What's Your Theory of Effective Schematic Map Design?

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***Abstract*—Amongst designers, researchers, and the general public, there exists a diverse array of opinion about good practice in schematic map design, and a lack of awareness that such opinions are not necessarily universally held nor supported by evidence. This paper gives an overview of the range of opinion that can be encountered, the consequences that this has for published designs, and a framework for organising the various views.**

Keywords—schematic mapping; lay-theories, expectations and prejudices; effective design; cognition; intelligence.

I. LAY-THEORIES OF DESIGN

Whenever I create a controversial new schematic map and publish it on the internet, the diversity of opinion that it evokes is striking. The same design can trigger rage and delight in equal amounts, but people are not just commenting on appearance and aesthetics. A sizable number will be making opposing claims about usability: *this map is impossible to understand* versus *this map is really clear and simple*. Often, in tandem with such strong evidence-free assertions, is the utter disbelief that these could be in error in any way.

Internet comments generally do not influence my usability predictions for two reasons. First, all of my research [e.g., 10] *always* demonstrates a clear dissociation between subjective opinions about usability versus objective measures of performance. Put simply, people often prefer maps that the test data prove they find difficult to use, and reject maps that they find easier to use. Furthermore, I have yet to find in my research any map that results in a polarisation of performance data, such that *map A is very easy to use by this type of person but map B is very difficult* and conversely that *map B is very easy to use by the other type of person but map A is very difficult*. In reality, the advantage of one map over another might be large for some people, smaller for others, perhaps even slightly reversed for a few, but a dramatic and substantial polarisation, such that, for example, one design is particularly well-suited for use by males, and a complementary design is well-suited for use by females, is both unknown and unlikely.

Usability assertions are nonetheless of interest because they reveal individuals' lay-theories of effective schematic map design. People may not realise that they possess them (in which case, these theories are *implicit*) but any person who has seen a schematic map and made a claim about its usability, either by itself, or in relation to other designs, is effectively making a prediction that could be tested in a laboratory study, and a prediction cannot be made without some sort of underlying theory. Lay-theories of design will determine whether the general public accept or reject radical new creations. Furthermore, the lay-theories held by designers will affect the products that they create and the recommendations that they make. Similarly, the lay-theories of transport managers will determine design specifications and the acceptance or rejection of end-products. With so many different theories in circulation, conflicts will be inevitable, hence the polarised response to the controversial Madrid Metro map of 2007, which generated a huge adverse reaction amongst residents: presumably, the transport authority believed that this was a sound design. Likewise, the adverse public response to the removal of the River Thames from the London Underground map in 2009. The lay-theory held by officials, presumably, was that the river was irrelevant to usability. The public disagreed, and the river returned a few months later. Hence, lay-theories of design influence the maps that are provided to the general public, and whether they will find these acceptable. Understanding lay-theories and their origins is, therefore, of great importance.

II. AN INTERNET SURVEY

In order to provide an indication of the coherence and prevalence of lay-theories of design held by the general public, an internet-based survey has recently commenced. This comprises nine different specially-designed matched London Underground maps which vary along two dimensions: their *design rules* and their *design priorities* (see Figure 1). People are asked to rate each of the nine designs, identifying maps that they believe are *hard to use*, *easy to use* or *neutral* compared with the rest and, subsequently *attractive*, *unpleasant*, or *neutral* compared with the rest.

A. Design Rules

Three different design rules have been implemented: (1) *octolinear* – the most commonly used, and first applied to the London Underground by Henry Beck in his creation published in 1933; (2) *multilinear* – rarer, and generally applied ineptly if at all, but used to great effect on Moscow Metro maps in the 1970s; and (3) *curvilinear* – generally not used, although Roberts *et al.* showed that a curvilinear Paris Metro map was easier to use than the official octolinear design.

Octolinear designs have only horizontal, vertical, and 45˚ diagonal straight lines permitted, with tightly radiused corners. This has become a gold-standard of schematic maps, with many people expecting these to be designed in this way, evaluating maps positively if they conform, but harshly if they do not [4, 6, 7]. *Multilinear* designs are also straight-line only, with segments linked by sharply radiused corners, but with any angle permitted. This enables the straightest line trajectories,

Fig. 1. The matrix of nine maps used in the survey to identify implicit theories of effective design held by the general public.

although the payback is that the larger number of angles increases complexity, and can reduce the overall coherence of the design. *Curvilinear* maps comprise only Bézier curves, with the intention of smoothing away harsh corners. These designs tend to polarise opinion, with many extreme views expressed concerning usability.

B. Design Priorities

Three different design priorities were applied in order to give a matrix of nine maps: (1) *geographical* designs were intended to be spatially informative, created by applying a pinch distortion to a topographical map of London and attempting to preserve the resulting station locations while achieving reasonably simple line trajectories; (2) *compact* designs were named so as to disguise their true status: as deliberately poorly optimised designs with complex line trajectories and little attempt at geographical accuracy; and (3) *stylised* designs were also named to avoid revealing their true status: as carefully optimised versions with the simplest line trajectories feasible in the available space, and particular attention given to the centre of London inside the Circle Line.

