J Geograph Syst (2006) 8: 269–287
DOI 10.1007/s10109-006-0021-1

ORIGINAL ARTICLE

Adam D. Sobek · Harvey J. Miller

U-Access: a web-based system for routing pedestrians of differing abilities

Received: 18 July 2005 / Accepted: 3 November 2005 / Published online: 26 April 2006

Abstract For most people, traveling through urban and built environments is straightforward. However, for people with physical disabilities, even a short trip can be difficult and perhaps impossible. This paper provides the design and implementation of a web-based system for the routing and prescriptive analysis of pedestrians with different physical abilities within built environments. *U-Access*, as a routing tool, provides pedestrians with the shortest feasible route with respect to one of three differing ability levels, namely, *peripatetic* (unaided mobility), *aided mobility* (mobility with the help of a cane, walker or crutches) and *wheelchair users*. U-Access is also an analytical tool that can help identify obstacles in built environments that create routing discrepancies among pedestrians with different physical abilities. This paper discusses the system design, including database, algorithm and interface specifications, and technologies for efficiently delivering results through the World Wide Web (WWW). This paper also provides an illustrative example of a routing problem and an analytical evaluation of the existing infrastructure which identifies the obstacles that pose the greatest discrepancies between physical ability levels. U-Access was evaluated by wheelchair users and route experts from the Center for Disability Services at The University of Utah, USA.

Keywords Accessibility · Disability · Pedestrian · Routing · GIS

A. D. Sobek (✉) · H. J. Miller
Department of Geography, University of Utah,
260 S. Central Campus Dr. Room 270, Salt Lake City,
UT 84112-9155, USA
E-mail: adam.sobek@geog.utah.edu
E-mail: harvey.miller@geog.utah.edu

1 Introduction

Accessibility is an important issue in urban and built environments. Urban designers and architects are actively developing new spaces that are easy for people to navigate (Thompson 2005; Foster 2004; William and Patterson 2004). However, retrofitting existing urban environments to assist people with different physical abilities can be difficult and expensive. While much work is being completed in the planning realm (Franklin 2005), there is a need for continued research on assessing the accessibility of pedestrian networks and assisting people with disabilities in negotiating urban environments. This paper describes a web-based system to: (1) assist pedestrians of differing physical abilities, and; (2) evaluate the built environment with respect to affording access for users with different physical abilities.

U-Access is a World Wide Web-based system that allows users to obtain shortest pedestrian routes through a built environment which are feasible with respect to their physical abilities. Similar to other navigational tools (e.g., Map Quest® and Map Point®), U-Access allows users to select an origin and a destination. However, users are also able to specify their physical ability level. Three ability levels recognized by U-Access are: (1) *peripatetic*, meaning walking on foot without assistance, (2) *aided mobility*, meaning requiring the assistance of a cane, walker, or crutches, (3) *wheelchair users*. The physical ability variable distinguishes which edges within the pedestrian network are traversable for that person. This ensures that that the route provided to the user is feasible. U-Access also supports the prescriptive analysis of routes of people with different physical ability levels; this can assist in assessing the built environment and identifying high-priority obstacles that should be mitigated or removed.

The next section provides a general background of transportation optimal path routing applications for automobiles and pedestrians. Specifically, it addresses the needs for people with physical disabilities, as well as current practices at the study site. Section 3 provides an examination of alternative systems for routing pedestrians and how they can be coupled with a geographic information system (GIS). This section also outlines the system design for U-Access including a data model, algorithm and the interface design. Section 4 provides examples of U-Access as both a pedestrian routing and prescriptive analytical tool, as well as the results of expert evaluation. Section 5 concludes with some brief comments on the strengths and weaknesses of U-Access, as well as frontiers for additional research and development.

2 Background

2.1 Transportation routing

Transportation routing problems, in the most general terms, attempt to find optimal paths and locations within a network (Miller and Shaw 2001). For realism and relevance, the network must capture actual travel conditions as completely as possible. For example, in vehicle routing applications, algorithms should account for one-way streets, traffic signals, and congestion (Sheffi 1985). Commonly used web vehicle routing applications such as MapQuest® (http://www.mapquest.com) and MapPoint® (http://www.mappoint.msn.com) capture some phenomena such as one-way streets; however, they are limited in that they only utilize distance or time as an impedance (i.e., the cost to traverse a link in the network).

As suggested by their popularity, web-based vehicle routing applications such as MapQuest® are useful for their designed purpose. However, they are not suitable for pedestrians routing, particularly if we wish to consider the physical abilities of the user. Vehicle routing applications assume that all vehicles can traverse all links in the network: in other words, all users are interchangeable. However, it is not realistic to assume that all people can traverse every link in a pedestrian network. Pedestrian environments are comprised of such built structures such as stairs, curbs, and steep slopes that can hinder the mobility of some people, perhaps restricting their participation in social, educational and economic activities that are often taken for granted by the much of the population.

2.2 Physical ability and accessibility

In 1990, the United States government recognized a need to define built environments to allow equal access to all people. The United States Congress took action by passing the Americans with disabilities act (ADA). The main goals of the ADA are to provide people with disabilities access to buildings, equal employment opportunities, equal access to public transportation, the opportunity to attend school and the chance to be eligible for social security support (Little 1995). Section 4.3.2 of the ADA states that "at least one accessible path within the boundary of the site shall be provided from the street...."

While progressive, the view of absolute accessibility embodied in the ADA is also somewhat naïve. Although a single accessible path may exist, this path may be onerous relative to paths used by people without physical disabilities, creating a relative disadvantage. Church and Marston (2003) suggest a more sophisticated approach, discussing relative accessibility measurement that is sensitive to both the number of feasible routes in addition to the length of each route. The valuable insight by Church and Marston (2003) is that society should not categorize people as merely disabled or not disabled; rather, there are degrees of physical ability, and consequently degrees of accessibility.

