The Secret is to Follow Your Nose

Route Path Selection and Angularity

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Abstract

This paper presents the results of an experiment in which route-choice decisions made by subjects at road-junctions are recorded. It will then demonstrate that a route can be expressed as the sum of the individual decisions made or as the sum of all possible decisions available (i.e. potential choices) during a journey. The relationship between these two values will be compared statistically indicating that the decisions made at road-junctions correlate more strongly with maximum angles of incidence of road-center-lines leading from a junction than to mean or minimum angles. One interpretation of this phenomenon is that subjects appear to be attempting to conserve linearity throughout their journey. Since any theory based upon the conservation of angular linearity appears to be refuted by certain, informal observations of subjects traversing urban grids, the first theory put forward in this paper is then modified to account for this particular case. The final hypothesis presented in this paper is based upon acts of rule-based decision-making combining principles of the conservation of linearity whilst minimising the angular difference between bearings. The two key bearings are those of the direction of potential route choices compared to the perceived bearings of the wayfinding goal as judged from sequential instances of the observer's location. This theory of modified angular conservation is called 'The British Library Theory'.

In (Conroy, 2001) it was demonstrated that the most popular routes from a sample (as calculated using string-matching techniques) also appeared to be more 'linear'. This observation reproduces similar findings made in (Golledge, 1995). The question that these observations prompt is what route choices are individuals making at road junctions such that their actions result in this apparent conservation of route linearity? Therefore, in this paper a method is proposed for the determination of route choice decisions made at consecutive road junctions over the duration of a single journey. This method employs a measure of angular deviation (from a straight line or direction) and uses this to develop a cumulative measure for an individual's entire journey, based upon the summation of all choices made at every junction encountered along the route.

The hypothesis that this method was developed to test is that an individual subject will follow as straight a route as possible with minimal angular deviation (from a straight line) on condition that this choice always approximates the direction of their final destination. Another way of stating this hypothesis is that essentially people 'follow their noses' whilst navigating through an environment.

The Test Environment

The environment used to test this hypothesis was particularly suitable for the purpose; it is a virtual simulation of an urban environment containing a variety of urban 'block' shapes (the majority are either squares or equilateral triangles) and subjects navigated through the environment immersively (using a virtual reality headset). See figure 1.0 for an eye-level view of this world. The male subjects composed 67.7% and the female subjects 32.3% of the experiment-participants. Thirty volunteers took part in this experiment with a mean age of 28.

Were it a real environment, this virtual world would cover an area of 650 x 650 metres (711 x 711 yards). Assuming an average walking speed of approximately four miles per hour, it would take a subject six minutes to traverse one side of the equivalent real world area or approximately eight and a half minutes to traverse diagonally from one corner to another. The subjects participating in this experiment were in the virtual world for a maximum of ten minutes and their walking speed approximated a real word walking speed. All the subjects entered the virtual environment and started 'walking' from the same starting position (the top right-most corner on plan, see figure 1.1) and were instructed to 'walk' to the opposite corner by the most direct route possible. The subjects were requested not to walk around the outer edges of the world and the majority of the subjects heeded this instruction.

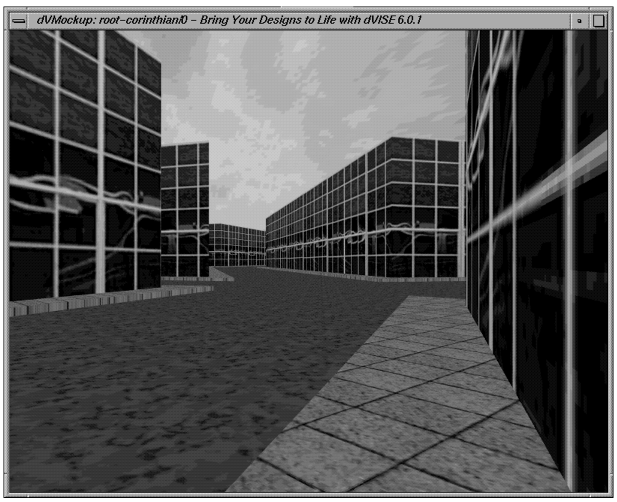


Figure 1.0: The virtual test environment

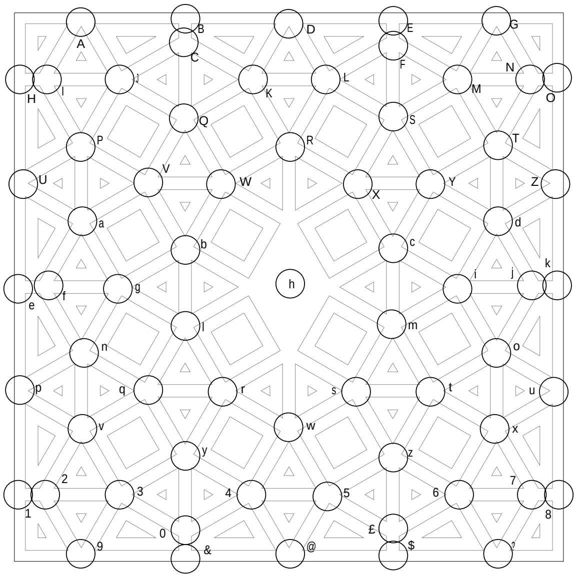
There were two design criteria for this theoretical world that made it the most suitable environment for testing measures of angular deviation. The first criterion dictated that a standard length of 'street' to be used wherever possible. The use of a standard street length ensured that the subjects could not be basing their route choice decisions upon this factor, e.g. choosing to follow the longest street at each junction. The second criterion for the design of this test environment concerned the type of junctions formed by the streets. It was determined that the street system in the world should contain as large a variety of junction types as possible causing subjects to be presented with a range of alternative choice decisions at every junction.