Because of London's somewhat chaotic rail network, it was inevitable that the *geographical* maps would have complex line trajectories for all three design rules. These maps were included to identify the extent to which people expected spatial fidelity for schematic maps. Frequent complaints tend to be made against designs which fail to achieve this. The *compact* maps, with few redeeming features, should be rated as easy to use only by people who believed that the simplicity of line trajectories is irrelevant to usability. The *stylised* maps were also included to identify people who were sensitive to the simplicity criterion. Differing choices along the *design rules* dimension would indicate any expectations or prejudices concerning this aspect and usability. [Unpublished research indicates little to choose from in terms of usability for octolinear and curvilinear maps of the London Underground.]

C. Preliminary Findings

The responses of the first 100 people to complete the survey are summarised in Tables I and II. The *octolinearity bias* of the predominantly British sample is noteworthy, with usability ratings disproportionately high compared with equivalent multilinear and curvilinear designs. The octolinear *geographical* and *compact* maps, with their complex line trajectories, appear to have been particularly over-rated for usability. In general, people have been sensitive to the design priorities, with the simplest line trajectories receiving the highest usability ratings, and the ratings of the geographical maps are in line with their moderately complex line trajectories compared with the stylised maps. There is no obvious bias towards spatial informativeness in terms of usability ratings.

TABLE I. Usability ratings of the first 100 people to complete the internet survey into lay-theories of map design

Usable?	Geographical	Compact	Stylised
Multilinear	24% Easy 28% Neutral 48% Hard	18% Easy 27% Neutral 55% Hard	33% Easy 39% Neutral 28% Hard
Octolinear	42% Easy 34% Neutral 24% Hard	37% Easy 32% Neutral 31% Hard	89% Easy 7% Neutral 4% Hard
Curvilinear	13% Easy 29% Neutral 58% Hard	4% Easy 25% Neutral 71% Hard	17% Easy 29% Neutral 54% Hard

TABLE II. Attractiveness ratings of the first 100 people to complete the internet survey (Attr = attractive, Unpl = unpleasant).

Attractive?	Geographical	Compact	Stylised
Multilinear	9% Attr 32% Neutral 59% Unpl	8% Attr 20% Neutral 72% Unpl	23% Attr 35% Neutral 42% Unpl
Octolinear	33% Attr 42% Neutral 25% Unpl	36% Attr 37% Neutral 27% Unpl	75% Attr 21% Neutral 4% Unpl
Curvilinear	22% Attr 40% Neutral 38% Unpl	25% Attr 22% Neutral 53% Unpl	34% Attr 34% Neutral 36% Unpl

What is the source of these lay-theories of usability? In the absence of actual data, their basis is likely to be a combination of expectations and prejudices in conjunction with aesthetic preferences. The British *octolinear bias* can be investigated in more detail once a greater number of international internet survey responses have been collected. However, interestingly, the bias seems to be towards linear maps in general, with an overall belief that straight lines improve usability no matter what their angles. We reach this conclusion by comparing attractiveness ratings with usability ratings. The linear maps are overall *always* rated as being more usable than they are attractive, and the curvilinear maps are *always* rated as being more attractive than they are usable.

The summaries conceal considerable individual differences in ratings, but more data are required before this aspect can be investigated meaningfully. Demographic data have also been collected (age, sex, profession) which can be analysed in conjunction with ratings. With clear usability assessments, future research should investigate objective usability data, testing all nine maps, to see whether these match the ratings.

III. Science Meets Theories of Design

In comparison with the lay-theories held by the general public, graphic designers and scientists have also attempted to compile theories, or criteria for effective design. One of the most comprehensive of these has been assembled by Ovenden [8] as a result of interviews with many designers (Figure 3). Subsequently, in formulating criteria for automated schematic map generation, Nöllenburg & Wolff [6] compiled a smaller number of criteria (Figure 2), although correspondences between the two sets are clear. For example, simplicity, defined as a function of the line trajectories and the number of angles, is specified in both, along with various criteria for ensuring that stations are labelled clearly without interrupting lines. The requirement to expand the complex centre of a map and compress the suburbs is also present in both, although operationalised in different ways

These criteria highlight the difficulties faced by theorists in this domain. Graphic design, like many intellectual disciplines (such as psychology), does not have anything like a single all-encompassing grand unified theory. Instead, within each of the various sub-disciplines (typography, page layout, information graphics, signage, branding) there is a collection of isolated and disconnected heuristics, principles, and rules of thumb, which vary in their applicable context, and the extent to which they are derived from logic, empirical testing, observation, intuition, or prejudice. This lack of orderliness inevitably means that the components vary in their precision of specification, and there will also be inconsistencies, or even conflict, between them: optimisation for some criteria may prevent optimisation for others. In theory all could be tested and their contribution to usability evaluated. Some criteria may be too subtle to have any measurable effect (although they may contribute to the overall aesthetics of the design) but others may turn out to be broadly correct, or else correct with important caveats, or fail magnificently.

