# Cognitive Modeling of Information Sources for Human Wayfinding Under Uncertainty

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## Abstract

The growth in the global population and rapid urbanization has put tremendous stress on existing infrastructures. The increasing influx of people in built environments such as transportation hubs, hospitals, office and educational buildings, and shopping malls has become a cause of concern. The ability to maintain wellbeing and people's comfort in a densely populated, large, and complex building during a general circulation or disaster is an essential design issue. This issue is equally relevant when considering yet-to-be-built environments of the future. Architects, designers, and planners must rely on their expertise and intuition when accounting for how people navigate when designing spaces, which becomes prohibitive when accounting for the myriad of contexts that spaces must accommodate. A critical challenge towards managing and designing built environments is understanding (from a cognitive perspective, "User in Mind") how humans rely on various external indicators when navigating in these spaces.

This research attempts to model how humans acquire, perceive, and interpret information sources in their surroundings (e.g., signage, spatial features, crowd characteristics, and familiarity of the environment) when navigating in complex indoor environments. The main goal is to develop a cognitively grounded computational framework of human wayfinding, which models the uncertainty and fusion of multiple potentially conflicting information sources. The research can potentially have a transformative impact on our understanding of human wayfinding's cognitive underpinnings and enhance practices for architects, urban planners, and civil engineers, enabling real-time crowd management, disaster, and security applications well as aid in the design of smart and connected environments.

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## 1 Introduction

Wayfinding is a goal-directed coordinated movement that involves planning a route and moving along it in an environment [Montello, 2005]. With the rapid increase in population and urbanization, the existing infrastructure (e.g., transit hubs, shopping malls, hospitals, office buildings) often witnesses large numbers of occupants. To accommodate this increase in the number of occupants, existing and future buildings are becoming larger and complex in structure. The ambitious and intricate architectural design to accommodate more crowd in an indoor complex built environment may pose multiple problems for building occupants. Specifically, it introduces spatial uncertainty that causes wayfinding challenges when occupants need to find a path to reach their destinations [Passini, 1984]. Such challenges get more evident in an emergency, such as fire evacuation. During such emergencies, some routes may get blocked and are no longer available for safe evacuation [Grosshandler *et al.*, 2005]. In such dynamic scenarios, occupants have to respond quickly and use the available wayfinding information instead of relying on memory's original routes.

Spatial wayfinding researchers have identified directional changes, choice points, misalignment of reference points, floor plan complexity, and distances as factors in the environment that pose a challenge during wayfinding. Signage and maps are often employed to overcome such challenges in an indoor environment. In some cases, such wayfinding aids improve occupants' wayfinding performance, but some research has highlighted that a substantial proportion of signage is inefficient and does not provide the wayfinding information it is intended to [Werner and Long, 2002]. It can be due to multiple reasons such as improper placement of signage [Dubey *et al.*, 2020], occlusion, font size, and font colors [Dubey *et al.*, 2019]. This issue is equally relevant when considering yet-to-be-built environments. Architects, designers, and planners must rely on their intuition and expertise when accounting for how people navigate when designing spaces, which becomes prohibitive when accounting for the myriad of contexts that spaces must accommodate. A poorly designed indoor environment with insufficient wayfinding cues and deficient crowd management [Schrotenboer, 2013; Connors, 2007] may lead to a stressful navigational experience and may cause injuries or even death on a massive scale, respectively. A critical challenge towards managing

