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REPRESENTATIONS OF STREET NETWORKS IN SPACE SYNTAX:

Towards flexible maps and multiple graphs

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ABSTRACT

The shift from Axial to Line-segment maps is one of the most important developments in Space Syntax analysis, both theoretically and methodologically. It followed a long line of investigations and discussions within the field of Space Syntax, which addressed critical issues related to the Axial map representation (e.g. Hillier and Iida,2005; Hillier,1999a,1999b; Turner,2001; Steadman,2004, Dalton, 2001). At the same time, it opened up new possibilities by allowing for the use of Road-centre-line maps in Space Syntax analysis; that is, largely available GIS-based segment maps, used in most areas of urban modelling (e.g. Turner,2007; Dalton et al.,2003). Today, several models implement syntactical analysis to Road-centre-line maps, while claiming to form valid alternatives to the Axial map, not least in capturing the perceptual and cognitive affordances presented by the environment.

This paper focuses on such alternative models with a twofold aim: first, to help make well-grounded choices in applying syntactical analysis to Road-centre-line maps; and second, to explore the methodological potentials of Line-segment maps, which are created by their flexibility, by being the least aggregated representations of street networks. The paper introduces an experimental software application to push the investigations and exploit these methodological possibilities even further.

The models discussed in this paper are: 1) Angular Segment Analysis (e.g. Turner,2007; Hillier and Iida,2005); 2) Natural Streets maps (Jiang and Liu,2007) and Continuity maps (Figueiredo and Amorim,2005); 3) Directional Distance model (Peponis et al.,2008). Based on a systematic comparison of: a) their geometric representation of the street network (the 'map'), b) the dual-graph they calculate, and c) the measure of distance they use, we argue that they can all be seen as parametrically defined representations, based on a Line-segment map. In other words, with the same Line-segment map one could produce all of them, if a different set of angular parameters was used, to either define the graph elements (nodes, edges), or to calculate

distance. These models, parametrically redefine the relation between the 'map' and the 'graph'; thus, challenging the one-to-one relation between the two, that the Axial map was founded upon.

The methodological importance of this development goes beyond the specific models described in this paper. If the same Line-segment map can produce different graphs by using a different set of angular parameters, then, for instance, one could easily change the parameters to follow the latest theoretical insights on human cognition, without having to change the map. Going even further, one could develop and test different representational models to explore new theoretical and methodological paths, by using one single map. The experimental tool also presented in this paper is a step in that direction, allowing to test different models using a single software.

KEYWORDS

representation, graph, Axial map, Line-segment map, Road-centre-line map

1. INTRODUCTION

The Axial map has been Space Syntax's emblematic representation when it comes to urban modelling. Although it is not merely a representation of the street network, it has been largely used as such, with fruitful results in the study of urban space. The gradual shift from Axial to Line-segment maps is one of the most important developments in Space Syntax analysis both theoretically and methodologically. It followed a long line of investigations and discussions within the field of Space Syntax, which addressed critical issues related to the Axial map representation (e.g.Hillier and Iida,2005; Hillier,1999a,1999b; Hillier and Penn,2004;Turner,2001; Dalton,2001; Steadman,2004; Ratti,2004; Batty,2013). At the same time, it opened up new possibilities by allowing for the use of Road-centre-line maps in Space Syntax analysis; that is, largely available GIS-based segment maps, used in most areas of urban modelling (e.g.Turner,2007;Dalton et al.,2003). Today, several models implement syntactical analysis to Road-centre-line maps, while claiming to form valid alternatives to the Axial map, not least in capturing the perceptual and cognitive affordances presented by the environment.

This paper focuses on such alternative models with a twofold aim: first, to help make well-grounded choices in applying syntactical analysis to Road-centre-line maps; and second, to explore the greater methodological potentials of Line-segment maps, which are created by their flexibility, by being the least aggregated representations of street networks. The paper introduces an experimental software application to push the investigations and exploit these methodological possibilities even further.

The models discussed in this paper are: 1)Angular Segment Analysis (e.g.Turner,2007; Hillier and Iida,2005); 2)Natural Streets maps (Jiang and Liu,2007) and Continuity maps (Figueiredo and Amorim,2005); 3)Directional Distance model (Peponis et al.,2008). The model descriptions focus on three fundamental choices: a) the geometric representation of the street network (the 'map') b) the dual graph they produce and c) the measure of distance they use, in relation to their viewpoints on environmental perception and cognition.

The aim of this paper goes beyond the systematic comparison of different models. Figueiredo(2015) has already provided a similar and comprehensive overview, although with a different aim and perspective. Our model description is far from being exhaustive, as for example the models are not compared against empirical data, nor their ability to capture pedestrian and vehicular movement is tested and scrutinized. Our focus lies on the fundamental elements of the representation and analysis. Our purpose is to explore and build on a central idea proposed collectively by these models; an idea highlighted after close inspection and comparison. We argue that they all take the step to introduce angular parameters in the representation and analysis of street networks, although in different variations. We consider this methodological step of great importance as they parametrically redefine the relation between the 'map' and the 'graph'; thus, challenging the one-to-one relation between the two, that the Axial map was founded upon. Once they relativized this closed relationship by adding parameters, they opened up great methodological possibilities for future research.

One of the potentials, that we explore further in this paper, is that they can all be seen as parametrically defined representations, based on a Line-segment map. In other words, with the same Line-segment map one could produce all of them, if a different set of parameters was used; more interestingly, one could produce even more. To exploit this potential further, we developed an experimental software, allowing to create alternative models based on different parameters, using a single Line-segment map.

In the first chapter, we introduce the background of Space Syntax representations, focusing on the Axial map. In the second, we present the alternative models developed and a comparative discussion. In the third chapter, we build on the systematic comparison and elaborate on the idea that all models can be derived by the same Line-segment map and a different set of parameters. In the fourth, we introduce the experimental software tool for analysing multiple graphs using the same Line-segment map. In the final chapter, we discuss the methodological potentials of flexible Line-segment maps, the parametric representation of street networks and the open relationship between the 'map' and the 'graph', further.