2.3 Current practices at application site

In response to the ADA, the University of Utah in Salt Lake City, Utah, USA, established the Center for Disability Services (CDS). At present, if an individual has a disability, he or she can inquire at the CDS for information about navigating the university campus. The CDS uses a combination of paper maps and expert knowledge to assist individuals in finding optimal routes between campus origins and destinations. In some cases personal accompaniment is necessary to ensure the arrival of the individual to their desired destination. This procedure has several drawbacks. First, it is both difficult and costly to update paper maps in a timely manner. Second, this method relies heavily on the availability and knowledge of experts which increases the time required to generate optimal routes and limits the ability to transfer information within the university community. If a CDS employee leaves, his or her expertise is lost. A third consideration is the lack of data. The current paper maps identify stairs; however, they do not include other obstructions that may hinder or prevent a disabled person from passing, such as curbs and steep slopes. Even if a paper map could include all relevant factors, the resulting map will be complex and untrained users are likely to make large errors in route estimations (see Golledge and Stimson 1997; Satalich 1995). The development of an efficient, effective and user-friendly pedestrian route-finding decision support system has the potential to save both time and resources, as well as provide better pedestrian navigation.

3 GIS and routing pedestrians

3.1 Pedestrian routing applications in a GIS

There are several constraining factors in determining appropriate paths of travel for people with differing abilities. The first and most obvious is distance or time. The path returned to the user should be the shortest feasible route with respect to network distance between origin and destination pairs. A second constraining factor is the physical ability of the user. Knowing the ability of the user is the essential consideration in determining if a route is feasible. Barriers that may be imperceptible to many people may hinder or totally restrict access to people with disabilities (Matthews and Voujakovic 1995). Examples include uneven pavement slabs, cobblestone courts and gravel. Consequently, there has been a move towards utilizing GIS and global positioning systems (GPS) to assist disabled people in navigating through urban spaces (Dewey 2001; Golledge et al. 1991; Golledge et al. 1998; Matthews et al. 2003).

Matthews et al. (2003) and Dewey (2001) developed GIS pedestrian routing applications that are similar in their system design and functionality. Their applications use ESRI's® ArcView GIS and customized it using Avenue (ArcView's scripting language) and Java, respectively. Both applications provide wheelchair users with detailed, customized information to assist them in planning and managing their mobility within urban environments.

Several problems associated with the routing applications of Matthews et al. (2003) and Dewey (2001) inhibit the wide spread use of these applications. One problem is data acquisition. The applications use very high-resolution data, for example, the measurement of all bumps and abnormalities in the sidewalk. This is extremely costly to acquire and maintain, and is unnecessary for the majority of routing problems. A related problem is the overwhelming number of variables to be entered before determining the optimal route, such as the wheel diameters of the wheelchair and the maximum height of largest obstacle the user can traverse. The intensive data requirements burden both the developer and the user. This limits the practicality of these applications. Another problem is the requirement for proprietary software on behalf of the user. These applications deliver their solution on the client side via ArcView 3.x®. Therefore, only people who can afford this commercial GIS are able to use the applications. There is also a steep learning curve required to master the GIS software. This can be difficult and time intensive for people outside the professional GIS community.

U-Access is a more universal tool than its predecessors. Rather than requiring expensive and complex proprietary GIS software on the user side, U-Access delivers results using the World Wide Web (WWW). The WWW is increasingly the common medium for the transmittal of aspatial and spatial information, it provides a degree of accessibility to the public that proprietary software packages cannot offer. U-Access capitalizes on emerging technologies that are increasing the overall accessibility of the WWW, namely, scalable vector graphics (SVG) (W3C 2000a). SVG provides optimal display functionality through vector technology and offers a set of powerful querying tools which are based on eXtensible markup language (XML). As a result, U-Access is able to generate fast, correct paths of travel for all people who have access to the Web. This application also capitalizes on the speed and efficiencies of Java's object oriented technology for a 'back-end' optimal route computation. This elegant system design for a WWW-based pedestrian routing service provides an efficient, scalable, and robust application that offers both planners and users the ability to identify feasible routes through urban environments in a cost effective and timely manner.

3.2 System design

3.2.1 Data model

Spatial network databases (SNDB) form the kernel of many network applications such as transportation routing, air traffic control utilities, river transportation and irrigation canal management (Shekhar and Chawla 2003). Unlike traditional spatial databases that store objects based on their spatial proximity, SNDB are based on both proximity and connectivity. This section focuses on the conceptual, logical and physical levels of SNDB data modeling for pedestrian routing applications.

At the conceptual level, all the available information related to the application is organized using a high-level semantic modeling technique. The conceptual modeling process focuses on data types, their relationships and their constraints. Figure 1 shows a universal modeling language (UML) diagram of the essential environmental elements and their relationships

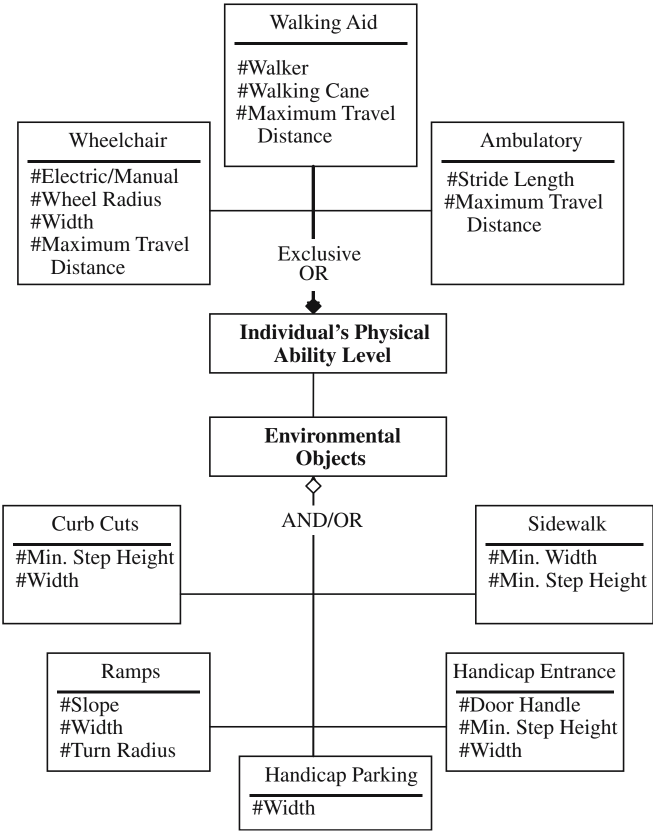


Fig. 1 The *essentials model* in a UML format. The phenomenon that U-Access represents is the interface between individuals and urban environments. The individual is defined as one of three categories based on their physical ability. The pedestrian urban environment is defined by several objects. The location and attributes that define the environment determine whether a pedestrian with a given physical ability can overcome the urban obstacles

