Using Mobile 3D Visualization Techniques to Facilitate Multi-level Cognitive Map Development of Complex Indoor Spaces

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Abstract. Several studies have verified that multi-level floors are an obstacle for indoor wayfinding (e.g., navigators show greater angular error when making inter-level pointing judgments and experience more disorientation when way-finding between floors). Previous literature has also suggested that a multi-level cognitive map could be a set of vertically super-imposed 2D cognitive maps and each level could be viewed as a region. However, little research has studied how one mentally connects / integrates the different levels of the 3D cognitive map. This paper provides new insight into how people may integrate multi-level cognitive maps based on the concept of a "transition point", a term used to represent the abstract point that connects different levels of the building. Based on transition points, we proposed the concept of simulated global indoor land-marks which are displayed on mobile devices. We predict that users can develop multi-level cognitive maps more efficiently when assisted by these global indoor landmarks. An ongoing behavioral experiment is briefly described aimed at providing empirical verification for these predictions.

Keywords: multi-level cognitive map, indoor navigation assistance, vertical information visualization, mobile information displays.

1 Introduction

From the first multi-level building of the Roman Empire to the world's highest (162-story) building, most public indoor spaces have been built based on increasingly complex indoor environments incorporating many underground levels and above ground floors. As a case in point, the growing size of malls makes these structures seem like an 'indoor city', meaning that they are large and cognitively complex environments with many possible destinations and heavy pedestrian traffic [1]. Multi-level buildings have the advantage of more efficient use of land space (particularly where space is limited or expensive), and are cheaper to cool or heat compared to a more spread-out single level structure. However, these complex multi-level buildings often cause navigators to become frustrated, disoriented, or lost during navigation (especially when traversing between floors). For instance, navigators have been shown to be significantly less accurate when pointing to locations between floors than within a single floor and inter-floor knowledge has been argued as the cause of disorientation in both physical and virtual environments [2–7]. Soeda et al. [5] demonstrated that Indoor wayfinding performance involving floor level changes is greatly hindered by disorientation during vertical travel. Likewise, Hölscher, et al. [2] reported wayfinding difficulties observed in a complex multi-level conference center, identifying incongruent floor layouts, disorienting staircases, and lack of visual access to important level-related building features as the main causes of this difficulty. Given the aforementioned literature highlighting the challenges of inter-level navigation and other relevant tasks, there is a surprising dearth of research into the underlying theory of why integrating multi-level building information is so challenging for human spatial cognition (question 1) , which is the core motivation of this paper.

Well-developed multi-level maps (whether cognitive or digital) are not only useful for the obvious applications of affording efficient inter-level indoor route planning and navigation, they could also be crucial for supporting many other scenarios. For example, in an emergency situation, firefighters needing to determine the correct location to break through a ceiling to rescue people trapped in a building, or maintenance workers needing to figure out the best route for drilling a hole to install conduit between floors. In each of these situations, a device providing perceptual information to help visualize the multi-level building structure would be extremely important for facilitating users in constructing multi-level cognitive maps which support spatial behaviors requiring integration of vertical knowledge. Therefore, we believe that the best solution to this vexing problem requires a two-pronged approach combining study of both the basic theoretical research relating to question 1 and the best interface design as assessed by question 2: how to design mobile visualization interfaces that assist tasks requiring vertical navigation, accurate learning of complex buildings, and the development of multi-level cognitive maps?

This is a position paper which aims to highlight a key problem for multi-level indoor navigation that has not been extensively studied but which represents a real and pervasive challenge given how often we are required to navigate within complex buildings. First, we provide new insights into the difficulties of inter-level indoor navigation and cognitive map development by discussing the concept of a transition point that connects different levels of a building. Next, we propose our visualization approach for integrating multi-level cognitive maps based on highlighting global indoor landmarks on mobile devices. Finally, an ongoing experiment is described that provides empirical verification of these ideas and that suggests a road map for future investigation.

