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# Beyond Beck: Design Of Schematic Maps From (Representational Epistemic) First Principles

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Text

***Abstract*— The *Representational Epistemic* approach to the design of notations and visualizations is used to create a new design transit map that is a fundamental departure from the near universal format that has nodes for stations, lines for tracks and symbols for details. Instead the new design exploits a container-node-symbol-colour format for stations, tracks, details and identities. The London Underground is used to provide an exemplar of the new design.**

***Keywords — transit map design; representational epistemic design principles; information access; London tube map; accessiblity.***

## I. Introduction

Harry Beck's 1931 [6] schematic map design for the London Underground set a near ubiquitous template for the design of schematic maps, at least for transit systems. Of the 100, or so, examples of schematic maps in Ovenden's [6] worldwide collection of transit maps, every design uses the same generic format: stations are represented by labelled nodes; tracks are shown as lines between them; symbols (textual labels or icons) are associated with the nodes. One might thus think this *node-line-symbol* (NLS) format is the best design for schematic transit maps — but is it? Is an alternative possible that adopts a fundamentally different scheme to the NLS format? Such an alternative might be superior in unexpected ways and reveal limitations to Beck style schematic maps. This paper addresses these issues by introducing a novel schematic map design based on a *container-node-symbol-colour* format and will re-encode the London Underground network as a case study. It is shown in Fig 1 (last page).

Evidence of one limitation with the NLS design can be found on the Transport for London (TfL) website [7], where not one but five schematic maps of the London Tube are found. In addition to the standard map, maps for toilet facilities, disabled accessibility maps (separate step free and avoiding stairs versions) and the carriage of bicycles, are provided. On top of the storage burden, the user faces the inconvenience of coordinating between alternative versions when planning some journeys: this is particular problem (a) for users with limited mobility, as accessibility information is distributed among maps, and (b) for users of small mobile digital devices. This is suggestive of a generic limitation of the NLS design that is to be discussed below.

The ubiquity of Beck style maps poses a challenge to the invention of new fundamental formats simply because their sheer familiarity inhibits one's imagination. One means to overcome this obstacle of preconceptions is to revert to first principles of representation design. There are various approaches to the design of information visualizations, graphical notations and user interfaces, e.g., [1,2], but here the Representational Epistemic (REEP) approach is adopted [3-5]. The approach differs from the others in its focus on creating specific novel visualisations or notations whose graphical structure (representation) *re-codifies* the knowledge of target topic (epistemic), rather than tailoring graphics to support particular goals [1] or to show first-order patterns in data [2]. REEP design has been used to create novel graphical interfaces for complex information intensive problem solving [5] and new diagrammatic notations for learning conceptually challenging topics in science, mathematics and logic [3,4]. The application of the approach to the schematic maps provides a further test of the validity of the approach as a general method for the design of representational systems.

This paper follows the usual steps of the REEP design approach. First, the underlying *conceptual structure* of our target *information-for-transit-system-users* domain is examined. Second, that conceptual structure is mapped to distinct *representational schemes* using the REEP design principles. The third stage is to normally to empirically evaluate the new design, but as such evaluation as yet to be conducted, the paper's third section will be limited to some general theoretical comments about the differences between the new design and conventional schematic maps. The paper ends with the consideration of who will be the likely users of the new map design.

## II. Conceptual structure: what's to be encoded?

The core theoretical claim of the REEP approach is that effective representational systems transparently and coherently encode the fundamental *conceptual structures* of the target domain in the primary *representational schemes* of a notation or visualization. This section examines conceptual structures and the next considers effective representational schemes to encode them. Conceptual structures in the REEP approach are the distinct classes of concepts, fundamental laws, invariants and constraints that make the target topic a unique domain (itself rather than some other topic). Identifying these classes of concepts is the first stage of the REEP approach to design.

