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PROPOSING A NEW LEAST ANGULAR PATH
Towards a new set of betweenness centrality measure

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ABSTRACT
The calculation of the least angular path between a pair of origin and destination is a key building block for space syntax measures. A common approach for solving this problem efficiently is the Dijkstra shortest path algorithm which finds in an angular weighted graph the global least angular path between a pair of origin and destination. We argue in this research that wayfinding is a complex endeavour where pedestrian may not necessarily have global knowledge of the network and that local knowledge as afforded by the environment can also be used for path identification. Thus, this research proposes a new least angular path method, that do not necessarily contain the global optimum path. The proposed algorithm starts from an origin and it selects the next node that minimises the angular distance to the destination repeatedly until it reaches it. Empirically, this research compares both qualitatively and quantitatively the extent to which the path generated by the proposed least angular path algorithm and the Dijkstra least angular path algorithm correlates with each other. It finds that the proposed least angular path overlap approximately 75% of the time with the Dijkstra least angular path. This means that the two paths are remarkably similar yet different. The importance of the result is it shows there is another perspective of identifying a least angular path and that the framework will allow for customisable priority of different weights during the routing process. Further research is required to better understand the difference between the two algorithms and importantly to validate the use of the method with pedestrian movement data.

KEYWORDS
Spatial networks, betweenness centrality, space syntax, wayfinding, shortest path

1. INTRODUCTION
One of the most important measure in space syntax is segment angular choice, also known as angular betweenness centrality in graph theory (Hillier et al 2011). The measure calculates the number of overlaps between every pairs of least angular paths for a dual graph street network. The structural measure is important as it correlates with movement hierarchy and retail uses distribution (Hillier and Iida 2005; Scoppa and Peponis 2015). Despite its importance, little

research in space syntax literature have examined the shortest path algorithm itself (Varoudis et al. 2011). One of the most common algorithm for this problem is the Dijkstra shortest path algorithm which finds in a weighted graph the global shortest path between a pair of origin and destination. However, we argue in this research that wayfinding is a complex endeavour where the user might not have complete knowledge of all possible paths in a system to find the optimal one. This extends from previous wayfinding research where pedestrian engage in different strategy dependent on the knowledge of the environment, its demographics and the current condition. As a result, the aim of the research is to propose a least angular path method that simulates local route decisions rather than a single global route decision. This paper will compare both visually and quantitatively how the new least angular path method differs to the Dijkstra least angular shortest path algorithm. The method sets out a framework that could be used to identify least angular path differently and to produce a new set of betweenness centrality measures to be used for future research. This research is set out as follows; we first begin by illustrating previous wayfinding literature. Second, we describe the difference between the proposed least angular path and the Dijkstra global least angular path. Third, we illustrate the empirical method to measure the differences between the two. Fourth, we describe and discuss the results.

1.1. PREVIOUS LITERATURE

Wayfinding involves a complex cognitive process of identifying the paths between origins and destinations for a city or building that are affected by spatial configuration, signage, built environment and visual access (Weisman 1981). This research focuses on the spatial configuration aspect of wayfinding where two general strategies are often employed. One strategy is to take the least-effort metric shortest path to reach its destination and the other strategy is to take the simplest path such as minimising the number of turns to reach its destination (Conroy-Dalton 2003). In reality wayfinding is complex and sits somewhere between the two that depends on user familiarity, complexity of environment, demographics and information availability. Figure 1 shows the spectrum of these possible paths between an origin and destination from a spatial configuration perspective. For example, Novice users are more likely to take paths with less information required such as the least turns path while experience users are more likely to use a more complex path which often requires greater knowledge of the environment.