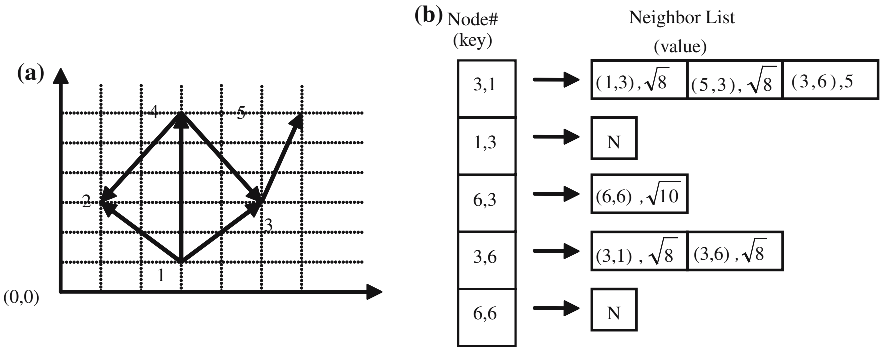
(OGC 1999). There are three relationships worth noting in this UML diagram. The first is the "Individual's Physical Ability Level." In U-Access, an individual must define their physical ability level as a *peripatetic*, *aided mobility* or *wheelchair user*. The pedestrian network incorporates sidewalks, handicapped entrances, handicapped parking, ramps, and/or curb cuts into the data model. Lastly, a one-to-many relationship exists that reflects the interaction between an individual and the urban structures.

At the logical level, graph theory is the foundation for SNDBs. The basic operations used comprise three fundamental subclasses, namely, *graph*, *vertex*, and *edge*. The *graph* class must be able to add, delete, or return a vertex of an edge given two vertices, return an adjacent node of a given vertex, find all adjacent neighbors, and finally, return the parent of a given vertex. The *vertex* class necessitates four basic operations, namely, the creation of a vertex with the appropriate label, returning a label associated with a given vertex, and marking a vertex as having been visited. The *edge* class is comprised of a constructor and has three functions, namely, to return the first node of the edge, to return the end node of the edge, and to return the length of the edge (Shekhar and Chawla 2003).

Since U-Access incorporates detailed and voluminous pedestrian networks, the solution speed is critical. U-Access uses the Java® hashmap data structure to represent the pedestrian network (see Fig. 2). Java program parses SVG files to create three Java objects, namely, a list of unique nodes (*nodeList.map*), a list of unique edges (*edge.map*), and a neighbor object for each node (*neighbor.map*). Nodes are zero dimensional objects defined by two numbers representing the two-dimensional locational coordinates. Edges are constructed using a start node, an end node, and a distance value representing the length of the edge. The neighbor objects are additional sources of information that are constructed in order to decrease the time necessary to compute the optimal path. A neighbor object is composed of a node object and a real number representing the distance (the length of the edge which connected the neighboring node). The neighbors are stored in a *hashmap* or aggregate categories based on some key or unique attribute. In this case, the key is a unique node, and the value stored is the list of neighbors for that node.

3.2.2 *Implementing the data model*

The two main goals of the data design for U-Access are: (1) easily updateable spatial data; (2) fast and accurate route computation. In order to accomplish these goals, there are four major steps involved in transforming the data



Directed Network

HashMap Representation

Fig. 2 Graphs (**G**) are composed of vertices (*V*) and edges (*E*). A graph can be stored using a Java2® hashmap data structure. U-Access utilizes the hashmap data structure by using objects that define the vertices as the index. The index is then mapped to a list objects known as neighbors (also known as the *forward star* or *f-star*). The neighbor is defined by a node and a distance value. For example, node (3,1) has three neighbors. The first neighbor is located at (1,3) and maintains a distance of √8 units. This structure provides storage for fast and efficient data retrieval while computing the shortest distance through the pedestrian network from a GIS to presenting pedestrian users with optimal routes (see Fig. 3). The first step includes the creation and maintenance of the spatial information within a commercial GIS. The second step transforms the spatial dataset from the GIS to an SVG file format. Thirdly, the SVG is parsed into three unique networks reflecting the three differing physical abilities. Finally, the SVG file is embedded in an HTML file and served to the community via the World Wide Web.

Spatial data acquisition and creation is the most critical step in the development of a successful web mapping application. We chose ESRI's® ArcGIS for several reasons. It is able to integrate and update spatial data from several different formats. It is also able to directly transform the data from a shapefile format to a SVG file format. We obtained spatial data from several sources including GPS-based georeferencing of stairs and curb cuts, general campus information from the University of Utah Facilities Management department, and accessible building entries from the CDS. A network dataset represents the pedestrian network with each edge attributed with a mobility index of 1, 2 or 3; these correspond (respectively) to edges that peripatetic people can traverse, edges that are feasible for users with aided mobility, and feasible edges for wheelchair users. Note that this is an increasingly restrictive categorization: we assume (realistically) that peripatetic people can traverse the entire pedestrian network, aided mobility users have a limited network but can traverse all edges feasible to a wheelchair user, and a wheelchair user has the most restrictive network. Prior to the data being exported into SVG file format, we presented the maps to the CDS for data validation and verification.