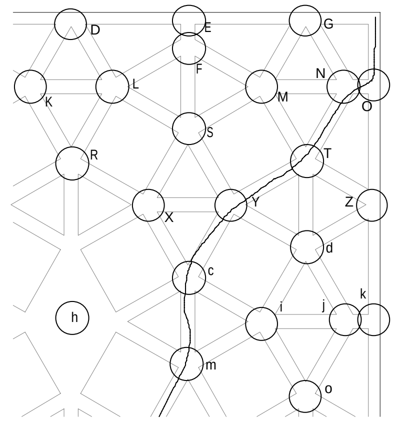
The variety of junctions constituting this urban simulation varied both in terms of the actual number of route choices available at any single junction (e.g. at a crossroads the number of route choices is four) and by the angles described between the streets leading from a junction. In some situations the choices available would consist of symmetrical options (i.e. at a T-Junction) and in other situations of asymmetrically placed options with reference to the approach road leading to that junction. In the test environment, the numbers of choices at junctions ranged from three (a classic T-Junction) to ten (where a number of streets converge at the center of the world). The minimum angle between any two roads in this world is 60° and the maximum angles 180° (straight on) and 150°.

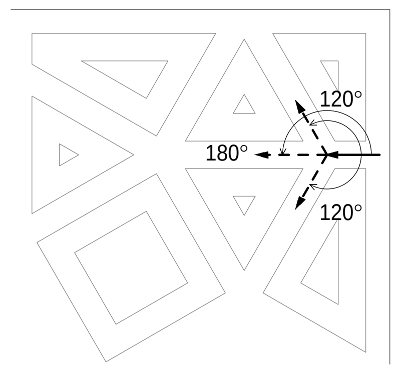
Method

The position of each subject was recorded ten times per second whilst they moved through the virtual environment and their paths were plotted onto a plan of the world. The resultant data set consisted of thirty trails each representing a different journey through the same urban simulation.

Before the route of each subject can be analysed individually, each junction in the world needs to be identified and tagged. Every junction, that is to say every location where a route choice decision has to be made, is marked with a unique identifier, in this case an ASCII[1] text







marker. These junctions will be referred to in this paper as route choice nodes. In the test environment, sixty-seven such route choice nodes were identified and named. The junctions are circled on figure 1.1 annotated with their ASCII text markers.

The route of each individual subject can then be broken down into a sequence of chronologically ordered route choice nodes. To illustrate this process a single route can be analysed as follows. Figure 1.2 shows the initial portion of a single route taken by an individual subject (subject number 021).

It can be seen that the subject passed through the route choice nodes labelled 'O', 'N', 'T', 'Y', 'c' and finally 'm' (after node 'm' the route taken is no longer shown in figure 1.2). These nodes can be listed sequentially in the order in which they were encountered by the subject. By listing the nodes in this manner, it can easily be seen that the first location where the subject needed to make a decision was route node 'O' and that the second location was route node 'N' et cetera. By continuing to list the route choice nodes in this way, the entire journey can be represented as a string of ASCII text characters. For example, the following ASCII text string can be used to represent this particular subject's journey[2].

O-N-T-Y-c-m-s-z-£-$-?

After the initial stage of determining where the subject was required to make decisions, the actual decision made at each junction can now be examined. Taking the same journey, O-N-T-Y-c-m-s-z-£-$-? it is possible to consider the range of choices available at the first node 'O' and the choice made by the subject. This can be analysed in the following manner.

At node 'O', the subject had a choice of two possible options. They could have taken the first right turn (i.e. turned through an absolute angle of 90°) or continued in a straight line, which can be considered either as 0° or 180°. For the purposed of this paper, continuing straight on will be held to be 180°. When first developing this method of choice analysis, the option of turning around completely and heading back in the direction from which the subject had already walked, was also counted as a valid choice. This option was held to be equivalent to an angular choice of 0° (which is historically why the choice of 'straight on' was

Figure 1.1 (top left): Unique identification of junctions using ASCII markers

Figure 1.2 (above): Initial section of route taken by subject number 021

Figure 1.3: The angles of choices available at junction O.

considered 180° rather than 0°).[3] Therefore, the number of choices available at each junction originally included the option choosing the road along which the subject had just travelled. For example, at choice node '0' instead of two choices there would be three, since returning to the starting point would also be considered to be a valid option. However after analysing all decisions made by all subjects at all junctions, it was apparent that none of the subjects in the sample ever made such a choice (termed 'backtracking' in wayfinding literature) and it was ultimately removed from the analysis. Subsequently the number of choices available is calculated as being the number of roads forming the junction (n), less the approach road (i.e. n-1). However, the convention of counting 'straight on' as a 180° choice rather than 0° has remained unchanged. These are the conventions used in the rest of this paper.

In summary, for node 'O' it can be stated that the absolute angle (it is irrelevant whether it is to the left or to the right, i.e. all angles are positive)[4] that the subject turned through at node 'O' was 90°. The number of choices available were two (turning back was not counted as an option), the maximum angle the subject could have chosen was 180° (i.e. continued straight on) and the minimum angle they could have chosen was 90° (turned right). The average value of the available choice angles at node 'O' was 135° or (90° + 180°)/2. These values are shown in the first row of table 1.0 below.

Route 021 Spaces	Abs. Angle Turned Through	Mean Angles at Route Node	No. of Route Choices	Max. Angle of Incidence	Min. Angle of Incidence	Random Choice of Angle	Angle Chosen Randomly
O	90	135	2	180	90	0	90
N	120	140	3	180	120	0	120
T	150	112.5	4	150	60	0	60
Y	150	112.5	4	150	60	1	150
c	150	112.5	4	150	60	1	150
m	150	105	4	150	60	1	150
s	120	105	4	150	60	0	90
z	150	112.5	4	150	60	0	90
£	180	100	3	180	60	1	180
$	90	90	2	90	90	1	90
?	180	120	3	180	60	2	180
ONTYcmsz£$?	139.09	113.18	3.36	155.45	70.91	0.64	122.73

Table 1.0: Choices available and selected during route 021

Also included in table 1.0 is a randomly chosen route decision (columns seven and eight). This choice was produced by using a random generator (column seven), based on the number of options available (column four). The route is then selected by counting the streets, as they appear in the world, rotating in an anticlockwise direction from the approach road. For example, at node 'O', as the subject turns in an anticlockwise direction (starting facing their approach road) the first street encountered is assigned choice zero, the second street choice one et cetera. Since the random generator produced a choice of zero at this junction, then the first choice counted in an anticlockwise direction is 90° (column eight). This process is analogous to the subject stopping at a junction, flipping a coin or throwing a dice (or performing an equivalent random act) in order to make a route choice decision. The subject then notes down what the outcome of the random process would have been, but nevertheless decides to make his or her own decision regardless of the outcome of the random act. The randomly generated choice does not, therefore, constitute a randomly generated route through the virtual world, it only represents a single random choice made at each individual node or junction and furthermore a choice that is not acted upon.

