Coming of Age

WAYFINDING & IMAGIBILITY

BUILDINGS, MEMORY, AND WAYFINDING

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ABSTRACT

This paper explores the role of generic knowledge in environmental cognition and wayfinding. Whereas most research has focused on the development of specific information about a city or building, people are able to use a general understanding about buildings, or about types of buildings, to find their way. Schema-theory in cognitive psychology and frame-theory in artificial intelligence provide suggestions about how general building-knowledge may be structured. Previous research and several small studies suggest that people's schemas include at two kinds of knowledge: 1) declarative knowledge about elements that are typically in a building or building component, topological relationships and local geometric relationships; and2) procedural knowledge about what to do in the situation, which may be rule-like or more prescribed "scripts." A preliminary computational approach to environmental cognition is described.

INTRODUCTION

What do we know about buildings that enables us to find our way even on first-time visits? How is this knowledge organized, accessed, and used in action? Most approaches to environmental cognition examine how people develop knowledge of specific places; in our work we are interested in the general knowledge people have about places and how people integrate this generic knowledge with their knowledge of specific places. We have adopted a computational approach to model wayfinding behavior. The several anecdotes that follow serve to illustrate the questions with which we began our inquiry.

Urgently seeking a restroom in a strange city, a visitor enters a hotel, passing by the bank next door. In the hotel lobby there is no obvious sign, so she heads for the hotel restaurant, confident that a restroom will be located nearby.

Stopping in an unfamiliar supermarket to pick up some milk, a shopper enters and proceeds directly to the rear of leftmost aisle and searches along the wall; not finding the dairy case there, the shopper proceeds to the rightmost aisle and finds the milk.

A visitor enters a hospital to visit a friend on the fourth floor. There is a line of people waiting at the information desk, so he gets on the first elevator he sees (not noticing it is marked "staff only"). He gets off on the fourth floor expecting the elevator to open a corridor similar to the one on the first floor. He is startled to find himself instead in the surgical suite.

These experiences are not unusual; they represent familiar events from everyday life. In informal discussions with colleagues we have been surprised and encouraged to find that almost everyone can relate a personal anecdote along these lines. People have expectations about how buildings are organized and what they contain. This is not surprising: buildings are often similar in form and plan organization, and architects usually try to make buildings easy to understand.

Research in knowledge representation and environmental cognition supports the idea that people structure experience and memory using generic knowledge or schemas. However, we are far from a formal theory that accounts for the generic knowledge that people seem to have about buildings, how this knowledge is structured, retrieved, and applied in solving wayfinding tasks.

This paper describes our initial thoughts and preliminary research on these questions. First we review research in knowledge representation and focus on one model—the use of schemas—that suggests how knowledge about generic or stereotypical situations may be structured. Next, we review several studies exploring spatial and environmental knowledge. These studies suggest that people use schemas or prototypes both to structure their memory and experience of buildings and places and to direct their wayfinding behavior. We then discuss research on wayfinding, both in buildings and in cities, including several computational models of cognitive maps and wayfinding. Although wayfinding would seem a logical application of schemas in environmental cognition, little work has been published using this approach. Finally we present our proposed schema model of wayfinding in buildings, a description of our initial efforts, and directions for further work that we are pursuing.

BACKGROUND AND REVIEW OF CURRENT WORK

Kevin Lynch in *The Image of the City* proposed that city-dwellers find their way about the urban environment using an internal memory structure he called the "cognitive map". He devised experiments aimed at revealing the characteristics and content of this structure, and he reported on the cognitive maps of inhabitants of three urban areas. Lynch found that people orient themselves using a small number of kinds of urban features and he proposed that people's cognitive maps consist of several kinds of elements: paths, places, nodes, landmarks, and regions. Lynch observed among other things that people not intimately familiar with Boston's geography, asked to sketch a map, tend to draw the Boston Common—a five-sided park in the center of town—as a square or rectangle. He remarks, "... an object seen for the first time may be identified and related not because it is individually familiar but because it conforms to a stereotype already constructed by the observer" (Lynch 1960). Lynch's evidence regarding the Boston Common would suggest that one stereotype for urban parks is a rectangle. This idea, the use of preconceived stereotypes, or schemas, in understanding and using buildings, forms the basis for our work in wayfinding and building memory.

