
A Location Representation For Generating Walking Directions

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1. Introduction

An expressive representation for location is an important component in many applications. However, current location representations model only the geographical aspects of a place. While this is a necessary feature to capture, it is far from sufficient. As a result, many location-aware applications only reason about space at the level of coordinates and containment relationships, but have no way to express the semantics that define how a particular space is used.

It is not uncommon for people to come home after running an errand, such as buying milk at the grocery store, and then realize they could have taken care of another errand while they were out, such as buying stamps at the post office. These “why didn’t I think of *that* when I was *there*” moments can be aggravating. A person could save time and avoid annoyance if he had recognized the opportunity in time to “kill two birds with one stone.” This type of situation can be generalized to situations where a lack of information, or perhaps incorrect information, leads a person to a suboptimal use of their time. Missing out on “opportunistic side acts” is one example; taking multiple subway trains to get to a destination because you didn’t know about the direct bus route is another. We are developing tools to help prevent these situations from happening. These tools would help a person make decisions regarding what to do when he is out and about by providing information relevant to his current task and to other things that are important to him. One issue that many of these applications need to address is a model of space that represents not only where a person is, but also what a person is near and what he can do at those nearby places.

We present LAIR (Location Awareness Information Representation), an ontology that addresses this problem by modeling both the geographical and topological relationships between spaces, as well as the functional purpose of a given space. We also describe how LAIR was used to create an application that produces walking directions comparable to those given by a person, and briefly describe an evaluation in progress.

2. LAIR

The representation is inspired by Ben Kuipers’ TOUR model of a person’s cognitive maps of large-scale spaces (Kuipers, 1977). The TOUR model is based not just on metric distances but on higher-level concepts such as places and paths between places. This allows us to model the topological and geographical relationships between different places. We supplement the TOUR model by associating a place with a description of its functional purpose. For example, a particular building may function as any number of the following: grocery store, bank, or shoe store. A certain area of a building may be a meeting area, lounge, or kitchenette. These descriptions are represented in LAIR by a **Functional Place**. Instances of locations modelled in LAIR are stored in a semantic network (Peters & Shrobe, 2003). This allows us to make inferences about the relationships between different places and the paths between them.

We now describe some of the concepts that LAIR models. Due to space limitations, we limit the discussion to the concepts that are most relevant to the development of the Stata Walking Guide. A complete description of LAIR can be found elsewhere (Look et al., 2004).

Places in LAIR have the following properties:

Name. A way to refer to this Place.

On. A list of the Paths this Place is on.

Star. A list of triples (Path, heading, Path direction), that describe the geometry of the intersection formed by the Paths that meet at this Place. The value for heading ranges from 0 to 360. The zero mark for each Place is arbitrary; the Stata Walking Guide sets the zero mark for each Place to be cardinal north. The value for path direction is either +1 or -1, and indicates the direction of travel along the Path if a person were to travel from this Place along the given heading. Path direction will be discussed shortly.

View. A list of triples (Place, heading, distance) describ-

ing the other Places that can be observed from this Place. The means by which Places can be observed are not limited to visual detection (Kuipers & Levitt, 2000), but for the Stata Walking Guide, we assume a line of sight between a Place and the other Places in its list of Views.

Contained. An unordered list of Places. The geographical extent of a Place is not limited by size, and a Place p may be geographically subsumed in any number of other Places. The Places that subsume p are in p 's Contained list. Contained is an unordered list because there may not necessarily be any sort of strict containment ordering between the Places listed in Contained. For example, the state of Connecticut is contained within both New England and the "Tri-State Area." However, since only parts of the Tri-State Area are in New England (namely, Connecticut) there is no strict ordering between these two Places.

Function. A list of the Functional Places that describe what can be done at this place and how this place is used.

Paths link one Place to another. Travel along a Path can be made in either the +1 direction or in the -1 direction. Determining which direction is +1 is arbitrary. Paths in LAIR have the following properties:

Name. A way to refer to this Path.

Row. A list where each element is an ordered list of Places. Each ordered list contains a sequence of Places that would be encountered when travelling along the Path in the +1 direction. To support incomplete knowledge of all Places along the path, Row is a list of these ordered lists.

