Algorithm
Analysis

Computation

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Environment

A Computational Approach for Evaluating the Facilitation of Wayfinding in Environments

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IN ANY ENVIRONMENT, WAYFINDING IS A KIND OF SPATIAL PROBLEM THAT PEOPLE ENCOUNTER ALMOST DAILY. Although it has been well documented that environmental cues significantly facilitate wayfinding, there has been little work done to examine the effectiveness of the facilitation. In particular, wayfinding manageability is considered in this paper, and, to this end, a computational approach to its evaluation is proposed. This is illustrated through simulation, employing a quantifiable measure for wayfinding facilitation. The measure is statistically determined from experimental data on certain wayfinding variables.

1 Introduction

Wayfinding is the process of determining and following a path or route from an origin to a destination (Golledge 1999). Wayfinding generally takes place within an environment, a three-dimensional space, albeit physical or virtual, with elements reflecting content, context and people. Objects in such an environment, for instance, signs, maps, landmarks and architectural features, serve as environmental cues (Lynch 1960; Weisman 1981; Seidel 1982; Shanon 1983; Passini 1984; Arthur and Passini 1992; Dennis 1997; Tversky 1999; Michon and Denis 2001). When people act in the environments, they receive wayfinding information from such cues in the environments (Lynch 1960; Passini 1984). Failure in comprehending the information can pose wayfinding problems, for example, as in getting lost.

In realistic situations, although people complain about environments in regard to wayfinding, there are no objective ways to specify what constitutes a good environment for wayfinding. O'Neill (1991) attempts this by proposing an InterConnection Density (ICD) model, based on the density of interconnections between decision points in a building floor plan, as a way of indicating the complexity in an environment. However, as described later, complexity is only one such characteristic that influences wayfinding. Even in Environmental Graphic Design (EGD), in which evaluation of wayfinding designs are critical, there are no other evaluation approaches beyond on-site observation after installation (Calori 2007).

In this paper, a computational approach—wayfinding manageability—is introduced and described. This is based on an objective measure for evaluating facilitation of wayfinding within environments. Manageability specifies how easily navigable an environment is. It is understood in this sense: whenever a wayfinding task is 100% manageable, then the way-seeker can get to a decided goal in planned time without impediment. Manageability can be considered as variant of the legibility problem (Lynch 1960; Passini 1984).

The paper is organized as follows. First, we elaborate on environmental cues for wayfinding (Lynch 1960; Passini 1984; Raudal and Worboys 1999). Next, variables for wayfinding manageability are introduced. Then, the experiment, statistical analysis and the computer simulation for determining wayfinding manageability are described. Last, contributions of the approach are outlined.

2 Environmental Cues

Wayfinding is based on "a consistent use and organization of definite sensory cues from the external environment" (Lynch 1960). Wayfinding exhibits both decision-making and decision-execution behavior (Passini 1984). It is well understood that people rely on cues that can be retrieved from the environment to generate knowledge for further actions (Raudal and Worboys 1999). Cues are objects within or of environments that people employ to generate mental representations.

Environmental cues fall into several familiar types:

- Signs (e.g. directional signs and informational signs) (Weisman 1981; Passini 1984);
- Maps (e.g. You-are-here (YAH) maps and layout maps) (Levine Marchon and Hanley 1984);
- Landmarks, certain objects that are more prominent than others; (Shanon 1982; Sorrows and Hirtle 1999; Denis et al. 1999; Allen 2000; Michon and Denis 2001);
- Architectural features that are not landmarks (Lynch 1960);
- Layout and structure of the environment (Weisman 1981; Seidel 1982; O'Neill 1991);
- Verbal cues (e.g. communication with other people and/or available help centers) (Freundschuh et al. 1990; Allen Miller and Ondracek 1997; Denis et al. 1999).

Of these, signs provide the most straightforward wayfinding information (direction, location or confirmation of location). Maps have the capacity to provide all possible information to assist the way-seeker. However, as every person has a different ability for comprehending information, compounded further by design and alignment issues associated with maps (Levine 1982; Levine Machon and Hanley 1984), a map may also hinder wayfinding.