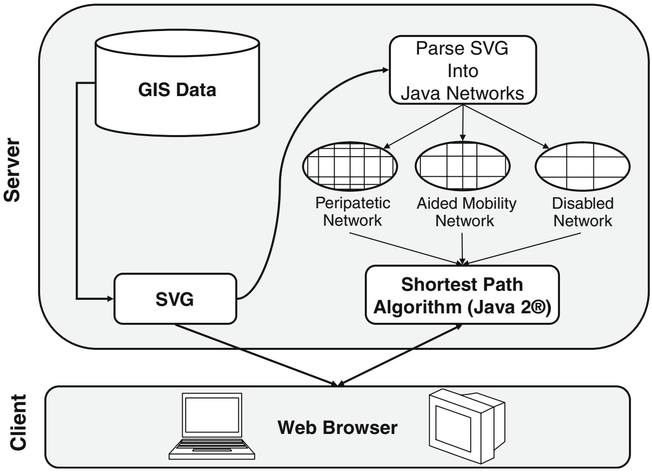


Fig. 3 U-Access has two major components, namely a client and a server. On the server side, the geographic information is stored and maintained within a GIS environment. The data is then exported into a SVG format. It is then read with a Java program and stored into three separate networks in order to minimize the time necessary for route computation. Lastly, the user, or the client, interacts with the data via a web browser

The second step in the data model is the modification of the spatial information from ESRI's proprietary data format to the SVG XML using a third-party open-source extension called GeoClient©. GeoClient provides both standard interactive map functionality such as zoom-in, zoom-out and identification, and a SVG file. As an XML file format, SVG incorporates both attributes and spatial information within a single file, and therefore can support both textual and geographical queries. Second, since SVG is a vector file format, the display properties are independent of the client device screen size and resolution (see Plewe 1997). Finally, the seamless integration of SVG and JavaScript® through the use of GeoClient creates a robust, scaleable, and effective Web environment that incorporates a full suite of tools for data querying and optimal path routing.

The third step in the data transformation process uses the geographic information within the SVG file to create three SNDBs which allows for efficient search and retrieval of locational information for the shortest path algorithm. The extraction of the pedestrian networks uses a Java® program that parses the SVG file into three pedestrian networks, namely, (1) peripatetic routes, (2) aided mobility routes, and (3) wheelchair user routes. This method of storing redundant data minimizes the number of edges that the shortest path algorithm considers, and therefore minimizes the optimal route computation time.

The fourth and final step in the data transformation process is to embed the SVG file into an HTML document. This enables the integration between the SVG objects and the stored Java SNDB. JavaScript is used to communicate between the two different datasets by passing five parameters from the SVG document, namely the origin coordinates, the destination coordinates and an ability level. The JavaScript then parses the list of edges that identify the shortest feasible route that is returned from the Java shortest path applet and highlights them on the map.

3.2.3 Algorithm design

At the heart of all optimal path applications are algorithms for solving the routing and location problems within a network. All shortest path algorithms use the same fundamental operations; however, they differ with respect to physical implementation, or the low-level data structures (see Cherkassky et al. 1993; Gallo and Pallottino 1998; Goodrich and Tamassia 1998; Miller and Shaw 2001). This section discusses the U-Access implementation of Dijkstra's shortest path algorithm (Dijkstra 1959) with respect to the above mentioned data storage structure.

The high-level description of Dijkstra's shortest path algorithm is deceptively simple. There are four temporary storage elements to the algorithm. The first stores the best estimate of the shortest distance from the source to each vertex, **D**. The second temporary storage is **P**, also known as the parent or predecessor tree, which stores the predecessor of each vertex on the shortest path from the source. The third set is **S**, the set of settled nodes, or those nodes whose shortest distances from the source have been identified. Lastly, **Q** represents the set of unsettled nodes. The three main steps in implementing Dijkstra's algorithm are (1) while **Q** is not empty, extract the node with the minimum distance (*u*) from **Q**, (2) add *u* to **S**, and finally (3) *relax* the neighbors of *u* (Waldura 2003). Relaxing a node finds all nodes connected to the current node, calculates their respective distances, and then adds the nodes to a queue of sorted nodes. This insures that **Q** contains a sorted list of nodes that do not already exist in data set **S** and the distance is defined in data set **D**.

While the shortest path applet utilized by U-Access follows the general steps in Dijkstra's algorithm, an enhancement is the use of neighbor objects when relaxing neighbors of node *u*. Traditional network data storage techniques use the forward star structure (FSS): this method organizes the SNDB by nodes and the set of arcs leaving each node. This requires three separate data structures: (1) an arc array; (2) an arc weight array, and; (3) a pointer array for accessing the two data arrays (Miller and Shaw 2001). Thus, this data structure requires three steps to identify the adjacent nodes to node *u* and their corresponding distances. In contrast, U-Access uses the hashmap data structure to capitalize on an efficient access function within the Java environment. When the path-finding algorithm needs to identify the list of adjacent nodes and their corresponding distances, it simply uses node *u* to reference a list of neighbors. Although the hashmap data structure appears to behave much like the FSS, the number of steps necessary to retrieve the connected nodes is reduced from three steps to one.

