# CAPRIO v2.0: A Context-Aware Unified Indoor-Outdoor Path Recommendation System

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***Abstract*—The *CAPRIO v2.0* system is the evolution of *CAPRIO*, our context-aware path recommendation system that has as its primary objectives the minimum outdoor exposure and distance of the recommended path. *CAPRIO v2.0* offers enhanced indoor context-awareness in terms of accessibility and congestion. In this demonstration, we exhibit *CAPRIO v2.0* and present its novel graph representation that integrates accessibility, congestion, indoor, and outdoor information to discover paths satisfying accessibility, outdoor exposure, and distance constraints of an individual. We further present a new spatial model index, called *SMI-tree*, which enables *CAPRIO v2.0* to quickly forecast the congestion in corridors and hallways. Individuals can interactively engage with the *CAPRIO v2.0* GUI using any of their devices to appreciate how our proposed structures and algorithms can provide an alternative context-aware path by combining outdoor, indoor, congestion and accessibility information.**

***Video*  https://db.cs.pitt.edu/caprio/v2**

***Index Terms*—indoor, outdoor, navigation, path recommendation, graph processing, disability, congestion forecasting.**

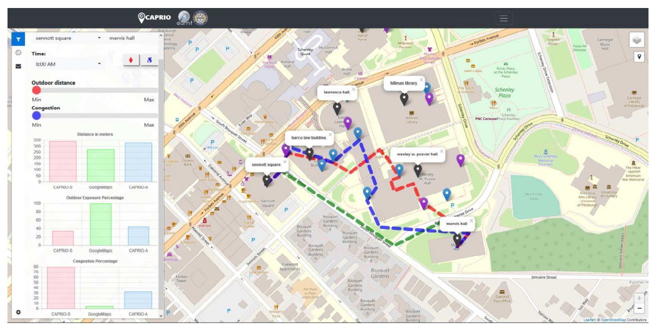

Fig. 1. The *CAPRIO v2.0* user interface offers the options to the users to choose the start, the destination, and the accessibility constraints as well as their outdoor exposure/distance and the congestion preference (Left). The user interface enables a direct comparison among the *CAPRIO* recommended path (red line), the *CAPRIO v2.0* path (blue line), and the path from Google Maps (green line). The *CAPRIO v2.0* also graphically compares the three paths in terms of distance, outdoor exposure, and congestion in bar plot form (Left) along with the respective path on the map (Right).

## I. Introduction

Currently, navigation solutions are primarily focusing on indoor or outdoor localization and navigation. However, only a handful of the state-of-the-art solutions exploit both indoor and outdoor information at the same time. Most of these solutions focus only on the indoor-outdoor seamless transition techniques [1] instead of a unified model that can be beneficial for the shortest end-to-end path discovery [2]. Context-aware paths are essential for the everyday activities of an individual and minimizing the outdoor exposure of a recommended path is of great importance to wide range of users. For example, during severe weather conditions, such as the heatwave in Japan 2018 and the 2019 polar vortex in the USA, pedestrians are more vulnerable to heat and cold-related illnesses. This observation has motivated our work on *CAPRIO*[1] [3], [4], which is a novel context-aware path recommendation system that aims to minimize the outdoor exposure and distance of the recommended path.

Indoor congestion is a particular type of indoor obstacle that has attracted less attention in the current navigation solutions and which has a broader health impact. The coronavirus outbreak is in the spotlight right now due to the severity and rate at which the virus spreads, and the influenza virus is a re-occurring problem of similar magnitude. *Clearly, providing a context-aware path that avoids congested areas is important for people that must move indoors and simultaneously be safe from diseases.*

A particular class of people that are benefited by a context-aware path recommendation system are those with a mobility disability. According to the Centers for Disease Control and Prevention (CDC)[2], 61 million adults in the United States live with a disability, and 53% of them have some form of mobility disability. *Clearly, the movement and transportation of those people require paths that consider handicap accessible entrances and exits, and avoid staircases as well as congestion in corridors and hallways.*

In this paper we demonstrate *CAPRIO v2.0*, an extended version of *CAPRIO* that addresses the aforementioned shortcomings. It implements new components, which enhance the system with accessibility routing and congestion avoidance. The core of the system is an improved version of our novel *GIPD* algorithm (*GIPDv2*), which integrates the external nodes (e.g., building) with the internal nodes (e.g., entrances, escalators, exits) to discover a path with least outdoor exposure, indoor accessibility, minimum average congestion and shortest distance overall.

[1]CAPRIO: https://db.cs.pitt.edu/caprio/

[2]Centers for Disease Control and Prevention: https://www.cdc.gov/

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*CAPRIO v2.0*'s newest contribution is the congestion forecasting component, which predicts the congestion for each indoor segment at a specific time. Central to the congestion forecasting component is a novel spatial index, called *SMI*. Using *SMI*, *CAPRIO v2.0* can quickly retrieve the trained models to achieve a prediction with high accuracy. Our learned congestion forecasting models are LSTM networks [5] based on historical building traffic patterns.

## II. The *CAPRIO v2.0* Architecture

*CAPRIO v2.0* has a modular design and an exposed API to allow the scalability and extensibility of the system. This allows the core of the system to be updated using different graph-based algorithms without affecting the user interface. We express our proposed architecture in three layers, namely *Data Layer*, *Processing Layer*, and *Application Layer*.