2 Relevant Properties of Multi-level Cognitive Maps

Previous literature has suggested that a multi-level cognitive map could be conceptualized as a set of vertically super-imposed 2D cognitive maps having the vertical segments encoded as junctions between those maps [8], with each level being viewed as a region based on variants of the fine-to-coarse theory described in [2, 6]. However, we are not aware of any formal research that has extensively studied how one mentally connects the different levels of the 3D cognitive map. In this paper, we provide insight into how people connect these super-imposed 2D cognitive maps and introduce new visualization techniques for facilitating this process during real-time navigation.

2.1 Transition Points

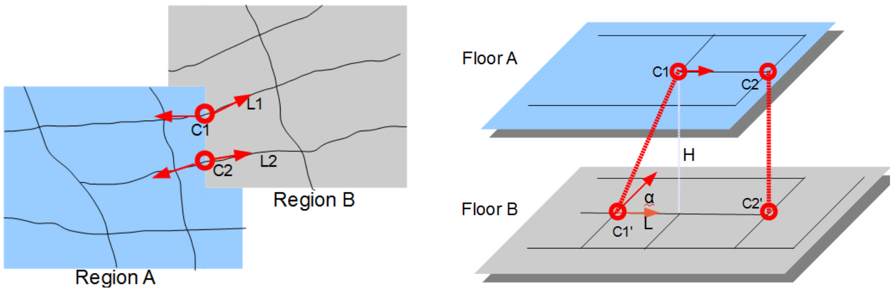

Fig. 1. Transition point in indoor and outdoor spaces

In the research by Wiener et al. [6] "region" represents perceived and encoded representations in spatial memory in which locations are grouped together and form superordinate nodes. In our research, we build on this notion by further confining the region for an indoor context as the floor's spatial extent.

The transition point represents an abstract point where navigators enter or exit a region along a route. As shown in Fig.1,an outdoor transition point is the intersection between two adjacent regions' common boundary and a route that goes through the two regions, whereas an indoor transition point is the point where users pass through a portal to enter or exit a region by an elevator or staircase. As shown in Fig.1, for outdoor space, C1 and C2 are the transition points which are the intersections between route L1 and L2 with the common boundary of region A and region B. For indoor space, there are two pairs of transition points that connect floor A and floor B (c1 with c1' and c2 with c2'). An outdoor transition point usually has two directions which are the transition point's two tangent lines' directions in two regions as shown in Fig.1, while an indoor transition point usually has one direction based on the navigator's facing direction when they get out of a portal. This notion is different from the related term, decision point, which usually refers to the intersection of corridors or travel paths [9] or the point where two route-segments meet[10], transition points are the connecting points of two regions/floors. Some indoor transition points will overlap with the decision points and therefore have several directions (e.g., one elevator has two doors or the staircase connects to a T intersection of corridors.).

When people navigate between floors, they will pass a pair of transition points (c1 with c1' or c2 with c2'). For each pair, there is a vertical transition offset H, a horizontal transition offset L, and a transition angle offset α, as illustrated in Fig.1. The transition offset H is the height between the pair of transition points located at different floors. The offset L is the distance between the transition point (e.g., C1') and the projection of the corresponding transition point (e.g., C1) on the former transition point's floor (e.g., floor B). If the two transition points are vertically aligned (e.g., an elevator connects the pair), the offset L is 0. The transition angle offset α is the difference between the directions of the two transition points. If the directions of the two transition points are the same, the offset α is 0 (e.g., an elevator connects the pair). Thus, we predicted that although multi-level indoor cognitive maps could be simplified as a 3D variant of the cognitive region, the offsets of transition points between regions/floors, particularly the horizontal and angular offsets, cause users to have greater difficulty in maintaining their spatial orientation and in developing an accurate globally coherent cognitive map of the indoor space.

2.2 Simulated Global Landmarks

The offsets between transition points illustrated above may provide insight into the known difficulties of humans in building multi-level cognitive maps based on a spatial parameter. Another potential reason for this challenge is the lack of availability of local versus global landmarks in indoor spaces [11]. Giudice et al. illustrated that the advantage of these global landmarks is that they afford an excellent fixed frame of reference which helps ground what is perceived from the local environment into a global spatial framework. However, they are often greatly reduced when learning and navigating indoor spaces. As a consequence, it is generally difficult to acquire survey type knowledge of the global spatial configuration of indoor spaces [11]. To eliminate this disadvantage and improve indoor navigational and representational efficiency, we proposed two types of simulated global indoor landmarks, transition landmarks and contiguous landmarks, which can be displayed on a mobile device. The goal is that access to these landmarks during navigation will facilitate user's ability to visualize the vertical structure of the space, which will in turn yield more accurate multi-level cognitive map development.

