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Pedro Atã, Breno Bitarello and João Queiroz*

Iconic semiosis and representational efficiency in the London Underground Diagram

Abstract: The icon is the type of sign connected to efficient representational features, and its manipulation reveals more information about its object. The London Underground Diagram (LUD) is an iconic artifact and a well-known example of representational efficiency, having been copied by urban transportation systems worldwide. This paper investigates the efficiency of the LUD in the light of different conceptions of iconicity. We stress that a specialized representation is an icon of the formal structure of the problem for which it has been specialized. By embedding such rules of action and behavior, the icon acts as a semiotic artifact distributing cognitive effort and participating in niche construction.

Keywords: iconicity, operational iconicity, optimal iconicity, representational efficiency, diagrammatic reasoning, London Underground Diagram, Peirce

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1 Introduction

The design of the London Underground Diagram (LUD) is a well-known example of representational efficiency, facilitating urban transportation for thousands of everyday users, copied by urban transportation systems worldwide. Present in virtually every major city in the world, it has established an international paradigm on how to perform simple decision-making tasks regarding networks of stations and lines. Its origins date back to 1933, when the engineer draughtsman Henry C. (Harry) Beck proposed several innovative features to the old Underground Map, sacrificing geographic accuracy in favor of specialization in particular tasks (see Walker 1979).

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This paper explores the design of the London Underground Diagram identifying the semiotic basis of its representational efficiency. Efficiency in a representation is a matter of iconic semiosis.[1] Several conceptions of iconicity have been acknowledged: the icon is operationally defined as a sign whose manipulation reveals, by direct observation of its intrinsic property, some information on its object (operational iconicity) (CP 2.279[2]; Stjernfelt 2011: 397); but it has also been connected to representational features involved in the specialization of signs for certain purposes (optimal iconicity) (Stjernfelt 2011: 415). It is the type of sign whose signification is S-dependent (that means, dependent on the sign itself) and, more traditionally, it has been defined as similarity between the sign and its object. These different conceptions of iconicity sometimes appear to generate contradictory claims regarding representational efficiency. To solve such contradictions, we stress that a specialized representation is an icon of the formal structure of the problem for which it has been specialized.

Icons are cognitive artifacts, material tools that embed cognition and shape our minds. The London Underground Map is a remarkable example of a cognitive artifact, providing a niche[3] built for extraction and manipulation of relations, capable of generating overall changes in the behavior of the users and influencing in the understanding of the city itself.

In the following sections, we (i) introduce Peirce's concept of iconic sign, (ii) describe the London Underground Diagram and its representational features, (iii) investigate the LUD's efficiency by examining its relevant innovations in the light of different conceptions of iconicity, (iv) describe its role in cognitive niche construction. Our conclusions relate cognitive distribution and niche construction with representational efficiency as a matter of iconicity.

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1 We employ the term "representational efficiency" in the sense used by Zhang (1997), meaning the easiness of use of representations in problem-solving tasks, which can be empirically measured through the comparison of cognitive performances on isomorphic representations (see Zhang and Norman 1994; Zhang 1997; Chuah et al. 2000). In this sense, representational efficiency is an influence that is directed from the material features of the representation to the cognitive performance. This process is identified as iconic: signification is determined by the sign materiality (criterion of relative dependence of the sign process) and problem-solving involves the discovery of information about an object (operational definition of the sign) (see Atã and Queiroz 2014). This is not to say that indexical and symbolic signification is absent, but rather that the decisive element for efficiency is iconicity.

2 Following a scholarship tradition, Peirce's work will be referred to as CP (followed by volume and paragraph number for quotes from *The Collected Papers of Charles S. Peirce*).

3 In Ecology, the concept of niche means the environmental conditions required for a certain species to live. Cognitive niche construction is related to the transformation of problem spaces in order to aid thinking (see Clark 2006a).

2 Peirce's iconic semiosis

Peirce defined semiosis (sign-mediated processes) as an irreducible triadic relation between a sign (S), its object (O) and its interpretant (I). We will hereafter refer to this triad as S-O-I. That is, according to Peirce, any description of semiosis involves a relation constituted by three irreducibly connected terms (CP 2.242), S-O-I.