Functional Places have a name and a list of Actions that can be performed at that Functional Place. The Stata Walking Guide uses the name of a Functional Place to describe waypoints along the route it produces. The list of Actions can also be used to manage access control to the Functional Place (Kottahachchi & Laddaga, 2004).

An abbreviated example showing how LAIR can be used to model an area of Cambridge, Massachusetts is shown in Figure 1.

3. The Stata Walking Guide

To demonstrate the use of this representation, we created the Stata Walking Guide. This application provides a route map and written walking directions between different places in the Stata Center. This building is home to

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PLACE1:
Name: MIT
On: { Massachusetts Avenue (Mass Ave), Memorial Drive }
Star: { (Mass Ave, 315, +1), (Mass Ave, 165, -1), (Memorial Drive,
        65, +1), (Memorial Drive, 245, -1) }
View: { (John Hancock Tower, 135, 1 mile) }
Contained: { Cambridge, Massachusetts, New England }
Functions: { Teaching Institute, Research Institute }

PLACE2:
Name: Central Square Transit Point
On: { Mass Ave, Prospect Street, Western Avenue, River Street }
Star: { (Mass Ave, 135, -1), (Mass Ave, 315, +1), (Prospect Street,
        30, +1), (Western Avenue, 270, -1), (River Street, 225, +1) }
Contained: { Central Square, Cambridge, Massachusetts, New Eng-
        land }

PLACE3:
Name: Harvard Yard
On: { Mass Ave, John F. Kennedy Street }
Star: { (Mass Ave, 160, -1), (Mass Ave, 350, +1), (John F. Kennedy
        Street, 190, +1) }
Contained: { Harvard Square, Cambridge, Massachusetts, New
        England }

PATH1:
Name: Massachusetts Avenue
Row: { {MIT, Central Square Transit Point, Harvard Yard} }

FUNCTIONAL PLACE1:
Name: Teaching Institute
Actions: { Lecturing }

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Figure 1. An abbreviated example of modelling an area of Cambridge, Massachusetts using the LAIR ontology

MIT's Computer Science and AI Lab (CSAIL). The application is especially useful since many visitors (and current occupants!) find the building's irregular floorplan bewildering. The written directions produced from our representation also include landmarks. This is in contrast to the type of directions produced by Mapquest, which only lists a sequence of "go-to" and "turn" instructions. The written directions supplement the route information presented on the map and provide further information to help a person develop his cognitive map of the Stata Center.

3.1 System Architecture

The Stata Walking Guide consists of two parts, a route-finding component that produces the graphical route map between two places and a translation component that converts the route information into written directions. The route-finding component uses A* search to produce a series of waypoints that represents a route from one place to another. This route-finding component was an existing piece of software, written before LAIR, so the A* search is done over a simple coordinate system. The resulting path is represented as a sequence of vertices in this coordinate system. We included the graph used by the route-finding component into our LAIR representation of the Stata Center, but instead of rewriting the route-finding component to search over the LAIR representation, we decided to use the LAIR representation to infer the written directions from just the

sequence of vertices produced by the route-finding component. Being able to infer descriptive written directions from this lower-level abstraction illustrates the richness of our representation.

4. Generating Written Directions

To generate written directions from a sequence of waypoints, we first group the waypoints into sets, with each set representing part of a path along the route. The points that are in the intersection of two sets represent places where two or more paths intersect in reality. Since we model the geometry of intersections and we know the previous and the next waypoint on the route, it is straight-forward to determine where to turn and in which direction.

To describe where to turn, we use a number of different rules. The first rule uses the fact that sometimes, a particular path will come to an end, forcing a person to turn one way or another. Since we model where paths begin and end, it is straight-forward to generate statements such as “turn right at the end of the hallway,” when appropriate. The second rule used to describe where to turn reflects the fact that landmarks are usually used at decision points to identify the places where a turn is required (Denis et al., 1999). At these decision points we insert a functional description of the area that a person has entered, for example, “when you enter the lobby, turn left.”

Landmarks are also used to confirm that a person is headed in the right direction, for example, “walk down the hall, pass the copy room on your right...” The translation component inserts a landmark if the length of a particular path on a route, as measured by the number of waypoints provided by the route-finding component, is above a particular threshold. For these long paths, the translation component searches for landmarks along the path and inserts the landmark that is nearest the midpoint of the path segment.