Returning to the route of subject 021, the next choice node this subject reached was node 'N'. The choices at this junction were quite different to node 'O'. This time the subject has a choice of three routes. Listed in an anticlockwise direction, they are 120°, 180° and 120° again. The second 120° option is listed as 120° rather than 240° because we are primarily interested in the deviation from the straightest route and not interested in the 'handedness' of the choice selected[5]. Another point to note about this node is that the choices appear to be symmetrical when approaching the junction from the direction of node 'O', see figure 1.4.

At node 'N', the subject chose to take the leftmost road (considered from the direction of 'O'), choosing one of the 120° options. The maximum angle they could have chosen was 180°, the minimum choice being 120°. The mean choice would have been 140° or (120°+180°+120°)/2. This time, the random generator also selected choice zero (namely the first street to appear when turning in an anticlockwise direction, starting from the current street). In this case, choice zero, the random choice, would also have been 120°. This data can be read off the second row of table 1.0.

If this process (of analysing all possible choices and recording which choice the subject made) is repeated for every junction encountered by this subject during the journey O-N-T-Y-c-m-s-z-£-$-?, then this information can be entered into each row of the table 1.0 until the choice data for each junction is completed.

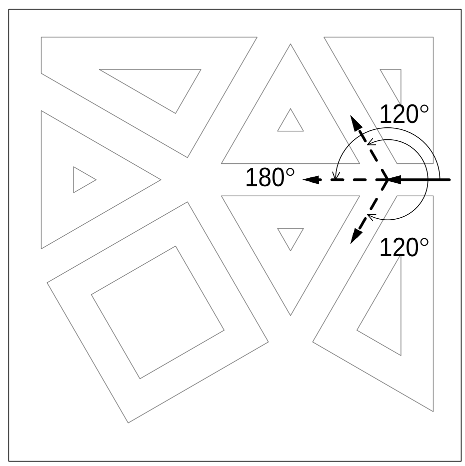


Figure 1.4: Angles of choices available at junction N

In summary, this subject passed eleven locations where route choice decisions needed to be made. The average choice of angle can now be determined for the route as a whole. This is measured by taking the absolute angle selected by the subject at each individual node and calculating the average value of all angles selected at all nodes constituting the route. Subject 021 chose an average angle of 139.09° over their entire route, as shown in the last row of column 2 of table 1.0. The average maximum angle available for choice over all eleven junctions can also be calculated and is shown in the last row of column 5 of table 1.0. For subject 021 the mean maximum angle value is 155.45°. The final value in column 6 shows the average minimum angle over the eleven junctions, which is 70.91°. The column entitled 'Mean Angles at Route Node', column 3, calculates the average angle for all choices at any individual node and then calculates the average angle over the entire journey. For subject number 021 this value was 113.18°. Finally, column 4 indicates the average number of choices available throughout the journey, which in this example is 3.36. The final column shows the value of the randomly chosen angle at each junction, averaged over the duration of the subject's journey.

Once the choices made by each subject at each junction along their journey have be translated into average values for the journey as a whole, it is possible to compare these average-route values to every other subject participating in this experiment.

Subject Number	Route Represented as ASCII String	Mean Angle Turned Through at Route Choice Nodes	Mean of all Possible Angles at Route Choice Nodes	Mean No. of Possible Route Choices Available	Mean Maximum Angle of Incidence	Mean Minimum Angle of Incidence	Mean Random Choice of Angle	Mean Angle Chosen Randomly
Subject 001	ONTYXRWVPU	133.33	114.72	3.67	156.67	70	1.33	123.33
Subject 002	GMSXhw 5@$?	138	108	4	159	57	2	111
Subject 003	GMFLKDBA	120	109.69	3.25	153.75	63.75	1.38	123.75
Subject 005	GMSLRWVaUe	137.5	112.29	3.42	157.5	65	1.08	130
Subject 006	OZdiox6£$@&	147.5	112.71	3.17	155	67.5	1.25	117.5
Subject 007	GMSLKCBA	135	107.19	3.38	146.25	63.75	1	116.25
Subject 008	OZdimsw 40&9	144.55	108.64	3.36	150	65.45	1.27	100.91
Subject 009	ONTYcmsz£$?	139.09	113.18	3.36	155.45	70.91	1.09	103.64
Subject 010	OZdimsz£$?	147	109.75	3.3	156	66	1.1	123
Subject 011	GMSXhw 5@$?	138	108	4	159	57	1.3	87
Subject 012	OZku8?$@&9	180	127.5	2.5	180	75	0.8	132
Subject 013	OZdimsz£$$@	154.62	114.42	3.08	161.54	69.23	0.92	101.54
Subject 014	ONTMSFLDKQJ	90	107.12	3.46	154.62	66.92	1.38	117.69
Subject 015	OZdimsw 40&9	144.55	108.64	3.36	150	65.45	1.55	114.55
Subject 016	ONTYchry39	141	113	4.1	156	63	1.7	111
Subject 017	GMSLDBA	145.71	111.07	3.29	158.57	64.29	1.57	132.86
Subject 018	OZdiox7?	131.25	107.81	3.38	150	63.75	1.5	112.5
Subject 019	ONTYcmsz£$?	139.09	113.18	3.36	155.45	70.91	1.45	117.27
Subject 020	GMSXhlqv39	138	103.5	4.3	153	54	2.2	105
Subject 021	ONTYcmsz£$?	139.09	113.18	3.36	155.45	70.91	0.64	122.73
Subject 022	OZku8?$@&9	180	127.5	2.5	180	75	0.8	129
Subject 023	ONTYXRKDBA	135	115	3.3	159	72	1.1	126
Subject 024	GEDKRhw 5@&	152.73	112.5	3.73	163.64	65.45	1.45	109.09
Subject 025	ONMSLKQJIH	138	111	3.4	153	72	1.1	123
Subject 026	GEDBAHUep1	180	127.5	2.5	180	75	0.5	117
Subject 027	GMSLKCJIHUep	150	112.31	3.15	156.92	66.92	1.08	115.38
Subject 028	GEDKQVafep1	150	112.73	3.09	155.45	68.18	0.64	111.82
Subject 029	GMSLKCBA	135	107.19	3.38	146.25	63.75	1	116.25
Subject 030	OZdiox7?	131.25	107.81	3.38	150	63.75	1	116.25
Subject 031	GMSXhw 5@$?	138	108	4	159	57	1.7	102