2. URBAN MODELLING AND SPACE SYNTAX: THE CRITICAL ISSUE OF GEOMETRIC REPRESENTATION

Urban modelling concerns the fundamental relation between structure and process, where the physical environment generally constitutes the structure and human activity, the process. According to Wilson(2000), urban models are constituted by three components: some measure of attraction; some measure of distance; and some form of geometric representation of space. Recently, we have seen an important shift from location-based models, aiming to model the flow (people, goods, information) generated by the location of attractions, to flow-based models, aiming to model how the pattern of flows generate location (Batty,2013). This new emphasis has led to an increasing interest in representing cities as networks (Newman,2010), acknowledging that the pattern of connections between urban attractions influences flows and that this is essential for understanding both the performance of urban systems as wholes and the properties of their components. Formally, networks are described using graphs, which represent components by nodes and connections between components by edges; a simple notation that allows a wide range of phenomena to be represented as networks.

Space Syntax research has put great effort into the development of representations and demonstrates a long series of descriptive techniques (e.g.convex maps, interface maps, j-graphs; Hillier and Hanson,1984). With origins in architecture and aiming to study spatial form, Space Syntax models are concerned with structure rather than process. Even so, they are not simply representations of the physical environment, but rather of its affordances (Gibson,1986), that is, what emerges in the meeting between properties of the physical environment and human abilities of both physical and cognitive kinds (Marcus,2015). The Axial map is a fundamental example.

2.1 AXIAL MAP

The originality of the Axial map is found in its emphasis on human cognition in space. The Axial map is colloquially defined as the least amount of straight lines that cover all accessible urban space shaped by built form, where each straight line (axial line) represents an urban space that is possible to visually overlook and directly access. The Axial map takes the form of a network representation of urban space from the point of view of what we may call a cognitive subject, that is, a perceiving human being moving through space; where the network components are affordances related to human visibility and accessibility.

What distinguishes Axial map from typical urban network analysis is not only the conceptualisation of space represented by the axial line, as a form of 'cognitive geometry', but also the shift in graph notation(Fig1). In typical representations street networks, such as the Road-centre-line maps, the geometric features are polylines representing street segments which span between street junctions. In the respective network graph, the nodes are the street junctions and the edges are the street segments(primal-graph); thus, putting emphasis to the points of route choice, especially important to traffic modelling.

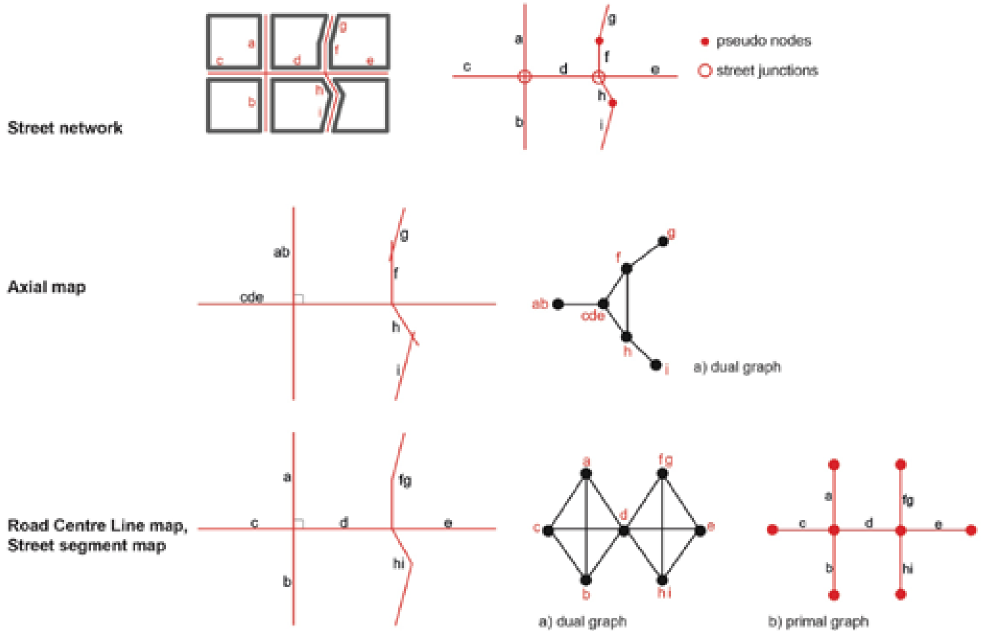

Figure 1 - Axial map and Road-centre-line map

Conversely, in the axial graph the nodes are the axial lines instead of the intersections between them (dual-graph). In this respect, the axial lines are not only the units of representation, but also the units of the analysis, creating a one-to-one relation between the 'map' and the 'graph'.

The analysis of the axial graph is based on measuring the topological distance from each node (axial line) to every other node in the system[1] and is related to typical network analysis. However, following the 'cognitive geometry' of the axial map, a topological distance of 1, not only represents a 'step' from one axial line to another; from the point of view of a moving subject it also represents a discrete change of direction.

3. ALTERNATIVE STREET NETWORK REPRESENTATIONS IN SPACE SYNTAX

In the past 15 years, alternative models of street network representation have been introduced in Space Syntax research. Although they are closely related to central tenets of Space Syntax theory and some can even be seen as variations of the Axial map, they do form discrete models in their own right. Moreover, they can be built on Road-centre-line maps and, thus, take advantage of greatly available ready-made GIS maps; a methodological step with looming advantages, especially regarding the feasibility of large scale analysis. However, researchers do not use and analyse Road-centre-line maps as they are; rather, they edit and manipulate them intentionally, to produce elaborate models of street network representation, in accordance with their particular viewpoints on environmental perception and cognition.