As it is well known, sign-mediated processes show a notable variety. There are three fundamental kinds of signs underlying meaning processes – icons, indexes, and symbols. Respectively, a sign may be analogous to its object, spatio-temporally connected to it, or might represent it by means of a law, rule, or norm. These classes correspond to relations of similarity, contiguity, and law between sign and object (see Table 1). Icons are signs that stand for their objects through similarity or resemblance, irrespective of any spatio-temporal physical correlation that sign S may have with an existent O. If a determinative relation of the S by the O is a relation of analogy, that is, if S is a sign of O in virtue of a certain quality that S and O share, then S is an icon of O. S and O are related due to the identity of some aspect they share. Icons are very dependent on the material, form, and structure of which they are made – "An Icon is a sign which refers to the Object that it denotes merely by virtue of characters of its own, and which it possesses, just the same, whether any such Object actually exists or not" (CP 2.247). In contrast, if S is a sign of O by reason of "a direct physical connection" (CP 1.372) between them, S is said to be an index of O. In that case, S is really determined by O, in such a way that both must exist as events – "An Index is a sign which refers to the Object that it denotes by virtue of being really affected by that Object" (CP 2.248). The notion of spatio-temporal co-variation is the most characteristic property of indexical processes. The examples range from a pronoun demonstrative or relative, which "forces the attention to the particular object intended without describing it" (CP 1.369), to physical symptoms of diseases, photographs, weathercocks, thermometers. Finally, in a symbol, the relation between S and O is logically dependent on the third term, I. In a symbolic relation, the interpretant stands for "the object through the sign" by a determinative relation of law, rule or convention (CP 2.276).

Table 1: The fundamental types of signs underlying meaning processes – icons, indexes, and symbols. They are characterized in terms of relative dependence of sign-object-interpretant (S-O-I) components in triadic relation.

Sign	S-O relation	S-O-I dependence	
Icon	Similarity	Monadic (S)	Dependent of intrinsic properties of S
Index	Contiguity	Dyadic (S-O)	Dependent of S-O spatio-temporal correlation
Symbol	Law	Triadic (S-O-I)	S-O dependent of I mediation

The icon is the only type of sign that involves a direct presentation of qualities that pertain to its object. Analogies depend on icons. When manipulated, the icon "reveals" aspects or qualities of its object.

The key of iconicity is not perceived resemblance between the sign and what it signifies but rather the possibility of making new discoveries about the object of a sign through observing features of the sign itself. Thus a mathematical model of a physical system is an iconic representation because its use provides new information about the physical system. This is the distinctive feature and value of iconic representation: a sign resembles its object if, and only if, study of the sign can yield new information about the object (Hookway 2002: 102).

The icon is not just the only type of sign involving a direct presentation of qualities that pertain to its object; it is also the only sign through which, by its direct observation, it is possible to discover something about its object.