Table 1.2 Cumulative angular choices for all routes

Results

Table 1.1 records the route choice data averaged over the entire journey for each subject participating in the experiment. Each route was reduced to available choices and the decisions actually made at each junction in the same manner as the previous example for subject number 021. Column 1 of table 1.1 shows the subject number, column 2 is the ASCII string representation of the route, listing the junctions the subject encountered and the order in which they passed through them. The third column illustrates the average choice of angle that each subject made over the duration of the journey. For example, if a person, hypothetically, were always to take a right turn followed by a left turn whilst navigating (an option not actually possible in this test environment) then the average angle chosen by that person throughout their journey would be 90°, since this would be their choice at every junction. Equally using a second hypothetical example, if a person were to choose to go straight on at every junction (assuming a world where this were possible) then the average angle over their entire route would be 180° (using the angular conventions established earlier in this paper).

Column 4 in the table shows the average choice of angles available to the subject over their chosen route. This is simply a measure of the average angle of all available choices at any single junction, which is then averaged over the journey as a whole. This measure is most usefully read alongside columns 6 and 7, which show the average maximum angle and average minimum angle available over the route. This is simply a case of noting down the maximum angle of incidence available at every junction and then averaging them for the whole journey and performing the same calculation for the minimum angle of incidence. Column 5 simply indicates the average number of choices available over the entire journey. If we round this number to the nearest integer value (since it is not possible to have a fractional number of choices) then the distribution is as follows - the majority of subjects (23 people or 76.7% of the sample) had an average of three possible route choices at every junction (e.g. a crossroad offers three choices assuming that turning around completely is an invalid option). Seven of the subjects (or 22.6% of the sample had an average of four choices available to them over the entire route (a junction formed by five roads).

The two final columns in the table contain information that relates to the random generator. Using the example of route 021 again, at every junction where a decision needed to be made, a random act occurred. This act was analogous to flipping a coin at a T-Junction or rolling a (tetrahedron) die at a junction of five roads, or indeed rolling a hypothetical three-sided die at a crossroad. At each node the randomly generated act is specifically tailored to that particular junction. Column 8 simply illustrates the average outcome of this random act over the entire route, whereas column 9 (the last column in the table) shows the angle of the road that would have been chosen by the subject if they had used the random generator to guide their decisions (which they did not). This randomly chosen angle is averaged over the whole journey in a similar manner to all the other measures. It is then possible to compare graphically some of these values for the overall journey for all subjects. The chart in figure 1.5 below compares four of the values from table 1.1, plotted as a line chart.

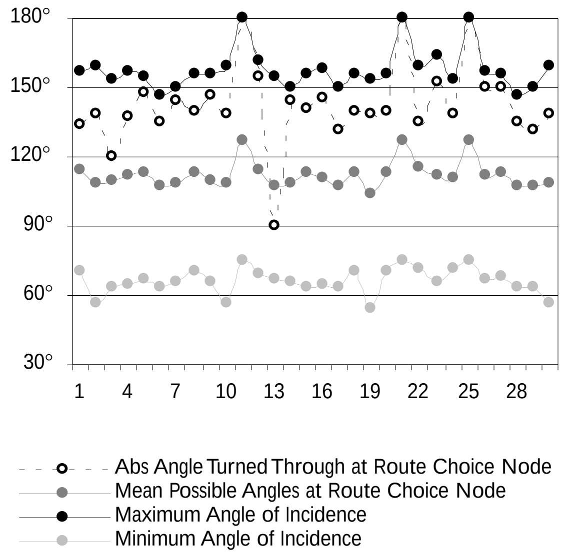


Figure 1.5: Chart comparing cumulative angular choices for all routes

The information in figure 1.5 represents columns 3, 4, 6 and 7 of table 1.1. The chart shows four values that have been plotted for each of the thirty subjects. The values plotted are the mean maximum choice angle available (in black), the average choice angle available (in gray) and the mean minimum choice angle available (in light gray). These values vary from person to person since they are entirely dependent on the exact route taken through the environment and not a property of the environment as a whole. However, the values for the average choice angles (gray) lie approximately halfway between the mean maximum choice angles (black) and the mean minimum choice angles (light gray), which is exactly as expected. The dotted line shows the exact choice (in terms of angle) taken by the subjects and averaged over the journey as a whole. Therefore the three shaded lines represent the range of available choices, whilst the dotted line represents the choices actually taken by the subjects.