One way to elaborate the fundamental concepts in the information-for-transit-system-users domain is to examine what is already encoded within existing representations. In the case of the London Tube we may consider all the variants of the tube map that exist. In addition to the TfL maps for toilet faculties, disabled accesses and bicycle carriage [7], other map variants can easily be found on the WWW that show a whole host of potentially useful, or at least interesting, information. Further, inspection of mobile phone applications and informal interviews with frequent users of the London Underground reveals that some users desire detailed information down to platform and even the train carriage level.

The REEP approach provides a generic classification of classes of concepts, which may be used as a guide to identify domain specific ideas [3-5]. For each class some examples of concepts are presented. Where existing maps include particular concepts the graphical techniques used in their representation is noted: {official TfL maps in curly brackets}; [other maps in square brackets]; (NR – not represented in existing maps). Classes of *elementary entities* include: tube stations {nodes as circles or ticks}; transits between stations {connecting lines}. *Properties of entities* include: station identity {name labels}; tube line identity {line colour}; fare zone of stations {concentric area shading with numerical labels}; subterranean location [background shading]. *Temporal* concepts include: transit time between stations [numbers adjacent to lines]; walking time to/from station exit (NR); walking transfer time between platforms (NR). *Structural* concepts include: topological relations applied to stations and lines {spatial layout}; parallel running or crossing tube lines {lines align or cross}; location of toilets within or beyond the ticket barrier {toilet icon colour}; spatial relation to the River Thames {thick blue line}; co-location with other modes of transport {pictograms}. *Behavioural* concepts: direction of train travel, geographically or relative to specific platforms (NR). *Functional* concepts include: recommended station for transfer between lines {circle icon, not tick}; recommendation to walk between nearby stations [connecting line between nodes]; different levels and modes of accessibility {coloured icons, node perimeter colour}; the carriage of a train adjacent to the platform exit (NR); regular service restrictions {superscripts with associated legend}.

The precise classification of some of these concepts under particular categories is debatable, however, for the application of the REEP it is most important all the core concepts of the domain are identified and that some organization is initially imposed on which the principles for the design of representation schemes can start being applied. During the process of design one naturally gains a deeper understanding of the domain, so there is typically some reconceptualization of the classification of concepts. Obtaining some "absolute" a priori classification is less important in the REEP approach than achieving a semantically transparent and coherent encoding of some "sensible" conceptual organization within a set of representational schemes.

Our topic has many of the typical characteristics of knowledge rich domains. It spans many types of concepts: taxonomic, property, temporal, structural, behavioural and functional. The topic is informationally intensive as instances of types of thing are numerous (e.g., many stations (260), track segments (>1 per station), platforms (up to ten per station), exit routes, toilets). Concepts span multiple levels of granularity (from train carriages to the whole network), which mostly involve hierarchical organizations. Items often encompass multiple alternative perspectives (e.g., connectivity vs. adjacency; time vs. modes of accessibility). The topic also exhibits a diversity of cases from the typical to the unique and extreme (e.g., stations on a single line vs. interchange stations on 6 lines; bi- and uni-directional loops). Unlike many domains, this topic does not encompass multiple levels of abstraction. Nevertheless the complexity and richness of the knowledge to be encoded presents a substantial design challenge.

These observations explain the limitation of the NLS format of Beck-style maps noted above. Most information of interested is naturally related to stations, but there is a limit to how many symbols can be place around each node before their unique association with that node is obscured. The TfL maps mainly avoid this spatial limitation by distributing information across multiple maps, or superimposing selected symbols over some nodes. They also just avoid the problem by adding symbols to index list of stations accompanying the map.

## III. REPRESENTATIONAL SCHEMES: CODIFYING KNOWLEDGE

Given the overall conceptual structure of the target domain the next step is to find core representational schemes (formats) to coherently encode the component conceptual structures. The REEP approach provides principles to guide this process:

- P1. Encode the primary conceptual structures in distinct representational formats.
- P2. Each representational format in P1 should coherently integrate and differentiate the particular concepts in the primary conceptual structures.
- P3. Provide a global scheme to coherently combine the representational formats.
- P4. Secondary conceptual structures should be integrated within the global representational scheme of P3.