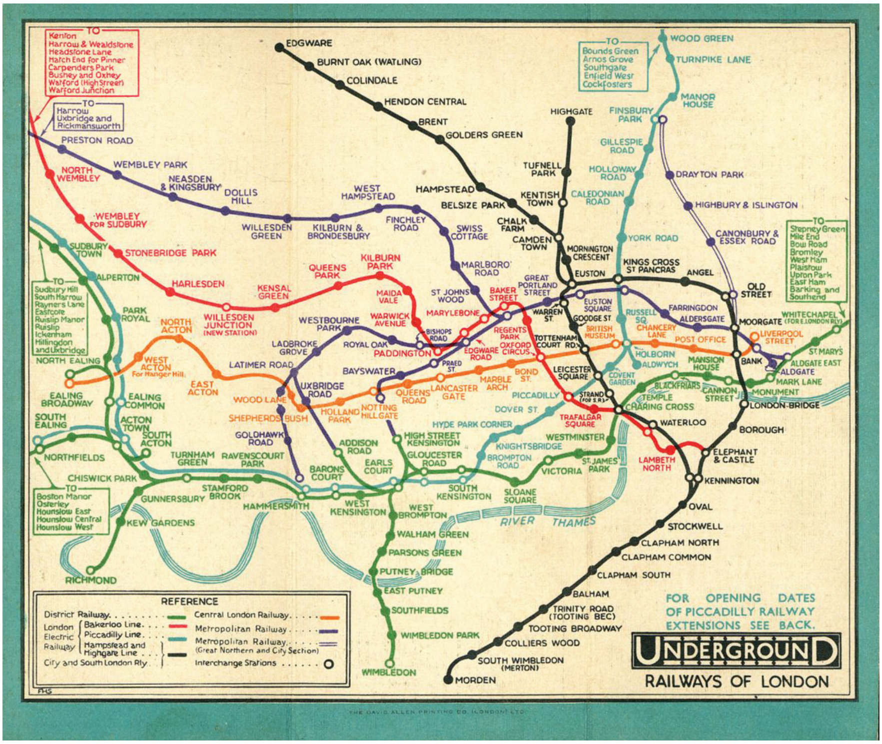
Maps, graphs and diagrams are special types of icons. As soon as an icon can be considered as consisting of interrelated parts, and since these relations are subject to experimental manipulation governed by laws, we are working with diagrams (see Stjernfelt 2007: 92). Diagrams are the principal way of acquiring new knowledge about relations. They represent, through the relations between its parts, the relations that constitute the related parts of the object it represents. The object of the diagram is always a relationship, and the related parts of the diagram represent the relationships that constitute the object represented. The prototypical diagram is described as the manipulation of a geometric figure for the observation of a theorem. But the idea is quite general. An example taken from algebra is enlightening: "In fact, every algebraic equation is an icon, since that *shows*, through their algebraic signs (which are not themselves icons) *relations* of the quantities involved" (CP 2.282, emphasis added). Indeed, if a sign is observed as a whole consisting of interrelated parts, and these related parts are subject to experimental modification governed by rules, we are operating with a diagram.

The London Underground Diagram is an example of a diagrammatic cognitive artifact, providing a niche built for extraction of relational properties.

3 London Underground Diagram (LUD): A cognitive tool for its users

The London Underground Diagram (LUD) is a hallmark of information design that influenced many other public transportation diagrams, a "form of representation judged to be so effective that it is now employed by virtually every transportation authority in the world" (Spence 2007: 77).

The original version of the LUD was created by the Henry C. (Harry) Beck in 1933. Previously to the LUD, maps of the London Underground System adhered to geographically more accurate representations of the lines and station locations (see Figure 1).



Q4 **Figure 1:** A route guide of the Underground System made by F.H. Stingmore, published circa 1932 (this is an overall equivalent version of Stingmore's 1919 guide shown in Garland [1994], the only difference being the addition of a few stations and lines). The background is blank and the different lines are color-coded. Although the concern for geographic accuracy diminished in comparison with the previous maps, it is a central component of the design. © *TfL from the London Transport Museum collection*.

Beck produced his first sketch for the London Underground Map in 1931. The design was based upon and adapted from an electrical circuit diagram (with which Beck was familiar as he was an engineer draughtsman). Such diagrams omit or falsify the relative physical position of wires in order to convey the information about connectivity. Beck saw a similarity with the underground railway network in that it was possible to ignore the geographical information altogether and remove some of the sources of confusion in the previous, more literal maps (Whitby 1996: 70).

Beck’s initial sketch was transformed into a properly labeled and color-coded diagram (Figure 2) where he compressed the outlying portions of lines. The central area of the network appears to be viewed through a convex lens so as to enlarge its scale, and route lines are simplified in verticals, horizontals and diagonals (45°) (Garland 1994: 16).

Q5 **Figure 2:** Beck’s original Underground Diagram, from 1933. © *TfL from the London Transport Museum collection.*

In later versions of the London Underground Diagram based on the last of Beck’s diagrams (published in 1959), his successors retained the essential structure from the original: octagonal grid and colored lines meeting at angles of 90° or 45°; stations arranged to show the position of each one to the next instead of the real geographic distance between them; the presence of the simplified River Thames along the bottom of the diagram helping the notion of position and scale; non-interchange stations represented by ticks and interchange stations represented sometimes by rings sometimes by diamonds (Garland 1994). Graphical changes such as changing the color of the lines and the fonts used in the names of the stations in order to improve the grasping of information by the users and reduce their possibility of confusion were made, also to accommodate the expansion of the transport system. As a result of the adaptations and modifications made by Beck and his successors, we have the diagram as we know it today.

