ORAL PAPER

Spatial Cognition and Wayfinding Strategy During Building Fire

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Abstract Simulation of human behavior in space is a powerful research method to advance our understanding of the interaction between people and their environment. It allows for both the examination and testing of models and their underlying theory of cognitive and perceptual phenomena as well as the observation of the system's behavior. This paper outlines the use of specific spatial objects to facilitate escaping from an indoor environment in a crisis situation. To represent and simulate people's processes of wayfinding it is necessary to understand how people immediately make sense of spatial situations while performing a wayfinding task which will occur in a building during fire emergencies. The theoretical outset of the research is the observation that humans show distinct behavioral and cognitive preferences when dealing with wayfinding tasks in dangerous situations. The goal of the research is to organize environmental cues and to use them in decision-making and navigation in an indoor environment in a fire emergency. Construction and inspection of mental representations of spatial environments and exploring these models have been discussed and the proposed computational model tested in an indoor complex building. Initial results verify the reliability of the model.

Keywords spatial cognition · fire emergency · wayfinding · crisis management · indoor environment

Introduction

There have been a number of events in which extensive life loss happened because the time needed for safe evacuation from a threatened building was not adequate (Peacock and Kuligowski, 2004). This paper outlines the cues used in decision-making and navigation in an indoor environment in a fire emergency case.

There is a need to understand how people, buildings, and environment react during a fire. Spatial cognition, occupant characteristics, human response to cues, decision-making and wayfinding in building fire emergency management will be discussed in this paper. Previous research on human wayfinding has focused primarily on mental representations rather than processes of wayfinding (Raubal, 2001b). This paper presents a model of some aspects of the process of wayfinding in a building fire emergency, where appropriate elements of human perception and cognition are realized using knowledge gained by cognitive spatial cues in the environment.

The goal-driven spatial reasoning that leads to action begins with incomplete and imprecise knowledge derived from imperfect observations of the space. In some cases the situation is critical and people should find their destination by means of external information while no maps are available. A scientific wayfinding strategy in a fire emergency is developed in this research, which would allow the assessment of the achieved information for people in a critical situation.

Background

Several recent events have motivated discussions on how to protect and safely evacuate building occupants during fire emergencies. In this modelling, we should not neglect the different behaviours of human beings in crisis situations. Therefore, major concepts and scientific backgrounds including spatial cognition and wayfinding have been introduced below.

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Spatial Cognition

Simulating people's wayfinding behavior in a cognitively plausible way requires the integration of structures for information perception and cognition in the underlying model (Raubal, 2001a). Spatial cognition concerns the knowledge and beliefs about spatial properties of objects and events in the world as well as the way human beings deal with issues concerning relations in space, navigation and wayfinding. Cognition is about knowledge: its acquisition, storage and retrieval, manipulation, and use by humans, and intelligent machines (Raubal, 2001a). In humans, cognitive structures and processes are part of the mind, which emerges from a brain and nervous system inside a body that exists in a social and physical world (Raubal, 2001a). Spatial properties include location, size, distance, direction, separation and connection, shape, pattern, and movement (Raubal, 2001a). Spatial abilities are cognitive functions that enable people to deal effectively with spatial relations, visual spatial tasks and orientation of objects in space. One aspect of these cognitive skills is spatial orientation, which is the ability to orient oneself in space relative to objects and events; and the awareness of self-location.

Wayfinding

Wayfinding and route directions have developed into central research areas in cognitive science (Klippel, 2003). Finding one's way in the environment, reaching a destination, or remembering the location of relevant objects are some of the elementary tasks of human activity. Wayfinding is a basic activity that people do throughout their entire lives as they navigate from one place to another. Many theories of spatial cognition have been developed to account for this behavior (Raubal and Egenhofer, 1998). In order to represent and simulate people's processes of wayfinding it is necessary to understand how people immediately make sense of spatial situations while performing a wayfinding task (Raubal and Worboys, 1999).
Wayfinding is the cognitive element of navigation. It does not involve movement of any kind but only the tactical and strategic parts that guide movement. Wayfinding is not merely a planning stage that precedes motion. Wayfinding and motion are intimately tied together in a complex negotiation that is navigation. Navigation is the aggregate task of wayfinding and motion. It inherently must have both the cognitive element (wayfinding), and the motoric element (motion). Consequently, we use this term only when we mean to imply the aggregate task and not merely a part. When focusing on the mobility of humans, the ease of wayfinding within a building can be seen as an essential function of a building's design (Arthur and Passini, 1992; Passini, 1984).