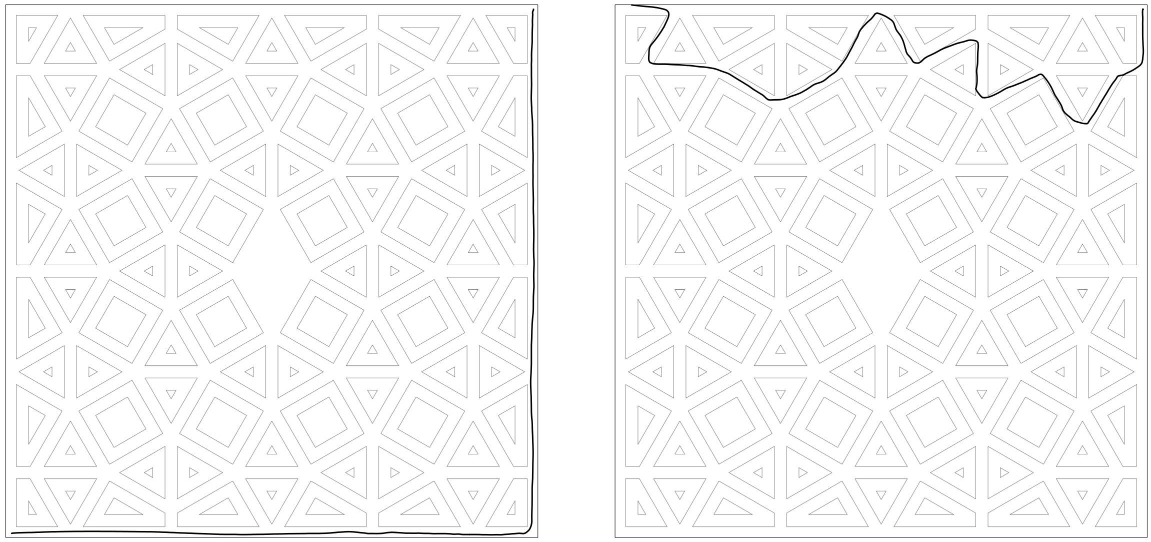


Figure 1.6: The 'straightest' (left) and most 'deviating' (right) routes in sample

The dotted line has three principal maxima, these represent routes where the average angle of incidence chosen is approximately 180° (i.e. straight on). Since it is not actually possible to cross the test environment from one corner to the other by choosing 180° at every junction (since such a choice is not available), these three subjects were only able to attain such a high cumulative angle score, by walking around the edge of the world (see uppermost diagram of figure 1.6). This is precisely the strategy taken by these three subjects despite that fact that they were instructed to traverse the world diagonally from one corner to the other rather than to 'circumnavigate' it. However, it serves as a valuable illustration for the use of this method for gauging the choices made at junctions compared to the choices available.

The subjects who chose to circumnavigate the test environment were subjects number 12, 22 and 26 (see table 1.1). There is only one subject whose angular choices were actually less than the average (the point where the white line dips below the yellow line). This is subject number 14. Essentially, subject number 14 took the most meandering route of the sample, hence the corresponding value of their mean angular choice. Figure 1.6 below shows images of the routes of subject numbers 12 and 14 (namely the 'straightest' and most 'meandering' routes in the sample).

Having examined some of the particular areas of interest of the graph illustrated in figure 1.5, namely the maximum and minimum values of the individual routes, it is clear that subjects are tending to choose roads that are on average closer to the maximum angle of incidence than to either the average or the minimum. Another way of phrasing this, is that as far as possible, subjects are choosing routes which tend to approximate as straight a line (the value of going straight on being 180°).

Figure 1.7 above also shows the mean angular choice value of the routes taken by the subjects (dotted line) plotted against the randomly generated route choice (grey line). The three maxima are again obvious (subjects 12, 22 and 26) as is the minimum value, subject number 14. It can be seen here that for every route excluding two (subjects 14 and 3) the routes chosen exceed the randomly chosen routes (in terms of angle), i.e. people are not only choosing straight paths, but furthermore, that this strategy appears to be the result of a deliberate rather than a random process. This would appear to begin to provide evidence to support the hypothesis put forward at the beginning of the paper, namely that that an

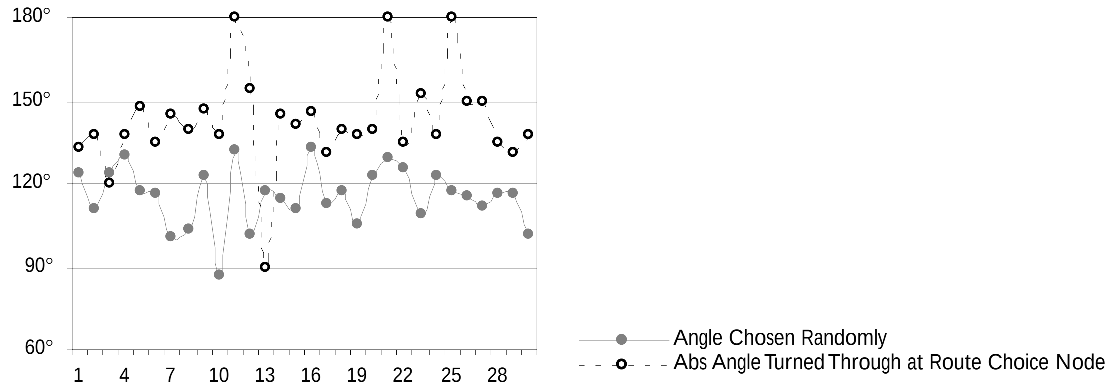


Figure 1.7: Cumulative choices made compared to random choices

individual subject will follow as straight a line as possible, with minimal angular deviation (from that straight line), on condition that this choice is always approximately in the direction of their goal.

Statistical Results

It is possible to examine the above graphs (figures 1.5 and 1.7) by eye and form the judgement that it appears that people are making route choice decisions at junctions, taking roads which are closer to the maximum angles of incidence (measured between their approach road and their selected road) than to either the average or minimum angles. This judgement arises from the fact that the line on figure 1.5 which represents the selected angles (the dotted line) seems closer to the maximum angles line (the uppermost black line) than to the line representing the mean angles (the middle grey line). However, is there a more objective method to confirm this finding, compared to subjectively scrutinising these graphs?