1 More precisely the 'distance' of the 'shortest' path between every pair of nodes

The models presented are:

1. Line-segment maps and Angular Segment Analysis (ASA), developed in Space Syntax research (e.g.Turner,2007; 2005; Hillier and Iida,2005; Hillier et al., 2012).
2. Natural Street maps, introduced by Jiang and Liu (2007); a model closely related to proposals from Figueiredo and Amorim (2005) and Thompson (2003)
3. Directional Distance model, introduced by Peponis et al. (2008)

They will be explored according to:

- the geometric representation of the street network
- the dual graph, on which the calculations are made
- the measures of distance they propose

3.1 LINE-SEGMENT MAPS AND ANGULAR SEGMENT ANALYSIS

The Angular Segment Analysis(ASA) has formed the main alternative to the Axial map analysis and is being extensively used by Space Syntax researchers. The analysis uses a Line-segment map, generated either from an Axial map, or from a Road-centre-line map. This paper will only focus on the second. The Line-segment map is produced by exploding the street segments, which are polyline features, to their constituent straight line segments; thus, a straight street segment is represented as one line, but a curvilinear one is represented as many lines following its geometry.

The graph of the analysis is constructed as follows:

- nodes: line segments
- edges: street junctions and pseudo nodes. Pseudo nodes occur where only two lines meet in different angles

ASA weights this simple graph by an angular cost. The analysis records the sum of angles turned from any origin segment to any other segment within the system[2] (Turner,2007). Hillier and Iida (2005) set the convention to translate actual angular degrees to values ranging from zero (no turn) to 2 (180°turn). This value is added to each graph edge as weight. A new measure of distance is here introduced; angular distance – or, as Hillier and Iida(ibid.) call it, geometrical distance – as opposed to the topological distance of the Axial map. ASA is implemented in various software (Depthmap, PST Place-Syntax-Tool[3]).Following the rule, a right angle turn (90°) is assigned a value of 1, matching the value which was assigned to each directional turn (step) in Axial map analysis. Moreover, collinear segments are assigned no angular cost (0°), becoming similar to axial lines (Fig2). This way, the Line-segment map seems to form a subtler variation of an Axial map. The segmentation of long axial lines makes the analysis subtler by measuring each segment individually, thus picking up differences in the density of intersections along a street. Also, by taking angular turns into account, geometrical properties, like sinuosity, are acknowledged. Moreover, it distinguishes between changes of great angular magnitude, such as right angle turns, and changes of a very small magnitude. However, there is a clear shift of focus from the topological to the geometrical properties of the street network. Furthermore, ASA steps from a purely topological graph to a weighted graph, thus changing its ontology.

2 following the shortest path between any pair of segments

3 Mapinfo-plugin developed by KTH-School of Architecture, Chalmers University of Technology, SpacescapeAB,Sweden; to be available as QGIS-plugin

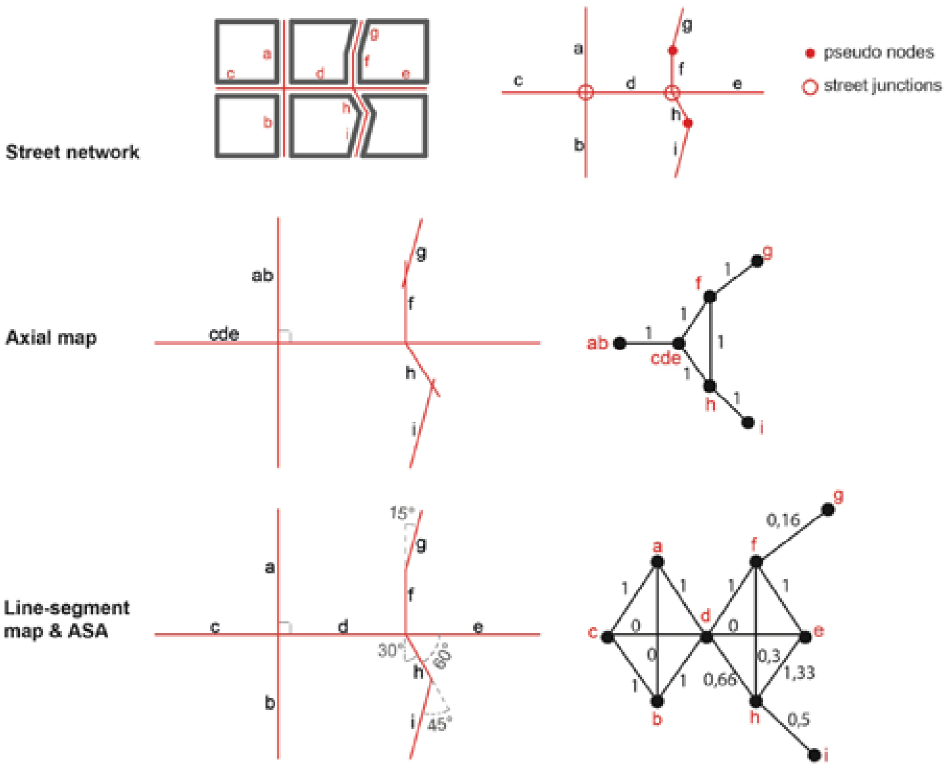

Figure 2.- Angular Segment Analysis and Axial map

The Line-segment map takes a rather undifferentiated approach to the street network. Graph nodes can be either actual street segments, or somewhat arbitrary fragments of sinuous streets; the latter often being an artefact of the digitization of the Road-centre-line map. Also, the graph edges can represent either street junctions or pseudo nodes; the latter again being arbitrary points of the mapping procedure. However, both are analysed as equal, although junctions are points of actual route decision; hence well-formed cognitive entities in relation to how we plan our journeys or give directions[4].

Related to that, the theoretical foundations of angular distance are still being formulated. Researchers use references from cognitive science to argue for importance of the angular turn (e.g.Turner,2007;Hillier and Iida,2005); and observational data showing that people tend to minimise angles toward their destination (e.g.Conroy-Dalton,2003). Still, one can't argue that it is the actual degrees of turn that influence human behaviour; nor that all angular turns, however small, are perceived by pedestrians, let alone drivers.