Further, people tend to seek landmarks (often 3d), to construct mental representations of unfamiliar environments (Shanon 1983; Michon and Denis 2001), especially in the situ-

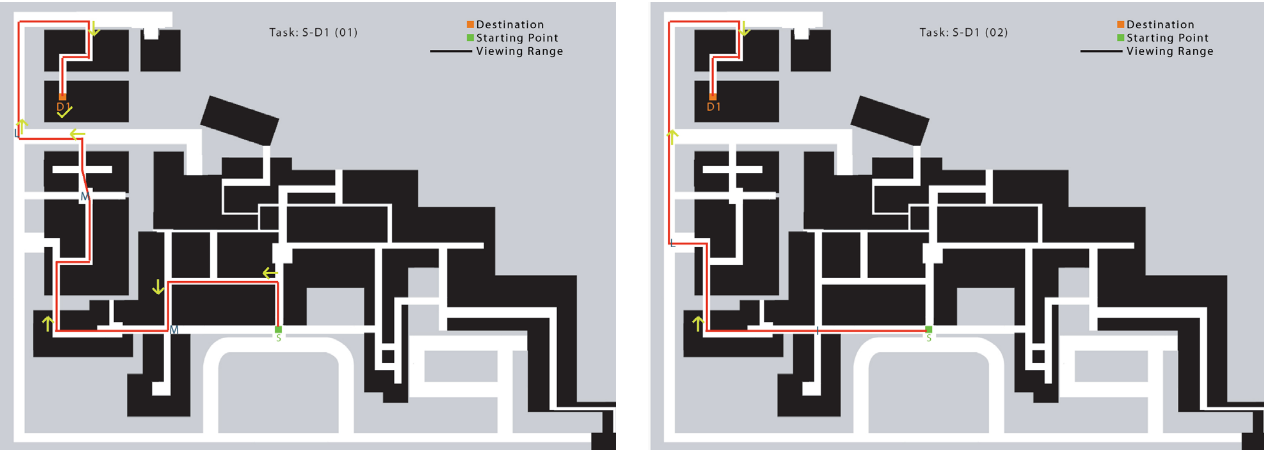


FIGURE 1. TWO EXPERIMENTAL ROUTES.

ations, when the navigated target is near a known landmark (Tversky Taylor and Mainwaring 1997).

When a way-seeker fails to either find the requisite cues (see Braaksma and Cook 1980; Dada and Wirasinghe 1999; on the viewability of cues), or comprehend conveyed information from a cue, the often consequent behavioral response is to seek help, where available, from information desks or others (Freundschuh et al. 1990; Allen Miller and Ondracek 1997; Denis et al. 1999).

3 Wayfinding Variables

If we regard an environment as a geographical graph (Bondy and Murty 1976)—with each point (intersection) as a node in the graph, the edge connecting nodes as paths with the nodes on the same path as a node-pair—then a route is composed of a set of paths from one node to another. This graphical construct gives identity to six wayfinding variables, considered at the node, node-pair and route levels (Braaksma and Cook 1980; O'Neill 1991; Denis 1997; Dada and Wirasinghe 1999; Allen 2000).

3.1 NODE VARIABLE: V1—NUMBER OF EXIT PATHS * ITS NAVIGATIONAL VALUE

The number of exit paths varies depending on the node's intersection type. An incoming path is not counted. The more exit paths a node has, the more likely a way-seeker will make mistakes (e.g., make a wrong turn), and the lower, manageability of the node will be. If the node has a valid navigation attribute (e.g., the presence of a significant environmental cue), it means it can provide wayfinding information. Different environmental cues provide different degrees of assistance on wayfinding. For this paper, the navigational value assigned to a node is based on its environmental cue type. (Directional sign = 1.0, information desk = 0.8, map = 0.5, landmark = 0.2, null or invalid = 0).

- V_1 is the aggregation of its exit paths * its navigational value of each node along a route.

For example, if a node represents a T intersection and a landmark, its V_1 value is (3 -1) * 0.2 = 0.4.

3.2 NODE VARIABLE: V_2—THE CONFIRMATION OF INFORMATIONAL SIGN IN THE DESTINATION NODE

A way-seeker needs an informational sign to confirm arrival at the destination node. The existence of such an informational sign at the destination node increases the manageability of the node and the route.

- V_2 is true (1) if destination is confirmed, and false (0) otherwise.