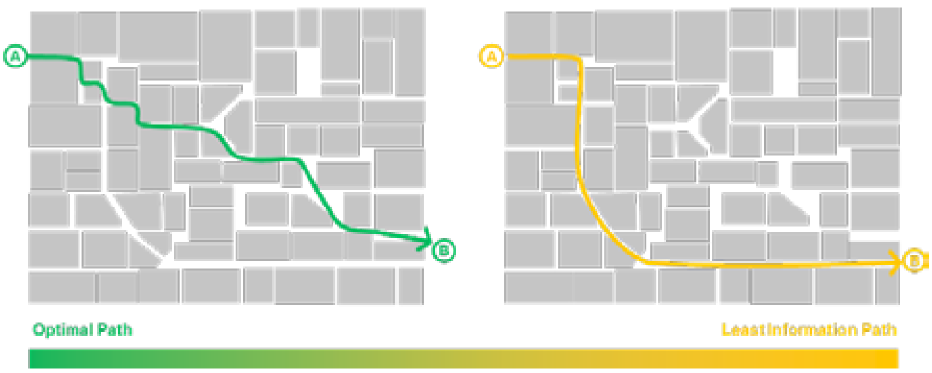

Figure 1 - Least effort path versus least information path.

Two important insights can be deduced from this. On the one hand, individual can choose from different strategy (least effort vs least information) dependent on who they are, where they are and what they know. This leads to the second insight which suggests individuals are in a constant process of routes evaluation based on the information afforded by the environment. This is related to the concept of bounded rationality in behaviour economics where we do not have perfect knowledge of the environment but rather partial knowledge (Simon 1991). This is also related to recent spatial cognition research where we are constantly retrieving information from our hippocampus (Javadi et al. 2017). Inspired from these concepts, this research proposes a new least angular path method that optimises at every step along the route. The path created is not necessarily an optimal path. This would allow future research to ask; do pedestrians have perfect information when they are navigating in an urban environment? Or do pedestrians have partial information when they are navigating.

These insights bring about two research questions; one is how can we consider this local evaluation during the route search process between origin and destination, second is do different ways of identifying least angular path make any difference empirically and third is how can we consider different weights during the route search. This paper will set out a methodological framework to potentially look at the first question and to test the extent there is overlap between a Dijkstra least angular path and the new least angular path method. This framework can then be used to answer the second question, if the new least angular path improves pedestrian movement correlation and to answer the third question, on the consideration of different weights such as metric and angular weights during the route search process. The two ladder questions will be explored in future research and described in the discussion.

1.2. DIJKSTRA LEAST ANGULAR PATH

In order to describe the proposed least angular path algorithm, we first describe the Dijkstra least angular shortest path algorithm. Dijkstra least angular shortest path algorithm starts from the origin and it searches every neighbour's node and from every neighbour's node to its neighbour's neighbour's node. This create a search tree that repeats until it reaches the destination. It adapts from the breadth first search (BFS) algorithm for a weighted graph. A least angular path is then found by minimising the global angular total depth between the origin and destination from all possible alternatives along the search tree. The algorithm involves two process the search and the path identification from all alternatives. This ladder condition finds the global least angular path. One must also note the least angular shortest path implemented in space syntax is a variation of the Dijkstra shortest path where the backward loop is not allowed. This was needed from a spatial cognition perspective as users do not backtrack to minimise angular depth. This constraint will not be studied in this paper.

1.3. PROPOSED LEAST ANGULAR PATH

The proposed algorithm uses the Dijkstra Least Angular Path algorithm within an iterative route decision process. We start from the source node. For each step within the routing process, these connected nodes calculate the distance to the target. The next node in the path is the one that is closest to the target. Here, the Dijkstra algorithm is used as a heuristic to select the next node and to approach the destination. This ensures the path will reach the destination by choosing a local optimum at every node but not necessarily its most optimal shortest path. The proposed least angular path function is described with a simplified code below which takes a graph, a source node, a target node and the angular cost as weights.

1. The function reads a dual graph, the angular weight, a source node and a destination node.
2. Start from the source node **s**, select the neighbour node **n**, that minimises the total angular length to the destination using the Dijkstra algorithm.
3. Set source node **s** = neighbour node **n**
4. repeat step 2 and 3 until it reaches the destination

Algorithm: Path Function

```
Path_function(Graph, Source, Target,Angle):
  current_distance = shortest_path_length(Graph, Source, Target, Angle)
  distances = [ ]
  Neighbour = neighbour of Source
  for node in Neighbour:
    distance = shortest_path_length(Graph, Neighbour, Target, Angle)
    if distance < current_distance: # Don't choose 'rear' nodes
      distances.append(distance)
   if distance == min(distances): # Finding 'closest' node
     Target = node
return target_node
```

We illustrate the differences between the Dijkstra least angular path algorithm and the proposed least angular path algorithm using a simple example below. Consider an agent that needs to go from Origin (O) to Destination (D) highlighted in the abstract graph (G) of figure 2.