3.2 NATURAL STREET MAPS

Natural Street maps were introduced by Jiang and Liu(2007), building on previous work by Jiang and Claramunt(2002;2004). It is a street-based topological representation that was presented as an alternative GIS-based model to the Axial map. However, the concept of Natural streets is closely related to the concept of Continuity lines, introduced by Figueiredo and Amorim(2005) and to ideas of Thompson(2003).

The idea is that a street, however straight or sinuous, is a solid cognitive entity and should be represented and analysed as such; addressing the segmentation of curvilinear streets, typical in Axial map representation. Thompson(ibid.) early suggested that a curvilinear or sinuous street should be treated as a bent axial line and thus, keep its cognitive integrity. Figueiredo(2009) later proposed that instead of breaking curvilinear streets into many axial lines, we should

4 We don't say "go straight, turn 30∞left, then straight, then 80∞left "; we say "take the first left"

consider them as Continuity lines, again arguing that they are generally recognised cognitive entities.

This idea is based on the good continuity principle, a concept introduced by the gestalt theory in the early 20th century psychology. This principle predicts the preference for continuous figures; the fact that we tend to group lines or curves that follow an established direction, over those representing abrupt changes in direction. Based on that, streets are naturally merged segments forming good continuities.

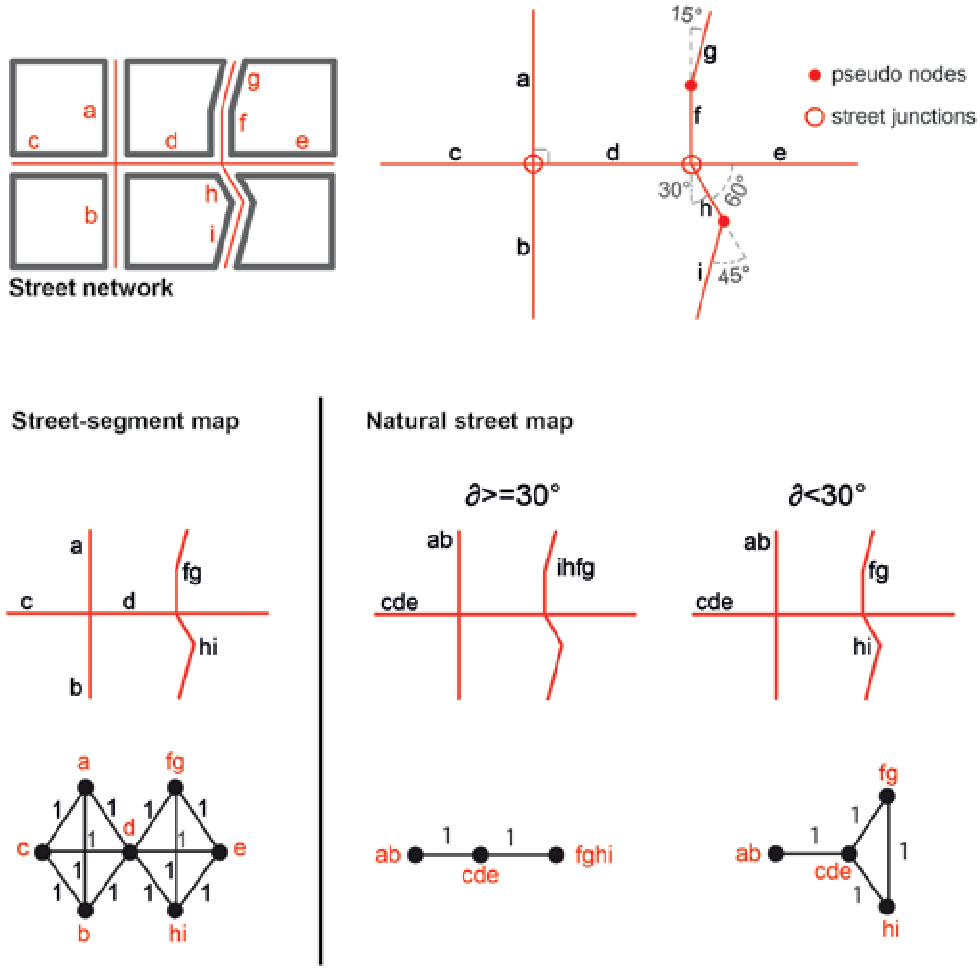

Figure 3 - Natural Street map

We will look more into Jiang and Liu's approach(Fig3). As they are working with Road-Centre-line maps, they introduced algorithms and parameters in order to merge street-segments into Natural streets, based on their continuities. The basic criterion is an angular threshold between the street segments, that should be applied to decide which segments are in good continuity and which are not. In each junction, a segment is concatenated to the adjacent one with the smallest deflection angle, provided that it meets the threshold criterion.

The continuous lines produced by that procedure are the nodes of the network graph. The graph edges are the line intersections. The graph is analysed using topological distance. The algorithms of the Natural Street model are integrated in Axwoman[5].

Jiang and Liu(ibid.) examined many angular thresholds ranging from 10∞ to 70∞. When applying large thresholds like 60∞, many streets are merged forming very long continuities. Jiang and Liu proposed that this approach would be more suitable for vehicle modelling

5 ArcGIS plugin software

which is more cognitive-based, memory-oriented and global in nature; whereas pedestrian modelling, which is more perception-based, visibility-guided and local in nature should use axial line representation. However, one can argue that such large-scale continuities would not form cognitive entities, even to a driver's mind.

3.3 DIRECTIONAL DISTANCE MODEL

Peponis et al.(2008) developed an analytical model of the street network, based on a new version of topological distance, called directional.