R1. Restrict all line segments to the four *octilinear* orientations horizontal, vertical, and $\pm 45°$-diagonal.
R2. Do not change the geographical network topology. This is crucial to support the mental map of the passengers.
R3. Avoid bends along individual metro lines, especially in interchange stations, to keep them easy to follow for map readers. If bends cannot be avoided, obtuse angles are preferred over acute angles.
R4. Preserve the relative position between stations to avoid confusion with the mental map. For example, a station being north of some other station in reality should not be placed south of it in the metro map.
R5. Keep edge lengths between adjacent stations as uniform as possible with a strict minimum length. This usually implies enlarging the city center at the expense of the periphery.
R6. Stations must be labeled and station names should not obscure other labels or parts of the network. Horizontal labels are preferred and labels along the track between two interchanges should use the same side of the corresponding path if possible.
R7. Use distinctive colors to denote the different metro lines. This means that edges used by multiple lines are drawn thicker and use colored copies for each line.

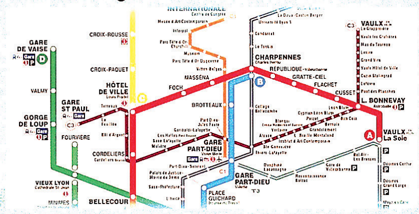
Fig. 2. Criteria for effective design compiled by Nöllenburg & Wolff in 2011 [6]

Fig. 3. Criteria for effective design assembled by Ovenden in 2008 [8].

Good practice in diagram design

This list of concepts is sometimes abbreviated throughout the book as 'Good design practice'.

- **Remove unnecessary topography** (though leaving important waterways or green spaces – often stylised – is sometimes considered useful for a vague orientation). Vignelli says: *'I would love to have dropped* all *surface geography from my New York Subway diagram – even waterways'.*
- **No streets are shown** (though occasionally key highways like arterial roads may be acceptable).
- **Straighten out lines** (avoid changing direction of a line unless totally necessary). Roberts says: *'an unnecessary change of direction is a design flaw'.*
- **Use only horizontal and vertical lines and one diagonal angle**. Spandonide says: *...'to use any more is both pointless and untidy'*
- **45 degrees is the most common angle for all diagonals** (though 20°, 30°, 35°, 60° and 65° have also been utilised to good effect).
- **Create at least one simple axis** (north-south or east-west if relevant, though stylised 'circle' lines are also utilised as perfect circles).
- **Compress the suburbs** (or areas where stations are spaced far apart geographically).
- **Enlarge central area** (or areas where stations are in close proximity geographically). Beck said: *'I tried to imagine that I was using a convex lens.....to present the central area on a larger scale'.*
- **Do not change line direction under a station marker** (especially at interchanges). Foale says: *'The eye can cope with sections of line passing under things but if a direction change occurs while the line is beneath a symbol or another line, it can be quite confusing'.*
- **Do not change line direction more than once between stations** (it hampers clarity).
- **Leave adequate space for the text of the station name** (it is as crucial as plotting the lines). Foale says: *'the space for text is* as important *as the trajectory of the lines'.*
- **Station names should never crash over lines.**
- **Station names must be close to station marker** (and clearly relate to only one station).
- **Equalise station spacing wherever possible** (it looks much neater).
- **Line width should be in aesthetic balance** with the overall space and point size of station names.
- **Make all lines the same width** (unless they are part of another service i.e. Tram/mainline rail etc).
- **Station markers should be universal** (except at interchanges).



ABOVE: Simplification, legibility and common sense are the prime ingredients of great schematic design. A detail from the Lyon diagram by the Latitude agency demonstrates how a 20 degree angle can be just as effective as 45.

- **Make a clear distinction between ordinary stations and interchanges** (this greatly helps passengers planning journeys).
- **Interchange station markers should be universal** (though at extremely complex or lengthy interchanges a white-line connector or variation of this symbol may be necessary as long as it fits with the overall style of the others).
- **Station markers should be ticks or 'blobs'.** Dots, open circles and 'blobs' are the most common. Ticks come second. Avoid line breaks as these can be confusing.
- **Station names should all be horizontal** (if at an angle, all should follow same angle; mixing horizontal names with angled ones looks bad).
- **Background colour is generally white** (pastel shades can be used if they do not clash with the line colours). Very dark backgrounds (black, dark blues etc) can work with the same proviso but primary colour backgrounds should be avoided.
- **Simplify complex interchanges/service patterns** (badly drawn interchanges will let down the entire diagram).
- **Keep all station names the same size** (though in systems where terminal stations play a key role, there may be a good reason to enhance their appearance in bold/caps/reversed-out etc).
- **Keep all stations on the same side of the line** (this is rarely possible all over but looks neat on a long simple line).
- **Use upper and lower case text** (it is softer).
- **Stay within corporate identity** (the in-house operator style should permeate every feature of the diagram – anything that does not fit will look hideously out of place when the diagram is on display in situ).
- **All text must be in the operator's house font** (never condense/alter a font to squeeze text into a badly designed space).
- **Station names to read exactly as on the platform signage** (this avoids passenger confusion). Abbreviations on the map to squeeze in text are unacceptable – however heritage signage may still show abbreviations, in this case use the full name on the diagram. Woods says *'it's amazing how many official maps spell their own station names incorrectly'.*
- **Diagrams do not need to be totally abstract** (with modern computer graphics and good design most diagrams can give a reasonable reflection of at least the key features of city geography without losing all points above). Roberts says: *'preserve spatial relationships where possible'.*
- **REMEMBER: Someone else may re-design your diagram at a later stage!** Beck said: [the diagram] *'...must be thought of as a living and changing thing, with schematic and spare-part osteopathy going on all the time'.*