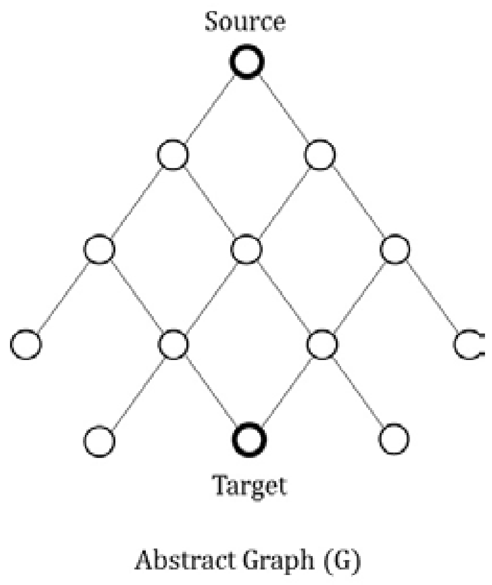

Figure 2 - Abstract graph (G).

Figure 3 shows the difference between the two methods. Fig 3a shows the Dijkstra least angular path which minimises the global total angular costs in reaching the destination. Fig 3b shows the new least angular path which minimises at each node the angular costs in reaching the destination but not necessarily attaining the global one. The new least angular path can differ or overlap with the Dijkstra optimal least angular path.

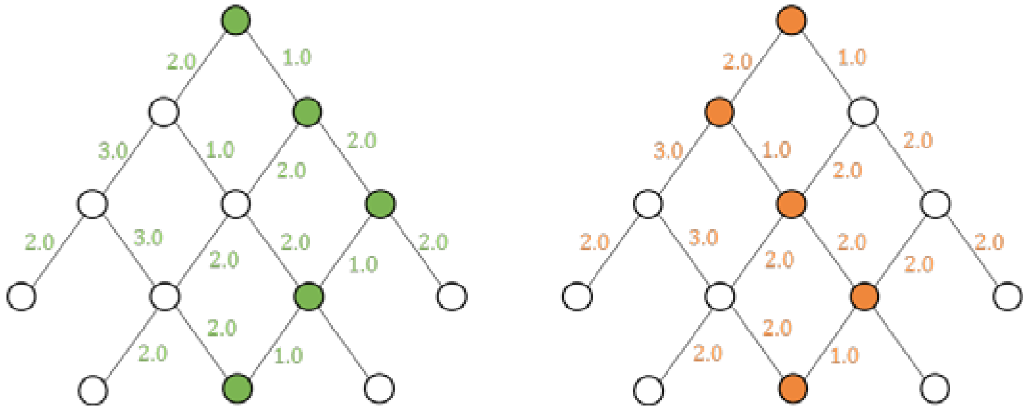

Figure 3.

a. Dijkstra least angular path. b. New least angular path.

2. METHOD

The aim of the study is to empirically test the extent the Dijkstra global least angular path differs to the new least angular path. We will conduct a comparative study between the two least angular path methods through visual and statistical analysis. Further empirical analysis will be conducted in future researches.

The visual analysis illustrates in GIS the paths generated from the Dijkstra algorithm and the new least angular path algorithm to see how the two differ visually. The quantitative analysis on the other hand tests the extent the two paths associate statistically. The steps are as follow; we first identify a set of random origin and destination. As long as, the origin (O) and destination (D) do not match (i≠j), we run both the Dijkstra least angular path and the new least angular path between the OD pair. After this we calculate the similarity coefficient between the two paths to test the extent the two sets of elements correlate. This gets repeated 250 times. We then report a basic similarity coefficient for comparison.

$$Similarity = \frac{2|X \cap Y|}{|X| + |Y|}$$

X and Y are the number of elements in each set

Equation (1)

For the experiment, this paper uses three separate case study; the City of London, Barnsbury in North London and Soho in Central London. The City of London is the financial district for the Greater London Area. Barnsbury is a predominately residential area to the north of London which had been used in previous space syntax research (Penn et al 1998). Soho is a neighbourhood in Central London with a more gridded layout. The street network for the three case studies are visualised in figure 4.