4 Representational efficiency and iconic semiosis in the London Underground Diagram

The LUD (Figure 2) has been recognized as more efficient than a geographically more accurate map (such as Figure 1). We assume that the type of semiosis involved in the signification of the efficient properties of a representation is the iconic semiosis (see Atã and Queiroz 2014; Zhang and Norman 1994; Zhang 1997). Efficiency corresponds to advantage in the material manipulation of the sign for a certain goal. Iconicity is involved whenever signification is dependent on the materiality and structure of the sign. However, to say that difference in efficiency is due to iconicity is not enough to clarify *what* happened in the transition from the old map to the LUD that has shaped the cognitive niche of the users. In the following paragraphs, we further analyze the notion of iconicity and the representational differences between the two representations of London Underground System.

The notion of iconicity can be understood in different ways. Traditionally, it has been defined as "similarity" between sign and object. It has also been defined as relative dependence on S in the S-O relation (see Queiroz 2012). Stjernfelt (2011) identifies two different contrasting conceptions of icon and iconicity in Peirce's work: first, the icon can be operationally defined as any sign whose manipulation is able to reveal more information about its object. This operational definition of the icon focuses solely on the capability of a sign to enclose information about its object. Following the author, we use the term "operational iconicity" to refer to the conception of iconicity arising solely from this operational definition. Operational iconicity contrasts with a stricter notion that considers factors such as immediacy of the information presented and economy of elements. We refer to the conception arising from these stricter criteria as "optimal iconicity" (Stjernfelt 2011: 400).

Stjernfelt (2011: 414) exemplifies the distinction between operational and optimal iconicity through the example of a digital picture. A picture can be digitally represented as pixels on a screen or as a linear sequence of digital information. If we only take into account the operational definition of the icon, the two representations are equally iconic: they are informationally equivalent (i.e. enclose the same amount of information), and one can be algorithmically transformed into the other. However, this operational definition alone ignores some representational features that are decisive for the S-O relationship in each sign: in the pictorial image, for example, object contours are represented as continuous lines while in the linear digital representation this information is scattered throughout the code. A single object contour is materially closer to a single continuous line than several scattered pieces of information, regardless of the interpreter (see Stjernfelt 2011: 414). Therefore, it is more iconic. Put in another words, a one-to-one correspondence holds some kind of logical and phenomenological intrinsic iconic value that is shattered by a one-to-several correspondence.[4] This is an example of the optimal notion of iconicity.

In the LUD, the operational iconicity criterion is able to unambiguously identify the diagram as an icon. It must be iconic semiosis, since a user manipulating the LUD is able to discover implicit information about the Underground System, e.g. on which line to embark to get to a specific station. It does not differentiate, however, between the LUD and older maps. On the other hand, the optimal iconicity criterion is able to stress the LUD's specialization as a problem-solving tool, thus differentiating it from other representations equally capable of revealing information about lines and stations.

The LUD has proved to be more efficient for navigation in the Underground System than a geographically more accurate map (such as Figure 1), even though the latter contains more information about the Underground System than the former (see Table 2).

Table 2: A comparison between information of O (the Underground System) contained in S (maps and diagrams) for the LUD and a geographically accurate map of the Underground System. The LUD contains less information about the Underground System than the map. Therefore, it is less iconic for operational iconicity, suggesting it to be less similar to the Object. However, it is more efficient, therefore more iconic for optimal iconicity, suggesting it to be more similar to the Object.

Information of O accurately contained in S	Geographically accurate Map	London Underground Diagram
Stations	Yes	Yes
Connections between stations (tube lines)	Yes	Yes
Connections between lines (interchange stations)	Yes	Yes
Distance between stations	Yes	No
Geographic location of stations	Yes	No
Length of lines	Yes	No
Specific directions and changes of directions of lines	Yes	No

4 Stjernfelt (2011) has related the development from a more operational to an optimal conception of iconicity to the transition to a more realist stance in Peirce's philosophy.

