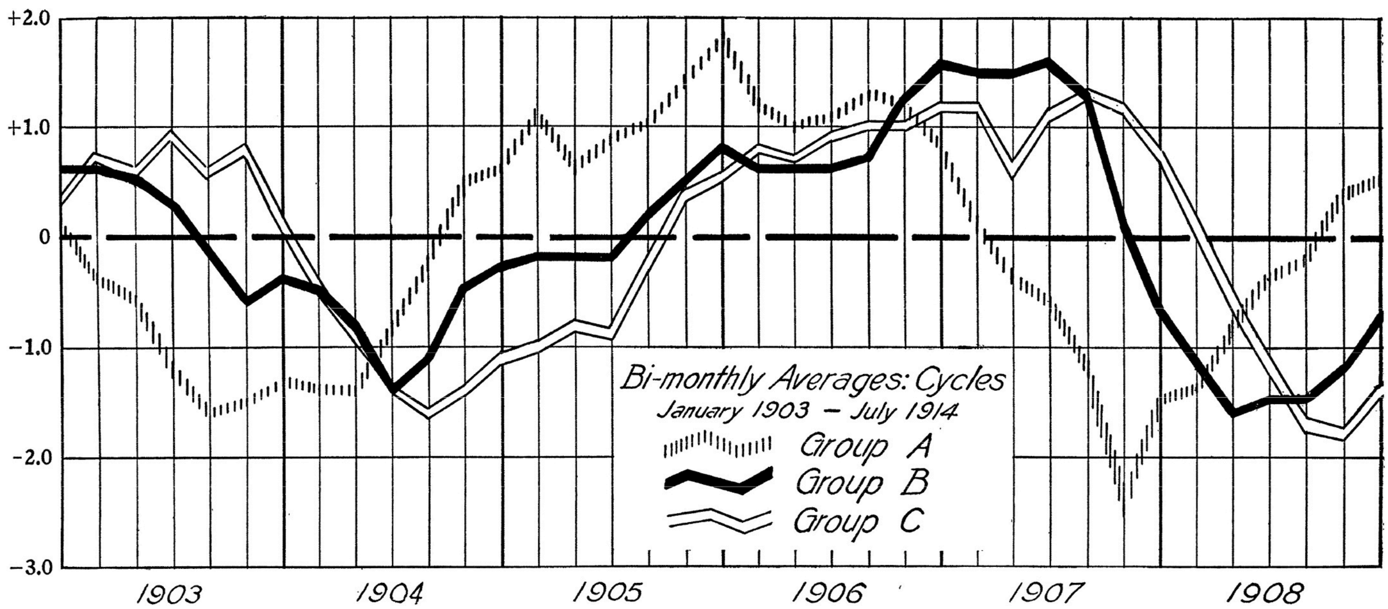

Fig. 2. Harvard A-B-C barometer.
Source: Persons 1919, p. 112.

grids provide is not, in the first instance, quantitative but qualitative. The first meaning the Oxford Dictionary attach to 'in-form-ation' is 'the shaping of the mind or character.'[6] For these visualisations, form is a primary site for sense-making agency, so we focus first on topologies instead of metrics, though this does not imply that the role of metrics can be ignored. These economists began with metrics, working intensively with the statistical data as individual series; these were then conceptualised as a set of elements making up a single complex phenomenon with a particular topological representation. But as we shall also see, metrics were critical in creating the representations, and so fundamental in the colligating process. As the case of the NBER reference chart (see Fig. 3) shows, a metric can also be a critical part of the sense-making performance.

To discuss this comparison between these three visualisations in more detail, we will first explore for each visualisation the interdependency of sense-making between the conceptualisation of the business cycle, the topology involved, and the colligating processes of composing, decomposing and fixing that visualisation into the space and time grids. (Again, a warning, these processes found here are not necessarily those that are relevant to all kinds of colligating in visualising processes of sense making.)

2.1. Harmonic cycles

As we noted above, the early twentieth century is when economists first started framing 'the business cycle' phenomena, and in many respects, Moore can be understood as working in the older conceptual space of the trade cycle and its visualisation.

As the title of his book, *Economic Cycles: Their Law and Cause*, clearly indicates, Moore (1914, p. 1) was interested in answering the question 'What is the cause of this alternation of periods of activity and depression? What is its law?' The line of inquiry to find this law was quite simple: He expected that explanation of the economic cycles was to be

[6] Information, n. OED Online. March 2022. Oxford University Press. https://www.oed.com. Marcel would like to thank Mor Lumbroso for bringing this to his attention.