Figure 4 - a. City of London b. Barnsbury c. Soho in Central London

Table 1 illustrates the descriptive statistics for the three case studies. It shows the three case studies have roughly 2000-3000 segments. City of London has a mean angular connectivity of 2.75 and a standard deviation of 1.04. Barnsbury has a mean angular connectivity of 2.70 and a standard deviation of 0.90. While Soho has a slightly higher mean angular connectivity of 3.08 and a standard deviation of 1.21. This shows that Soho in Central London has a more gridded street layout with a higher angular connectivity illustrating more choices at each junction.

City of London	Angular Connectivity
N	2957
mean	2.75
std dev	1.04
min	0
max	7.55
Barnsbury	**Angular Connectivity**
N	2431
mean	2.70
std dev	0.90
min	0
max	5.7
Soho	**Angular Connectivity**
N	2080
mean	3.08
std dev	1.21
min	0
max	10.39

Table 1 - Descriptive statistics for the spatial network of the three areas

3. RESULTS

The result shows there are similarities and differences across the paths generated from the two algorithms both visually and statistically. We illustrate here some example paths using the two least algorithms in QGIS for the City of London case study. Figure 5 shows an example of the two least angular paths. The one on the left uses the new least angular path in red and the one on the right uses the Dijkstra least angular path in blue. The result shows the two paths can completely differ. The new least angular path in this case is metrically closer than the Dijkstra least angular path. Figure 6 shows another example. Similarly, the one on the left uses the new least angular path and the one on the right uses the Dijkstra least angular path. In this case the two paths overlap in the beginning and in the end but not in the middle. What is interesting is that the proposed least angular path meanders towards the destination while the Dijkstra least angular path takes a route with one large turn in reaching it. The result also shows that even for the path that differs there are still section of the path where the two overlaps. Figure 7 shows one more example where the two paths completely overlap. The path is noticeably shorter than the other two. There is a possibility that the shorter trips (fig 7) are more likely to overlap than longer trips (fig 5&6). This is logical as longer trips would also have more decision-making points than shorter ones. For brevity reasons, only three examples have been visualised here. On average, the two paths generated from the two algorithms appear to be quite similar. Further research on individual paths are needed to understand the two methods empirically.

To summarise, the proposed least angular path algorithm can create a different path in comparison to the Dijkstra least angular path algorithm by selecting a different tree during the routing process. Secondly, even when the two paths differ, there can be sections where the two paths might overlap. This means, the probability of having two completely different path is low. Thirdly, there are many cases where the two paths overlap completely or for large section of the path. This means the two algorithms produce similar results where the similarity coefficient is likely to be high.

Figure 5 - Shortest Path Comparison - When the two do not overlap (City of London)

Figure 6 - Shortest Path Comparison - When the two differ in some section (City of London)

Figure 7 - Shortest Path Comparison - When the two are the same (City of London)

3.1. QUANTITATIVE RESULTS

Table 2 shows the similarity coefficient for the City of London case study. Figure 8 shows the histogram of the results. The City of London area has an average similarity coefficient of 0.76 meaning that the two paths overlap roughly 76% of the time. The histogram shows nearly 50% of the path have a perfect match. The standard deviation is approximately 0.28 suggesting there are significant variations.