IV. Psychology and Schematic Map Design

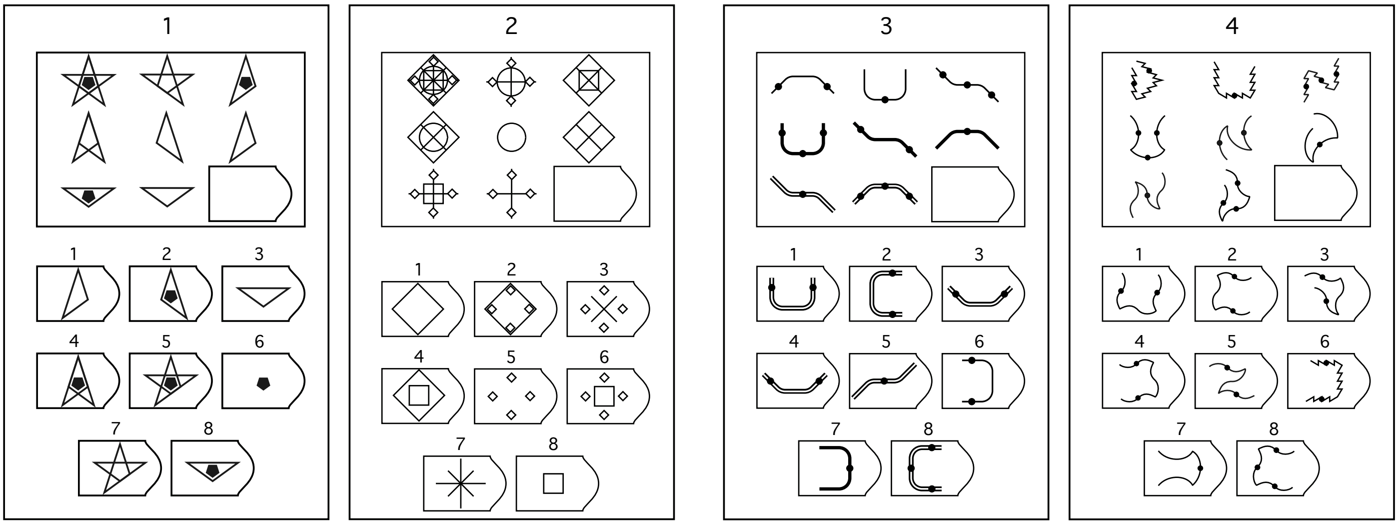
This is a suitable point to step back and consider whether other disciplines might offer concepts that can be used to unify, organise, or inform criteria for effective map design. Psychology, in particular, has a long history of investigating reasoning, planning and problem solving in complex environments. However, in many cases it is difficult to identify a sound basis for direct generalisations to be made. For example, claims have been made that certain studies [3, 11, 12] have demonstrated that *octolinear* angles are optimum and should always be used for schematic map design. In reviewing these, Roberts [10] suggests that the evidence provided is far from strong, and that if the structure of a network is incompatible with octolinearity, then other design rules should be used instead [9].

What psychological research *can* offer is concepts and constructs that can account for why schematic maps might be useful to the user, and indicate in what ways designs should be optimised [1]. Research can also alert designers to the sorts of reasoning failures that humans are prone to, and therefore, for example, help to avoid presenting information in ways that might put people in difficulty, for example, if the information is ambiguous, involves logical inferences that people find particularly demanding, or else is formated in a way that is incompatible with its intended usage [5]. It is also worth noting that psychologists have been researching into intelligence testing and individual differences in intelligence for several decades, and that poorly designed information on a schematic map bears all the hallmarks of a difficult intelligence test, putting people at the lower end of the scale in difficulty disproportionately [4].