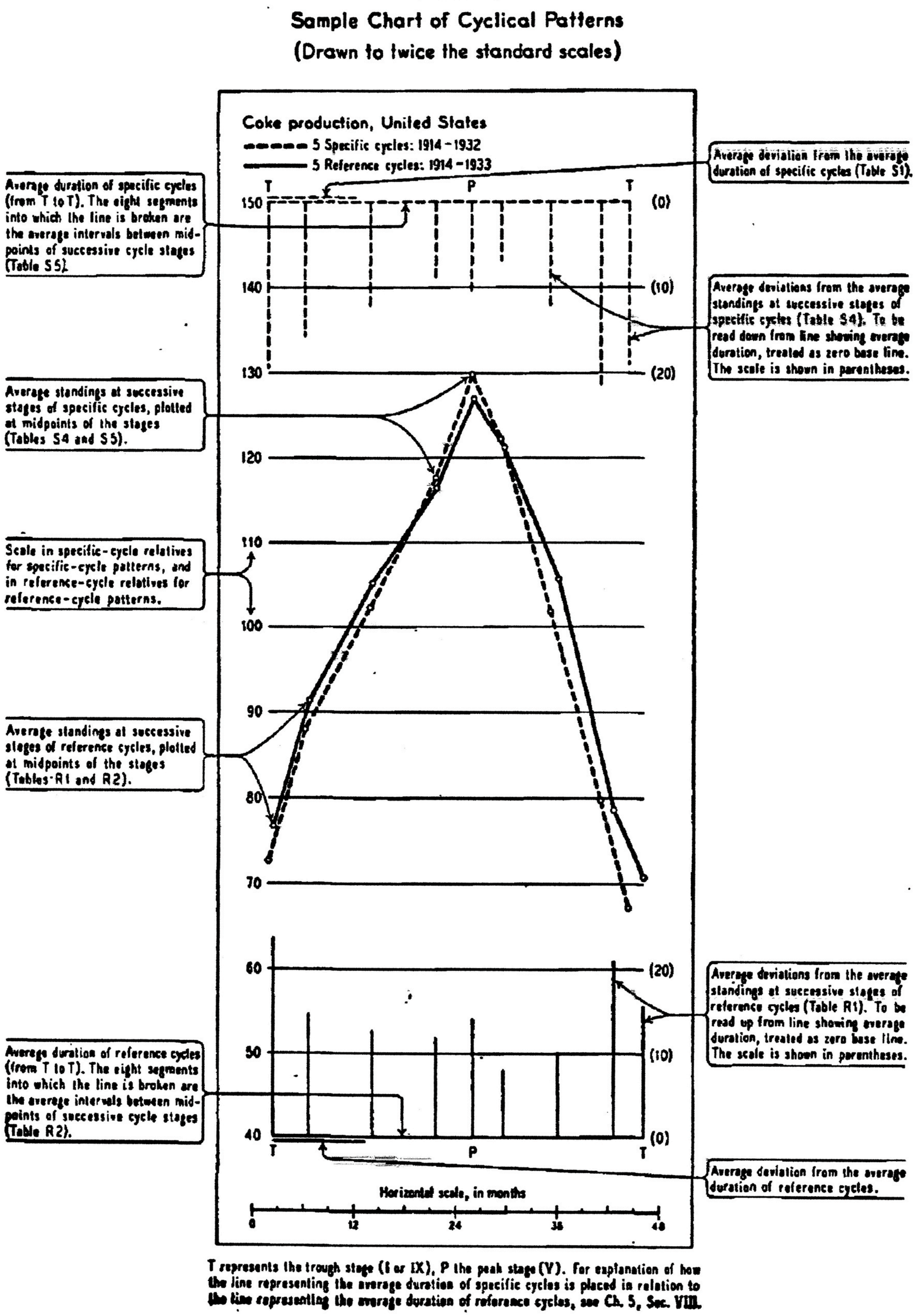

Fig. 3. The reference cycle chart.
Source: Burns and Mitchell 1946, p. 35, Chart 2

found in the 'law' of the changing supply of agricultural products, and subsequently that this latter law is 'associated' with a 'law of changing weather' (p. 2).