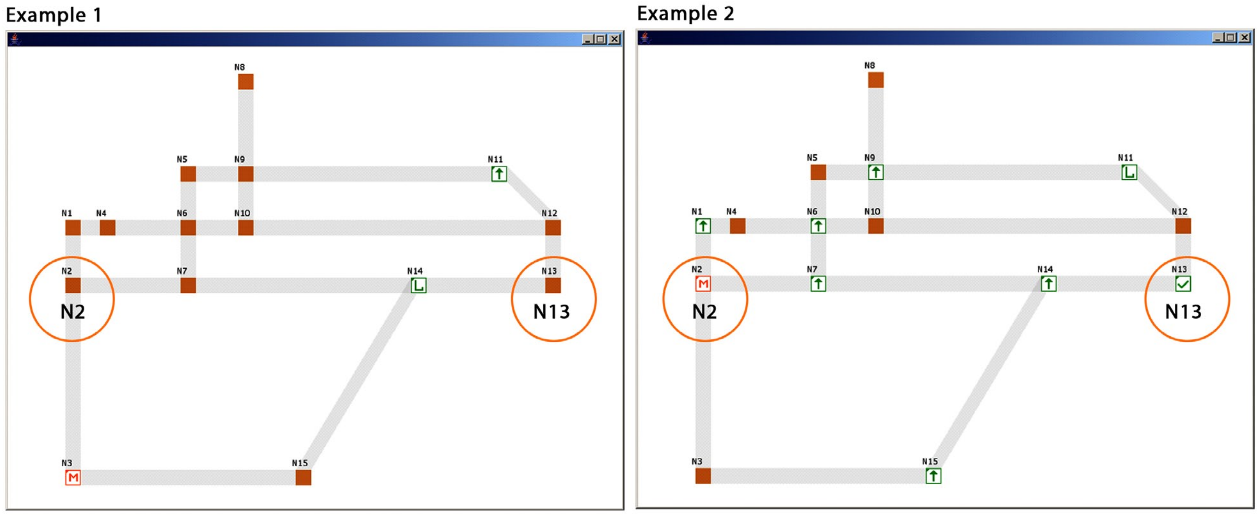
3.3 NODE-PAIR VARIABLE: V_3—SPATIAL VIEWABILITY

Spatial viewability refers the ability for the way-seeker to see the next node of the node-pair from the current node.

- V_3 is the total number of node-pairs with positive spatial viewability along a route.

3.4 NODE-PAIR VARIABLE: V_4—IMAGINARY VIEWABILITY

Imaginary viewability refers to the ability of the way-seeker to imagine (remember and execute) subsequent node-pairs from the current node via the assistance of a map or an infor-



Level	Variable	Description	Type	Setting
Node	V_1	Number of exit paths	Integer	1,2,3
		Navigational value	Float	Directional sign Landmark Information desk Map
	V_2	Confirmation of informational sign in destination	Integer(1/0)	True/False
Node-pair	V_3	Viewability in space	Integer	True/False
	V_4	Viewability in mental image	Integer	Map/Infodesk
Route	V_5	Length in distance	Integer(1/2/3)	Short/Medium/Long
	V_6	Length in segments	Integer	<3, 3-6, 6-9, >9

mation desk staff. An information desk staff can provide assistance on up to 4 imaginary viewable node-pairs, while a map can provide at most 2.

- V_4 is the total number of node-pairs with positive mental imaginary viewability along the route.

3.5 ROUTE VARIABLE: V_5—LENGTH IN DISTANCE

The length in distance of a route means the exact metric distance of a route. The longer a route, the more likely a way-seeker will make mistakes on wayfinding.

- V_5 is determined by the route's perceptual distance of whether the distance is short, medium or long.

Short distance is 1, medium distance is 2 and long distance is 3.

3.6 ROUTE VARIABLE: V_6—LENGTH IN SEGMENTS

The length in segments of a route means the total number of node-pairs of a route. The more segments, the more likely the way-seeker will make mistakes on wayfinding.

- V_6 is the total number of node-pairs along a route.

4 Experiment

4.1 OBJECTIVE

We assume that manageability of a route, M, can be described by the hyperplane:

$$M = X_1V_1 + X_2V_2 + X_3V_3 + X_4V_4 + X_5V_5 + X_6V_6,$$

where V_1, ..., V_6 are the wayfinding variables defined above, and X_1, ..., X_6 are the cor-

FIGURE 2. SIMULATION EXAMPLES.