The new map will be described whilst simultaneously explaining how the principles were applied. Fig 1 shows a section of the new map and Fig 2 is a guide to the details of the design at two levels. The new design may be summarized as a *container-node-symbol-colour* (CNSC) format.

**Hierarchy of spatial containers and nodes**. Structural concepts are a core class for this topic, so an effective representational scheme for a rich hierarchy of spatial relations is critical. As the 2D space naturally preserves many of the domain's spatial concepts it is the obvious choice for this class of concepts: but how precisely should domain entities be encoded? A problem of the NLS format, in which the colocation of symbols with nodes is limited, suggests that the new map should provide a means to associate many symbols with stations. Thus, the new design has large rectangles (with rounded corners) to serve as *containers* for multiple symbols, see Figs 1 and 2. As users care relatively little for the precise spatial details of transits between stations these are represented as nodes (*transit-nodes*), which sit on the perimeters between containers (cf. lines NLS maps). The layout of the containers and nodes has been organized to display the relative spatial location of stations and transits. As access to and transfer between platforms is important to users, these are represented as lines (*platform-lines*) within the containers and small (rectangular) *path-nodes* are placed at the intersection of these platform lines to represent the passage (walking) between platforms. The grouping of path-nodes with platform-lines within station-containers between transit-nodes is a scheme that both integrates and differentiates these hierarchical spatial concepts: this satisfies principle P2 for the structural class of concepts. Further, it provides a basis to denote other spatial information, such as: *exit-nodes* on container boundaries that represent the entrance/exit path to a station; location of toilet facilities within or beyond station ticket barriers by the placement of the icons (man, woman, baby change, wheel chair) within or beyond the container perimeter.

**Numbers and letters in nodes – time and accessibility**. Numbers in nodes are used exclusively for transit times (in minutes); between stations, for walking between platforms, or platform to exit times. The letters in the platform and station exit nodes indicate the functional nature of the path: what it involves. The mapping between particular combinations of obstacles (gaps, steps, escalators, lifts, stairs, ramps) and letter may be arbitrarily established using a key, but it would sensibly be ranked by the difficulty of the path. The use of numbers for temporal concepts, letters for functional accessibility concepts, and 2D space for structural concepts satisfies principle P1, whereby each primary class of concepts has its own distinctive representational format. P1 is also satisfied by the use of other formats for the classes of concepts below. The cognitive benefits of this are considered in the discussion.

**Colours – line identities; icons – things**. Tube lines and objects associated with stations are two different sub-classes of identity properties that use different representational schemes, implementing principle P2 at the level of each sub-class. Where colour varies between graphical objects of the same type in the map, it represents the identity of the line for which information is provided. This applies in a consistent way to transit-nodes and platform-lines, but also to numbers and letters within exit-nodes (but not to number in transit-nodes, because the nodes are themselves coloured). Transit nodes between platforms are grey (not coloured), because they do not belong to a single tube line. Things associated with stations, such as rail stations, airports and toilets are represented by common pictograms.

**Arrows – behaviours**. Platform-lines with arrows (e.g., Heathrow T4, not shown) indicate that trains on the indicated line (colour) pass through in just one direction. Arrows beside a platform shows the overall direction of train travel, but as users do not typically know their own absolute orientation, coloured dots by the arrows represent the users relative orientation to the direction of travel upon entering the platform. For example, in Fig 2b, the westward pointing arrow below the top brown dot indicates the train will run towards users' left as they enter the platform, but the position of the same arrow above the green dot indicates travel to users' right. As multiple entrances to a platform from different lines may exist, a dot's colour represents from where the user has come, with the exception that the first dot is the same colour as the platform-line in order to stand for an entrance directly to the platform from the street. The same symbol colouring scheme applies also to the strings of letters and symbols associated with each platform, explained next.