> Supposing that it is possible to discover that the weather passes through cycles of definite periods and definite amplitudes, it will then be necessary to show how the crops are affected by the weather and how the cycles of the weather are reproduced in cycles of the yield of the principal crops. [...] When the physical yield of the crops has, on the one hand, been related to the cycles of the weather and, on the other, to the prices of the respective crops, it will then be possible to take the final step and to show how the cycles in the physical yield of the crops produce the cycles in the activity of industry and the cycles of general prices, and how, finally, the law of the cycles of the crops is the law of Economic Cycles. (Moore 1914, pp. 2–3)

Hence the first step in his investigation was to find this 'law of changing weather' and subsequently to show that this law is 'associated' with the 'law of changing supply of raw material.' To complete this investigation, he then had to show that this law of changing supply was associated with the economic cycle. This is where his colligating processes come in.

To find these associations, Moore employed a method based on a theorem of Joseph Fourier, called harmonic analysis. The theorem tells us that any periodic curve, however complex, can be exactly reproduced by superimposing a sufficient number of simple harmonic curves. Moore legitimised the adoption of this method by stating that it satisfies two conditions: '(1) It shall be consistent with recognized mathematical processes; (2) It shall afford means of testing the degree of probability that the results are not chance phenomena' (p. 7). The second condition expressed the worry that the periodicity found in the data might be artifactual, that is to say created by the employed smoothing technique.

His colligating processes involved *decomposing* and then *recomposing* certain data sets. In the first, decomposing move, Moore applied harmonic analysis to the rainfall data of the chief grain-producing area of the United States, he found two cycles of 33 years and 8 years respectively. These two cycle periodicities could then also be detected in the crop (corn, hay, oats, and potatoes) data and – in a recomposing move – he showed them to be highly correlated with the rainfall cycles, as displayed in Fig. 1 above: 'When the graphs of the cycles of the crops were superposed upon the graphs of the cycles of rainfall of the respective critical seasons, the two curves were found to present a very remarkable congruence' (p. 142). Although, he *fixed* his data series onto an absolute time scale in order to measure their periodicity, the dates are not relevant when it comes to the congruence of both series, and so the visual comparison is actually on a relative time scale. Moore concluded his colligating processes (decomposing, recomposing and fixing into a form) by putting the two series together, claiming: 'with a high degree of probability, that the rhythmical movement in the weather conditions represented by rainfall is the cause of the cycles of the crops' (p. 56).

In the subsequent chapters, Moore showed that there is also a high correlation between the crop cycle and the cycle of general prices, and hence that 'the law of the cycles of crops is the law of the cycles of general prices' (p. 124). And so bringing both results together, the main conclusion was: 'The law of the cycles of rainfall is the law of the cycles of the crops and the law of Economic Cycles' (p. 135). In many respects, Moore can be understood as continuing Jevons' work in a series of papers from 1875 to 1882 in which he sought to link the periodicity of sunspot cycles with the nineteenth century trade cycle of Great Britain with India – an account that depended equally on natural law basis, and causal connections, and though less persuasive than in Moore's work, he did produce some visualisation of the relationship.[7]

The sense-making topology of Moore's approach relied on a congruence of harmonic functions: for him, congruence indicates causal connection. This assumption of a close connection between the shape of a phenomenon and its underlying causal mechanism, such that the shape can be used to reveal this mechanism, has its origins in physics and was not uncommon in economics in the first half of the twentieth century.[8] Because of the growing influence of Trygve Haavelmo's (1944) probabilistic approach and particularly his (1940) critique of mechanistic approaches based on mathematical shapes, and natural law notions of recurrence, these approaches became unpopular in the second half of the twentieth century, though harmonic analysis of business cycles has never completely died out and the visualising project re-appears periodically.

2.2. The Harvard barometer

We see in this next example, a step change in the cycle concept and colligating processes in the work of Persons. For him, appealing to the weather was no longer an appeal to a causal mechanism, but an appeal to a 'barometer', a visualisation that would work as an indicator system, a qualitative form, that would indicate the past, current and possible future of business activity in a roughly cyclical pattern.

In 1917, Harvard University had organized the Committee on Economic Research to study economic statistics and improve the scientific quality of economic investigation. To lead this statistical work, a year later the committee hired Persons. His primary responsibility was to edit the committee's quarterly journal with monthly supplements, *The Review of Economic Statistics*, which first appeared in January 1919. As editor of the *Review*, Persons was also in charge of the formation of the index of business conditions, a 'business barometer.' In his presidential address read at the Annual Meeting of the American Statistical Association in 1923, Persons (1924, p. 2) emphasized the 'necessity of the accumulation of statistics of the complex world of affairs in which we are immersed and the equal necessity of the development of special methods, different from those of the exact sciences, for summarizing these data.' The summary of the data was an index, a 'barometer.'[9] This label is highly indicative of the conceptual elements. The index, or indicators, are designed to capture the behaviour of the phenomenon in a visual way, not in a tabulation (a mid-nineteenth century representation), nor in an implied causal visual account as in Moore's case, yet something more than Jevons' plate stacking of lining up individual series above each other in the time graph. The term 'barometer' was first used in economics by Roger Ward Babson in 1909 and was borrowed from meteorology; it was supposed to resemble the continuous recordings of barometric pressure over time in graphical form (also called a barograph).[10] The visualisation represents a conglomeration of elements that make up the business cycle (compared to Moore's use of single series), and is committal about their time patterned relationship but non-committal, or open, about their causal relationship. These relations are both inexact compared to Moore's visualisation, and also depict looser associations between the parts.