If the data for all nodes is considered in isolation, i.e. particular groupings of subjects, routes or sequence are completely disregarded, then it is possible simply to consider every junction where any subject made a decision. In this way every subject/junction decision can be compared statistically against every other (regardless of all other information). Over the thirty routes and thirty subjects, there are data for 306 individual node decisions (this is an average of 10.2 junctions per subject, namely that any subject encountered 10.2 junctions on average over a single journey.) If the data for all these nodes is considered as a single data set, the following properties of this data can be examined; the choice taken by any subject at a junction, the maximum angular choice available, the average angular choice available and the minimum angular choice available. It is also possible to calculate the difference and absolute difference between the angle chosen and the maximum, mean and minimum angles available for choice at each node.

The first node from route 021 can, once again, be used as an example (see figure 1.3). The first decision that subject 021 was required to make was at junction 'O'. The maximum angle available to choose was 180°, the minimum angle was 90° and the average was 135°. The angle actually chosen by the subject was 90°. The absolute difference (here it does not matter if it is greater than or less than the angle chosen, it is simply the difference measured in degrees) between the chosen angle and the maximum angle would be (180°-90°) = 90°. The

	Mean/Degrees	Variance/ Degrees	Standard Deviation/ Degrees
Difference betw een chosen angles & maximum angles	15.2	750.95	27.4
Difference betw een chosen angles & mean angles	36.89	820.48	28.64
Difference betw een chosen angles & minimum angles	76.08	1387.19	37.25

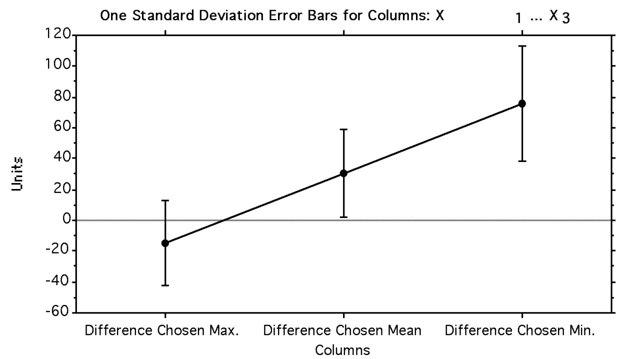


Table 1.3: Statistical comparison of difference between maximum, minimum, and mean cumulative route choices

Figure 1.8: Statistical comparison of difference between maximum, minimum, and mean cumulative route choices

difference between the chosen angle and the mean angle would be (135°-90°) = 45° and finally the difference between the chosen angle and the minimum angle would be (90°-90°) = 0°. In this single example it is clear that the choice made by the subject was in fact closer in absolute degrees to the minimum angle than to the maximum or to the mean angles. How does this pattern change when such 'difference values' are calculated for all 306 nodes with route decision data?[6].

Once this node-data has been isolated from the subject/route data, for each of the 306 junctions-decisions it is possible to calculate an average value for each of the three 'difference-values'. The average, absolute difference between the value chosen at the 306 junctions and the maximum angle is 15.20°. The average, absolute difference between the chosen angle and the mean junction angle is 36.89° and finally the average, absolute difference between the value chosen at the junctions and the minimum angle is 76.08°. From this, it is clear that the subjects are tending to choose roads that are far closer to the maximum angle than to either the average or minimum. These values are summarised in table 1.3 alongside the variance and standard deviation for the 306 'difference-values' between the chosen angles and the maximum/mean/minimum angles.

These statistics show that both the variance and standard deviation is less for the absolute difference between the chosen angle and the maximum angle than between the chosen angle and either the mean or minimum angles. It can also be noted that the values for both variance and standard deviation are quite similar for the difference between the chosen and maximum/average values when compared to the difference between the chosen and minimum values. This implies that the angles selected by the subjects actually lie approximately halfway between the mean and maximum values although they are slightly closer to the maximum angles.

This same information can perhaps be seen most easily on the graph below, which shows the standard deviation of the difference values in degrees between the angle chosen by the subject and the maximum angle available (leftmost bar on chart) the mean angle (middle bar on chart) and the minimum angle available (rightmost bar on chart). The difference between the maximum and chosen angles is negative since the chosen angle was often less then the maximum angle chosen but greater than the mean and minimum (absolute angles were not used to generate this chart). It can be quite clearly seen on the chart, figure 1.8 overleaf, that the standard deviation is less for the difference between the chosen and the maximum angles, than for the mean or minimum angles. Namely, the standard deviation of the difference between the maximum and chosen angles is closer to zero than the other difference-values. Were the standard deviation to be zero, then the chosen and maximum values would be identical, so the closer to zero the standard deviation is, the more similar are the values.

Summary and Conclusions

The method of assigning a score to a route is achieved by noting, at each junction along a route, the range of possible route choices available and comparing these to the choices actually made by the subject. By noting the choice made at each junction, the journey of a subject can be expressed solely in terms of the decisions made by the subject. Equally, all the decisions made by a subject can be summed to produce a cumulative score. If the average decision (in degrees) made by a subject (for a single journey) is plotted alongside the maximum, mean and average angles at each junction (also averaged over the route), then the choices made by subjects appear to lie closer to the maximum angles than to either the average or the minimum. It was also noted that the variance and standard deviation of the 'angular difference' between the chosen angle and the available angles for all 306 junction-decisions in this sample is less for the angular difference between the chosen angle and the maximum angles than for the mean and minimum angles. In other words, it appears that subjects are choosing the straightest possible routes as opposed to the more meandering routes. This particularly significant result supports hypotheses made by Hillier in which he states that people tend to follow the longest line of sight that approximates their heading. This finding would certainly begin to suggest the type of micro-scale decisions necessary to produce the aggregate patterns of pedestrian movement observed by Space Syntax researchers over the last twenty years at UCL, that correlate so well with axial analysis. By following the longest lines of sight, a subject is both deviating as little as possible and behaving axially.