Schemas - an Approach to Knowledge Representation

The idea of stereotype as a basis for memory corresponds with proposals from cognitive psychologists and artificial intelligence researchers to explain the mental representation of space, place, situation, and other complex phenomena. Proposed knowledge representation structures include: frames (Minsky 1975), schemas (Rumelhart 1980; Brewer 1987; Mandler 1983); scripts (Schank and Abelson 1977) and mental models (Johnson-Laird 1980, 1983; Gentner and Stevens 1983; deKleer and Brown, 1981). All these approaches attempt to explain the role of long term or generic memory in structuring action or memory of a specific episode. Minsky's "frames", for example, are data-structures that represent stereotypical situations, providing default information about what to expect and what to do. Frames are linked in a network and retrieved by an associative matching process that compares characteristics of the situation at hand with stored characteristics in the frame. Minsky's theory, which was widely adopted and adapted by workers in artificial intelligence, proposes mechanisms for learning, adaptation, and error-recovery. Schank and Abelson's "scripts" and "mops" (Memory Organization Packets) represent concepts and dependencies, and support reasoning about goal and intentions. Scripts and mops have been used to explain routinized streams of behavior such as ordering in a restaurant.

Another approach, case-based reasoning (Kolodner and Riesbeck 1986), suggests that specific experiences—not generic stereotypes—are stored, recalled, and adapted to new and different specific situations. In Lynch's example, a visitor from New York would assume that the Boston Common is a rectangle not because of default schema knowledge, but because it brings to mind the specific case of Central Park. In this paper we do not explore this promising and plausible alternative to schemas, however both approaches raise many of the same questions about indexing and retrieval.

A short article by Brewer (1987) reviews many of the proposed structures and the theories of knowledge and action that they imply. Of particular relevance to our question — the role of expectations in wayfinding in new but typical buildings — is Brewer's "distinction between underlying knowledge structures and the episodic representations formed from those underlying structures; and ... between representations which are derived from old generic knowledge and representations which are constructed at the time of use." Following Bartlett (1932), Mandler (1984) and Brewer (1987) we adopt the word "schema" to refer to a structure for generic knowledge that can be applied to guide action in specific instances and episodes. Whereas other ways of defining mental structures, such as "categories," may be assumed to be hierarchical and have a small number of defining characteristics, schemas are assumed to include a rich and diverse set of relationships that go together. For example, if one approaches a 1920's hotel as a category, the dominant questions become how to differentiate it from other hotel types: what are the key characteristics? A schema approach changes the focus of this investigation to ask: what are the elements and spatial relationships that often or always go with such a schema?

Schemas and Environmental Cognitition

Several experiments on spatial memory and the imageability of buildings support the idea that schemas or prototypes structure our experience of the built environment. For example, Rumelhart and Norman (1975) found that their graduate students systematically misrepresented the floorplan of their own apartments—buildings that they had seen many hundreds of times—depicting their balconies as flush with the building front rather than extending beyond it. Evidently the students were retrieving a prototypical representation of the building fronts rather than a specific memory of their own building.

Some additional work on categorization suggests that there is a "basic" or natural level of representation that many people use in everyday life. Tversky and Hemenway (1983) studied the categories that people use in describing environmental scenes, and constructed a taxonomy of environmental categories based on perceived shared attributes. They found that "when subjects are asked to label photographs or describe the setting of some activity, they prefer basic level terms". For example, "school" is preferred over "high school".

Mandler and her colleagues (1984) have studied schemas in structuring visual images or scenes. They found that "organized scenes" in which the spatial relations between picture elements make sense were more easily remembered than unorganized scenes. For example, clocks belong on walls; chairs face tables, etc. Mandler concludes that "scene schemas consist of certain objects in various spatial relations..." but that more work is needed to investigate the structuring of scene schemas. Results of an experiment by Purcell (1986) support the idea that prototypes play a role in people's experience and memory of the environment, at least with respect to building categories. Purcell showed subjects photographs of churches. He found that subjects agreed as to which photographs showed the best examples of the church category. Examples judged farthest from the prototype were also judged most or least interesting.