FIGURE 3. SIMULATION RESULTS OF EXAMPLE 1.

TABLE 1. VARIABLES OF INTEREST FOR THE EXPERIMENT.

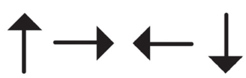
Image	Meaning
	Starting point of each route
	Destination of each route This symbol represents the destination has indication sign
	Destination of each route This symbol represents the destination has no indication sign1
	Map
	Information desk
	Landmark
	Directional signs pointing to the destination
viewing range: ———	The length of the line represents the viewing range

TABLE 2. DESCRIPTION OF THE IMAGES OF THE EXPERIMENTAL ROUTES.

responding weights (coefficients) for $V_{1...6}$. The purpose of the experiment is to determine the coefficients for M.

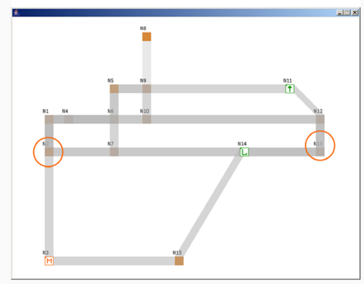
4.2 METHOD

4.2.1 PARTICIPANTS

Fifteen individuals, ranging from ages 20-40, comprising 7 males and 8 females, all from a single university, participated in the experiment voluntarily. None of the participants had knowledge of the objective of the experiment prior to the process. Participants were asked to rank the experimental materials.

4.2.2 VARIABLES OF INTEREST

The variables of interest for the experiment are the wayfinding variables specified above. Their description and settings are shown in Table 1.



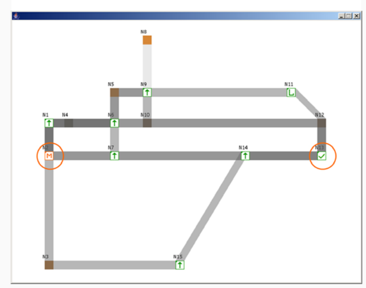


FIGURE 4. SIMULATION RESULTS OF EXAMPLE 2.

4.2.3 MATERIALS

Experimental wayfinding routes were generated as maps with various settings for the six variables. 10 wayfinding routes (Figure 1) were represented as route maps. The experimental routes are randomly sampled from variables from each level (viz., node, node-pair and route). See Table 1. Extreme cases were eliminated.

Each route map includes the layout of the environment, a line indicating the solution route from the starting point to the destination, and symbols representing environmental cues and indication. See Table 2.

4.2.4 PROCEDURE

Participants were shown the experimental maps and asked to rate these, on a scale of 1-10 from easiest (1) to the hardest (10), depending on how difficult they think it would be to successfully complete the wayfinding task (i.e., from the starting point to the destination following the solution route). There was no time limit for the procedure.

4.2.5 ANALYSIS

The average score among the participants is the dependent variable; V_1 to V_6, previously defined, are the independent variables. Analyses were by linear and stepwise regressions.

4.2.6 RESULTS

A total of 140 data points were collected (14 participants * 10 scores). The equation for M determined by linear regression is:

$M = 2.954 - 0.285\ V_1 - 2.035\ V_2 - 0.219\ V_3 - 0.333\ V_4 + 1.79\ V_5 + 0.45\ V_6$.

R = 95% and R^2 = 90.3%.

It is clear that lower the value for M, the more manageable and easier it is to navigate the environment. Standardized Coefficients Ð values are V_1 (-0.568), V_2 (-0.468), V_3 (-0.401), V_4 (-0.217), V_5 (0.638) and V_6 (0.801). From the stepwise regression, V_5 (P-value = 0.014) is the most significant variable, followed by V_2 (P-value = 0.088) and V_1 (P-value = 0.095).

5 Simulation

The aim of the simulation is to demonstrate, both numerically and visually, wayfinding manageability of the environment at the route level. The simulation program is written in JAVA. The input to the program is a XML file representing the environment, comprising nodes (id, x and y coordinates and environmental cue type) and paths (id, starting and ending nodes and path width). The program takes the input XML file and creates an undirected graph of nodes and paths. Once the starting and destination nodes have been specified along with any corresponding settings (the short and long distance and viewing range in this environment), the simulation begins. It provides two kinds of output (text-based and image-based).