While starting with a straightforward line-segment representation, the dual graph produced is not that simple. Graph edges are not predefined; instead they are defined based on a parametric measure of directional distance. An angular threshold is introduced to define which direction changes will be taken into account in the analysis and which won't; any angular turn below or equal to the set threshold is not considered a change of direction, but a continuation(Fig4).

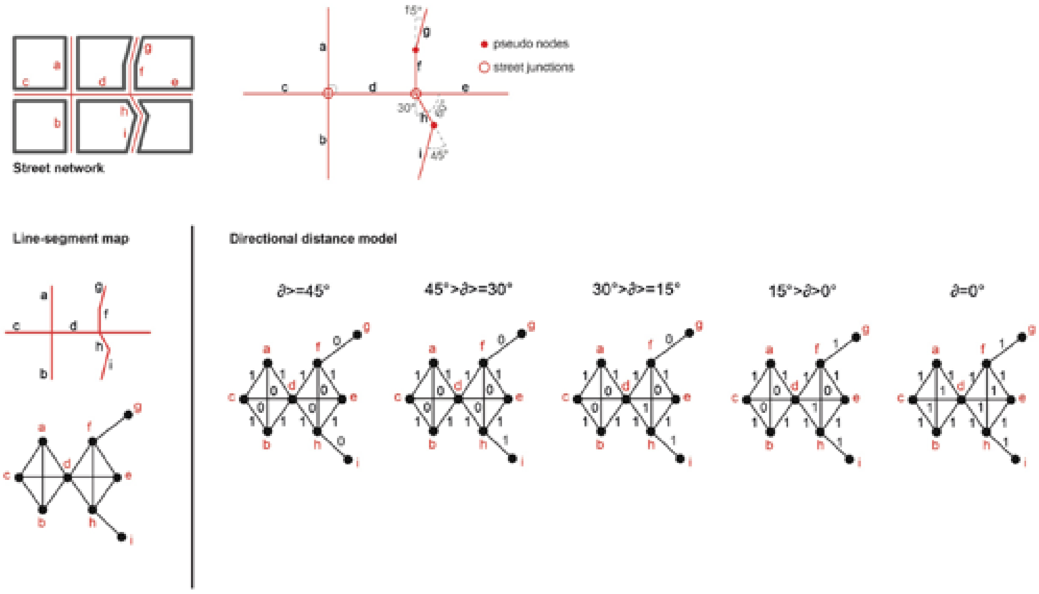

Figure 4 - Directional distance model

Hence, direction changes are treated as binary states; if they exceed the angular threshold they count as one(1) and if they don't, they count as zero(0)[6]. The authors argue '...we make no prior assumption about the existence of directional elements, or their perceptual or cognitive status. Also, we define direction changes parametrically, so that analysis can be arbitrarily sensitive.'(ibid.,p.899) The Directional distance analysis has been automatized in Specialist Lines software[7].

Their idea behind the parametrical definition of distance is that although changes of direction in general have been proven to be a fundamental element of the way people perceive and conceive the street network through movement, there is no proof that all changes of direction are perceptually significant; for example, we perceive quasi-linear streets as entities and not as a succession of fragments. However, instead of the angular distance introduced by the ASA model, they argue for the parametric definition of directional distance, as a necessary way to control the relationship between geometry and topology. It is clear that all of the above place extreme importance to the angular threshold chosen by the researcher; a specific number that defines which is the cognitively significant direction change and which isn't; a number that requires theoretical founding and empirical testing.

6 A metric threshold is also added to the analysis, to account for curvilinear streets consisting of many short lines, where even a relatively sharp direction change can resolve itself into many smaller, that are below the threshold angle.

7 also run in Grasshopper plugin

3.4 COMPARATIVE DISCUSSION: PARAMETRICALLY DEFINED REPRESENTATIONS OF THE STREET NETWORK

The different models present alternative approaches to the analysis of street networks; they produce different geometrical representations, they define the graph elements differently and they analyse the graph using a different concept of distance. However, they are all closely related to central tenets of space syntax theory; hence, they are different, but still comparable to each other and to the Axial Map. As Figueiredo(2015) has demonstrated, they could actually be described by the same Unified-Graph-Model; a unified representation of the street network that could adapt to almost any concept of distance.

What was already implied from Figueiredo's account, is that all are more or less parametrically defined; the ASA uses a weighted graph based on angular distance; the Natural Street model [8]uses angular thresholds to define the graph nodes; and the Directional distance model uses angular thresholds to parametrically define distance. They do not produce straightforward graphs that immediately relate to the representation, nor use a predefined set of graph elements, as did the Axial Map. There is a parametric definition of what counts as a node and what counts as an edge. Put differently, they parametrically redefine the relation between the 'map' and the 'graph', challenging the one-to-one relation between the two.

Following this idea, we argue that they can all be seen as parametrically defined representations based on Line-segment maps, the least aggregated representations of the street network. As will be shown, the same Line-segment map can produce all different graphs by using a different set of parameters.

4. LINE-SEGMENT MAPS AND A MULTIPLICITY OF GRAPHS

We compare the different geometric representations and their related graphs using a simple network(Fig5). What becomes evident is that what separates and identifies the different approaches can be essentially described with three interrelated questions:

- Which change of direction can be considered as cognitively significant?
- Are street junctions cognitively significant points in space, irrespectively of whether they lead to a change of direction?
- Are pseudo nodes cognitively significant at all?

These questions are answered differently by each model, leading to a different definition of which are the cognitive elements of the street network, and consequently, to a different definition of which are the basic elements of the graph; which are the nodes and which are the edges?

The Axial map considers all changes of direction to be significant[9]. However, it ignores street junctions if they don't lead to a direction change. This happens already in the drawing of the map. An axial line can transverse many street junctions if the street is linear, but a curvilinear street is usually broken in many axial lines, even when there is no street junction. All pseudo nodes are included in the graph, since by definition they lead to a direction change.