N	Average	std dev	Min	Max	Median
250	0.762	0.270	0.036	1	0.889

Table 2 - Similarity Coefficient Statistics for City of London

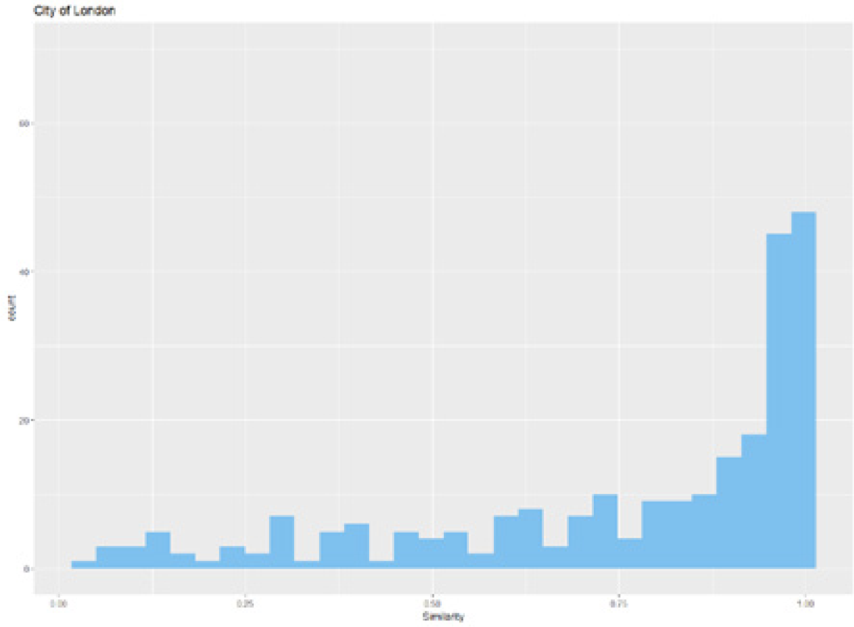

Figure 8 - Similarity Coefficient histogram for the City of London

Table 3 shows the similarity coefficient for the Barnsbury case study. Figure 9 shows its corresponding histogram. The area of Barnsbury has an average similarity coefficient of 0.75 meaning that the two paths overlap roughly 75% of the time. These results are consistent with the City of London case study.

N	Average	std dev	Min	Max	Median
250	0.748	0.269	0.029	1	0.847

Table 3 - Similarity Coefficient Statistics for Barnsbury

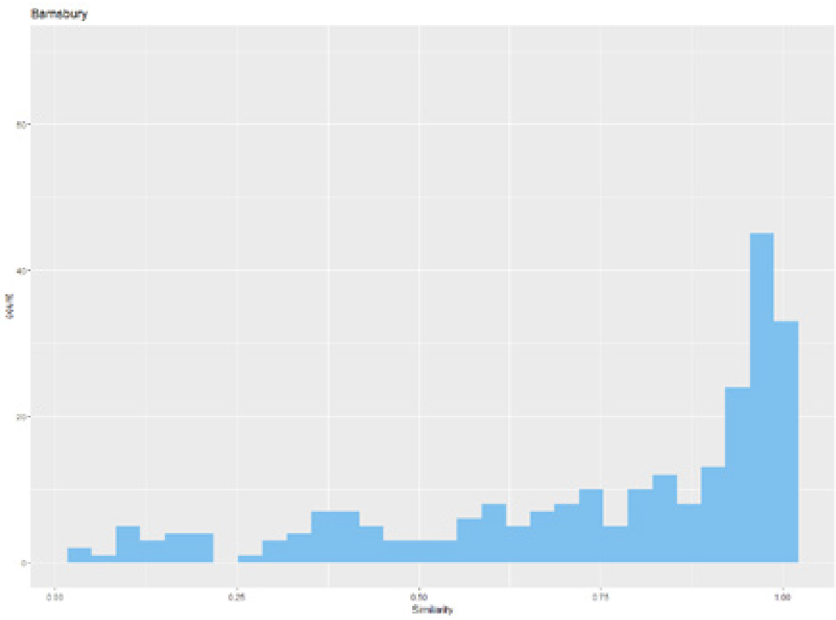

Figure 9 - Similarity Coefficient histogram for Barnsbury

Table 4 shows the similarity coefficient results for the Soho case study. Figure 10 shows the histogram of the results. The area of Soho has on average a similarity coefficient of 0.69 meaning that on average the two least angular paths overlap 69% of the time. The similarity coefficient is slightly lower for this case study. A plausible explanation is that this could be related to the more grid-like layout of Soho where there are greater choice at each junction.