5. Grouping Directions For Easier Understanding

Finally, the last part of the generation process groups directions into segments to make it easier for a person to understand the directions as a whole. The grouping is a recursive procedure that counts how many instructions are presented in a given segment. If the number is above a certain threshold, the instructions are split into two groups, with the starting and ending points in separate groups. Points along the route (and their corresponding directions) are grouped together based not on metric distances, but rather on geographic similarities, as modeled in the ontological structure of the knowledge representation. For example, depending on the length of a route, two points may be grouped together if they are on the same floor of a building. A third

grouping may be required for intermediate points that differ greatly from both the start and end points.

For example, consider a route from my office to the CSAIL main office (see Figure 2). In our representation, my office, 224, is contained in the AIRE research neighborhood, which is contained in the second floor, which is contained in the Stata Center (we denote this by writing $224 < \text{AIRE neighborhood} < \text{Second floor} < \text{Stata Center}$). CSAIL’s main office is located in the north wing on the fourth floor of the Stata Center’s Gates Tower (Main office $< \text{North wing} < \text{Fourth floor} < \text{Gates Tower} < \text{Stata Center}$).

In our representation, the most significant geographic difference between my office and CSAIL’s main office is that my office is located on the second floor whereas the main office is located in the Gates Tower. This forms the basis of our first split. This procedure is then applied recursively to the resulting two sets of directions and terminates when either the number of directions is below threshold or when the start and end points of a segment differ only at the level of spatial containment immediately one level above them. While the recursion is not very deep for routes within the Stata Center (usually, only one segmentation is needed for routes between floors, and none for intra-floor routes), this algorithm can segment directions for longer routes, such as those used for coast-to-coast road trips.

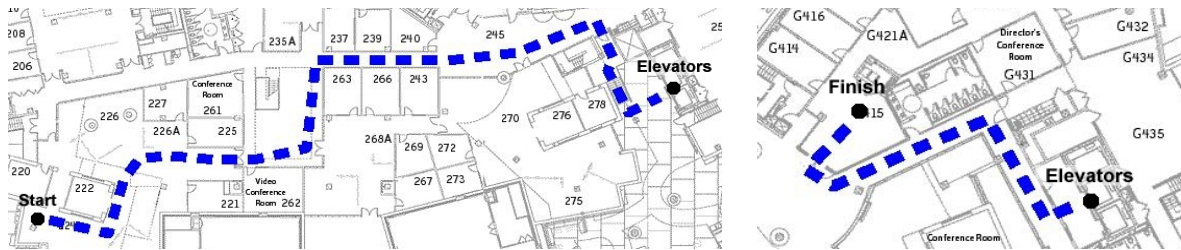
6. Evaluation and Future Work

An evaluation of the quality of the directions we produce is underway. In this study, visitors to the Stata Center will be asked to compare how understandable a route description taken from our corpus is to the corresponding route description produced by the Stata Walking Guide. The goal of this study is to gauge how well a person understands the directions presented to them, and how effective the directions are at presenting a cognitive overview of a particular route. We also plan to investigate how this subjective assessment of a person’s understanding of a route correlates with his ability to actually follow the route.

There are two areas of future work. The first is being able to automatically build up a model of space from architectural CAD drawings (Kulikov, 2004). The second is to deploy the Stata Walking Guide to OK-Net, the Stata Center’s information kiosk network (Van Kleek, 2003).

7. SUMMARY

This paper makes three contributions. First, it argues why location representations that only model geographical relationships restrict the degree of intelligent interaction applications can have with users. Second, it describes LAIR, an ontology that addresses this shortcoming by represent-



Face the main entrance. Walk out the main entrance into the lounge. At the lounge, turn right onto the main hallway. Walk down the hallway. Near the end of the hallway, turn right. Walk down the steps to the elevator lobby and then take the elevator to the 4th floor.

On the 4th floor, turn right from the elevator lobby and then left at the end of the hall. Walk down the hall and the main office will be on your right.

Figure 2. An example of a route and written directions produced by the Stata Walking Guide.

ing both the geographic relationships between spaces, as well as the functional purpose of a particular space. Third, it presents an application in the Stata Walking Guide. The Stata Walking Guide demonstrates how LAIR can be used to create an application that addresses a problem domain requiring intelligible user output (walking directions).

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