To develop this visual index, Persons (as Moore) relied on using the two colligating principles of composition and of decomposition of time series. Developing both kinds of processing, and used in sequence, enabled Persons to conceptualise, that is to make-sense of, the business cycle as a complex changing process, made evident or *fixed* in his

[7] See Chapter 1 of Morgan 1990, for a detailed discussion of Jevons' research on the connection between sunspots and the British trade cycle.

[8] See Boumans (2013), for a detailed discussion of this connection in economics and how it gradually disappeared as epistemic methodology. Morgan (1990) provides the earlier and contemporary attempts using harmonic analysis.

[9] See Boumans (2016), Lenel (2021b), and Morgan (1990) for a more detailed exposition of Persons' approach.

[10] See Friedman (2014) for a detailed historical account of the creators of these first economic barometers.

visualisations.

Composing: A time series is a sequence of data, called 'items,' observed at successive points in time spaced at uniform time intervals. The principle of composition is that 'isolated items of statistical series [...] can have no significance by themselves. Only by a comparison of items over a period of time can we ascertain their meaning' (Persons 1920, p. 39). That is, the time series composed as a whole, and not the individual items, are the objects that will be compared with each other. But only the cyclical characteristic of the time series were compared. Therefore, each series has to be decomposed to abstract the cyclical fluctuations.

Decomposing: The principle of decomposition is that 'items pertaining to widely separated periods cannot, however, be used in their crude form' (Persons 1920, p. 39). Each monthly item is considered to be a composite of four separable elements: a secular trend, seasonal variation, cyclical fluctuations, and a residual factor. The secular trend is the regular increase, 'according to some principle,' over the whole period under consideration. According to Persons, the secular trend is a growth element, 'a normal change,' dependent upon population growth and the development of industry. The seasonal variation is the movement of the items within a year, attributed to the change of seasons. The cycles, then, are the components secured by removing from the actual items the secular trend and the seasonal variations. The residual element includes 'all sporadic developments which affects individual series, or widespread changes due to momentous occurrences, such as wars or national catastrophes, which affect a number of series simultaneously' (Persons 1920, p. 39). There was no general rule to specify this highly idiosyncratic component, indeed, it seems that the unsystematic character and sporadic nature of these real economic elements could be considered equally part of the business cycle, and not necessarily to be eliminated from the cycle component. This shows nicely the difficulty of visualising (and indeed, fixing) any messy phenomenon, where messy means not exactly defined.[11] Which business conditions have to be captured? Is a war or a natural catastrophe a business condition or not?

Re-Composing: to get a visualisation of the cycle conceived as a complex or conglomerate phenomenon, the isolated individual cyclical series had to be grouped together. To be a good barometer, to be informative about the general business conditions, these series had to be clustered into groups with similar behaviour patterns. The clustering depended on him 'seeing' which of the series had wave movements that were somehow similar and simultaneous (using a light-box to observe and align the relative patterns in the graphed data) to create an ordered sequence of these grouped visual waves. Next, the 'synchronous items of the series in each group' as judged by eye, were averaged so that three series of 'synthetic group indices' were secured. These three series of indices 'epitomize the business situation' (p. 111) and were presented graphically, or fixed, in three curves (*A*, *B*, and *C*), see Fig. 2. The criteria for grouping the series were, thus, similarity and simultaneity of the cyclical components, that is, those criteria made sense of the time series. This barometer encapsulated the concept of the phenomenon and vice versa.