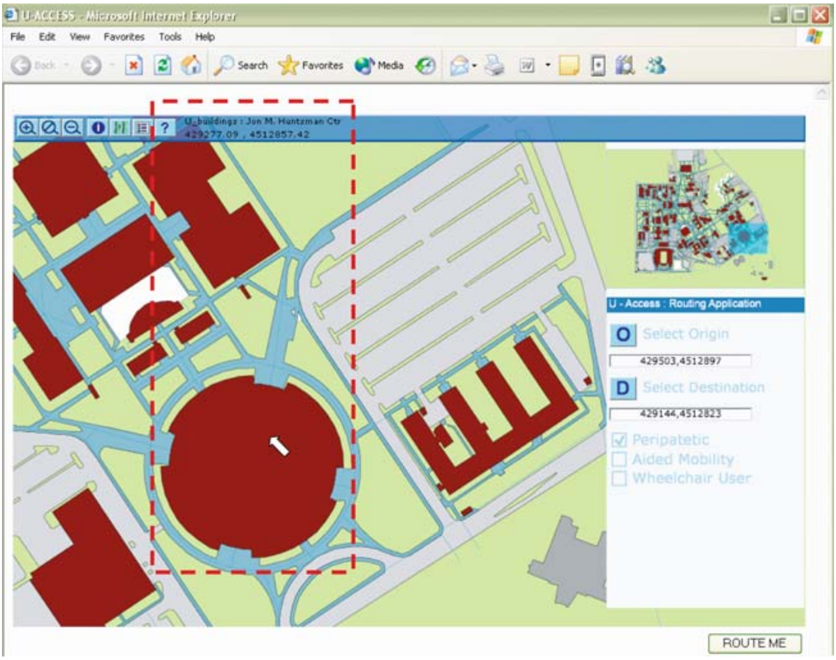
3.2.4 Interface design

U-Access provides a clear, straightforward Internet application for inexperienced computer users. Since we cannot assume that computer ability is sufficient among all potential users (see, e.g., Matthews and Vujakovic 1995), all choices are made by using mouse clicks on either the 'buttons' or on the map. Key commands are kept to a minimum to ensure clarity and visibility, as well as to guard against mistakes.

U-Access begins with a user loading the Web page. The page consists of four components. The main component is the *Overview Map* that provides the user with a spatial reference and attributes about the data. When a user 'hovers' the mouse over a building, the name is automatically displayed in the center of the toolbar. Within the dashed line in Fig. 4, the user is hovering over the "Jon M. Huntsman Center" and thus its name appears in the toolbar.

The second component of U-Access is the *Locator Map*. The locator map is a smaller scale map of the entire study area located in the upper right hand corner of the browser window. When the user zooms in on the main map, a box in the locator map highlights the viewable area, as it is linked to the scale and location of the main map. This allows the user to easily identify where he/she is relative to the entire study region (see Fig. 4).

The third component of U-Access is the *Tool Bar*. The tool bar is a series of buttons located at the top of the map which aid the user in navigating through it. Within the tool bar there is a 'zoom-in' function, 'zoom-out,' a search tool that enables the user to search for a building by



U_buildings : Jon M. Huntsman Ctr
429277.09 , 4512857.42

U - Access : Routing Application

Select Origin
429503,4512897

Select Destination
429144,4512823

☑ Peripatetic
☐ Aided Mobility
☐ Wheelchair User

Fig. 4 U-Access utilizes web technologies in order to maximize the user base. The basic components include (1) the map, (2) an overview map, (3) map tools, and (4) the U-Access tool set. The identified box reveals some basic functionality where when the mouse is moved over a building, the building name appears at the top of the screen in the *tool bar*

name, and an identify tool that allows the user to 'identify' features on the map (see Fig. 4).

The last component of the U-Access interface is the *Routing Tool Box*. This is a frame under the locater map that allows the user to select an origin, a destination, and an appropriate mobility level. Within the routing tool box there are three buttons as well as a "radio button" which allows the user to select one and only one ability level. The first button activates a tool that allows a user to define their origin. The second button allows the user to define their destination by clicking on the appropriate location on the map. The coordinates of the origin and destination identified by the user are recorded in the text box under the tool. Third, the user must choose an appropriate ability level. This option is selected with radio buttons to ensure that the user only selects one ability level. In this manner, the user can personalize their route parameters (see Fig. 4). If the user has failed to enter in any of the necessary parameters, a pop-up window appears telling the user to finish supplying the necessary information. Finally, the user selects the "ROUTE ME" button located in the lower right corner of the explore window. Once a user enters in the necessary data, the user may then select the "ROUTE ME" button to invoke the application to find and highlight the route.

Once the user invokes the path-finding routine, the shortest path algorithm solves for the optimal route. A single Java program executes using the parameters defined by the user. Note that the network is not rebuilt each time the program executes: a separate network is maintained for each ability level. The path-finding algorithm uses the physical ability level input to determine which data set to use. This minimizes computation time at the expense of redundant data storage. Since data storage is inexpensive, this is not a major concern; however, it is critical that any changes in the built environment are propagated to all three networks or else the database will be inconsistent

Once the Java program has computed the optimal path, the system displays the result for the user. The route-finding algorithm returns a list of edge features that compose the optimal route. JavaScript parses the string of feature numbers and highlights each edge feature that is a part of the accessible route. The total distance is displayed in the bottom text box within the routing tool window. If no route is found, the distance is set to zero and the system notifies the user that a feasible path does not exist between the two points they defined.

4 Implementation and evaluation

4.1 Pedestrian routing

As a routing application, U-Access provides routes to pedestrians based on their physical ability. In this section we provide a simple example to demonstrates how U-Access identifies feasible routes. In this example, it is clear that there exist discrepancies in distances between ability levels; it reveals the circuitous routes that people with disabilities require to navigate through a built environment such as a university campus.

We chose a very common origin-destination pair to demonstrate our point. In this example, pedestrians are traveling from the Student Union Building (the most utilized building on a daily basis) to the ticket office inside Kingsbury Hall (see Fig. 5). The path for the peripatetic individual is relatively direct and is therefore easy to navigate. In contrast, the path for an aided mobility individual is very different: it takes a turn towards the north and utilizes several parking lots and alleyways to avoid a long flight of stairs.

The route for the wheelchair user must avoid these stairs but also avoid several curbs along the path. This leads to an even more sinuous and circuitous route.

In addition to the increasing length of feasible routes with additional physical ability restrictions, is also important to point out how the numbers of turns in route greatly increase. The peripatetic route has only four major modifications in directions; this results in an easy route to follow. However, aided mobility user has to navigate 10 major turns, and the wheelchair user will attempt to correctly navigate 12 turns. Therefore, a routing system such as U-Access becomes more critical with greater mobility restrictions since the route-finding and navigation process becomes more complex.