Wayfinding in Urban Environments

Since Lynch's work in the early 1960's, several studies have looked at wayfinding in urban environments. One of the best known is Pailhous' study (1970) of routes used by experienced Parisian taxi drivers. Pailhous found that drivers use a network of major streets to get near their destination, using smaller local streets to connect the major network with their origin and destination, even when this plan does not result in the shortest route. In another study, Elliott and Lesk (1982) asked people to plan routes in two suburban locales in California and New Jersey. Their findings supported Pailhous' research: subjects sought major routes connecting the neighborhoods of origin and destination. They also observed that subjects often planned a route by working from both ends towards the middle.

Wayfinding in Buildings

Several studies (Passini 1984; Carpman, Grant, and Simmons 1986) offer designers specific guidelines to make buildings that are more understandable in terms of wayfinding. Weisman (1979) identifies four factors that affect people's ability to find their way in buildings: overall plan configuration or layout, signs, visual access both to points within and outside of the building. (Weisman is not explicit about how one defines "plan configuration," and we suggest below that the adequacy of a plan in supporting wayfinding is related to its ability to be understood as part of an existing schema.)

Hunt's (1985) survey of building imageability research aims to identify requirements for understandable buildings and proposes an "environmental learning strategy" that emphasizes the connection between imageability and wayfinding. Although he doesn't use the word "schema," Hunt suggests that buildings that fit existing schemas are easier to teach and that adaptive wayfinding schemas can be taught.

Computational Models of Wayfinding

Computational models offer a formal means to express and demonstrate a theory of environmental cognition and wayfinding and have received attention in the environmental cognition literature as a promising research method. A useful introduction is the article by Smith, Pellegrino, and Golledge (1982) entitled "Computational Process Modeling of Spatial Cognition and Behavior". A brief review is also given in Golledge's chapter on Environmental Cognition in the *Handbook of Environmental Psychology* (Golledge 1987). One of the earliest computer models of cognitive maps and wayfinding was Kuipers' Tour model (Kuipers 1978). In this model a simulated wayfinder explores a map of an urban area and constructs an internal representation that it uses subsequently to plan routes. This internal representation, the program's "cognitive map" is based on Lynch's categories: paths, places, nodes, landmarks, regions. Kuipers' more recent experiments (Kuipers and Byun 1988) use the same topological model of the environment with a set of nodes and arcs representing places and paths, but concentrate on the problem of identifying and recognizing "distinctive places" where some function of sensory inputs is at a local maximum. Kuipers also argues for a multi-tiered organization of environmental descriptions: landmarks and places, routes, topology, and metric information.

A different method for wayfinding in large scale urban space is proposed by Levitt et al. (Kuipers and Levitt 1988), that uses pairs of landmarks (such as tall buildings) and imaginary lines to divide the terrain into polygons. Based on the observed relative position of landmarks along the horizon, the wayfinder can determine which polygon he is in.

Another approach is the "fuzzy maps" of McDermott and Davis (1984). This approach generates an approximate Cartesian map from propositions about relative positions of buildings or landmarks: "the library is south of the cafeteria." As additional propositional information is obtained, the zone of possible locations is narrowed. Using the fuzzy map to plan a route from one place to another, the program first connects the two places with a straight line, then identifies and finds ways to bypass barriers that intersect the line. Monnai, Hiiro, and Hara (1988) report on a preliminary way finding study in Tokyo's Ginza district. They asked visitors to "think out loud" as they find their way from inside the Ginza subway station to a well-known landmark such as the Sony building, and they have built a Logo program that models some wayfinding strategies.

W.K. Yeap (1988) shows how a simulated robot moving through a floorplan can construct, incrementally, a representation of the contained spaces and their boundaries. (We have followed a similar approach in our initial computer experiments.) He discusses some particular characteristics and difficulties of this computation, including the matching problem of recognizing a room you have been in before when entering it from a different door.