A. Cognitive Load

A complex task imposes a high *cognitive load* on the user: a large quantity of information must be processed in order to solve the task. The greater the quantity of information, the greater the cognitive load (see Figure 4). Irrespective of how

Fig. 4. Four items typical of the sort used in intelligence tests. Items 1 and 2 both have a rule that is straightforward to identify and apply, but Item 2 has more elements (six, as opposed to four for Item 1), making these harder to discern, and in turn the rule harder to identify. Item 2 should be the harder of the pair because of its higher cognitive load. Items 3 and 4 also have a straightforward rule, but the line trajectories in Item 4 are more complicated, making their relationships harder to identify, and therefore the rule harder to discover. Item 4 should be harder to solve than Item 3, despite being otherwise logically identical.



information quantity might be measured, the general principle that can be derived from this is that the user must be supplied with the least information necessary to perform the task. Supplementary and superfluous information should be avoided.

B. Cognitive Capacity

As measured by intelligence tests, individuals differ in their *cognitive capacity* – their ability to cope with a large quantity of information, for example differing in their ability to identify complex relationships and prioritise between multiple goals. The important skill for an information designer is to be able to appreciate that not all people are able to cope with a complex task without assistance, and structure the necessary information accordingly, for example by breaking down a task step-by-step, feeding people with information sequentially, only providing what is needed to complete each stage of the task.

C. Expertise

As a result of functioning successfully in an environment, people learn about it. In other words, they acquire *expertise*. In the context of maps, this might manifest itself as learning about the city public transport network or, after visiting several cities, identifying the key recurring features so that novel networks can be tackled with reasonable performance. Tourists are effectively novices, and therefore require the most assistance. Possession of expertise enables people better to focus on just the information that they require, and can also mitigate against high cognitive load and low cognitive capacity. However, high cognitive capacity is required in order to acquire expertise rapidly. Expertise can result in a cost to the user: it is possible that redesigning information in novel unexpected ways will temporarily impair their performance.

D. Attention Capture

Another important concept is *attention capture* – where is attention focused in a complex, noisy environment? Ideally, the focus will be the location of the key information that a user requires in order to complete a task. In practice, in today's information-rich environment, this may not always be the case. For example, advertisers may be more adept at capturing attention than designers of transport information.

E. A Psychological Perspective on Schematic Maps

How did Henry Beck's schematic map assist the user? To understand this, we need to see a previous design, and note how much information it contains in the form of twisting line trajectories (See Figure 5). This information is unnecessary for planning a journey between two known stations, adding

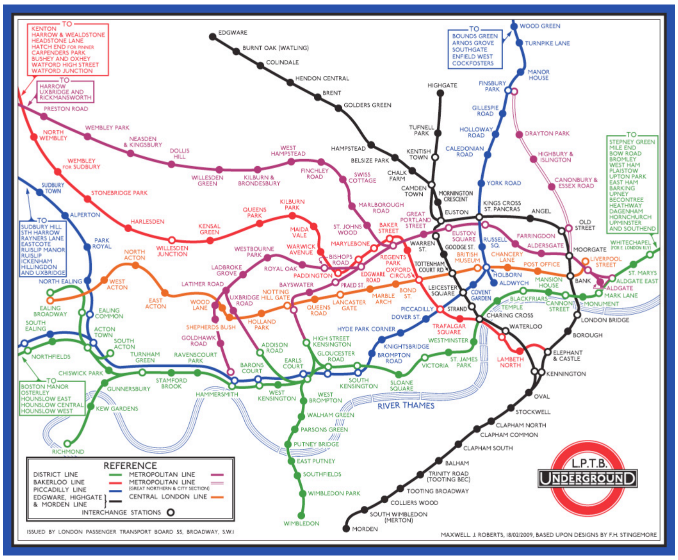
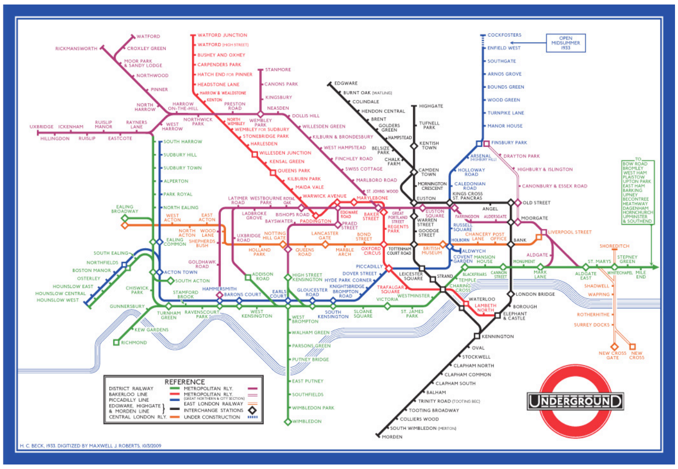


Fig. 5. London Underground network map in the style that users would have been accustomed to before Henry Beck produced his schematic (based on a 1933 design by F.H. Stingemore, digitally recreated using vector graphics by the author).

