DEVELOPMENT OF A HEURISTIC APPROACH FOR WAYFINDING AND NAVIGATION IN A STREET NETWORK AS A GEOGRAPHIC SPACE

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ABSTRACT:

The purpose of this study is to explore human wayfinding behavior within a familiar street network in a purely qualitative manner. So, the most significant criteria of making decision in the network is the cognitive map which has been learnt before during the human beings daily activity. The cognitive map includes a great deal of details of environmental descriptions but it seems that pre-acquainted people find routes in the street network by finding a connection from an origin to skeleton of major paths then moving to the proximity of the destination. Hence, we evaluate a heuristic approach for qualitative wayfinding proposed by Kuipers et al. (2003) named boundary relations. In the process of implementation we encountered some problems which guide us to some considerations for refinements and developments. The concept of cardinal direction is added to the properties of paths of the skeleton and we use the qualitative spatial reasoning by means of it in the sub-goal refinement stage. In addition, we introduced a new obvious parameter that is used as an input of the problem; it is the cardinal direction from origin to destination. As a practical activity, the Dijkstra algorithm and the developed heuristic are implemented in the street network of Tehran, the capital of Iran, which has a complicated traffic problem. The outcomes of these algorithms are depicted in this paper that the first one is considered as an optimum way and the second one is a simulation of human behavior.

1. INTRODUCTION

Navigation is a fundamental human activity and an integral part of everyday life. People use their knowledge and their previous experiences with geographic space to find their way (Timpf et al., 1992). Considerable research in the areas of cognitive science, psychology and artificial intelligence has been carried out to examine the means by which humans navigate.
Cognitive maps are mental maps which are built from experience or from expectations of the real world (Lynch, 1960). There has been widespread acceptance that cognitive maps enable people to find their way to destinations. Hunt (1984) found that mental images, which consists of place identification, and spatial organization were good predictors of wayfinding performance, and that simulated learning with slides and a model of buildings were better than learning in the real setting.

Experienced people that everyday solve wayfinding problem in a complex geographic large-scale environment use a “skeleton” of important paths and places to guide their problem solving (Chase, 1982; Lynch, 1960). There are a number of graph search algorithms that can find paths in a topological map (Elliot and Lesk, 1982). Metric information such as estimates of path segment lengths can be used to guide heuristic search in the A* and Dijkstra algorithms. The method which is evaluated in this study is a qualitative approach of wayfinding and we avoid the metric data and information to attempt modeling human being behavior as he/she does in everyday life without any navigation equipments or maps. In other words, they find their way without aid of maps or navigators in a space that is too large to be perceived at once (geographic large scale space).

This topic of research is related to the field of spatial reasoning, which is concerned with spatial task planning, navigation planning, representing large spatial databases, symbolic reasoning, the integration of reasoning with geometric constraints and accumulation of uncertain spatial evidence (Kak and Chen, 1987).
In order to solve this problem, a heuristic approach proposed by Kuipers et al (2003) was evaluated and after assessing it in different perspectives some notions are used to have more efficient and better implementation.. People do wayfinding in different circumstances using their commonsense knowledge of space. Spatial commonsense knowledge is knowledge about the physical environment acquired and used generally without concentrated effort to find and follow routes from one place to another, and to store and use the relative position of places (Kuipers, 1978)

Naïve geography is a current field of study that deals with common-sense geospatial world. It establishes the link between knowledge that people have about their surrounding geospatial space and the development of formal models that integrate such knowledge. Egenhofer and Mark (1995) define naïve geography as the study of “the body of knowledge that people have about the surrounding geographic world”. Also, we mention a set of qualitative deduction rules for spatial reasoning with cardinal directions and explain how they cause simplicity in more efficient solving.

After describing the developed algorithm and depicting the corresponding flowcharts, a scenario has been defined in the Tehran street network to try to find a route from an origin to a destination. A conclusion and future work is placed in the last section.

2. HUMAN WAYFINDING

Human wayfinding research investigates how people find their ways in the physical world and the ultimate goal of human wayfinding is to find the way from one place to another. Researchers from various disciplines have thoroughly investigated the role cognitive maps play in spatial behavior, spatial problem solving, acquisition, and learning (Kitchin 1994). Much less, however, has been found out about how people immediately understand different spatial situations, i.e., how they structure and make sense of practical space while performing a wayfinding task. Gluck (1991), therefore, suggested to explore the information needs-what information people need in order to understand their environment at a particular point in time. The idea behind this sense-making method is to look at the wayfinding process itself instead of looking at the final product (i.e., the cognitive map).