The *Data layer* transforms the data from various sources into a predefined format to ship them over to the Processing Layer. The input data can be regular files on a local or distributed file system, data streams, or external APIs.

The *Processing layer* comprises four components, which implement the *GIPDv2* algorithm: (i) the *graph-based integration*; (ii) the *path discovery*; (iii) the *congestion forecasting*; and (iv) the *accessibility* component. The *graph-based integration* component interacts with the *congestion forecasting* component and the *accessibility* component to integrate the congestion prediction, accessibility, outdoor exposure and distance information into one unified graph. The unified graph is used as input to the *path discovery* component where paths are evaluated with respect to congestion, indoor accessibility, outdoor exposure and distance.

The *GIPDv2* algorithm is triggered through a web request calling the *CAPRIO v2.0* API in order to discover the context-aware path using the above-integrated graph. Initially, the algorithm calculates the weights for each edge of the external graph by examining the travel distance within each internal graph (i.e., nodes). Once the weight for each edge has been assigned, traditional graph techniques are applied on the external graph that resulted from the previous step in order to obtain the path.

The *Application layer* is equipped with an intuitive map-based web interface layer that hides the complexity of the system through a simple and elegant web interface. Additionally, it provides an open API to enable the development of smart applications over the *CAPRIO v2.0* architecture.

To combine the external graph with the internal graph of each building, *CAPRIO v2.0* uses both the street distance reported by the Google Maps API and the internal travel distance of each building produced by Anyplace [6], in order to calculate the integrated weights of each external edge.

## III. Demonstration Scenario

During the demonstration, the attendees will be able to appreciate the key concepts of *CAPRIO v2.0*, the visualization abstraction, as well as the performance of our propositions by interacting with a user-friendly interface.

### A. Demo Artifact

Our prototype of *CAPRIO v2.0* incorporates an interactive map on top of Google Maps along with several graph techniques provided by JGraphT library. The back-end was developed using the Play Framework 2.7 and Couchbase 5.0. The *CAPRIO v2.0* web interface is implemented in HTML5/CSS3 along with extensive usage of Leaflet and Cytoscape.js.

An illustrative path exploration interface is shown in Figure 1. We have implemented a query sidebar that allows the user to execute a variety of template queries. The query sidebar has three main tabs: (i) the *Options Tab*, which enables the user to choose the source, the destination and the accessibility of the recommended path along with its outdoor exposure/distance and the congestion preference (shown in Figure 1); (ii) the *Graph Tab*, which animates the paths using graph visualizations to show graphically the algorithms and techniques behind the paths; and (iii) the *Settings Tab*, which activates/deactivates elements on the main user interface such as entrances and exits that constraint the overall recommendation.

### B. Demo Plan

*Datasets*: A variety of real datasets are already pre-loaded to the *CAPRIO v2.0* back-end. The loaded data exposes the graph-based data integration and are very useful to visually show how the *CAPRIO v2.0* path recommendation engine works over real data.

*Scenarios*: The *CAPRIO v2.0* server is publicly available allowing the conference attendees to use their own devices such as a standard laptop, a tablet or a smartphone. The conference attendees can interactively engage with *CAPRIO v2.0* by changing the parameters of the system and observing the recommended path on the user interface along with the animated graph illustrating the discovery process in the *Graph Tab* discussed above.

In order to present the benefits of our propositions to the attendees, the video presentation provides visual cues that enable the audience to understand the performance benefits (i.e., outdoor exposure, distance and congestion).

## References


[1] H. S. Maghdid, I. A. Lami, K. Z. Ghafoor, and J. Lloret, "Seamless outdoors-indoors localization solutions on smartphones: Implementation and challenges," *ACM Comput. Surv.*, vol. 48, no. 4, pp. 53:1–53:34, 2016.

[2] S. K. Jensen, J. T. V. Nielsen, H. Lu, and M. A. Cheema, "Outdoor-indoor Space: Unified modeling and shortest path search," in *8th ACM SIGSPATIAL Int'l Workshop on Indoor Spatial Awareness*, pp. 35–42, 2016.

[3] C. Costa, X. Ge, and P. Chrysanthis, "CAPRIO: Context-aware Path Recommendation Exploiting Indoor and Outdoor Information," in *20th IEEE Int'l Conference on Mobile Data Management*, pp. 431–436, 2019.

[4] C. Costa, X. Ge, and P. K. Chrysanthis, "CAPRIO: Graph-based Integration of Indoor and Outdoor Data for Path Discovery," *Proc. VLDB Endow.*, vol. 12, no. 12, pp. 1878–1881, 2019.

[5] Y. Lv, Y. Duan, W. Kang, Z. Li, and F. Wang, "Traffic Flow Prediction with Big Data: A Deep Learning Approach," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 2, pp. 865–873, 2015.

[6] D. Zeinalipour-Yazti, C. Laoudias, K. Georgiou, and G. Chatzimilioudis, "Internet-based Indoor Navigation Services," *IEEE Internet Computing*, vol. 21, no. 04, pp. 54–63, 2017.




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