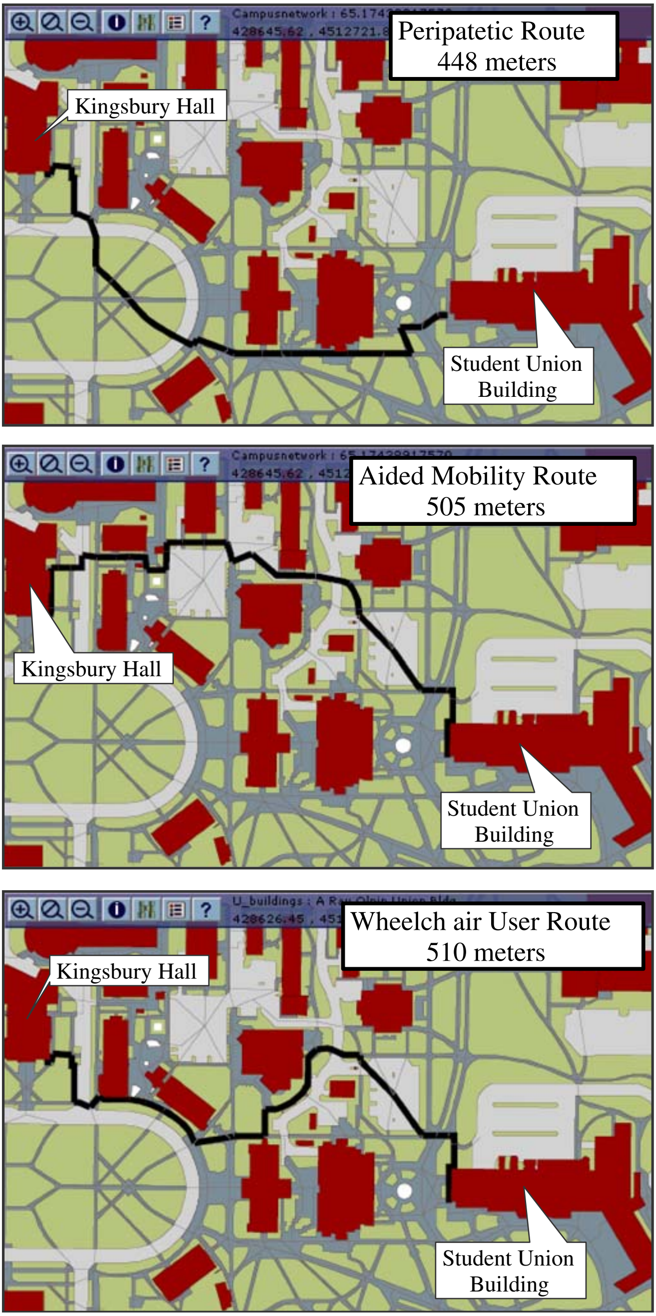


Fig. 5 The route between a single origin destination pair can differ greatly depending on physical ability of the user. This figure is provided not only to show distance discrepancies between ability levels, but also to provide an example of how routes may greatly differ

4.2 Prescriptive analysis of pedestrian networks

In addition to routing, U-Access is also a prescriptive analysis tool. It can be used to perform quantitative analysis of distance discrepancies among the three ability levels. It also enables the user to visually analyze paths in order to identify problem areas. The information gained from identifying potential bottleneck areas could be used for decision support for campus construction and renovation.

A prescriptive analysis was completed for the University of Utah campus using U-Access. For this analysis, seven campus buildings were chosen based on the number of students that frequent them on an average day. Three additional buildings were chosen based on their spatial location on the periphery of campus. All ten buildings are highlighted in Fig. 6. U-Access is used to generate the total distance traveled among the ten origin-destination pairs for the three ability levels.

Figure 7a shows the total route lengths between the ten origin-destination pairs for each ability level. Clearly, a wheelchair user traveling between the same origins and destinations in this environment must traverse substantially greater distances than both the peripatetic and aided mobility users. In one case, the required distance was twice as far for a wheelchair user than a peripatetic user (302 and 770 m, respectively). This particular case is due to five small steps in front of an entry way. If a ramp were constructed, the

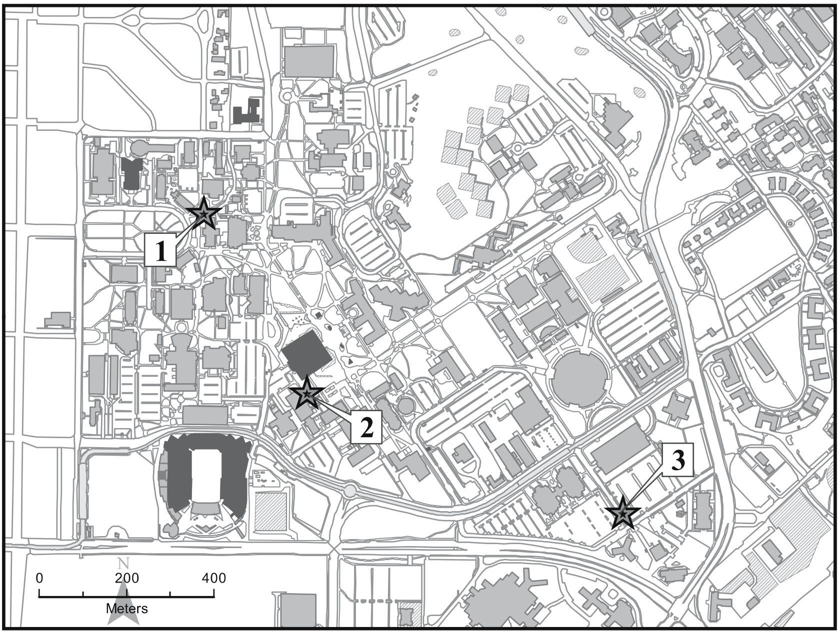


Fig. 6 The highlighted buildings are the basis for prescriptive analyses at The University of Utah. After the analysis was completed, three "bottle neck" areas, or areas that cause the greatest discrepancies in distance to physically disable people, were identified and are marked by a star