For the *A-B-C* barometer, it is similarity and simultaneity of the three lines that are relevant, not so much a specific shape. A topology that is able to account for the typology of a barograph is René Thom's *Structural Stability and Morphogenesis* (1975). Thom explored the kind of topology needed to study the change of forms, which he called morphogenesis. According to Thom, there is a 'natural tendency of the mind to give to the shape of a graph some intrinsic value; it is this tendency that we shall develop here to its ultimate consequences.' The forms for which he aimed at a mathematical theory were the complex forms as 'the cracks in an old wall, the shape of a cloud, the path of a falling leaf, or the froth on a pint of beer' (p. 9), to answer questions like 'why do clouds and mountains not have the same shape and why is the form of crystals different from that of living beings?' (p. 8). The forms itself are considered to be 'gestalts,' in the sense that they are 'subjectively identifiable' and imply 'nothing about the "ultimate nature of reality"' (p. 6), but have 'special value for us or are biologically important, for example, the shapes of food, of animals, of tools' (p. 13), so they can vary with someone's 'psychological state' and 'conscious and unconscious desires,' 'the Rorschach tests are based on this variability' (p. 14).

For science, forms that are stable are generally considered key in the interpretation of phenomena – as in Moore's periodic visualisation. By stable Thom meant not only the forms that are identifiable and 'represented in our language by a substantive' (p. 14), but all forms of objects that (despite disturbing influences of the object's environment that have some effect on the form) have a (mathematically defined) permanence. Actually, for Thom, forms are by definition stable: 'unstable forms do not merit the name of forms and are strictly *nonforms*' (p. 14). In other words, the more stable the patterns are, the more they make sense. When it appeared that the movements of *A*, *B*, and *C* were similar but with some time delays (i.e. *B* lagged six months after *A*, and *C* four months after *B*), *A* was *briefly* seen as a forecast of *B*, and both *A* and *B* as a forecast of *C*. But it soon appeared that the economic world is not that stable. Although Fig. 2 shows this stable pattern for the period between 1903 and 1908, any similarity between the movements of *A*, *B* and *C*, evaporated a few years later; each had developed its own particular movement. Strong benchmarking into a fixed time-period, and fixed pattern was not possible. And so the barometer lost its stricter sense as forecasting tool; but it retained it usage as visualisation that made sense of the data of the phenomenon with some indicative power.

The lack of stability, as in Persons' indexes, also, perhaps strangely, contributed to its persuasive qualities for economists and commercial commentators: life is uncertain, business life is not easily pinned down in stable patterns, and is somewhat unpredictable (cf. Lenel 2021b). Our weather barometers are not exact forecasters of, but indicators for, changes in the weather, just as business barometers are indicators for changes in 'business conditions.'

Two elements of their ongoing usage are of particular interest in terms of the way these visualisations offer persuasive versions of the business cycle concept. First, the barometer registered the unpredictable and erratic fluctuations of the economic conditions and so the sense-making aspect was captured by its typical topology: it informed when conditions were good and when bad, but not how long conditions would be good or bad. Second, barometers are used as local sense-makers, they are about our weather at our time and place. Business barometers are similar. At their time of their development in the 1910s and 20s, it was understood that each nation developed their own business barometer both in terms of its relevant elements and in terms of their timing – cycles were neither lawlike over time, nor over space. These kinds of business barometers remain valid visualisations in the public domain of economic information, taking over from the nineteenth-century 'business annals.'

2.3. The NBER's reference cycle chart

Burns and Mitchell (1946) were not aiming at something like registrations of 'economic weather conditions' like the Harvard *A-B-C* barometer, but the recording of something less local and time-bound, such as solar radiation. Not – to keep to the same metaphor – to detect the underlying the sunspot laws but to measure the main characteristics of economic radiation. These 'new and strange symbols' were displayed by the reference cycle charts, a completely different visualisation, topology, and *fixing* into time than either Moore or Persons. 'Our measures are averages covering groups of cycles; rarely if ever do they fit snugly any one cycle.' (Mitchell 1951, p. 29). The business cycle was 'defined' to consist of at least the following 'phases': 'expansion,' 'recession,' 'contraction,' and 'revival' (Burns and Mitchell 1946, p. 3). In the charts (see e.g. Fig. 3) they actually distinguished 9 phases. Their new

[11] This applies of course not only to visualising, but to any representing activity, such as measuring.

visualisations focussed on the characteristics of each cycle phase rather than either the changing pattern or path of the cycle over the time period, or how these elements fit together.