N	Average	std dev	Min	Max	Median
250	0.762	0.313	0.049	1	0.790

Table 4 - Similarity Coefficient Statistics for Soho

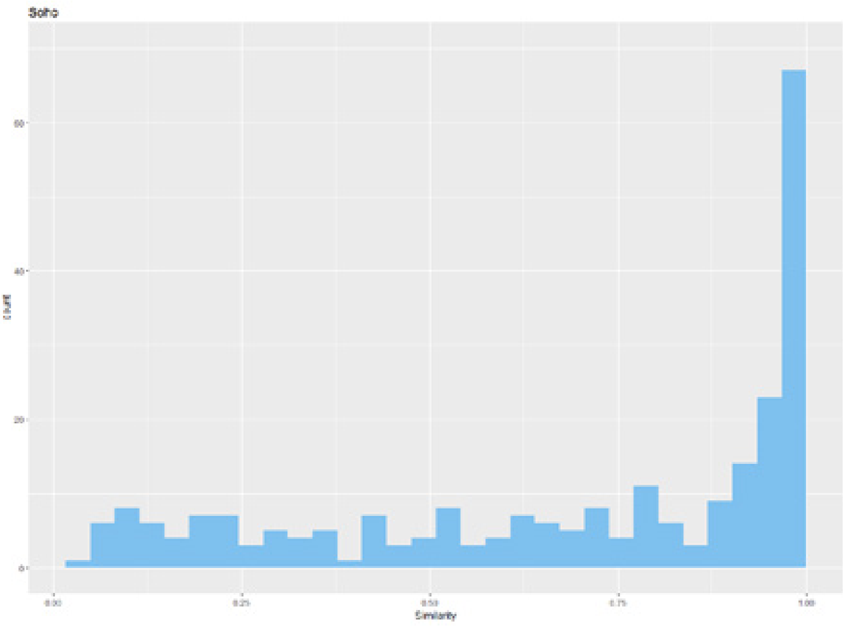

Figure 10 - Similarity Coefficient histogram for Soho

4. DISCUSSION

This study compares the Dijkstra least angular path algorithm and the proposed least angular path algorithm. The proposed algorithm starts from an origin and it selects the next node that minimises the angular distance to the destination repeatedly until it reaches it. In simpler terms, way-finding between an origin and destination follows a 'local' turn-by-turn route decisions rather than a single 'global' decision. The results showed the two algorithms are both visually and quantitatively different. Quantitatively, the Dijkstra least angular path and the proposed least angular path overlap approximately 75% of the time. This means that the two paths are remarkably similar yet different. The similarity varies between different origin and destination and is greater for shorter trips and lesser for longer trips. The visual analysis reveals the new least angular path produce plausible paths towards the destination. The importance of the result is it shows there is another perspective of identifying a least angular path that adheres to the local knowledge of human cognition. The main contribution of the research is the methodological framework allows for further investigation on how local knowledge of the environment can influence wayfinding. Route choice algorithm that tries to represent this local nature of wayfinding should be further examined.

There are a number of limitations to the research. Despite the proposed algorithm in using the Dijkstra algorithm as its path heuristic, it was surprising to see the extent the two algorithms differ in the path identification. There is no clear explanation to this difference. As a result, more research is needed to explain and describe the difference. For example, to what extent is the path identified by the proposed algorithm longer than the Dijkstra least angular path algorithm. How do these differences scale when the total length of the route increase? More importantly, this research only proved the two paths can differ significantly but not if the methodology proposed is a better predictor for pedestrian movement than the Dijkstra algorithm. Empirical analysis is therefore needed to validate the extent the new least angular path associate better or worst with pedestrian route choice or aggregate pedestrian movement. A new set of choice or betweenness centrality (Brandes 2001; Hillier and Iida 2005) measures can be formulated for this purpose. The last limitation is this research only applied a single set of weights in identifying a shortest path. Further research can explore how different weights can be embedded in the route choice process dynamically. One of the original conception of the research is to design an algorithm that would allow a prioritisation process between different weights during the route search. This will be discussed, implemented and validated in the next stage of the research using this methodological framework.

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