In summary, most computational models have addressed route-planning and navigation in large-scale (urban) space. Computer models have tended to concentrate on navigation and episodic learning of specific places. For example, the Traveller program (Leiser and Zilbershatz 1989) learns routes in large-scale space using production rules and neural networks. Frames, schemas, or scripts, while sometimes used to represent episodic or specific knowledge, are not used to represent generic or stereotypic knowledge of built environments. Kuipers' early work (1978) used frames to represent specific knowledge of a path or place. Golledge, Smith, Pellegrino, Doherty and Marshall (1985) describe a computer simulation of route-acquisition which differentiates long and short term memory using frames to represent knowledge. However the model is not concerned with generic environmental knowledge. Little work appears to have been done on acquisition of generic environmental knowledge and its use in solving specific wayfinding problems.

A SCHEMA APPROACH TO WAYFINDING

People seem to use generic knowledge, or schemas, to find their way in unfamiliar but typical buildings. A schema indicates what building features to expect as well as topological and geometric information about the overall layout that helps predict the location of features. We postulate that building schemas are indexed in memory by type, use, and possibly by other observable characteristics: for example, architectural style. For example, a "hotel" schema predicts the presence of a "lobby with a reservations desk", a "hall with private rooms adjoining the lobby", and a "restaurant". Likewise, "high rise building", "1950's high-school", "fast food restaurant", all suggest unique, typical layouts.

We suggest that schemas are organized in a directed graph of types, in which subtype schemas specialize the basic information in the schema, adding information and in some instances describing exceptions. For example, a "motel" is a kind of "hotel" (we may expect a reservation desk and private rooms) but unlike a hotel, the "hall with rooms" is to be found outside. Each schema contains smaller, linked schemas that describe places within the large building. For example, the schema for a department store indicates that a cafeteria will be found, probably on the top floor. The cafeteria in turn, is described by a schema that predicts the presence of a serving counter, cashier tables, and restrooms.

We can distinguish at least three kinds of declarative information that a schema can provide: 1) overall plan layout (e.g. central core, spine-with-wings); this information may be topological or geometric but it is often stretched, rotated or distorted; 2) presence or absence of features (a bank will have teller-windows but not a swimming-pool), and; 3) local configurations of building features (water-fountains near restrooms). Spatial knowledge in a schema cannot be precise: distances may vary, configurations may be reflected or rotated. In addition, a schema can have *procedural* information about how to find one's way or about how to behave. In a hospital this may be: "go to the information desk and ask what to do" whereas in a shopping mall it may be "wander until you find the store." These rules may also be social rules about how to behave: in a fast-food restaurant go to the counter to order; in a fine restaurant, wait to be seated.

Our approach suggests several questions pertaining to the learning and use of schemas in wayfinding. How do we construct schemas in the first place: for example, by generalizing frequently experienced built organizations? Can we also learn a schema by being told the spatial characteristics of a building type? What is the nature of generic knowledge? (For example, is it topological or geometric?) How are schemas indexed in memory? How are they retrieved? How do we use a schema in exploring a building and in wayfinding? How do we adapt the generic knowledge expressed in a schema to the actual situation at hand? Another set of questions deals with the role of schemas in learning the organization of particular buildings. When we use a building frequently we come to know it well; it seems we rely on a specific model or map of that building rather than a generic schema of the building type. How does this change occur? Is it a gradual transformation in which the generic schema is changed into a specific map? Or is the specific map constructed separately, eventually replacing the schema for wayfinding tasks in the particular building?

Preliminary Field Studies

In informal surveys taken in seminars, people—both architects and non-architects—have been quite willing to sketch a possible floorplan for a building when shown a photograph of its facade. They can locate elements like stairways, elevators, restrooms, and pay telephones in their plan. One explanation is that the photographs trigger retrieval of a prototype building which has enough spatial information to generate a floorplan. In a more formal study (Peponis, Zimring, and Choi (forthcoming)), we asked subjects to take fifteen minutes to explore a small hospital, then to find several places in the building. We found that most people chose paths with certain topological characteristics with respect to the building. We used Hillier and Hanson's (1984) "space syntax" methodology to characterize building topology; we found that people preferred to use "more integrated", or "shallower" paths. They maintained this preference even when the paths involved longer routes and used apparently minor corridors. This suggests that people use general schemas for wayfinding in buildings that are more global in scope than schemas based on building type.