The business cycle itself is not *observable*, as Burns and Mitchell (1946, p. 14) noted, 'what we literally observe is not a congeries of economic activities rising and falling in unison, but changes in readings taken from many recording instruments of varying reliability.' To make the business cycle *visible*, these readings have first to be 'decomposed' and then 'one set of components must be put together in a new fashion' (p. 14):

> Thus the concept of business cycles ties together in our minds, and gives meaning to, a host of experiences undergone by millions of men, few of whom think of themselves as influenced by cyclical pressures and opportunities. The concept, as we develop it, is itself a symbol compounded of less comprehensive symbols representing the cyclical behavior characteristic of many unlike activities. In turn, these symbols are derived by extensive technical operations from symbolic records kept for practical ends, or combinations of such records. We are, in truth, transmuting actual experience in the workaday world into something new and strange, much as a meteorologist transforms our experience of sunshine into new and strange symbols that record solar radiation. (Burns and Mitchell 1946, p. 17)

Their procedures can also be characterised as *decomposition* and *composition* – 'if we wish to know what the wholes are like, we must study the parts and then see what sort of wholes they make up' (Burns and Mitchell 1946, p. 11). The starting point of decomposition was the same as the Harvard approach in that the time series had to be decomposed into cyclical, secular, seasonal and random movements, in order to isolate the cyclical fluctuations. But once the movements had been distinguished, the NBER researchers proceeded in a very different way with very different techniques. For each specific subject data series, they dated the turning points, by taking the highest and lowest points of these decomposed cyclical patterns - the 'specific cycles' - as the dates of the cyclical turns, which they then used to determine a 'reference cycle' for that specific subject data set.

> This step is the crux of the investigation; it involves passing from the specific cycles of individual time series, which readers not embarrassed by experience are likely to think of as objective 'facts', to business cycles, which can be seen through a cloud of witnesses only by the eye of the mind. (Burns and Mitchell 1946, p. 12)

A reference cycle for a subject matter series is then defined as movement between successive reference phases. The next step is to take the average of the monthly values of the specific cycles during each reference cycle and convert them into percentages with respect to this average.

> The application of a uniform set of dates to all series for a given country, and the reduction of the original data expressed in diverse unites to relatives of their average values during the periods thus marked off, put all the materials into comparable form an enable us to see how different processes behave during successive business cycles. (Burns and Mitchell 1946, p. 24)

The specific cycles could then be compared with these reference cycles, both being recompositions of the original data. The statistical analysis was thereupon presented and *fixed* in charts picturing both a specific cycle with the related refence cycle and showing the averages and average deviations for each subject element. For example, Fig. 3 shows the reference cycle for coke production with a specific cycle. The lengths of the vertical lines show the average deviations of the individual cycles from the reference cycle at the nine phases of the cycle. The long horizontal lines above and below the cyclical patterns represent the average durations of the specific and reference cycles. The ruler at the bottom of the chart defines the time scale; with its aid all durations can be approximated. These charts of the reference cycles appeared in the second volume of the National Bureau's book series on business cycles, published in 1946. The first volume, *Business Cycles: The Problem and Its Setting*, by Wesley C. Mitchell had been published in 1927, so it took twenty years of empirical work from that earlier definition of business cycles into visualisation into the reference charts.[12]

The reference cycle apparatus is clearly a result of colligating, with its processes of sorting out and making wholes. But it remains an important point to note, that the re-composition did not lead to a visualisation of a general business cycle, each subject matter had its own reference cycle.

A closer investigation of the nature of grid on which the colligation is ordered is needed to see in what sense the reference charts give sense to the data and to whom.

The reference cycles defined the time scale, which was not an absolute but a relative time scale. But the concept of time was different from those of in the visualisations of Moore and Persons. To clarify this, we use another relevant distinction by Klein, namely the distinction between logical time and historical time. 'Lines imaged in logical time connect and compare static positions,' whereas the 'curves drawn in historical time attempt to pattern irreversible paths of change in temporal processes' (Klein 1995, pp. 98-9). Although the phases of the cycle have a historically fixed time order, the time scale comes closer to a logical time scale.

As Laetitia Lenel (2021a, p. 135) remarked in her study of the NBER, by the late 1920s, these researchers had analysed over 300 individual series from the United States, England, France and Germany. Over the years that followed, Mitchell and his colleagues assembled many more such series, unprecedented in chronological range, and covering economic activities ranging from aggregate transactions to transportation. Burns and Mitchell had developed the reference cycles in the hope to get 'a clear picture of the total movement' (Burns and Michell quoted in Lenel 2021a, p. 137). The reference cycle charts were meant to give a 'well rounded view' of something that 'cannot be seen by the eye' and as such they are meant to give sense to the 'bleak numerical records of certain mass activities.' (Mitchell 1951, p. 29.) But it is not obvious that these specific and reference cycles charts indeed give sense to the data such that the phenomenon of the business cycle made sense beyond the NBER circle. They hardly travelled beyond the NBER and what became used were the reference cycles' dating, rather than the visualisations (the charts) themselves. For example, Mitchell's closest collaborator at NBER, Burns, perceived Mitchell's reference cycle as a reference *scale* to arrange facts, 'not an index of general business': 'The scale simply consists of a succession of dates when economic activity at large appears to have reached a peak after a sustained upward movement or a trough after a sustained downward movement' (Burns 1951, p. 27).