Methods

The advent of performance based fire safety regulations and codes together with the needs for robust computer evacuation simulation models gives further impetus and sense of purpose for future endeavours. With increasing international emphasis on community fire safety policy initiatives, knowledge of occupant behavioral characteristics associated with fire is essential.
This research takes an approach from the field of cognitive science for modeling the wayfinding process. It deals with the study of the information transactions between living systems and their environments. This work focuses therefore on properties of the environment as perceived and cognized by humans. Much of the information people need to perform a task is in the world, and the human mind is perfectly tailored to make sense of this world. Formalizing the conceptual model for the cognitive wayfinding allows to describe it more precisely than by using a verbal description, and to create a practical tool for simulating the test case.
The main parts of the model are a wayfinder who tries to solve a wayfinding task in a crisis situation, objects within the built environment, information gained from the environment, and actions taken by the wayfinder based on such information (Figure 1).
The model simulates a passenger in the complex building that has to perform the task of finding the exit ways in a fire emergency. The outcome of the simulation shows whether the wayfinder using the information offered on signs has successfully reached its goal or not. Furthermore, the result of the simulation is a test of the signage in the building design to avoid wayfinding problems especially in crisis situations.

Results

Wayfinding in an Indoor Environment in a Fire Emergency

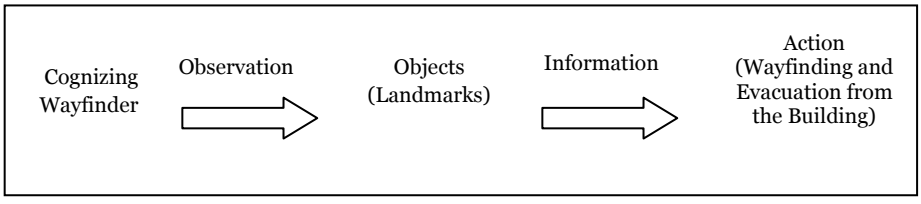

Fig. 1 The main parts of the process model for wayfinding in the environment

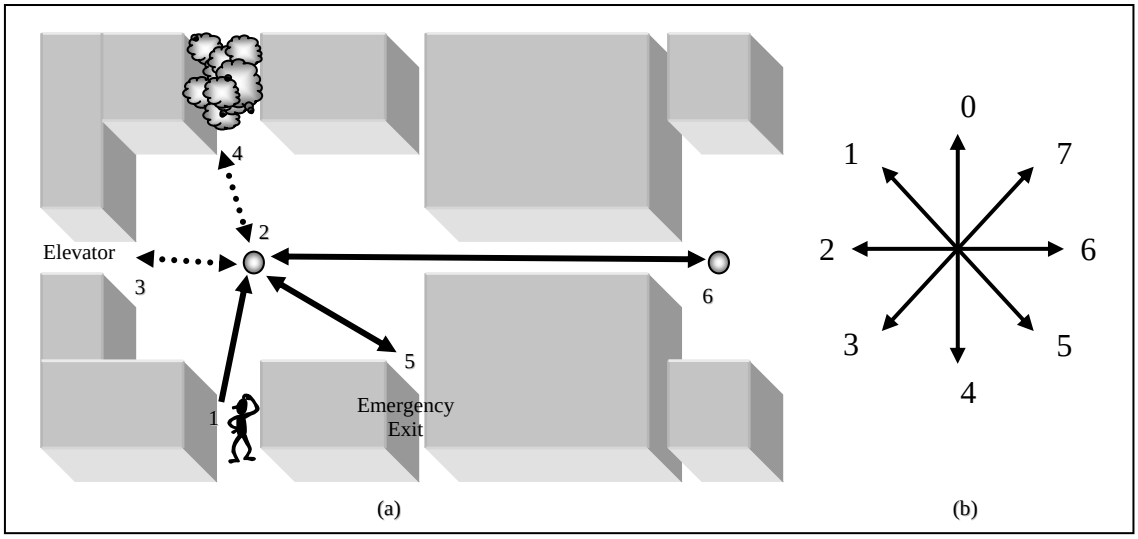

Fig. 2 (a) wayfinding environment by a transition graph, (b) preferred directions of the cognizing wayfinder

The need for understanding the reaction of people, buildings, and the environment involves an integrated "model" and a systematic view of the evacuation process. People are not credited for their abilities to adapt to dynamic scenarios. So, we need to integrate physical system approaches with the goal-driven adaptive performance of people (Peacock and Kuligowski, 2004).

In this paper we present a formal model of the wayfinding process in a fire building emergency. The model integrated elements of people's perception and cognition, therefore, focusing on how people make sense of their wayfinding environment. The wayfinder gains knowledge about the building through visual perception of sign information and environmental situations at decision points. In this process, one would decide upon paths with the use of signs and topological specifications in decision points in order to find his/her way to escape from the building. Starting with imperfect observations of the space, the wayfinder derives incomplete and imprecise knowledge and based on such knowledge takes an action. Actions lead to further observations and knowledge, recursively to further actions until the goal is reached. This process is represented through a transition graph consisting of nodes (decision points in the environment) and edges (paths between decision points) (Figure 2).