The Line-segment map, in its unweighted form, takes everything into account. All changes of direction matter and all street junctions and pseudo nodes are included in the graph edges. In the ASA, however, all changes of direction matter relatively to their actual angular change. That doesn't change the definition of the graph elements; it just weights the edges.

The Directional distance model builds on a simple Line-segment map, but then introduces an angular parameter to answer the first question. Changes of direction are considered significant as long as they are over a defined angular threshold.

8 Figueiredo uses Continuity maps as example

9 In drawing Axial lines, very small angular turns are actually ignored, by tracing the longest lines of visibility.

The street-segment map in its simpler form doesn't care about changes of directions in curvilinear streets, so pseudo nodes are completely taken out of the graph. The significant points are the street junctions and only these count as graph edges.

Last but not least, the Natural-street model also introduces an angular parameter to define which street junctions will be included in the graph edges. Street junctions are ignored if they don't lead to a direction change over a specified threshold. Since, it is based on a street-segment map it ignores all pseudo nodes.

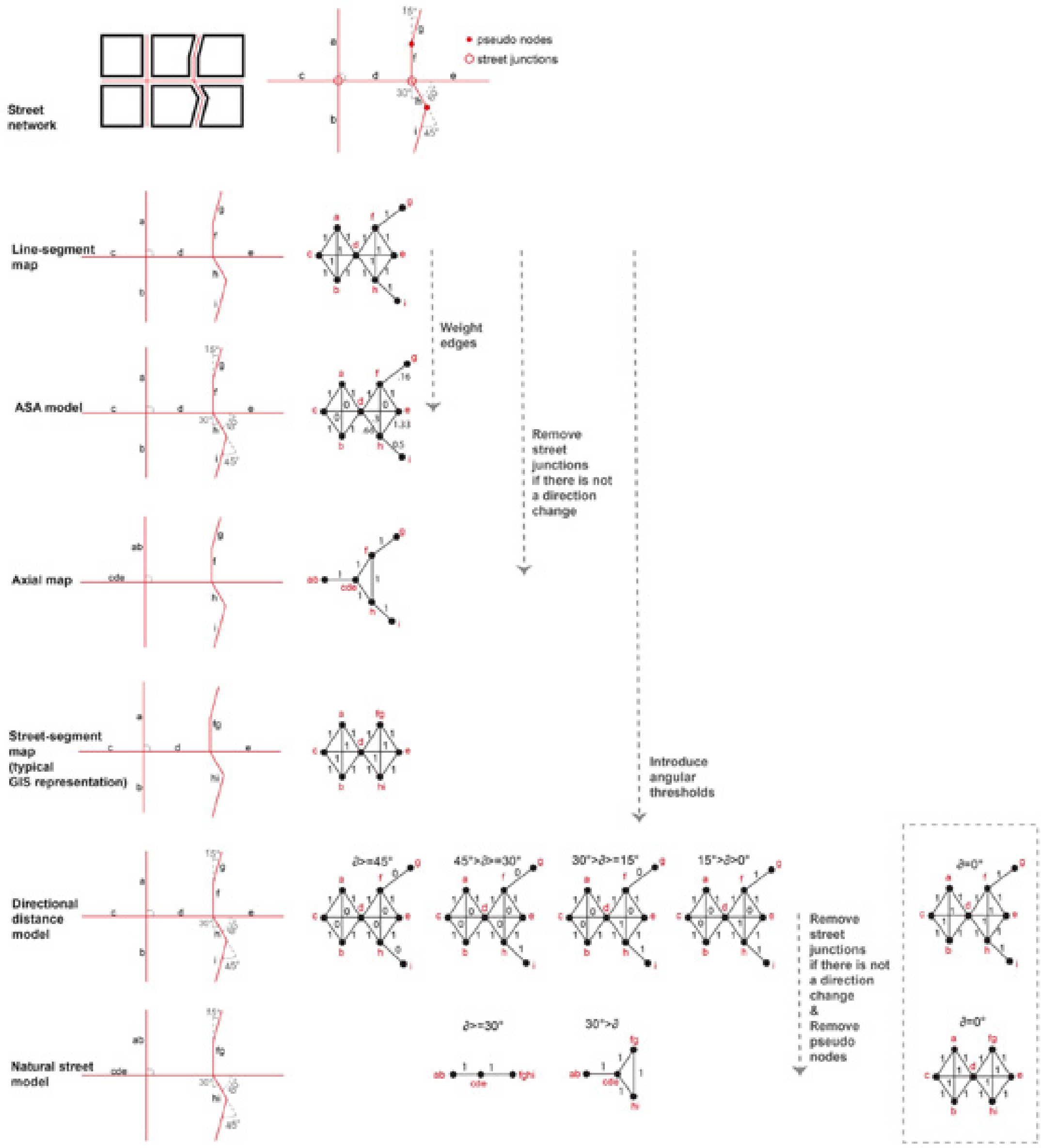

Figure 5 - Comparison and cross relations between graphs

It is evident that while the Axial map and the ASA model can produce one graph, the Directional distance model and the Natural-streets model can produce multiple graphs, by changing the angular threshold(Fig5). In an existing street network, which is far larger than the one used here, the results could be numerous.

A closer inspection reveals that the Line-segment map, produces the least aggregated graph and the Natural street map the most. What is also highlighted by the comparison of the graphs is the cross relations between them. The line-segment graph can be transformed into the Axial graph if street junctions are not taken into account, when there is not a direction change; it can also be transformed into the street-segment map, if it ignores pseudo nodes. What is more, the Line-segment graph matches the Directional-distance-model graph, in the extreme situation of a zero-angular threshold; the Natural-street graph matches the street-segment graph in the same situation. The Natural-street graph can be transformed into an Axial graph if it includes pseudo nodes and with an angular threshold just above zero; enough to capture collinearity. A Directional-distance-model graph, can be transformed into a Natural-street graph, provided that an equal angular threshold is used; first, by removing all pseudo nodes and second, by removing street junctions when the direction change is below the angular threshold.