**Symbol strings – carriage selection**. The strings of number and symbols alongside the platform-lines (e.g., 3> [4[2[4) is a scheme to encode functional information about which carriages arrives adjacent to platform exits that lead to the station exit or other platforms, see Fig 2b. The digit in each pair of symbols indicates the number of the carriage counting from the front '>' or from the rear ']' of the train. Although this scheme is more complex than simply numbering all the carriages, it is likely to be more convenient for the traveller as they immediately know to which end of the platform to head and have a smaller number of carriages over which to judge where to wait on the platform. The example string in Fig 2b is on a brown line; 3> means take the third carriage from the front to arrive beside the platform exit that leads to the street, and [4 means take the fourth carriage from the end to arrive by the platform exit that transfers to the red tube line.)

REEP design principle 3 requires the provision of a global scheme to coherently combine all of the individual representational schemes identified for principle 1. The global scheme of CNSC design does this by knitting together two independent approaches: (a) the hierarchical superposition of containers, nodes and their symbolic contents at multiple levels and (b) the thoroughgoing application of tube line colour across most nodes and symbols. In this way, information for all the different classes of concepts is not only well differentiated (P1) but closely related information across classes is also accessible at the same time.

In addition to the main classes of concepts so far considered, the CNSC design provides a basis to incorporate secondary concepts that are relevant to the domain but whose scope is narrower. According to REEP principle P4 they should be captured by formats that integrate with the design's global scheme. Examples of these – and how they are represented – include (see Figs 1 and 2): the fare zone – digits in a large open font; carriage of bicycles on certain segments – spokes radiating from the transit-nodes; it is faster to walk between stations – dotting lines between those stations' exit nodes; stations on the surface or below ground, which apart from the curiosity value serve as a quick proxy for accessibility – a horizontal line at top or bottom of each container standing for ground level.

## IV. Discussion

The new design is a further step away from the geographical realism in schematic map design with the abandoning of stations as nodes and connections between them as lines. The use of containers for stations provides ample display space for the many details that may be associated with each station. The design was created from first principles by followed the REEP approach to representation design and the application of the REEP principles [3-5]. The efficacy of the new design is yet to be evaluated with users, but the completion of a novel design provides some further support the potential of the REEP approach, because it extends its scope of application to a further type of domain beyond those which have been previously re-codified as new diagrammatic representations.

The principles aim to produce effective representations but the reader's initial reaction to the new map is likely to be that it is (horrendously) visually complex and therefore will not be effective. This is a reaction that other representations designed under the REEP approach have instilled but which have then been shown in user studies to be far superior to conventional representations [3-5]. The critical issue here is to examine the new design at a cognitive level, rather than in superficial perceptual terms. Performing a task involves a succession of sub-goals that each requires access to different sets of information. The new map deliberately encodes alternative classes of concepts into different representational schemes, so when a sub-goal demands information about certain concepts access to them is facilitated because the user need only focus on that representational scheme. In other words, the grouping of similar ideas into one graphical format supports the mind's natural attention focusing (or filtering) processes, so that search for particular information is confined to just to the one format rather than spread across many.

Although Beck's NLS design of transit maps is ubiquitous the creation of the CNSC format, at minimum, shows that distinct alternative formats are feasible and highlights the limitations of the standard design. In particular, just a few pieces of information may be associated with each station-node before ambiguities in spatial adjacency occur. Although the use of containers for stations solves the problem in the CNSC formant, the scheme has problems of its own, such as the unwieldy elongation of containers over long distance (e.g., Finchley Road to Wembly Park on the Metropolitan line, not shown) and the clumsy overlapping for containers to represent crossing but not joining tube lines (e.g., Warren St. and Euston Square). As both the NLS and CNSC designs have their own particular weaknesses this, in turn, the raise the intriguing question of whether some yet to be conceived format, devised from first principles, could be superior to both.