Allen (1999) proposed a taxonomy of wayfinding tasks based on functional goals that consist of three categories: 1) Travel with the goal of reaching a familiar destination; 2) Exploratory travel with the goal of returning to a familiar point of origin; and 3) Travel with the goal of reaching a novel destination. In this paper our hypothesis is that, we are in the first circumstance and try to formalize the model of the environment that people have been learnt, as a clear example we could mention taxi drivers. They try to find best routes from an origin to a destination based on their geospatial common sense knowledge. Many items and elements affect this process and to have a successful model of it we should consider many aspects. In this paper we take into account a method proposed by Kuipers et al. (2003) and after evaluating it we perceive some drawbacks for our implementations and for fitting it to our application, there were an obligation to develop an algorithm and introduce some new notions.

3. A WAYFINDING HEURISTIC CONCEPTS FOR DEVELOPMENT

A heuristic approach which was proposed by Kuipers et al. (2003) used the boundary relation as the basis for a purely qualitative reasoning to guide wayfinding search. Suppose we are searching for a route from place A to place B, and if there is a path such that A placed left of it and B placed on the right side, then consider that Path as a sub-goal and search for routes from A to sub-goal and from the sub-goal to B. This is a process which in a one dimensional sub-goal is set for a zero dimensional sub-goal that in the first iteration is destination. It is a module that named Sub-goal Selection.

Two places A and B may have multiple boundary relations with different paths. If there are several possible boundaries, order them according to the number of boundary relations they have with other places. This will increase the probability of finding a useful connection earlier in the search. We define a function named *rankPath* to perform this process.

$$rankPath :: [Path] \rightarrow [Path]$$

After finding the 1D sub-goal, the next step will be reaching the sub-goal and leaving it toward the destination. But a problem is remained here and it is which place on the sub-goal is the considered place? Here we obligate to produce a module named sub-goal refinement in which we reduce the 1D sub-goal to 0D sub-goal.

4.1 Boundary Relations

A path is a one-dimensional subset of the environment, with a direction implied by the order on its places. A directed path is described by (Path, dir), where dir is either positive or negative. If a directed path extends to infinity, it divides the places in the environment into three subsets: those on the path, those on the right, and those on the left. Note that right and left are used here as topological terms. If the path curves, a place that is topologically to the right may occasionally be visible to the traveler's egocentric left.

4.2 Cardinal Directions and Qualitative Spatial Reasoning

Instead of doing exact calculations, people most often apply qualitative methods of spatial reasoning (Frank 1996, Cohn 1995, Frank 1992a, Freksa 1992) that rely on magnitudes and relative, instead of absolute values. A qualitative approach can deal with imprecise data, and therefore yields less precise results than the quantitative one. This is highly desirable because precision is not always desirable and precise, quantitative data is not always available (NCGIA, 1989: Kuipers, 1983).

Qualitative direction is a function between two points in the plane that maps onto a symbolic direction or its equivalent, from a path onto a symbolic direction. The n different symbols available for describing the directions are given as a set C_n depending on the specific system of directions used, e.g. C_4 = {N, E, S, W} or more extensively C_8= {N, NE, E, SE, S, SW, W, NW}. The number of different qualitative direction symbols is finite and are cyclically ordered and equidistant. They can be mapped to the integers modulo (n - l), for example C_8 = {0, 1, 2, 3, 4, 5, 6, 7}. A cyclical positive (anti-clockwise) turn of $2\pi/n$, where n is the number of direction symbols, is useful and can be defined by a table, for example, turn (N)=E, turn (E) =S, turn (S) = W, turn (W) = N, or a full turnaround is turn$^{(n)}$, the identity operation (Frank, 1992b).

$$dir :: Location \times Location \rightarrow CardinalDirection$$
$$dir :: Path \rightarrow CardinalDirection$$

Cone Shaped Directions. This model of cardinal directions has the property that 'the area of acceptance for any given direction increases with distance' and is sometimes called "triangular".(Frank, 1992b). We use this model in this study. Figure 1 is a diagram of this system.

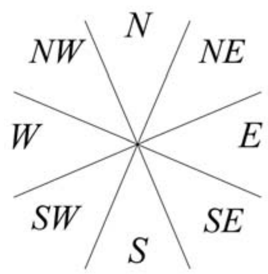

Figure 1.Cone Shaped Directions

As explained we consider two new properties for the elements of problem solving, at first we set the cardinal direction of each path along its conventional topological direction. The second thing that is significant and has an important role in solving the problem of wayfinding is Cardinal Direction of Origin to Destination *(CDO2D)*. These concepts never contradict the assumed conditions and they would be solved qualitatively. As it is shown in the next section, they are a number of approaches used in the perpendicularity function.