One interpretation of why people should wish to move in as straight a line as possible concerns human memory and complexity. It could be suggested that the act of deviating as little as possible serves to reduce complexity in an otherwise extremely complex environment. There is a well-documented finding termed route angularity, which is mentioned in the following papers (Tolman, 1938) (Sadalla and Montello, 1989) and (Montello, 1991). Route angularity is the phenomenon of judging a route that contains many changes of direction to be longer than a straighter route of identical length. This finding might also correspond to the 'magic number' in psychology. This was a finding by Miller in (Miller, 1956) that stated that people found it easy to remember (short term) up to seven items, give or take two. These findings begin to suggest that people unconsciously attempt to steer a straight path as a complexity-minimising strategy. An interesting area of future research would be to investigate the effects of route angularity using virtual worlds and in particular to determine whether or not 'seven, plus or minus two' junctions or changes of direction were significant.

The overall conclusion of the first section of this paper was that the choices made by subjects at junctions appeared not to be randomly made. It can be further suggested that there may be a pattern to the kinds of decisions that people are making[7]. It is suggested that another factor in determining route choice decisions is the approximate direction or heading of a route. Namely, that subjects will choose the greatest angle of incidence at a junction on condition that it is in the approximate direction that they are heading. This hypothesis can be used to begin to broach the question of why subjects have been observed to 'diagonalize' across urban grids.

Diagonalizing Grids

In the first half of this paper, it was found that subjects were inclined to take as straight a path as possible through an environment, avoiding particularly meandering routes. It was hypothesised that the reason that subjects selected straighter routes was in an attempt to avoid complexity. It was even suggested that there might be a connection between this phenomenon and the 'magic number' in psychology (first suggested by Miller in his 1956 paper (Miller, 1956)). In the case of route selection, subjects might be attempting to reduce the number of changes of direction to seven plus or minus two8. Golledge in (Golledge, 1995) is puzzled about this, since he surmises that the desire to reduce complexity can only be present if subjects have been told explicitly that they will be required to retrace their route. This was, however, not a factor in this experiment and subjects clearly preferred straighter routes. I would counter Golledge's theory by suggesting that even if a subject is not explicitly told to retrace their route and hence implicitly called upon to memorise it, that our basic, intuitive instincts are to take routes that could be retraceable were we called upon to do so. Another way of phrasing this is that it goes against all of our basic survival instincts to lose ourselves deliberately.

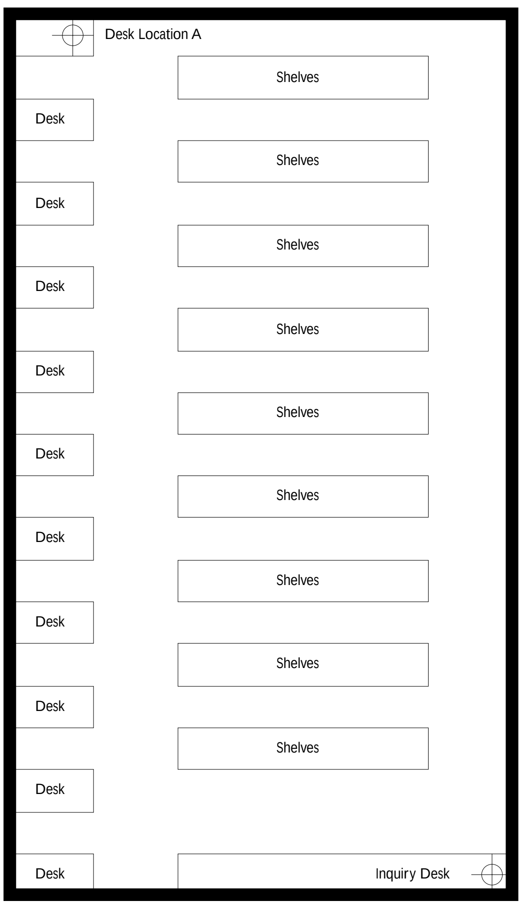


Figure 1.9 Schematic plan of the British Library reading room

However, it is clear that this factor (that of reducing complexity) cannot be the only one involved in route choice decisions. It is further hypothesised that subjects would always take a less complex route, only on condition that it is approximately in the direction of their destination. Try the following thought experiment. If you imagine for a moment, a regular grid made of square blocks, with a subject starting at one corner and given instructions to find their way to the opposite corner. If they were to take the straightest route, they would go around the edge of the grid, however in this situation the angular difference between the direction of the heading of the simplest route and the heading of their destination is 45 degrees. One possible hypothesis, is that this angle is simply too great - and therefore the subject instead attempts to find a route more closely approximating the diagonal. If the straightest route, for example, had only a 10-degree offset heading from the direction of their destination, then in this situation the straightest route would 'win', becoming the primary influence.

This theory is termed the British Library Theory, named after both the first practical application of this theory and the location in which it was coined. Imagine a simplification of one of the reading rooms in the British Library (new). This reading room is approximately rectangular and contains a series of evenly spaced bookshelves. These shelves extend from floor to a height of approximately two metres (and therefore can not be overlooked) they are also fabricated of solid wood (and therefore can not be looked through). A number of desks are located along one side of the reading room. A person, sitting in desk location A wishes to walk to the inquiry desk, location B. Figure 1.9 overleaf shows the schematic plan of one of the British Library reading rooms

The bearing of the inquiry desk from location A can be superimposed on plan as a dotted line. The subject has a choice of two routes, taking either shortest leg first or longest leg first. The first segment of each route is represented as a bearing and the two angles between the direct route and two route choices are shown on figure 1.10. The two angles inscribed by these bearings are 24° and 66°. These two angles are also superimposed on the plan in figure 1.10.

In this case, both possible routes from the desk location to the inquiry desk are of equal distance and equal straightness (each containing one 90° turn). However, the route that involves taking the longest leg of the journey first is only 24° from the bearing of the destination from origin. This can be compared to the option of taking the shortest leg first whose bearing is 66° from the bearing of the goal. Since 66° is more than double 24° it is hypothesised that the subject will chose to take the longest leg of the journey first. When returning from the inquiry desk back to the subject's desk the same logic applies, so that the subject would also take the longest leg first, but a completely different route through the reading room. This tactic leads naturally, therefore, to an asymmetry in routes. However, the desire to minimise the angular different between the bearing of routes choices compared to the direct, perceived bearing of the destination may often be in conflict with the desire to take a straight route.