There is more information to be discovered about the Underground System in a geographically accurate map than in the LUD. In this sense, we should conclude that the map is more iconic than the LUD with regard to operational iconicity. Since operational iconicity is a detrivialization of the psychological notion of similarity (see Stjernfelt 2011: 397), we can also conclude that a geographically accurate map is more similar to the Underground System than the LUD. The same conclusion might be reached intuitively: an observer, looking at the map which shows the real trajectories of the lines through the city might say that "it looks more like" the real Underground System than a simplified diagram.

The above conclusion appears to inflict a contradiction between similarity and representational efficiency. A geographically accurate map is more iconic (operational iconicity) and "looks more like" the Underground System itself, and yet it is less efficient for navigation in the same Underground System than a simplified diagram. The contradiction can also be understood in terms of opposing operational and optimal iconicity. Compared to a geographically accurate map, the LUD is simultaneously less iconic for operational iconicity, thus, less similar, and more iconic for optimal iconicity, thus, more similar.

This, we argue, is a false contradiction, that points to what is relevant in the transition from the old maps to the LUD: while the geographically accurate map might actually be more similar to the London Underground System understood as a whole, the LUD, with the rules of manipulation and behavior it entails, is more similar to the particular experience of the Underground users and the most relevant variables involved in the choices they need to make. This experience of orientation and navigation in the Underground System can be modeled as a game (see Walker 1979) with a formal structure that comprises an initial state (the user's current station), a final state (destination), intermediate states and a set of rules (see Table 3). The LUD is a more efficient representation because it embeds this formal structure more directly than a geographically accurate map.[5] It is easier to locate the user current location (initial state) and destination (final state). It is also easier to grasp the overall structure of possible lines and connections among which to choose (intermediate states), with no superfluous information such as changes of directions or specific distances between stations.

There are others notable factors why the LUD, with regard to its rules of action and behavior, can be seem as more similar to the experience of a user in

5 A similar argument is presented by Zhang and Norman (1994): in one of their experiments, the authors argue that the more efficient isomorph of the Tower of Hanoi puzzle game is the one that externalizes most rules of the game, so that the performance of the players is efficiently constrained. This process of externalization of constraints has been characterized as iconic (Atã and Queiroz 2014).

Table 3: The formal structure of the game-like experience a user has when trying to solve problems related to navigation in the Underground System.

The Underground User Game: Formal Structure	
Initial State	the user's current station
Final state	the user's goal station
Intermediate states	every the stations the user is going to access in order to go from the initial to the final state.
Rules for moving between states	In order to move the user embarks on a train, following its path on the line until the station (final or intermediate) she wants to disembark.
	The train will follow its path on one particular orientation until the end of the line. It will not change its trajectory, orientation or line while traveling.
	There are two types of stations: normal stations only allow for embarking or disembarking on one line. Interchange stations allow for changing lines.

the Underground System than a geographically accurate map. The concrete experience a user has on an Underground trip is one of no visible landscape or landmarks with which to mark and be conscious of the specific changes of direction of the lines or the specific distances traveled. Since there is also no traffic and the trains move in high speed, the differences in distance can be less significant for the amount of time a train will spend to get to the destination than the number of stops it will need to make. The experience the user has is, arguably, of a continuous homogeneous movement interrupted only by the stops in the stations, just like a straight line undisturbed by topographic issues and interrupted only by the chain of blobs or ticks that represent the stations. In this sense, a hypothetical user that is completely unaware of the geography of the city of London above the ground and is familiar only with the experience of the Underground might agree that, even intuitively, the LUD looks more like the Underground System than a geographically accurate map.

In comparison to its predecessor, Beck's diagram has diminished the amount of implicit reachable information in the map, reducing the number of possible operations to be performed (to know about real distances, for example). Beck has added features that do not increase the amount of information, but rather decrease the difficulty of the search for the proper information, which influences in the whole process of problem-solving. That means to say that the behavior of the user as well as the task itself are constrained and, to a certain extent, defined by the material iconic features of the representation. A problem solver behaves according to a problem space that corresponds to a formal structure of states and rules; this problem space is made available through iconic features of the representations involved in the cognitive process of solving the problem, so that this material representational features shape the behavior of the solvers. Change in efficiency in the transition from the geographically more accurate maps to the LUD corresponds to iconicity in the LUD putting the users in direct touch with rules that are really part of the experience of using the Underground System.