4.3 Image Schemas for modeling Skeleton Structure

Image schemata can be seen as a part of the topological information that is essential for common-sense reasoning: relating image schemata to real-world situations and objects is clearly based on topological concepts. Image-schematic reasoning is also qualitative because people do not use absolute values-such as the exact position of an entrance within a coordinate system-in their everyday lives.

According to Kuiper's heuristic approach for wayfinding, the complicated urban environment is reduced to a more abstract form in the mind of professional and expert wayfinders, which is skeleton. This skeleton has been established based on two fundamental schemas that are PATH and LOCATION. A question remained open as "what about boundary?" It is clear that this method is formed based on the concept of it. So we consider this relationship as a property of PATH schema. At the end of this section, semi formal representations of them are shown, the property descriptions are mentioned in {}.

***PATH*:**
<u>Name</u> *:{ name of this path}*
<u>ROW</u>*:{list of locations on the path}*
<u>TopologicDir</u>*:{a conventional direction exist which introduced the topological and order of locations on the path}*
<u>LeftLocs</u>*:{list of learnt and known locations which their positions are at the left of this path}*
<u>RightLocs</u>*:{list of learnt and known locations which their positions are at the right of this path}*
<u>CardinalDirection</u>*: {its value will be one of the N, NE, E, SE, S, SW, W or NW}*

***LOCATION*:**
<u>Name</u> *:{ name of an intersection or a specific place or square}*
<u>On</u> *:{a list of paths which this location is on them}*
<u>Star</u>: *{it implies the local geometry by triples of (cardinal direction, path name, topologic direction +1/-1)}*

4. DEVELOPMENT OF THE HEURISTIC APPROACH

The process of the algorithm has been defined in two iterative sub algorithms, *Sub-goal Selection* and *Sub-goal Refinement*. As it has been shown in the heuristic approach, if the major goal is finding a route from an origin to a destination and there is a path such that the two places are located in the opposite sides of the path then that path is a sub-goal which the final route will cross this path, so we should get this sub-goal from the origin and from the sub-goal to the destination. The path is a one dimensional feature and expected nature of a sub-goal makes it inevitable that it must reduced to a zero dimensional feature and plan to reach a path in a specific place. This process is occurred in sub-goal refinement in which try to select one of the places on the path. In the next sections these two phases of the algorithm is explained in detail and the flow chart diagram is depicted.

It should be mentioned that there are some assumptions considered in the whole process. The first one is that when a person reaches a path or place, he/she has the capability of recognizing it. The second important assumption is that all of the paths in the network are straight, each two line has one and only one intersection and if they have more than one intersection, they are at the same path.

4.1 Sub-goal Selection module

In this module the main purpose is finding a path which plays the role of a boundary that the origin and destination located on the opposite sides of it, so it is a function as defined below:

$$subGoalSelection :: Location \rightarrow Location \rightarrow CognitiveMap \rightarrow Path$$

In which, two locations as origin and destination in the initial iteration and firstLoc and secondLoc in the next iterations, and a CognitiveMap that it is the Image Schematic Model of the Skeleton and comprises a set of Paths and Locations. The output is a Path or a one dimensional feature as a boundary.

In Figure 2 it is clearly depicted that after entering the module after four if clause the boundary status will be determined and a loop checks all paths of cognitive map participated in the skeleton structure. At the end of the loop all paths that have the boundary relation with the location in opposite sides will be the input of the *rankPaths* function and a Path with the highest degree of boundary relations with respect to all points in Cognitive Map will be the outcome.