Fig. 6. Henry Beck's first design of 1933 (digitally recreated using vector graphics by the author).



complexity, and therefore cognitive load, to interpreting the map. Complexity prevents the user from identifying the basic elements of the network and how they relate to each other in order to form its logical structure, in a similar way to the intelligence test items in Figure 4. Every user encountering the map in Figure 5 for the first time would need to overcome this difficulty. By creating a schematic network map in 1933, Henry Beck was effectively performing the network assimilation task on behalf of the users, supplying them with a pre-comprehended and ready-organised version, from which the network elements and their structure could be more easily identified (Figure 6). This reduces the cognitive load of understanding the network, and by making its elements more salient in this way, Beck also made the network structure easier to learn. In other words, he assisted in the formation of *expertise*. Hence, an effective schematic map creates a *virtuous circle*, so that every time this is used, more is learnt, and every time more is learnt, journey planning and using the network becomes easier.

V. A FRAMEWORK FOR EFFECTIVE DESIGN

Earlier, I discussed various theories of effective schematic map design, but rather than propose my own, I am going to suggest a *framework* instead. This is a way of trying to organise and understand the various theories: what they are suggesting, and how they differ, setting out the key criteria that need to addressed (or at least acknowledged). For schematic maps, the framework identifies and categorises the various design elements and priorities that might contribute towards optimisation. A designer who fully addresses these will be far more likely to create a usable and popular map. However, it is up to individual theorists to flesh out the framework in order to decide how exactly to address the subcomponents of each category, identify those that are most important, and to prioritise them. In this sense, the framework is unfalsifiable. None of its components is present in error, although some may be less important than others. There also might be other categories that need to be added to the framework.

To understand the framework fully, we should note that there seem to be two separate aspects to evaluating a map [10]. *Map usability* concerns objective measurements: how long it takes to plan each journey, whether a route is identified that satisfies the user's requirements, and whether any errors of planning occur, which could potentially send the user via an inefficient route, or the wrong way completely. However, *map usability* is uncorrelated with *map engagement*: a person's opinions concerning the usability and attractiveness of a design (although the internet survey data above suggests a dissociation between subjective evaluations of usability versus opinions on attractiveness). Map engagement is determined by subjective measurements such as evaluation questionnaires or choices between different designs. The lack of association between usability and engagement means that people can prefer maps that are difficult to use, and reject maps that are easy to use. Engagement is an important aspect of design; if people dislike maps, they are more likely to reject them and seek alternative sources of information instead. However, engagement is likely to be subject far more to individual differences than usability. A *basically competent design* should be usable for just about everyone, but opinions on it will differ between people far more. Bearing this in mind, what are the components of the framework for effective design?

A. Simplicity

Simplicity refers to the individual line trajectories. The single key-most requirement for a schematic map must surely be that it *simplifies* reality. By taking the complex twisting trajectories of real life, and converting them into simple straight lines, these are easier to discern and follow, and their broad trajectories and interconnections can be more readily identified. If reality is instead converted into numerous short zig-zagging segments, nothing has been simplified, and the situation might even have been made worse. Straightness of line trajectories is easy to measure, and should impinge on the cognitive load of using a design. For many people, this will also impinge on their aesthetic evaluation of it.

Reasonable simplification might be achieved by using *octolinear* angles, although Roberts [9] notes that for some networks, line trajectories conform poorly to an octolinear grid, resulting in more corners and less simplicity than if different, or additional angles had been chosen. Achieving simplicity therefore requires a compromise: the straightest lines that can be achieved using the smallest number of angles. Increasing the available angles can enable the designer to reduce the complexity of individual line trajectories, but replaces this with complex relationships between lines instead, leading to the next component in the framework.

B. Coherence

Simplicity refers to individual line trajectories, *coherence* is much more subtle, and refers to how the set of line trajectories relate to each other, giving the overall network 'good shape'. Coherence can be achieved via parallel lines, and aligning stations and termini. It might also be achieved by emphasising regular, easily identified shapes, such as circles, equilateral triangles, horizons (grounding the design using horizontal lines) and/or grids. A map with many angles might permit simple line trajectories (see above), but the design is likely to suffer from poor coherence if the use of parallel lines declines: these additional angles must be used carefully.

We can specify many necessary elements for coherence, although this means that their objective measurement will be difficult. In theory, the coherence of a design should impact on the cognitive load of using it, because a map with clear shape will have elements that are easy to identify (see Figure 4) but, again, these features will also have implications for aesthetic appreciation of a design, subject to individual differences.