As the title of the 1946 vol indicates, the aim was measurement, that is, the aim was to get quantitative facts about the business cycles. And its procedures described in detail explain how to get at these facts. The plotted time series have a clear role in these procedures, but the charts of reference cycles not. They appear as a *result* of the measurement procedures. But for what purpose? It appears to us that Mitchell saw them as tools to make visual comparisons: the reference cycle was a benchmark to assess – visually – each specific cycle. But it is not clear what they add to the corresponding quantitative facts. The only addition we can think of is that they show the 'typical' *shapes* of the cycles, or more specifically how steep the movements upwards and downwards in each cycle stage are, and the deviations between specific cycle and its reference cycle in each phase.[13] But the subsequent NBER publications show that there

[12] Morgan (1990, p. 49) notes that the first volume can be best described as 'Mitchell's search for the definition and the correct analytical approach to the business cycle: a survey of the problems in the field rather than a new empirical study solving these problems.'

[13] These can of course also be given in quantities – the drawing is actually based on these numbers – but it is hard to see a shape in numbers.

was no interest in the typical shapes of the business cycle, neither in the deviations between the specific and reference cycles, only the reference dates were seen of interest. If the sense-making aspect of the reference charts is indeed displaying the reference dates and the steepness of the upwards and downward movements, and the distances between specific and reference phase, the simple Euclidean topology of points and lines suffice. And because in later publications these distances and steepness of the movements were no longer of interest, only the reference dates, it clarifies why the charts felt out of use. There is no epistemological gain in visualising the dates, the dates make enough sense.

3. Sense-making topologies

Making sense of data, particularly today where we have to deal with 'Big Data,' is an important phase of research, often needed to go through before one even can start to think about explanation or prediction. A first understanding what sense-making entails is provided by the recent narrative accounts of sense-making, particularly the notions of colligating that involved: ordering and sorting out using similarities and juxtapositions, the notion of a grid along which the data is aligned, and the binding together of the elements. For visualising as sense-making, the parallel processes of colligating involve composing, decomposing and recomposing elements, and binding them or fixing them into a visualisation. We have applied these notions to investigate how visualisation can function as a sense-making tool.

For the business-cycle visualisations we examined, the most important grid was a time grid. But it mattered what kind of time was used. There are four different types time that can be distinguished – borrowed from Klein's analysis of visualisations used in economics: absolute or relative, and historical or logical. Each kind of time grid defining a specific time-relation put specific constraints on the kind of sense these visualisations, or colligations (the outcomes) make.

And, in summarizing our understanding of visualisating as a sense-making tool, it appears – for the three explored cases of business-cycle visualisations – that beside the notion of a colligation grid we also have to take into account the following closely related aspects: the fixation of the phenomenon into a shape within a visual space, and the topological possibilities offered by this visual space. These three aspects not only constrain the visualisations but also the kind of sense made in and with them.

In this context, we discussed three different topologies: a basic Euclidean topology, the topology of a barograph, and a topology of harmonic functions. A topology defines the kind of forms into which a phenomenon can be fixed. But it also constrains the kind of colligation that is possible. It appeared (from our examples) that colligation with harmonic functions is more straightforward than with barographs. It also appeared that not only is the kind of form relevant for sense-making but also its stability. When a relational grid was used as an addition to the time grid, unstable forms ('unforms') became a problem; perhaps causal relationships require very stable forms?

Comparison of the three cases suggest other kinds of insights. Thus the cases show how different topologies of the time-grids have different roles in sense-making for different concepts of the business cycle. But in each case, there is also a conceptual commitment to the kind of phenomenon the business cycle is which informs the visualisation and processes of creating it. For Moore, the cycle is understood as a law-like, time-based, event, and his visualisation treats time as a smooth harmonic grid pinning down the regular repetition – the topology of his visualisation goes along with these two elements. For Persons, time is an on-going grid, creating no constraints for his representation using only those of the human calendar to situate his curves. For both Persons and Mitchell, the business cycle is a complex phenomenon. For the former it is a flexible and changeable one, that can be indicated into a time pattern of an erratic and irregular shape. For the latter it is an equally complex phenomenon, but one that has certain timeless characteristics, it can be pinned down into a standardised form onto a fixed time-frame. So, like Moore, Mitchell sees it as fundamentally a repeating event. For all these three, concepts and envisioning the business cycle lead their processes of creating the visualisation of the empirical materials, while the particular topology of the grid operated in pinning down, grounding, and creating the actual visualisation. The topologies are critical in making sense of the data in different ways. In case of time grids, the role of type of time and topology can perhaps be clarified by making an analogy with composing a piece of music. A composer before starting the process of composition has already an idea about the kind of music, and hence has made a decision on the key and time signature. In the same way a key and time signature constrain the composition, the topology and type of time will shape the visualisation.