The text-based results, displayed on the console, include solution routes and their M values. The image-based results display the solution routes in different gray-tones, corresponding to their M values. The smaller the value for M, the darker the route, indicating better manageability.

Two simple examples of the same environment (Figure 2) are used to demonstrate the simulation of M. The wayfinding tasks (from Node 2 to Node 13) and other settings are identical in these two examples.

As shown in Figure 2, in example 1, there are few nodes with valid environmental cues, and the destination (Node 13) has no informational sign. The simulation results (Figure 3) are:

After modifying the input file to include more valid environmental cues, and placing an informational sign at the destination node, the simulation results change accordingly (Figure 4):

From a side-by-side comparison (Figure 5), the distinction is clear, both numerically and graphically. The average M value (9.905) in example 1 is greater than the value (5.65) in example 2. The graphical-visualization of the environment of example 1 is lighter than ex-

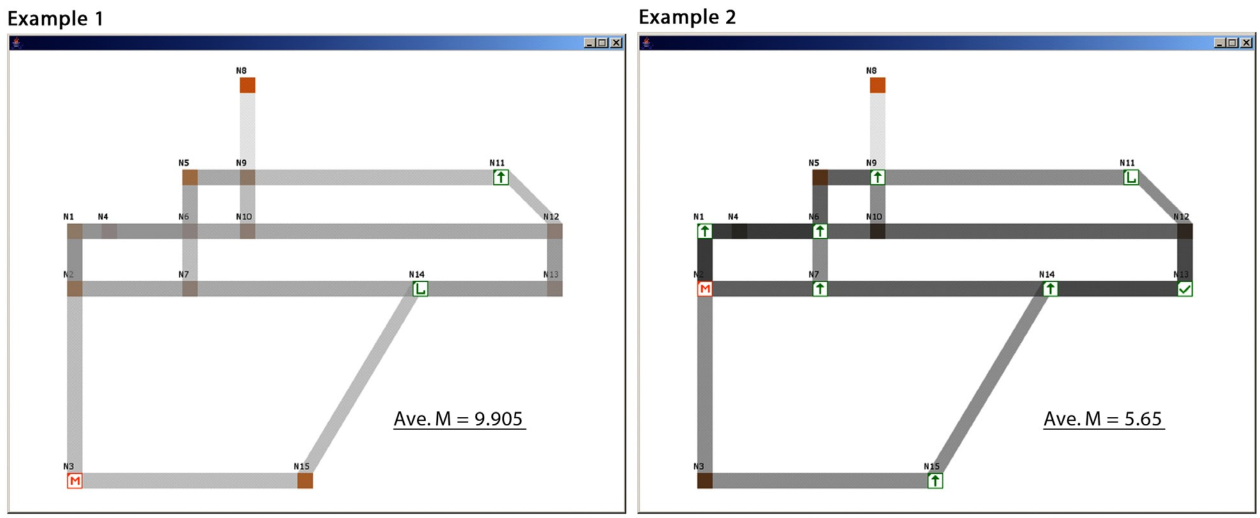


FIGURE 5. S SIDE-BY-SIDE COMPARISON OF TWO SIMULATIONS.

ample 2. The comparisons imply that wayfinding manageability (from Node 2 to Node 13) in the simulated environment of example 1 is worse than that of example 2.

6 Conclusions

In this paper a computational approach for evaluating the facilitation of wayfinding within environments is proposed. An expression for wayfinding manageability, M, was determined statistically, through an experiment for rating wayfinding tasks using settings for six predefined wayfinding variables. A simulation was implemented showing both text-based and image-based results for M. Two examples with different settings of cues for the same environment demonstrated the simulation. The lesser the value for M, the better the facilitation for wayfinding in the environment.

This paper takes a macro view to evaluating wayfinding in built-environments. This problem is significant in the fields of architecture, spatial cognition, and EGD. Future studies will concentrate on further developments of the simulation tool, a GUI and examining wayfinding through a combination of macro and micro (people-centric) views.

There are, of course, limitations to the present work. These include an insufficient number of subjects, limitations of the experimental approach itself of using paper-based imagination for wayfinding, the lack of validation for the experiment results, and lastly having an expression for manageability that is restricted the route level, and does not apply to the whole environment.

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