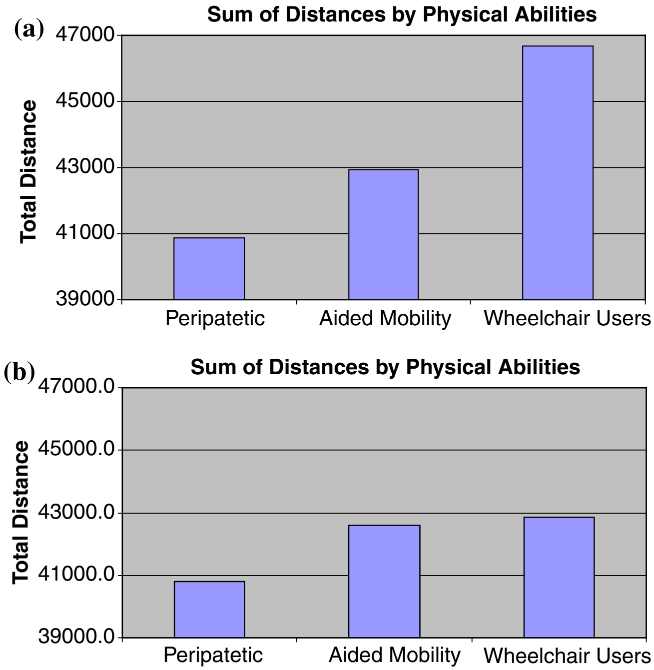


Fig. 7 **a** The total distance traveled for each physical ability level between each building in the study set is shown in meters. Wheel chair users are traveling as much as 5 km farther and people who walk revealing vast discrepancies between physical ability levels at the University of Utah. **b** The three obstacles were identified and removed from the dataset. The prescriptive analysis was run a second time and total distances are reported again. With the removal of three obstacles, the discrepancy between physical ability levels is greatly reduced

distance physically disabled people must travel would decrease from 770 m to approximately 390 m.

After the prescriptive analysis, the three origin-destination pairs which yielded the greatest distance discrepancies between peripatetic and wheelchair users were visually analyzed. In this analysis, three built obstacles were identified which appear to substantially impact the route length discrepancies; the locations of the obstacles are identified in Fig. 6. The single greatest obstacle that forces wheelchair users to travel much farther than walking pedestrians or aided mobility pedestrians is a curb at location three in Fig. 6. This small curb forces wheelchair users to travel an additional 400 m around the block in order to gain access to the Madsen Health Clinic. Alternatively, the wheelchair users can use roads to avoid the additional travel, but this poses a greater risk of physical harm due to vehicular traffic.

U-Access was used to conduct a "what-if?" scenario, namely, what would happen if the three major obstacles were removed. To remove the obstacles, the statuses of the three nodes were changed in the database reflecting the removal of the obstacles described above and the routes were re-computed. Figure 7b shows the results. By eliminating the three obstacles, the total distance discrepancy decreased from a 12 to 5% difference between physical abilities, a savings of nearly 3,700 m. One interesting finding through this analysis is that the difference between aided mobility and wheelchair users decreased from 8% to a mere 0.99% difference. Thus, removing only three barriers on the University of Utah campus could greatly assist wheelchair users by substantially reducing the distance they must travel. Although there is still a sizeable disparity in the distance that wheelchair users and peripatetic individuals must travel, it has been considerably reduced.

4.3 Expert evaluation

In order to assess the accuracy and usability of U-Access, we provided the application to the CDS. The CDS agreed to use the application for 3 weeks with their staff, as well as provide it to those students who use the computer lab within the CDS office. Each staff person that used the application was asked by the CDS to fill out an evaluation form. Users evaluated U-Access on four criteria: web page organization/layout, web graphics, technically, and utility. The Appendix provides the evaluation instrument. We received a total of eight completed expert evaluations. While this may appear to be a modest sample, the pool was limited to CDS employees and active users: we were restricted from surveying the broader disabled student community due to privacy concerns. Also, these are expert evaluations: we are not attempting to make statistical inferences to a larger population but instead gather initial design insights from individuals who are knowledgeable in the routing problems faced by disabled students in this environment as well as the challenges of transmitting this information to this student community.

Experts evaluated the overall organization and layout of the web page. This included questions about initial reactions to the initial page design and if the design had an affect on their ability to navigate the website. In general, experts felt the page needed more instructions on how to use the tools. Although U-Access utilizes common Web tool for zoom and identify, the tools for selecting an origin and a destination did not appear to be easily understood. Several experts felt that an initial dialog box with instructions would have been useful.

With respect to the graphics, experts felt the map was “readable” in that sidewalks, buildings, and vegetation were clearly delineated. They also felt that the optimal route was clear. However, there were two common critiques in this regard. The first was that the buildings needed to be labeled. Currently, users are forced to hover their mouse over the building as opposed to being able to simple glance at a building and identify it. The second critique was that while the optimal path was clearly presented, they felt that it is still difficult to navigate the path even with the map. We believe this is a function of the nature of unnamed paths. While streets have names to assist in giving directions, the sidewalks do not have such amenities.

Experts were asked to evaluate the technical performance of U-Access. This included questions on page load time, path correctness and interactions with the website. Experts felt the web page loaded quickly except if the computer had pop-up blocker software enabled. Further investigation determined that pop-up blockers prohibit the display of embed objects.

Thus, users are forced to turn off their pop-up blocker software before they were able to use the web page. The experts were impressed with the route accuracies. One expert decided to test the accuracy and traveled provided routes and verified their correctness.

The last component of the evaluation was utility. Experts had the chance to express whether they would use the application on a regular basis, and whether they felt an application such as this one would be helpful for the general public. There was an overwhelming response that they would have loved such an application when they first came to campus. This would make sense that after a person has been on campus long enough they know which routes are feasible, and which routes are not. One particular student felt that U-Access would be helpful at the beginning of every semester.

The expert evaluations were a necessary part of this research in order to test the utility of U-Access. The evaluations reinforced the need and demand for such an application. The comments received in the evaluation forms will be considered before the application is served to the general public.