The original motivation behind the design of the new schematic map was as a further test the scope of the REEP approach in a domain that has a distinctly different conceptual character compared with those previously used to evaluate the approach [3-5]. However, the new design holds some promise as a map for actual users of transit systems, with particular circumstances in which it may be of specific benefit to some classes of users. One of the aims of the new design was to overcome the limited range of information that could be encoded by the NLS format, thus a design has been produced that incorporates information that has been previously distributed across multiple different versions of the London tube map. This may benefit at least two classes of users. The first are sophisticated users of the tube network who wish to plan unfamiliar journeys and execute them efficiently, by making choices at the level of which stations to make transfers and where to wait on a platform in order to board the carriage that will arrive right by an appropriate exit. The second class of users is comprised of people with mobility difficulties. The new design allows this group of users to readily view accessibility information that is relevant to all the parts of a whole journey in one source (from station entrance to platform, platform to train, transfers between lines, and return to the street). Currently, such users must coordinate separate maps that cover steps, gaps, stairs, escalators, manual ramps and so forth, in different combinations.

One might assume that tube map applications on smart phones and tablets solve these information access issues, especially as they incorporate automatic journey planning routines that are displayed over the conventional London tube map. However, such applications have at least two generic limitations. First, they typically reply upon traditional button presses, menu selections or text entry to access the desired information, which demands a level of motor accuracy on the interface that is difficult when one is on the move. Second, automated planners tend to be relatively inflexible in the routes that they recommend, because they compute options using rather gross characterizations of users' preferences. The new map potentially avoids these two issues. First, the new design could be implemented on mobile devices as a simple graphic that would allow all the available information to be retrieved using simple screen scrolling and zooming actions, which can be a more robust and reliable mode of interaction, especially with touch screen devices. Second, the underlying approach of REEP is to encode all the information of the domain in the representation, so users of the design always have access to the full range of information. Thus, users have the option to make choices for themselves based on finer nuances about their own preferences and personal knowledge. Hence, it is suggested that the creation of the new design of schematic map may not only have implications about how to present rich information effectively but may have potential impact for the design of interaction with maps on mobile devices.

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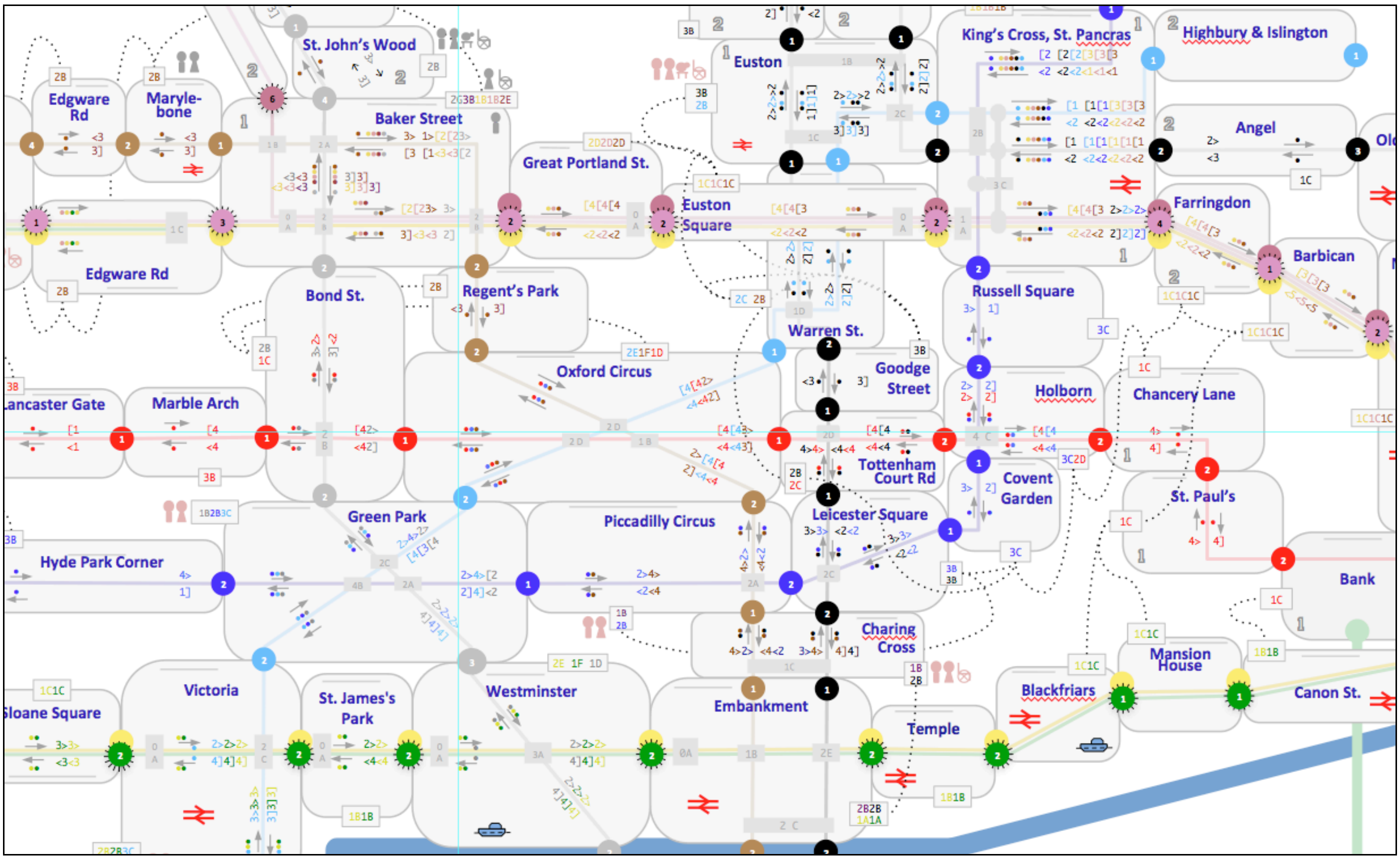