Transition landmarks are the highlighted information content displayed on mobile devices, composed of the transition points and directions of transition points as well as the lines connecting them, as illustrated in Fig. 2.

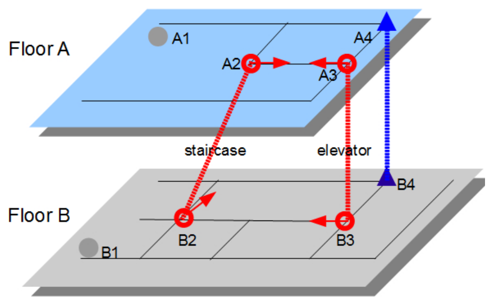

Fig. 2. Multi-level indoor global landmarks

Contiguous landmarks are also part of the highlighted information content displayed on mobile devices. They consist of vertically aligned landmarks and the lines that connect them. Landmarks are categorized as object landmarks and structural landmarks [12]. Accordingly, contiguous landmarks contain contiguous structural landmarks and contiguous object landmarks. If two floors have the same kind of structural landmarks (e.g. both floors have a cross intersection that is vertically aligned), we term it as a contiguous structural landmark. Similarly, if two floors have vertically aligned object landmarks (e.g. both of the floors have one unique blue wall at the same horizontal coordinates), we term it as a contiguous object landmark. As illustrated in Fig.2, A1 and B1 are object landmarks on each floor; A2 and B2 are the transition landmarks (staircase); A3 and B3 are both transition landmarks (elevator) and contiguous landmarks, as the transition points are located at vertically aligned T intersections; and A4 and B4 are contiguous landmarks, located at vertically aligned L intersections.

3 Experiment Design

In our research, we will experimentally evaluate whether highlighting the simulated global indoor landmarks will facilitate users' multi-level cognitive map development. In the experiment, the independent variable is the highlighting of the global landmark and there are three conditions: 1. control group: traditional 2D-based indoor maps (widely used in available indoor navigation systems); 2. birds'-eye view 3D-based indoor maps without highlighting global landmarks; 3. birds'-eye view 3D-based indoor maps highlighting global landmarks. Our hypothesis is that users in our experiment will navigate most efficiently and develop the most accurate multi-level cognitive maps with condition 3, as the global landmarks provide a fixed frame of reference in multi-level indoor spaces. Indeed, better visual access to these global landmarks is expected to facilitate improved knowledge of the landmarks interrelationship between floors and to help integrate them into a unified multi-level cognitive map.

Empirical experiments will be conducted using immersive Virtual Environments (VEs) coupled with a simulated PDA-sized screen as the visual interface to display information about navigation assistance. The advantage of using VEs is that we can leverage accurate real-time indoor positioning and tracking and easily manipulate the simulated building layouts and information content. The virtual building will be a three-level building with incongruent floor layouts and connected by confusing staircases, as the literature suggests that these factors cause the most confusion [2]. To maximize disorientation, staircases will be designed with a horizontal transition offset L and a transition angle offset α. Contiguous landmarks will be put in the environment. For example, we will make different floors have vertically aligned structural landmarks (e.g. cross -intersection).

The four main phases in the experiment are 1: *Route learning*. Participants will learn the route to each target picture with the assistance of the mobile device; 2: *Pointing criterion task*. Here we will test whether participants have successfully learned the four target locations from the first phase;3: *Unaided Navigation task*. Subjects will be asked to navigate to the picture using the shortest route; 4: *Drilling task*. Subjects will be asked to simulate "drilling" a hole to the above/lower floor or the left/right room. This task is designed to evaluate how efficiently users recall and calculate locations from the developed multi-level cognitive map.

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