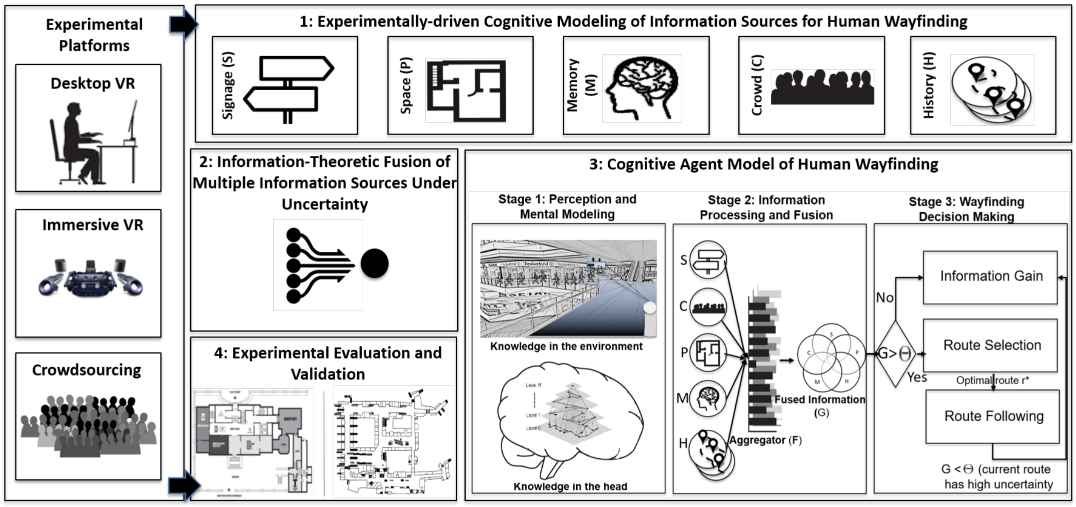


Figure 1: Overview of proposed research activities.

and designing built environments is understanding (from a cognitive perspective) how humans rely on various information cues when navigating in these spaces. In conclusion, the increasingly complex structure of current and future building designs incurs multiple wayfinding challenges under both general circulation and emergency evacuation. Research investment in solving these wayfinding challenges is crucial to create a stress-free and safe wayfinding experience in an environment [Arthur and Passini, 1990; Filippidis *et al.*, 2003; Filippidis *et al.*, 2006; Xie *et al.*, 2007].

This research investigates, learns, and models human wayfinding in a complex indoor environment by mathematical formulation, computer simulations, and behavioral experiments. It seeks to understand the psychology behind the interaction and exchange of information between humans and the environment during wayfinding. Specifically, we seek to model how occupants rely on wayfinding information sources in their surrounding (e.g., signage, spatial features, the presence and behavior of other people) and information in the head (e.g., the past familiarity of the environment and immediate short-term spatial memory) when navigating in complex indoor environments. This work's main objective is to develop a biologically inspired, cognitively grounded, the computational framework of human wayfinding, which models the uncertainty and fusion of multiple potentially conflicting wayfinding information sources.

## 2 Overview

The proposed research has four major components, as depicted in Figure 1. Below we describe each component briefly.

**Experimentally-driven Cognitive Modeling of Information Sources for Human Wayfinding** We propose a cognitively grounded computational model of the influence of individual information sources on human wayfinding. Specifically, we study (1) signage, (2) spatial features, (3) crowd characteristics, (4) spatial memory, and (5) history of past navigation decisions. We have conducted various experiments using Virtual Reality (VR) and crowd-sourcing to calibrate the models to reflect human wayfinding behavior.

**Information-Theoretic Fusion of Multiple Information Sources Under Uncertainty** We have developed an information-theoretic approach to fuse information from the sources as mentioned above, in order to provide a unified representation of all signals which influence human wayfinding, while capturing the uncertainty, contradictory information, and nonlinear dependencies of each wayfinding information source.

**Cognitive Agent Model of Human Wayfinding** The information procession and fusion frameworks will be used as the basis of a cognitive agent model for human wayfinding, for simulating human decision-making in complex environments, subject to different signage configurations, spatial features, crowd characteristics, and varying environment familiarity.

**Experimental Evaluation and Validation** We have performed virtual reality and real-world experiments to validate the fidelity of the proposed cognitive agent model. Finally, we will highlight our framework's benefits on case studies of real environments (e.g., a transportation hub, a shopping mall, and a museum).

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