Elements of a Computational Model

We have begun to build the pieces of a computational model for wayfinding. We simulate the movement of a wayfinder through a building as a "turtle" equipped with limited sensorimotor capabilities: it can move and turn, and "see" floorplan elements. A graphics editor enables us to draw floorplans for our wayfinding turtle to explore. Floorplan elements consist of labelled edges and rectangles belonging to a limited number of classes: door, window, wall, elevator. When instructed to "see", the wayfinder returns a list of objects that intersect its isovist, a 120 degree isosceles triangle trimmed by occluding edges. Distance is an argument to the vision primitive: 'short vision' includes only nearby floorplan elements and 'long vision' includes distant ones as well.

Local navigation rules, the lowest level of sensorimotor controls program obstacle-avoidance, edge-following and wandering behavior. These rules are expressed as productions in which the left-hand-side describes a possible isovist content and the right-hand-side provides a motor action:

standard-rule-form: [isovist-pattern] —> [action]

Items in the isovist list are ordered to describe what the wayfinder sees to the left, straight ahead, and right.

After every motor action, the isovist is compared with each rule's isovist pattern; if a match is found, the motor action is applied. For example, the navigation rule:

avoid-obstacle-ahead: [— edge —] —> [RIGHT 90]

instructs the wayfinder to turn right 90° whenever it finds itself directly facing a wall. The rule:

go-through-any-door: [— door —] —> [FORWAD]

instructs the wayfinder to enter any door it finds itself in front of, and the rule:

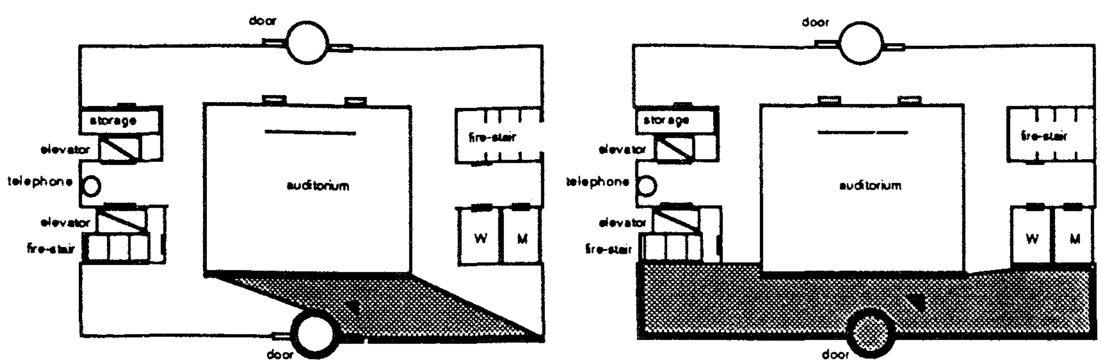
follow-right-wall: [— — edge] —> [FORWARD]

instructs the wayfinder to proceed forward following a wall to its right. The rule will repeatedly select until, as the wayfinder moves past the wall, the isovist no longer matches the pattern in the rule. The rule will no longer select; instead another rule will now match the new isovist and assume motor control. Using local navigation rules, we can program the wayfinder to wander about the floorplan, identifying places.

The wayfinder recognizes and instantiates a "place" structure that describes a region bounded by the edges of floorplan elements visible from its current location looking in all directions. This is a crude but easy-to-compute approximation. Short and long vision yield different places: figure 1a shows the entry of an office lobby identified using short vision, and 1b shows the larger entry hall identified using long vision. Darkened edges indicate visible floorplan elements and the black triangle indicates the wayfinder's location.

As a new place is instantiated it is also linked in a graph of connected places that represents the building topology. If the wayfinder is exploring a new building, the graph begins empty and grows.

Next, we would like to compare places identified in a floorplan with place-types in a schema memory. The comparison is to be done on the basis of features. We define the "features" of a place as the set of elements seen and any inferred boundaries with adjacent spaces.



(a) entry lobby place using "short vision". (b) entry hall place using "long vision".

Figure 1. Place recognition depends on parameters to the vision primitive.