5 The London Underground Diagram as a cognitive artifact

Peirce can be considered an important precursor of the situated mind and distributed cognition thesis (Atã and Queiroz 2014). Recently, the distributed cognition and extended mind approach have questioned the legitimacy of skin and skull to serve as criteria for the demarcation of the boundaries between mind and the outside world (see Clark and Chalmers 1998; Clark 1998, Clark 2006b). For Peirce, mind is semiosis (i.e., sign action) in a materially embedded form and cognition is the development of available semiotic artifacts, in which is embodied a power to produce interpretants (see Skagestad 2004). From this perspective, the fundamental unit of cognitive interest is reconceived and replaced by an environmentally embedded space of semiotic skills and artifacts. As we adapt the environment to facilitate our purposes, deploying our mind in external representations, we participate in the construction of cognitive (or semiotic) niches, which fundamentally alter our cognitive capabilities (see Clark 2006a).

Cognitive niche construction transforms the environment in which cognition takes place, through the selection of environmental features capable of mediating and controlling behavior (see Magnani 2009; Clark 2008: 61–63).

Beck's design has reduced the similarity of the LUD to the geographical identity of the Underground System and instead increased its similarity to a specific structure of rules and goals that characterizes a particular experience of urban transportation and urban space. It has selected a *habit* – a set of relations and rules of action – and materialized it through iconicity so that it manifests itself again as iconic semiosis in the behavior of the users. This formal structure thus becomes a coupled part of the mind of Londoners, now hybrid beings embedded with a particular set of rules of action. For them, the LUD stands as a common familiar model, a specialized environment built for extraction and manipulation of relations. In this sense, the impact of the efficiency of the

LUD goes beyond the scope of discrete particular problem-solving tasks. It becomes part of the semiotic niche of urban dwellers, making them more suited to the urban environment and influencing in their overall behavior and perception towards the city. It is “more than a simplification of Underground railway routes [...] it is an essential simplification of the city itself” (Garland 1994: 5).

6 Some conclusions

In our approach, while it may be of little relevance whether cognition is happening inside or outside the head, it is decisive that it must happen in representations: writing tools, modeling artifacts, notational systems, languages, and so forth. This conception neither restricts representations to symbolic semiosis as would orthodox representationalism nor rejects representations as would anti-representationalism. The study of distributed cognition benefits from the system proposed by Peirce in the sense that it offers a model of how and by virtue of what the mind semiotically unfolds itself. As the study of the representations and its functioning becomes a necessary part of the study of cognition, Peirce’s conception of icon arises as an important tool for the investigation of thought processes.

Iconicity is a central idea that connects cognitive distribution, niche construction and representational efficiency. An efficient representation is an icon of a structure of habits (rules of action) that foster certain kinds of cognitive behavior that are appropriate for an objective (here conceived as a game-like activity with an initial state and a goal state). Iconicity helps to clarify how it is possible for a habit to be embedded on a representation and be forced upon the user. Representational features act themselves as rules of action because of the interrelatedness of its parts being analogous to certain effects of the environment that allow: (i) the embedding of extractable information in the sign about the object (related to operational iconicity) and (ii) the direct manipulation of this information (related to optimal iconicity). Through iconicity, cognition is distributed. As representations mold cognitive behavior, they become part of an ongoing process of niche construction, where the cognitive potentialities of groups of individuals are expanded or directed towards certain purposes. In our example, a particular experience of urban transportation, partly determined by the technology itself of Underground transportation, materializes itself on a sign that causes urban dwellers to adapt to it, thus participating in niche construction. The most decisive step of the process happens through iconic semiosis. The reduction of the amount of information in a representation by virtue of its specialization for specific tasks does not oppose different conceptions about iconicity, but rather redefines the object of the sign, clarifying its role as the materialization of a problem space optimized to function as an environment where cognition develops through manipulation of diagrams.

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