What is inferred from these cross relations is that starting from a simple unweighted line-segment graph - the least aggregated graph - all other graphs can be produced, just by introducing an angular threshold and including or excluding street junctions and pseudo nodes from the graph. What is consequently clear, is that with the same Line-segment map one can derive multiple graphs using a different set of parameters; parameters which are dictated by the stance each model takes regarding the cognitive and perceptual structure of street networks.

However, what is most important is not the fact that the multiple graphs described here can be produced using the same Line-segment map. What is important is that we realize how many more graphs could be derived with a given Line-segment map and a different set of parameters. The flexibility of Line-segment maps open immense methodological possibilities, which go beyond the specific models described in this paper. For example, one could easily change the angular parameters to follow the latest theoretical insights on human cognition, without having to change the map. But one could also imagine a completely different set of parameters and decisions that could lead to different graphs, related to alternative theoretical rationales.

5. EXPERIMENTAL TOOL FOR ANALYSING MULTIPLE GRAPHS USING THE SAME LINE-SEGMENT MAP

To exploit these methodological possibilities further, we developed an experimental tool as part of PST[10]. The tool inputs a Line-segment map and can modify the graph on the fly, based on two different options; following the described models. The user first chooses an angular threshold under which all changes of direction are ignored and are not considered as graph edges. Then, the user decides whether or not to include street junctions as graph edges, even when they lead to a direction change that is zero or below the specified threshold; meaning that street junctions are considered significant, irrespectively of the actual change of direction.

What is important is that not only the graph-edges, but also the graph-nodes change in the background of the analysis(fig6). Line segments are grouped on the fly, to form greater entities depending on the parameters chosen; these groups are the graph nodes. This background operation doesn't change the integrity of the original data and the original Line-segment map; the line-segments remain unmodified. Imagine, for example, three segments which, according to the parameters of the analysis, are considered continuous and are 'compressed' to form one graph node; in the output table, they remain separate features and get the same Integration value. In simple words, a Line segment-map is analysed as if it was an Axial map or a Natural street map and so on(fig7).

To make the modification of the graphs more transparent to the user, another function is added, which reveals the different formations of the graph-nodes, by colouring the different segment groups (Fig6,7). This function also makes the testing of the tool itself easier.

In Figures 6 and 7 we see variations of segment groupings depending on a different set of parameters. As we see, there are options which match a known model, like the Axial map or the Natural street map(Fig6), but also some new variations (e.g.Fig7:cases3,4). This happens because the tool does not include or exclude all pseudo nodes from the graph by a 'True' or 'False' choice. It includes only those which are above the given angular threshold; allowing for numerous variations of the graph.

10 This experimental tool is implemented in the PST plugin to QGIS, developed by Chalmers University of Technology.

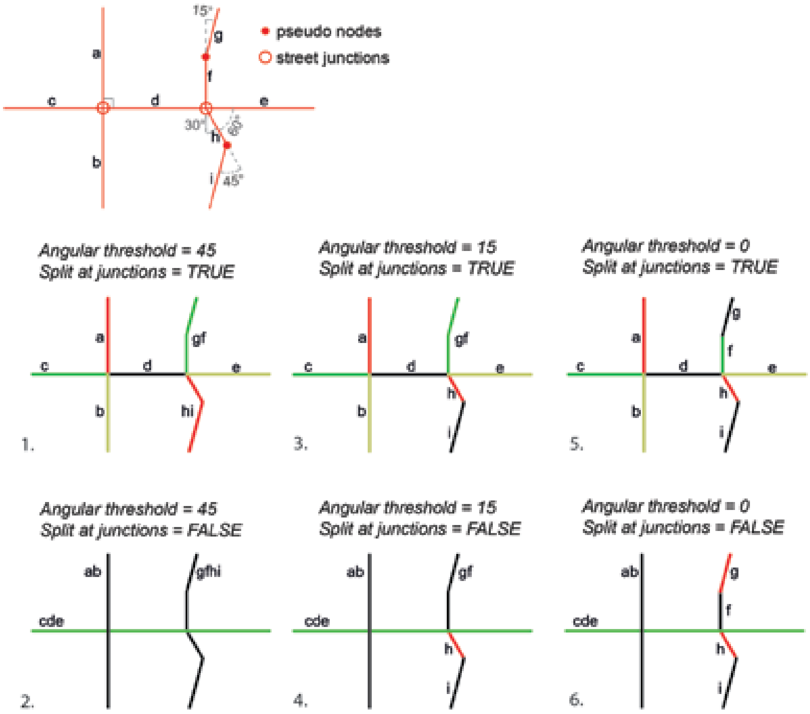

Figure 6 - Variations of a Line-segment map; segment grouping using different parameters.

