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Study of the applicability of cognitive path algorithms for 3D indoor navigation

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Abstract

Research on indoor environments has gained a fresh impetus over the last couple of years, making indoor spaces an indispensable part of current geospatial research. Navigational applications are one of the booming industries, focusing more and more on the indoor world. However, indoor navigation research has so far been limited to data modeling and technological developments, leaving the required algorithmic support quite untouched. This research has the purpose to extend a couple of more cognitive outdoor algorithms to indoor spaces and investigate the differences between both in terms of algorithmic structure and relationship to the 3D network structure. In this paper, we currently focus on extending the simplest algorithm to a three-dimensional application in the built environment.

Keywords

Indoor space, navigation, algorithm, 3D

1. Introduction

Outdoor urban environments already have a long history as research subject with for example applications of geospatial analyses of cities and transportation networks (Ban and Ahlqvist 2009). Research on indoor spaces recently gained a fresh impetus (Worboys 2011) with studies of the structural understanding and modeling of indoor environments. This has its origin in both an increased development of more complex three-dimensional vertical building structures and a recent succession of human-induced disasters mostly affecting the built environment and its occupants (Kwan and Lee 2005, Lee and Zlatanova 2008). These evolutions combined with the rapid progress in spatial information services and computing technology (Li and Lee 2010) have put three-dimensional modeling and analyses more and more in the spotlight. Also, given the fact that as human beings we spend most of our time indoors (Jenkins et al. 1992), indoor environments have become an indispensable part of current geospatial research.

Within indoor research, applications that support navigation and wayfinding are of major interest. Navigational applications have increasingly conquered the outdoor world with the ubiquitous availability of GPS systems, internet maps and smart phone distribution (Gartner et al. 2009). Indoor navigation has so far been challenging, but the last decade showed significant progress into the topic and far more recent the commercial interest with public data gathering for navigation support in several indoor buildings (e.g. Google Maps Indoor) has shown the importance of this application field.

2. Problem statement

Navigational applications commonly apply shortest path algorithms for their path calculations as they are one of the most fundamental network optimization problems, studied for over 50 years in mathematical sciences (Cherkassky et al. 1996). Many of them are based on the famous Dijkstra shortest path algorithm (Dijkstra 1959) with gradually more and more adaptations and extensions for better performance in terms of speed, storage and calculation flexibility (Zhan and Noon 1998). Over the years, those algorithms were tested on their validity and usage in a wide variety of outdoor transportation networks (Zhan and Noon 1998).

Over time, alternative algorithms were proposed adding a more cognitive notion to the calculated paths and as such adhering to the natural wayfinding behavior in outdoor environments. Examples are hierarchical paths (Fu et al. 2006), paths minimizing route complexity (Duckham and Kulik 2003, Richter and Duckham 2008) or optimizing risks along the described routes (Grum 2005). The major advantage of those algorithms is their more qualitative description of routes and their changed embedded cost function, simplifying the use and understanding of the calculated routes and as such improving the entire act of navigation and wayfinding.

Indoor navigation research currently focusses solely either on the technological aspect of indoor positioning and user support (Mautz et al. 2010) or on the creation of indoor data structures (Lee and Kwan 2005, Lorenz et al. 2006, Richter et al. 2011). The algorithmic development to support navigation in indoor built environments has so far been left mostly untouched. Most indoor navigation applications still mainly rely on adapting Dijkstra's shortest path algorithm to a three-dimensional network structure.

In this paper, we focus on calculating routes that are more aligned with human cognition for wayfinding in indoor environments than simply shortest distance or time calculations. The need for more cognitively rich algorithms indoors is highlighted by the difference in space structure between outdoor and indoor environments. Indoor spaces are often more fragmented, with less visibility, less orientation clues and confined areas resulting in a more challenged orientation and navigation task. As such, the clarity and easiness of route instructions is of paramount importance when distributing indoor route calculations. A shortest or fastest path indoors not necessarily aligns with the cognitive mapping of the building. Therefore, the aim of this paper is to extend those richer cognitive algorithms to three-dimensional indoor environments.

3. Methodology

In this first stage of the research, we chose to focus solely on the simplest path algorithm as described by Duckham and Kulik (2003). The main goal is to evaluate the applicability of the algorithm in 3D indoor environments. In a later stage, the least risk path as developed and tested by Grum (2005) will also be assessed for usage in indoor spaces.