Fig 1. The new design of schematic map: central area of the London Underground. © Peter Cheng, University of Sussex. (Details associated with each station are illustrative and not necessarily accurate.)

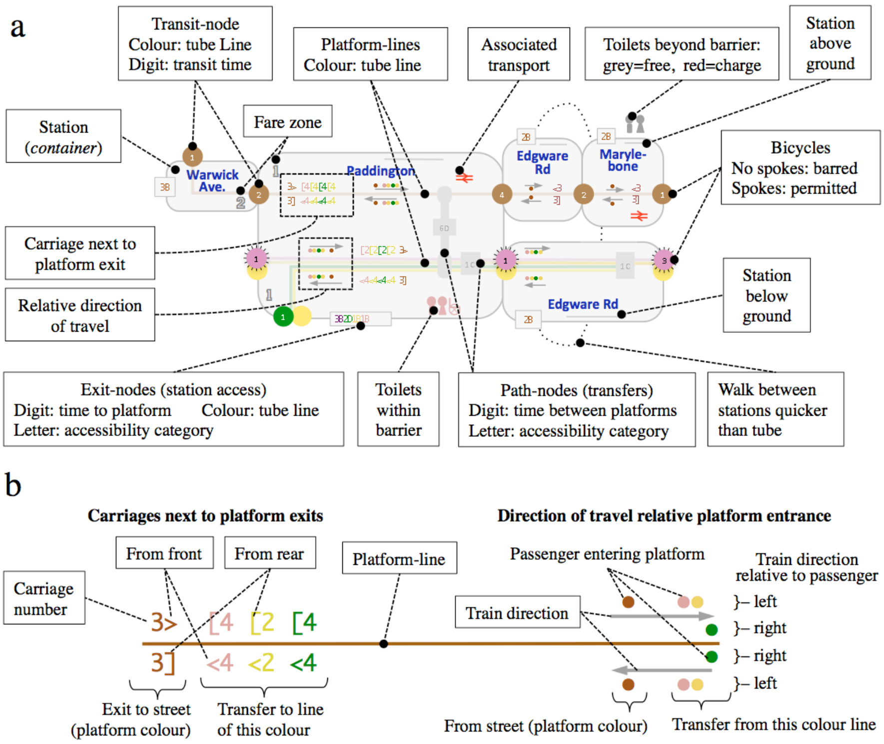


Fig 2. Key to the new design: (a) main components; (b) information about carriages next to exits and travel directions. © Peter Cheng, University of Sussex.