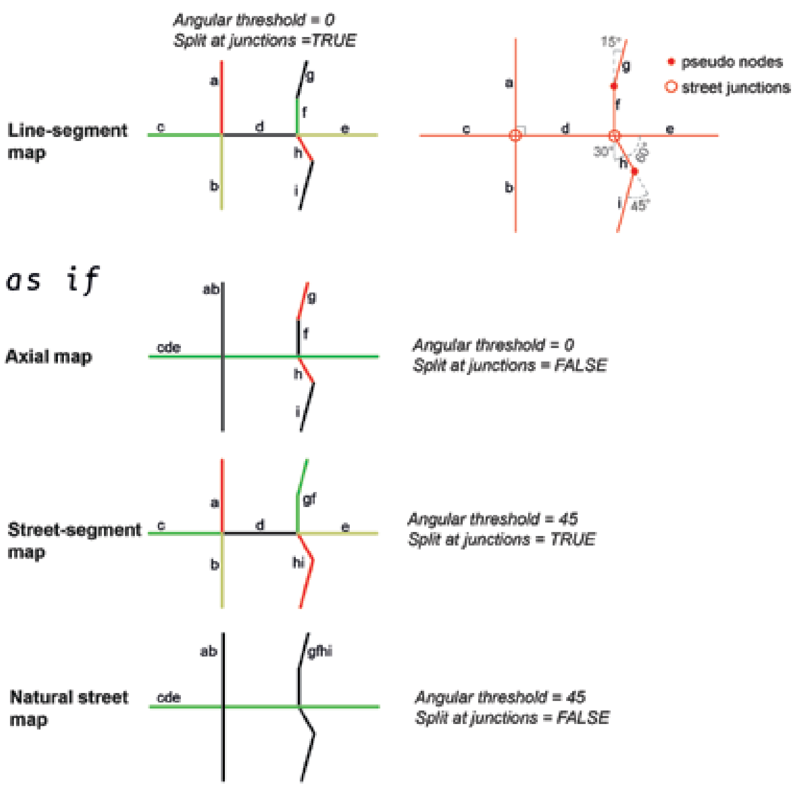

Figure 7 - Line-segment map analysed as if it was Axial map, Street-segment map, Natural street map

The experimental tool so far calculates Network Integration at different radii (steps or walking distance). Also, Node Count, Total Depth and Mean Depth are outputted in the results. One can run different analyses using a different set of parameters and the results of each calculation are written in the same table, making them easily comparable. The same map can of course be analysed using ASA in the conventional version of PST.

In Figures 8 and 9, there is an example of an existing street network and it is used just to demonstrate how the segments are grouped on the fly and how Integration results are outputted in the original map, depending on a different set of parameters[11]. The small area was picked because it includes both grid-like and more irregular network patterns. As expected, the differences are clear in both.

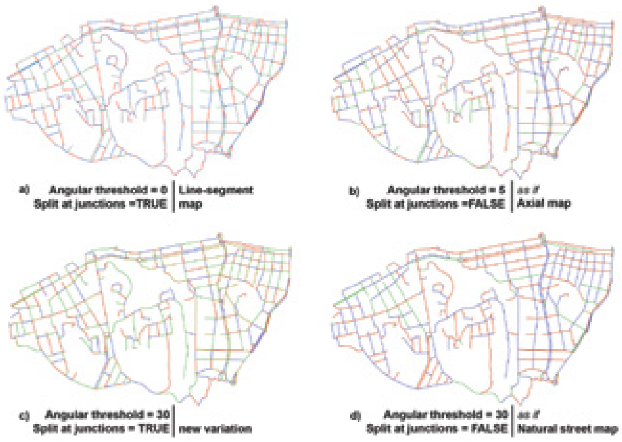

Figure 8 - Variations of segment groupings on the fly

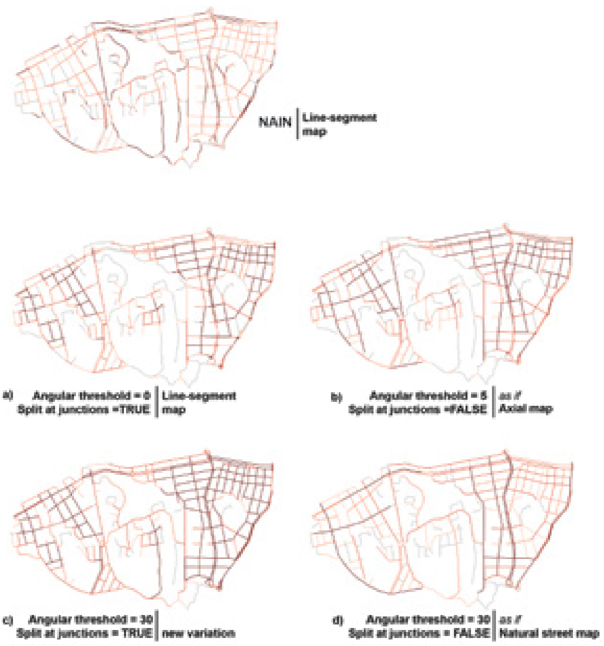

Figure 9 - NAIN and Network integration

11 As shown in Figure9b, in order to match the 'axial graph' an angular threshold of a little above zero is used. That accounts for the many small deviations between segments of linear streets, that are an artefact of the digitization of the Road-centre-line map. When drawing an Axial map such small deviations are ignored.

This investigation has not yet gone any further than to test the operational validity of the tool. We haven't reflected in depth on the results produced by the different parameters in the same urban area, nor have we tested against empirical data. These are further steps to be taken.

However, what is important in methodological terms, is that we can analyse the same street network from different cognitive and perceptual perspectives, using the same map. We can add and update results easily to follow the latest insights of cognitive science and environmental psychology. The map is 'augmented' to store all different approaches at all different times – in a way, to store past experience. Different rationales are embedded in one simple representation, in a way that can be easily comparable in a scientifically valid way. Moreover, the different variations can be comparatively tested against empirical data. Not least does this flexibility creates a great advantage in a phase where new measures are developed and thresholds and radii are tested.

6. FURTHER INSIGHTS

The value of the models described in this paper, goes beyond the question of whether or not they succeeded in offering a valid alternative to the Axial map, while using Road-centre-line maps in syntactic analysis. Perhaps it is too soon to tell; still a lot of empirical and theoretical validation might be needed. Their value lies in the fact that they enable different models to exist and to be used in syntactic analysis and that they challenged the one-to-one relation between the 'map' and the graph. Once they relativized this closed relationship by adding parameters, they opened up new methodological paths for future research.

It might not be as valuable to rush into looking for correlations to empirical data or for foundations in cognitive theory to either validate or disregard them. It is more useful to keep this discussion open, so we can exploit the potentials they created further. Should we look for one 'right' model for syntactic analysis or for a 'new' axial map; or should we explore further the possibility of Space Syntax analysis to be implemented in a multiplicity of representations and still keep its core theoretical principles? The development of these alternative models proves that it is possible. The experimental tool also presented in this paper is another step in that direction, allowing us to create and test different models using one single software.

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