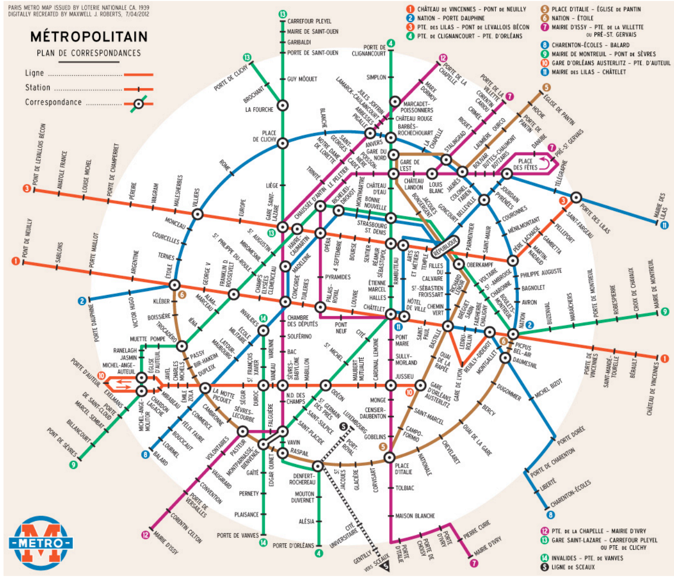
Coherence is a particularly difficult-to-attain criterion, very poorly understood, but making the difference between a good and a great map. A few token regular shapes seem to be of little help if the rest of the map is chaotic (see Figure 7). On the other hand, new explorations of maps based on concentric circles and spokes demonstrate the powerful effects that are possible if coherence can be maximised, in this case even at the expense of simple line trajectories (Figure 8).

C. *Harmony*

Despite the mysterious name, *harmony* is merely a placeholder in the framework for those elements that are likely to impinge on the aesthetic appreciation of a design, but whose effects are likely to be too subtle to make any detectable difference to its usability. The phrase was coined by the author who, designing a *decalinear* London Underground map (five evenly-spaced angles), determined that he found it awkward, despite its abundant parallel lines and neatly aligned stations. In the light of this, he wondered whether, like musical notes,

Fig. 8. Designed by the author in 2013, the New York Subway map based on concentric circles and spokes shows the powerful effect of a highly coherent design.

Fig. 7. An early Paris Metro schematic attempts to make the network coherent by showing the orbital lines as a circle. However, with little shape inside the circle, there is little benefit, and all that the circle achieves is to create a porthole on chaos (based on an independent 1939 design, digitally recreated using vector graphics by the author).



certain angle combinations might be naturally ‘discordant’ to the eye. In this design, the discordance manifested itself as tall thin isosceles triangles, and also line crossings not quite perpendicular. The psychology of aesthetics is a relatively neglected area, but testing people with various components of schematic maps, asking them to rate these to identify pleasing versus non-pleasing configurations, would be a straightforward exercise.

D. *Balance*

Another important criterion for an effective map is it’s *balance* – ideally, there should be an even density of stations across the page, or at least gentle density gradients, so that congested spaces and empty spaces are not adjacent. The balance of a design would be expected to impact on its attention capture. For example, a map with a very diffuse, open centre and dense, packed suburbs around the periphery, would lack a clear attentional focus, with attention incorrectly captured by the high station densities at the edges. Any map with balance problems might cause this type of difficulty. Hence if a city has a natural geographical focus (or foci) then the designer should ensure that this is clear from the map

E. *Topographicity*

Simplifying line trajectories inevitably leads to the issue of the extent to which topographical distortion is permissible. A map with good *topographicity* is one in which the distortion is kept under control, and is unlikely to have any negative impact, for example by leading to inappropriate journeys – roundabout, or encouraging people to travel by train when walking might be faster. In this respect, the current official London Underground map has poor topographicity in the Paddington area [2]. Preserving relative station positions is often put forward as an important design criterion (e.g. R4 in Figure 2) although there is little evidence to suggest that this is necessary in order to ensure effective journey planning.

In theory, deviation of station locations from reality can easily be measured. In practice, this is made more complicated by the fact that topographicity matters more in some locations of a map (the centre) than others (distant suburbs, where deviations may be particularly large and yet of little consequence). Poor topographicity can also be disturbing for people because of conflict with their knowledge of the structure of the city (known as their *mental models*). However, for city novices, such as tourists, there will be little knowledge with which to conflict, so all that is necessary is to ensure that the map is unlikely to be misleading for their *journey planning*. The task of choosing the best station in order to visit a tourist attraction or a hotel is probably better left for maps intended to be used in this way, such as topographical street maps. For city experts, conflicts may be more likely but, because of their expertise they are less likely to need a map in order to plan a journey, and less likely to be fooled by any deviations.

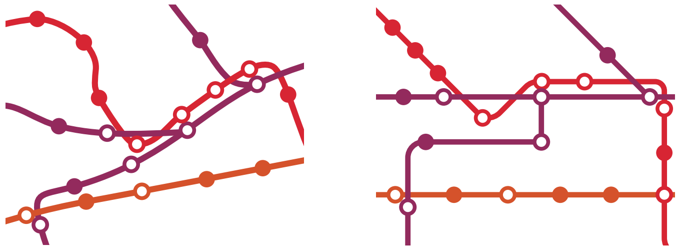
The topographicity criterion has clear relevance for effective design, but the effects of deviating from this are the least understood. There are some important issues to resolve: Figure 1 shows that a requirement for strict topographicity can conflict with the criterion of simplicity of line trajectories.