Table 1 shows the required test data for the representation of some parts of the wayfinding environment by the nodes 2, 3, 4 and 5, their positions, the nodes which the wayfinder is able to go at each decision point, and also the incoming-direction values assigned to adjacent nodes from where the wayfinder could have entered (Table 1). They are based on the preferred directions of the cognizing wayfinder.

The stressful situation in a fire emergency also affects human behaviours in the wayfinding task. For example, they may select the longer or obstructed way. The first floor windows also would be one of the exit ways of the building in a fire building case. So, the stress factor would be considered in the simulation. A successful navigation of the building corresponds to the wayfinder's traversing of the graph ending at a destination node.

This model is written in a simulation program with the building plans as an input. Using this model in two different complex buildings with various exit ways in order to study the efficiency of the wayfinding task, compares the escaping time duration from those indoor environments and determines which building design would be better in a crisis situation. Therefore, the result of this simulation can be used in improving building designs for efficient fire crisis management.

Position	Go-to	Direction	(Enter from, incoming Direction)
2	3 4 5 6	2 1 6 7	(1,4),(3,2),(4,1), (5,6),(6,7)
3	Elevators	2	(3,2) ...
4	Fire and Smoke	0	(4,0) ...
5	Emergency Exit	4	(5,4) ...

Table 1 Test data of the environment

Discussions

There have been different strategies to facilitate rescue operations in building evacuation in fire emergencies. Helping people to use environmental cues efficiently and find a less time-consuming way for escaping from the

building is one of the proposed strategies. The scientific result of this paper is the wayfinding model for finding exit ways from the building in fire emergencies. This model is based on the theory of perceptual wayfinding and is different from previous computational models for wayfinding, which were built to investigate how mental representations are created, stored, and used.

The model concentrates on people's actual information needs during wayfinding and does not focus on learning a spatial environment. Its main principle is that all wayfinding information about the different destinations have to be presented to the wayfinder at every decision point. From an engineering point of view, the main result of this work is a practical algorithm that can be used to test the wayfinding information presented to people in an environment in a crisis situation.

The research demonstrates the minimum amount of knowledge necessary for the wayfinder to find its goal. The model could be extended by explicitly integrating other essential elements at various situations.

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