This conflict between the straightest and simplest is reflected in Golledge's findings in his paper (Golledge, 1995). He states that the factors that are most influential in route choice selection are shortest path, simplest (fewest number of changes of direction) route and following the longest-leg first (i.e. starting the journey by selecting the longest line of sight). Golledge theorises that they have greatest influence in that order, with shortest distance being the strongest influence. However, this does not entirely explain the asymmetry of routes he finds (since certainly shortest distance and fewest numbers of turns are rules that are reversible - they will be identical factors irrespective of the direction a route is traversed.) As Golledge summarises this problem, 'This implies that, in addition to the previously discovered asymmetry of distance perception... perceptions of the configuration of the environment itself (particularly different perspectives as one changes direction) may influence route choice. Thus a route that seems shorter or quicker or straighter from one end may not be so perceived from the other end, thus inducing a change of route.' from (Golledge, 1995).

To return to the 'diagonalizing grid' problem, the theory being presented in this paper is that route selection is a competition between the desire to select the simplest route (in angular terms) and the desire to maintain a heading closest to the direction of the destination from the origin. Furthermore, that once the difference in angles becomes too great, the shortest route will always win out over the simplest. Of course, the two problems that Hillier mentions in his paper (Hillier, 1997) concern that fact that in a perfect grid, a diagonal route is exactly the same distance as the least complex route, namely around the edge. Golledge also discusses this phenomenon and attributes it to perception. Golledge describes it as Euclidean distance winning out over metric distance. The second question posed in this paper (Hillier, 1997) is why subjects are inclined to diagonalize

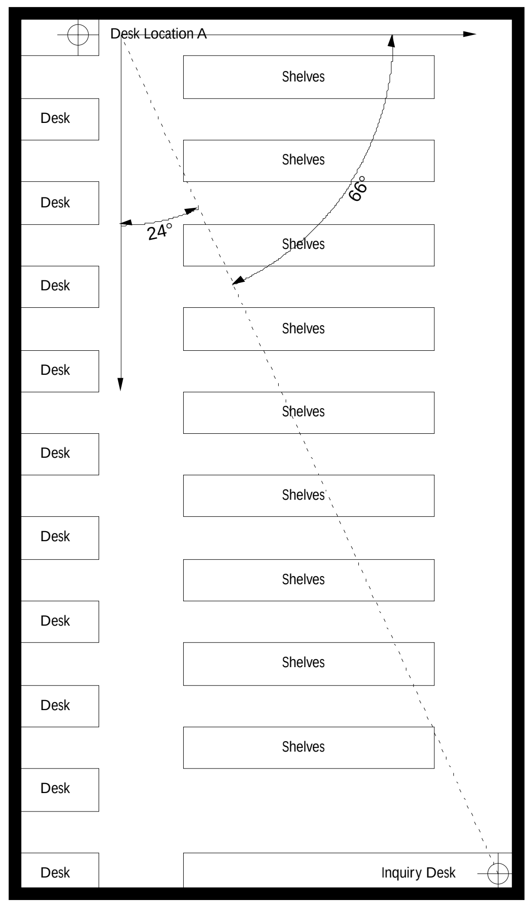


Figure 1.10: Relative bearings of routes compared to direct bearings of the goal from starting point

a more regular grid and not, for example, grids such as the Marquis Estate. Both of these phenomena imply an overall knowledge of the structure of the grid (i.e. the desire to diagonalize a grid can only be present if the grid itself is clearly comprehended.) - i.e. it is an efficient strategy to diagonalize a grid only if your knowledge of the structure of the grid is sufficient (cognitive map researchers would argue that this occurs when a subject's mental model is sufficiently robust) and/or you are provided with constant visual reference points to the edge of the grid (not present in the Marquis estate). By the time that all of the above factors are combined, the sometimes conflicting desires to take shortest routes versus simplest routes, to follow long lines of sight, maintain a good approximate heading from origin to destination and have/develop/maintain a robust knowledge of the grid you are traversing, it is clear that the problem of diagonalizing grids is an extremely complex, multifaceted and hence quite interesting one. Some of these influences are mutually reinforcing and some are contradictory - hence the almost paradoxical question of why we diagonalize grids. It could be said that is not one logic but rather a group of competing logics working together in a manner similar to those described by Marvin Minsky in (Minsky, 1988). It could be suggested that the determiners of individual route choices emerge from such a assemblage of competing logics.

Endnotes

1 ASCII abbreviation for American Standard Code for Information Interchange.

2 Note that ASCII text characters may include both upper and lower case letters as well as punctuation marks and other symbols.

3 In Turner, A. (2000). Angular Analysis: A Method for the Quantification of Space. London, Center for Advanced Spatial Analysis: 17., Dalton, N. M. (2000). Meanda. London, Architectural Association. and Dalton, N. (2000). Fractional Analysis. 2000. both authors consider 'straight on' to be a zero change in angle, the exact opposite to this paper. After completing the analysis and reading the above papers by Turner and Dalton the author feels that the convention of measuring angular deviation using the smallest angle (e.g. 60° instead of 120°) is by far the better method of the two possible options (the results would be identical). For any future work in this area it is suggested that this be the convention adopted.

4 In a series of seven experiments in (Conroy, 2001) the 'handedness' of choice decisions were recorded in order to determine whether or not there existed a left or right-hand bias to the sample of routes. Such a bias was not noted in these experiments (one of which includes the above data set) and therefore in this paper left and right decisions were held to be identical.

5 See endnote 4.

6 Since there are only 67 junctions in the world, then this data set (of 306 nodes) does not simply represent one choice for every junction, or alternatively an average choice for each junction, it is the complete set of all choices made by all subjects for all junctions

7 These findings appear to be the result of unconscious behaviour. In questionnaires given to the subjects to complete after participating in the experiments, there was a question asking whether subjects had used any specific strategy to aid their wayfinding task. None of the answers given could give rise to the results described above.

8 The average step depth of London is eight. Is this a coincidence?

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