VI. BACK TO BECK

Earlier, I discussed lay-theories of design and argued that understanding these was crucial in order to make sense of user-reactions to maps. I also suggested that, for designers, their lay-theories have implications for their output. For the general public, we can learn about their lay-theories via studies such as the internet survey discussed earlier. For designers, even long-deceased ones, we can attempt to understand their lay-theories by analysing their output. In the case of Henry Beck, it is particularly instructive to do this because his outstanding early work is often poorly understood, with commentators focusing on his use of *octolinearity* as the basis of his success, thus erroneously setting this up as a map design gold standard to the exclusion of any consideration of other optimisation criteria.

Beck's early work is almost a textbook case of his (implicit) adherence to the framework for effective design outlined earlier. Figures 9 shows the topographical reality of the Paddington area, in comparison with Beck's first attempt at this configuration. Figure 9 shows what can go wrong if the framework is neglected. Hence, if Beck had used *octolinear* angles, but had not addressed the requirement for simplicity (a) – perhaps attempting to match topographical reality – then a far less effective design would have resulted. Beck's early work was not special because it used straight lines, but because it had so few corners.

Fig. 9. A section of maps showing the line trajectories of an area of central London around Paddington. Left is the geographical reality, right is Beck's schematic depiction of reality.



Of course, Beck could have chosen other angles for straightening the line trajectories (b), but the risk of poor coherence would have been considerable, for example with many non-parallel lines. However, even if he had attempted a multi-linear map with parallel lines, he could have chosen angles with poor harmony (c) because of, for example, lack of perpendicular line crossings. Octolinear angles have a natural advantage in terms of this. Beck could have created an unbalanced design (d) or one with poor topographicity (e), in which the distortion conflicted too much with people's mental models of London. Beck's early work was relatively undistorted. Later, for London, and Paris, he created very distorted designs that were ultimately rejected probably because of this [8, 9]. Today, it is easy to find schematic maps worldwide which fail to address adequately one or more of the five categories of criteria for effective design from the framework. A better appreciation of Beck's early success might well lead to this happening less often in the future.

VII. FLESHING OUT THE FRAMEWORK

People's lay-theories of schematic map design are often in conflict with each other, and yet for designers and officials, these are crucially important in determining the schematic maps that are released to the general public. In an attempt to move forward, a framework has been proposed for organising theories of design and emphasising the basic requirements for effectiveness. This framework now needs fleshing out so that its elements can be fully understood and prioritised. Of course, the framework is incomplete, it says nothing about typography or symbology, on maps, both are additional factors important for legibility and understanding. The task of understanding effective map design is therefore a considerable one, but also important considering many of the official maps that have been released to the general public.

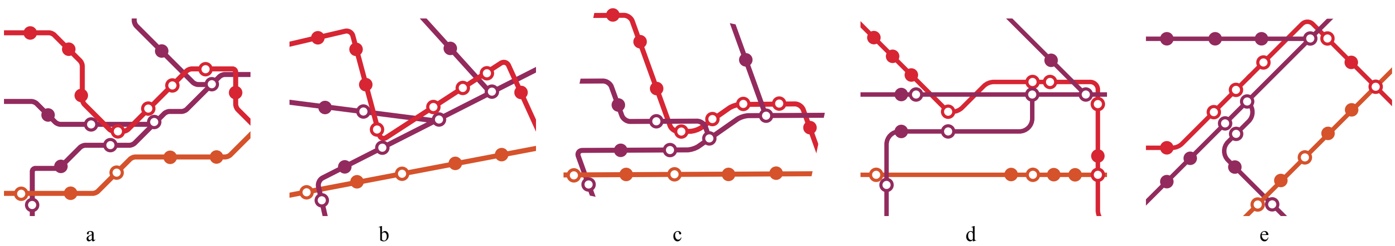


Fig. 10. Beck's first-ever design of Underground map adhered surprisingly well to the *Framework for Effective Design* outlined earlier. From left to right are the results he might have achieved had he neglected *simplicity*; *coherence*; *harmony*; *balance*; and *topographicity*.

There is a post-script to add to the framework: it is completely neutral in terms of the actual design rules. Hence, it does not specify whether a map should be octolinear, curvilinear, hexalinear, multilinear, or whatever. The key is the satisfaction of the five criteria, simplicity, coherence, harmony, balance, and topographicity in order to maximise usability and engagement. As long as these are achieved, the actual design rules do not matter. Of course, certain angle combinations may have a head start in fulfilling them, for example because few angles have been chosen (ensuring simplicity, provided that the line trajectories can be simplified). Also, certain angle combinations may lead naturally to coherence or harmony. In conjunction with this, every network in the world has a different structure, and different design challenges. Hence, the framework implies that different mapping solutions might suit different cities. What works well for London, Paris, or New York, might not work well for Berlin or Tokyo. We require a thorough understanding of the criteria for effective design, in conjunction with how these relate to network structure and design rules.

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