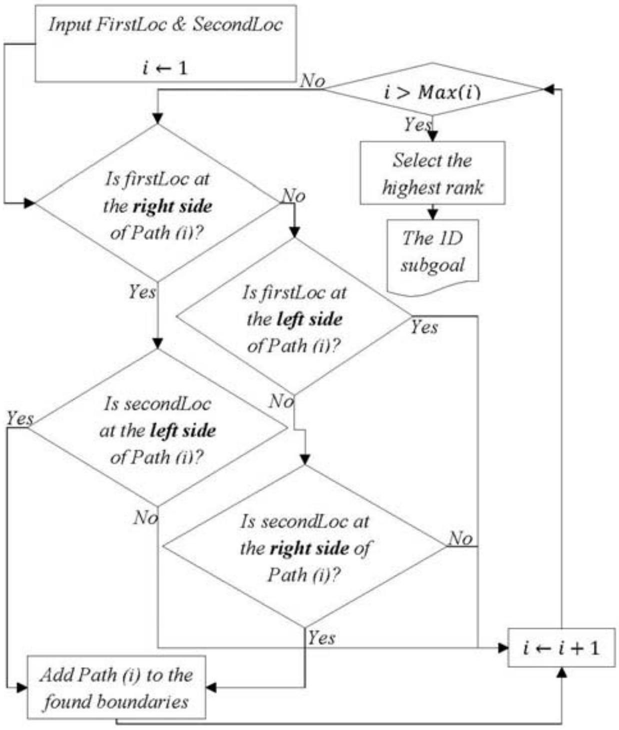

Figure 2.Flowchart diagram of sub-goal selection

This one dimensional sub-goal or the result of subgoalSelection module should be refined and reduced to a Location which should reach it on the sub-goal. This process will be done in the subGoalRefinement Module.

4.2 Sub-goal refinement Module

In this stage some conditions are evaluated for selecting one of the locations placed on the 1D sub-goal. At first the result of the previous module is checked and if its output is Null then it is considered that they are located on the two intersected Paths. If so, then the intersection Location is a zero dimensional sub-goal, but in spite of this, it will be tested that the firstLoc and secondLoc are on the same Path. In this case, all the locations between them will be reported. The terminating condition of this module is reporting the destination. Figure3. Indicates that it is communicative enough to understand what occurred during the process of finding a way.

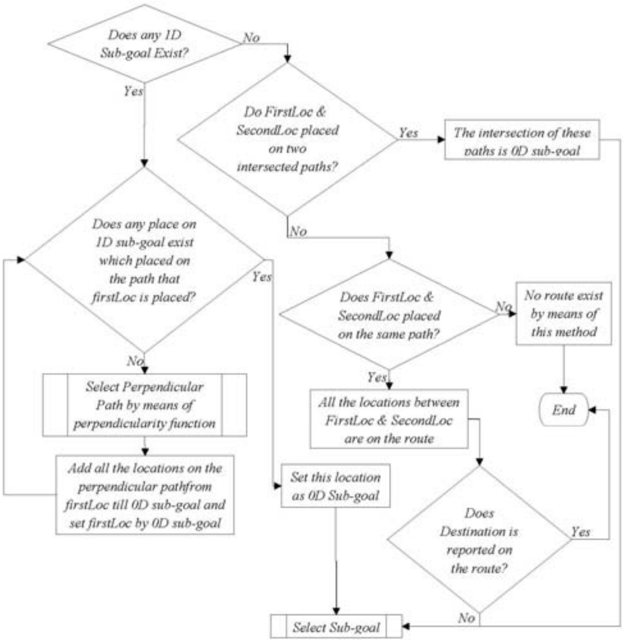

Figure 3.Flowchart diagram of the sub-goal refinement

An important function in the refinement level is perpendicularity which is explained in the next section.

4.3 Perpendicularity Function

A possible and probable circumstance during this process is that when one selects a one dimensional sub-goal, it is checked whether any location on the sub-goal exists which is located on the Path that firstLoc is on it, too. One has to choose a path that guides to the sub-goal. In order to achieve this aim, the perpendicularity function is used defined as:

$$perpendicularity :: Location \rightarrow Path \rightarrow Path$$

In such conditions the introduced concepts of cardinal directions and CDO2D is useful. At first, we select a path that its Cardinal Direction property is perpendicular to the Cardinal Direction Property of the boundary or one dimensional sub-goal. Table 1 presents all probable states.

Cardinal Direction of 1D Sub-goal	Location in Left Side	Location in Right Side
S2N	W2E	E2W
N2S	E2W	W2E
W2E	N2S	S2N
E2W	S2N	N2S
SE2NW	SW2NE	NE2SW
NW2SE	NE2SW	SW2NE
SW2NE	NW2SE	SE2NW
NE2SW	SE2NW	NW2SE

Table 1.Outcomes of Perpendicular Directions from firstLoc with respect to the 1D sub-goal

In order to simplify the understanding of our proposal, two rows of the Table 1 are shaded as example and their corresponded states shown in Figure 4. Note that the difference between shading degrees are intentional.