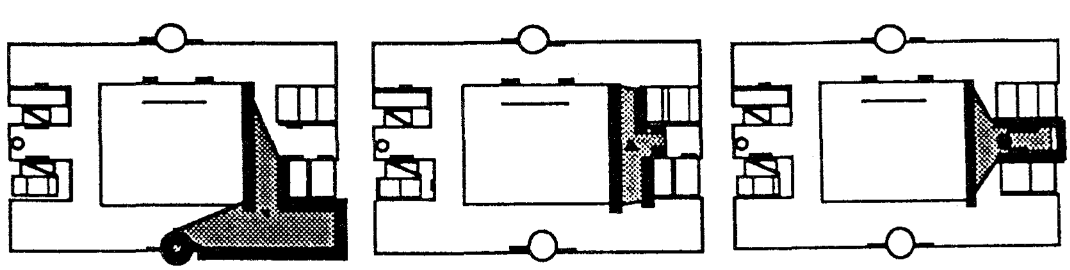


Figure 2. Spaces identified as wayfinder moves through plan.

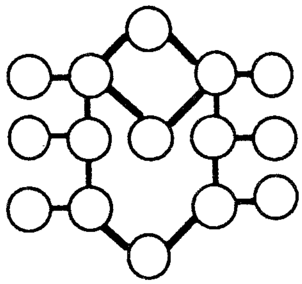


Figure 3. A graph of connected places is constructed.

A place-type schema contains a list of must-have-features that must be present, a list of cannot-have-features that must not be present, and a list of good-to-have-features that, if present in a place, increase the match score. (We have not yet included geometric relations between features.) For example, features in an entrance lobby schema look like this:

Entrance-lobby-schema:
must-have-features: [front-door]
cannot-have-features: [freight-elevator]
good-to-have-features: [building-directory passenger-elevator]

This schema says that a place with a front door and no freight elevator is likely to be an entrance lobby. If a building directory and or a passenger elevator is present, this increases the likelihood.

Our schema memory of place-types is organized as a hierarchical class-library in which lower-level (more particular) schemas inherit features from their superiors. This is simply implemented using an class-inheritance mechanism in an object-oriented Lisp (Apple Allegro Common Lisp) — a schema is an object with variables for the three feature lists. Our schema-retrieval procedure is a classifier that compares a place (a specific instance) with the class-library of schemas. It traverses the tree of schemas, computing a score for each schema by matching its features with the specific place instance, and returns the best-matching schema (class) in the library.

So far our wayfinder can: a) wander around a floorplan using local navigation rules; b) identify places in the floorplan; c) match places with place-schemas in a hierarchic memory based on the presence or absence of key features. One next step in developing the model will be to add topological links among place schemas. Then when a place matches a place-schema, a graph of linked place-schemas can be recalled to predict the layout of the particular building being explored. As mentioned above another important next step is storing geometric relations between features and schemas.

SUMMARY

The cognitive map has been the subject of much inquiry since Lynch (1960) but most research has focused on (1) episodic memory of a particular place and (2) large scale or urban space. We have proposed that people use schemas, or generic knowledge about building layouts to find their way in buildings that they recognize as belonging to a type, or schema, and that people use schemas that describe typical building organization patterns at various levels — as well as local navigational rules --to guide wayfinding. We cited anecdtal evidence that suggests this theory. Experimental evidence from psychology suggests that people may use schemas to mentally represent spatial organizations. Frames, schemas, and scripts have been used in artificial intelligence research to model memory as a process of retrieving stereotyped descriptions and filling in specific detail.

We reviewed the literature on computational models of navigation and wayfinding and found that most models reflect research interests in episodic memory and large scale space. We have begun to develop the pieces of a computational model of wayfinding based on our approach. Our wayfinder operates at the sensorimotor level using local navigation rules for edge-following and obstacle-avoidance. To inform a higher-level route-planner, a simple mechanism recognizes places bounded by visible edges. Places recognized are entered into a graph that represents an episodic memory of building topology; place features are also matched against a memory of place-schemas to identify the place as an instance of a known schema.

Our theory about wayfinding, if true, would add to rather than invalidate current thinking on this topic. We are, however, only at the beginning of developing a computational model sufficiently robust to demonstrate — much less test — our approach. Therefore this paper has concentrated on framing a question and proposing an initial hypothesis. We look forward to reporting on the results of our next round of model-building and experiments.

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