Whereas sense-making for categories relies on strategies of heaping or dividing, and that for narratives on meaningful ordering using time grids or relational grids, the sense-making of visualisation - at least here in these examples - depends primarily on time grids rather than rather than on relational grids. But we could also see that the latter were not entirely absent – a causal account played a role in Moore's visualisation, and the relation between the *A-B-C* curves of Persons were considered to be indicative (economists could and did speculate about economic life using them), and the reference cycle functioned as a benchmark in each chart of a specific cycle in Mitchell's visualisations.

The claim for narrative as a sense-making technology lies in the claim that narratives are more than chronologies – chronologies are descriptions that only order events in time, but narratives relate things together, using different processes of colligation (see Morgan 2017). Time sequencing along a grid provides a possible starting point for sense-making, but unless the elements are related together, all we have is a chronology, an ordered list in time, not an account that makes sense of the events through time. Moore, Persons, and Mitchell, each in a different way, provide this kind of relational sense coded within their visuals: that is, they showed relational elements of their conception of the business cycle phenomenon by a colligation in terms of a harmonic cycle, a barograph, and a reference cycle, respectively. So, visualisation sense-making can embed the same qualities and qualifications as narrative sense-making.

A couple of unrelated examples might help to make these points. John Huss (2022), in writing about making sense of the mass extinction events in palaeontology, presents two different visualisations on the same kind of time graph, one indicating periodic events, the other presenting irregular time events. The former, as Moore's business cycle graph, presumes some regular natural cause of the events, the later, assumes that a particular set of causes can be found for each event. The simple time series graphs are not the same, they do not provide the same sense-making – for the phenomenon is conceptualised differently, and made sense of differently. They open up the possibilities for explanation and rely on narrative input in full sense-making. Teru Miyake (2022) analyses the many different time graphs of the Tohoku earthquake. They were produced by recording devices, registering events second by second operating over spatial domains. Each graph offered a description of what happened at that place over time. They had to be composed (or as he says, 'integrated') into an overall visualisation-cum-narrative account of that earthquake. There are certainly similarities here to the approach of Persons, where we see more than a chronology, if not a fully integrated account.

Just as time-charts describe and *can* be a sense-maker for a particular time-based phenomenon, geographical maps *can* describe and make sense of some particular aspect of the spatial world. We might here then usefully contrast the visual sense making of time grids with the visual sense-making of spatial grids by thinking, as a contrast, of the various different ways that maps represent the world (on round or flat surfaces; with political colour coding; with contour lines to denotes physical features such as mountains; with different mathematical 'projections'; into a series showing the planet at different time periods over the millennia; and so forth). These different visualisations give us different possibilities of making sense of our geographical world, and we work with them and use them differently. But this comparative context of spatial visualisation can also take us back to our initial parallels with narrative sense-making. A single geographical map on its own may not be a sense maker. A map is in first instance a descriptor, the mapping of distances, ocean currents, and trade winds, or the mapping of political boundaries, colonial powers, and independence regimes. But it is these specific choices of what is represented that enable sense-making. Map-keys (see Morgan 2020), and the clever representation of dimensions, turn the map-description into a sense-making tool, for maps which mark political boundaries or battle fields indicate different terrains of sense-making than those that feature natural objects such as rivers and mountains.

Back finally to Morrison's argument about the role of material for when we think about visualisations or narratives. We can see in the comparable cases of geographical mapping, indications of how visualisations can be descriptors, but more usually and interestingly, are sense-makers and so see how they might be used by communities. But their very differences also exhibit their constraints. We can also see in the specific examples of mass extinctions and earthquakes, how the visualisations went along with certain kinds of narrative accounts, and not others. They enabled certain kinds of sense-making and ruled other out, just as in the business cycle cases examined here. Sense-making visualisations, like narratives, enable scientists to think, reason, explore, and understand their materials, but their specific visualisations also set boundaries on that activity.

Declaration of competing interest

None.

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