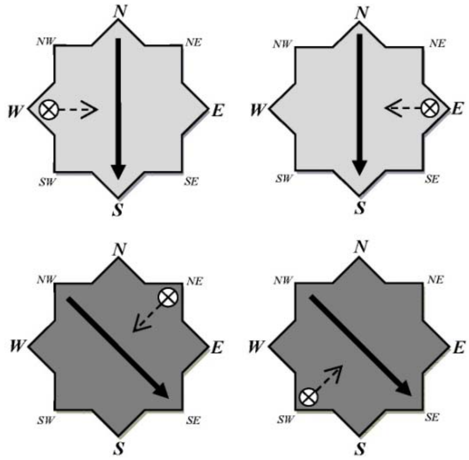

Figure 4.Two cases of possible conditions

If there is no path to satisfy these conditions we choose a path that has minimum difference between its cardinal direction property and CDO2D. Improving the kuipers et al. proposal and solving these deadlocks in the algorithm, make it applicable to a practical activity.

5. IMPLEMENTATION

To implement the algorithm, a street network is needed. A part of Tehran is considered and a scenario is defined to find a route from an origin to a destination. As it is clear in Figures 5 and 6, the origin is located in the south-west of the study area and destination is in the North-East, so the CDO2D is deduced SW2NE.

The problem has been solved in two separate methods, quantitative and qualitative. As a quantitative method we model the street network as an embedded graph (its node coordinates are known) and solve the problem of shortest path problem by means of Dijkstra's algorithm. The weights were calculated from the distances produced by means of coordinates of nodes.The proposed route by Dijkstra algorithm is illustrated in Figure 5.

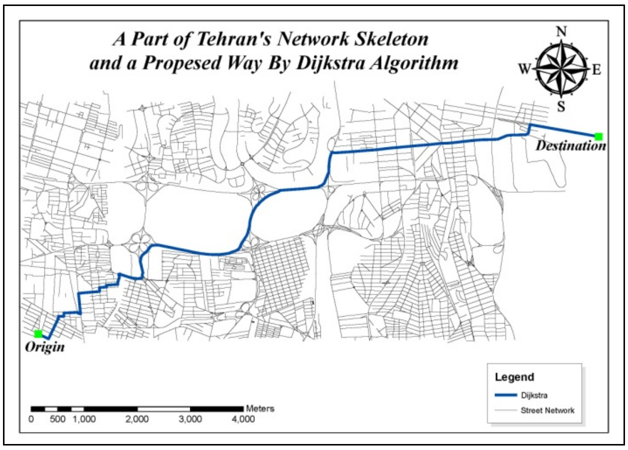

Figure 5.The result of Dijkstra algorithm

The main purpose of this study is to find a way under the simulated conditions in a qualitative manner.The outcome of the heuristic approach is illustrated in Figure 6. This route is produced by a computer program whose results were a list of (Location,Path) depicted on the map.

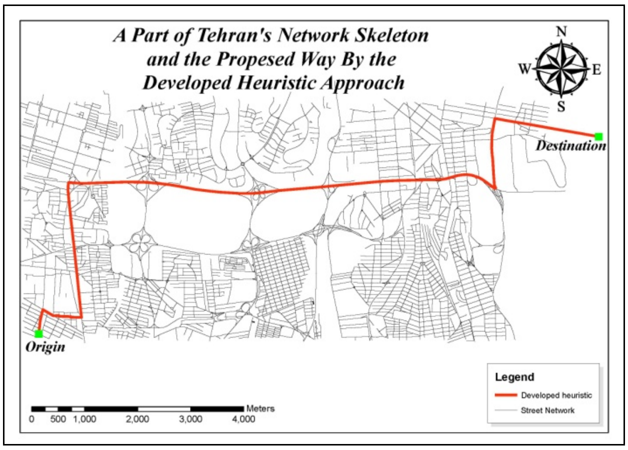

Figure 6.The result of developed heuristic algorithm

6. CONCLUSION

Modeling the behavior of the human being is one of the important subjects that many disciplines are interested in. In this study the main goal was developing a qualitative approach for wayfinding in a street network in a geographic space. Another aim of this research was a comparison between a qualitative algorithm which could be a representative of human being behavior and a quantitative approach which is representative of the optimum route that managers and other specialists would like people travel along it. This research could facilitate optimizing the urban signs and signals design.

Beside this comparison in a built environment, it could be helpful in the design process to consider the behavior of people by simulating them. For example we could select variants of urban highways by considering these parameters.

As future work we try to develop this algorithm in order to produce instructions to reach the destination. It could be useful for designing and implementing mobile agents which try to simulate the human behavior in an automatic way.

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