5 Conclusion

The U-Access application is a Web-based navigational system for routing people with varying ability levels in a built environment. U-Access is both a decision support tool to assist pedestrians of different mobility levels in identifying the shortest feasible routes on campus, as well as an analytical tool to identify obstacles and assess the impact of their mitigation or removal.

U-Access does not claim to be a "magic bullet" to cure the social exclusion that many disabled people face (Gleeson 1999). However, it is hoped that this application heightens awareness for the provision of accessible tools to people with disabilities in order to assist them in gaining independence within urban environments. While more universal than previous applications, U-Access may not be available to all people, in particular those who do not have ready access to Internet computers, or the skills to use these computers. Typically, the group of people that are most excluded from the benefit of these technologies are the elderly (Matthews et al. 2003). However, as Internet access begins to appear in public settings such as libraries, this barrier may become less severe.

Another group that may not benefit from U-Access in its current form are people with visual impairments. There has also been some research by the W3C (W3C 2000b) with their Web Accessibility Initiative. This initiative provides an XML based SVG-to-text converter for visually impaired Web users. Currently, when visually impaired people want to read an Internet map, they have a special printer that prints the map with raised lines for each feature on the map. The map is then placed on a tablet so that the user can interact with the SVG map by means of sound and touch. This allows them to query items on the map in a manner similar to non-visually impaired users who interact with the monitor (Campin et al. 2003). However, unlike vehicle routing where streets are named and intersections are clearly marked in the real world, pedestrian networks seldom distinguish among network intersections. While the visually impaired can make map inquiries on the Internet, there are still issues to be resolved regarding translating the optimal route from an Internet map to a useful tool in the real world. Thus, there is still much work to do in order to better route disabled people through built environments.

6 Appendix

6.1 U-Access evaluation dimensions

1. Organization/Layout:

(a) Was the design of the web page helpful in understanding the intention of the software?
(b) Does the layout of the page affect your ability to navigate? Are the tools clearly labeled?
(c) Comments/suggestions.

2. Graphics:

(a) Was all the information clearly presented?
(b) Were you able to clearly delineate the route provided to you?
(c) Comments/suggestions.

3. Technical:

(a) Does the page load reasonable quickly?
(b) Does the page respond well to your interactions (mouse clicks)?
(c) Did many events occur that were not expected?
(d) Please comment on the “correctness” of the routes?
(e) Comments/suggestions.

4. Usability:

(a) If you had this application, would you use it on a regular basis (daily, weekly)?
(b) Do you feel that an application of this type would be helpful for the general public?
(c) Comments/suggestions.

References

Campin B, McCurdy W, Brunet L, Siekierska E (2003) SVG maps for people with visual impairment. In: Proceedings from SVG Open Conference July 2003

Cherkassky BV, Goldberg AV, Radzik T (1993) Shortest path algorithms: theory and experimental evaluation. Discussion paper, Department of Computer Science, Stanford University, Stanford, CA

Church RL, Marston JR (2003) Measuring accessibility for people with a disability. Geogr Anal 35(1):81–96

Dewey C (2001) Navigation services for wheelchair users consideration of special physical demands in computer-based wayfinding. [Unpublished Master's thesis]: Institute of Geoinformatics, University of Muenster

Dijkstra EW (1959) A note on two problems in connexion with graphs. Numer Math 1:269–271

Foster L (2004) Progressive access: unique solutions for historic buildings. J Arch Conserv 10(3):73–86

Franklin K (2005) A three-stage test provides some answers in disabled access cases. Arch J 221(5):46

Gallo G, Pallottino S (1998) Shortest paths algorithms. Ann Oper Res 13:3–79

Gleeson B (1999) Can technology overcome the disabling city? In: Butler R, Parr H (eds) Mind and body spaces. Routledge, London, pp 98–118

Golledge RG, Stimson RJ (1997) Spatial behavior: a geographic perspective. Guilford, New York

Goodrich MT, Tamassia R (1998) Data structures and algorithms in Java. Wiley, New York

Golledge R, Loomis KM, Klatzky RL, Flury A, Yang XO (1991) Designing a personal guidance system to aid navigation without sight: progress on the GIS component. Int J Geogr Inf Syst 5:373–395

Golledge R, Klatzky RL, Loomis JM, Speigle J, Tietz J (1998) A geographical information system for a GPS based personal guidance system. Int J Geogr Inf Syst 12:727–749

Little J (1995) What has ADA really done? Accent Living 39(4):28–30

Matthews H, Beale L, Picton P, Briggs D (2003) Modeling Access with GIS in Urban Systems (MAGUS): capturing the experiences of wheelchair users. R Geogr Soc 35(1):34–45

Matthews MH, Vujakovic P (1995) Private worlds and public places: mapping the environmental values of wheelchair users. Environ Plann A 27:1069–1083

Miller HJ, Shaw S (2001) Geographic information systems for transportation: principles and applications. Oxford University Press Inc, New York

OGC (1999) The open GIS guide (3rd edition) introduction to interoperable geoprocessing and the open GIS specification, available at http://www.opengis.org/techno/guide/guide980615/Guide980615.rtf

Plewe B (1997) GIS online: information, retrieval, mapping, and the Internet. Onword Press, Sante Fe

Satalich GA (1995) Navigation and wayfinding in virtual reality: finding proper tools and cues to enhance navigation awareness. [Unpublished Master's thesis]: University of Washington, Seattle, WA

Sheffi Y (1985) Urban transportation networks: equilibrium analysis with mathematical programming methods. Prentice Hall, Englewood Cliffs

Shekhar S, Chawla S (2003) Spatial databases: a tour. Prentice Hall, Upper Saddle River

Thompson H (2005) Something for everyone. Blueprint. v227, p 90

W3C (2000a) Accessibility feature of SVG. http://www.w3.org/TR/SVG-access

W3C (2000b) SVG linearizer tools. http://www.w3.org/WAI/ER/ASVG

Waldura R (2003) Dijkstra's shortest path algorithm in Java. Available at http://www.renaud.waldura.com

William A, Patterson J (2004) Get your act together. Arch J 13:44