We divided our research into several steps. First, the exact algorithm developed for outdoor environments will be implemented and duplicated in an indoor space after which we will extensively test its performance. These tests will be executed on two levels by comparing several path calculations in terms of length and number of turns (as done in both Duckham and Kulik (2003) and Grum (2005)). On the one hand a thorough statistical comparison of the indoor simplest paths compared to traditional indoor shortest path algorithms can show the improvement in route description complexity and the increase in path length indoors. On the other hand, comparison of the proportional differences between the results of the indoor and outdoor calculations (both shortest and simplest paths) will be related to the dissimilarity of indoor and outdoor space structures. In a second step, a further investigation of a correct treatment of the third dimension is proposed by using the knowledge of the difference between indoor and outdoor spaces. The three-dimensionality of some intersections combined with the effort for vertical movement and a changed cognitive thinking requires an altered weighted cost function. In a third step, an improved indoor simplest path algorithm will be developed based on above results to account for the differences when dealing with a 3D network structure. Fourth, the integration of outdoor and indoor environments should be the ultimate pursuit of navigational applications, as it would support seamless movement between both. As such, the algorithm should be aligned to be usable in both environments independent of the space structure. This will be tested in a combined indoor-outdoor setting.

The algorithms developed require to be thoroughly tested in an extensive and complex indoor environment to be a valid alternative for outdoor algorithmic testing. The dataset for our tests consist of the 'Ledeganck' building of Ghent University (Figure 1). It is a complex multistory building where several wings and sections have different floor levels and are not immediately accessible.

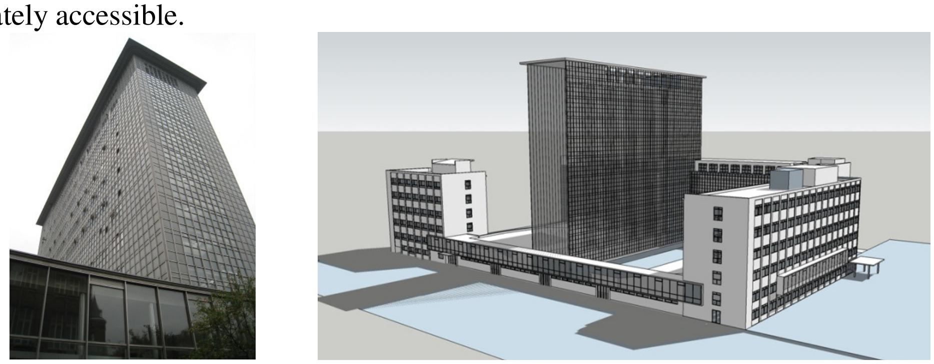

Figure 1: View of the main building section of the 'Ledeganck' building of Ghent University (left – Source: Ann Vanclooster) and model of the building (right - Source: http://www.skyscrapercity.com/showthread.php?p=50387053).

The dataset is manually created using ArcGIS software, since for the moment no universal automatic generation of 3D indoor networks has been developed. The algorithmic development and calculations will be programmed in Java programming language. The network structure is chosen to be compliant to Lee's Geometric Network Model (Lee, 2004) as this is one of the main accepted indoor data structues (Figure 2). In this model, each room is transformed into a node, forming a topologically sound connectivity model (Figure 2a). Afterwards, this network is transformed into a geometric model by creating a subgraph for linear phenomena (e.g. corridors), as such enabling network analysis.

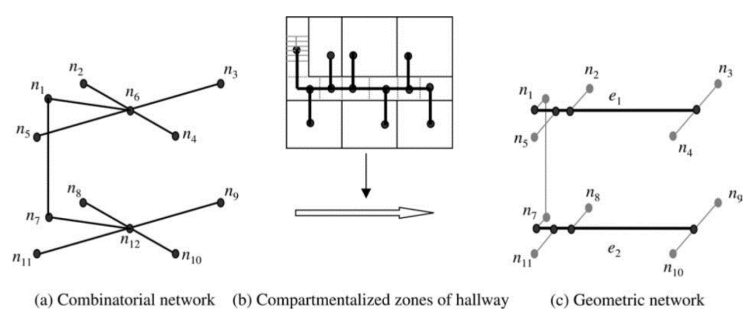

Figure 2: Design of the Geometric Network Model (Source: Lee (2004)).

4. Conclusion and future work

In this paper, we propose an adaptation and implementation of a simplest path algorithm in 3D indoor environments. Currently, this is work in progress but we believe that the results could be of interest for the community. Indeed, more cognitive navigation paths, especially in complex indoor environments, can significantly enhance the navigation experience and way finding task for users in unfamiliar environments.

This research is part of a bigger project, focusing on navigation and way finding in indoor and combined indoor-outdoor spaces. The second stage of this research is to investigate the dependence of the performance of the algorithms on the indoor network topology. So far, there has not been established an agreement on the general structure and modeling of indoor spaces, resulting in abundant use of possible network structures. By altering the network structures and calculating various paths, an evaluation will be made of the quality of these 3D indoor networks.

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