Context-Aware Processing of Continuous Location-Dependent Queries in Indoor Environments
Imad Afyouni
Naval Academy Research Institute (IRENav), 29240 Brest Cedex 9, France
imad.afyouni@ecole-navale.fr

1. Introduction

Continuous location-dependent queries can be considered as key elements for the development of different categories of location-based and context-aware services. Most work on location-dependent query processing focuses, however, on outdoor environments. The aim of this research is to study location- and context-aware services and queries in indoor environments (e.g., houses, commercial malls, etc.), with a special focus on navigation-related queries (i.e., mainly path search, range, and nearest neighbour queries). A unique combination of challenges arises, as the proposal must be able to process different kinds of queries, in a continuous and efficient manner, and to take into account additional context information, and the hierarchical layout of the indoor environment. This work presents a generic architecture to process continuous location-dependent queries in indoor environments. The architecture is built on top of a hierarchical and context-dependent spatial data model, which leads to the consideration of other context dimensions besides the location of the involved entities, such as time and user profiles. Moreover, the semantics of a continuous-based query language for location-dependent queries is presented. Furthermore, a hierarchical and incremental path search algorithm applied to both static and moving objects is proposed for navigation queries. For continuous range queries, an incremental approach has been developed, which performs a hierarchical network expansion and a mechanism to update the search tree based on the user’s movements. This research summary presents the outcome of the achievements performed during the STSM mission funded by the MOVE (COST Action IC0903) STSM committee and carried out at the University of Zaragoza, Spain, in collaboration with Dr. Sergio Iiarri (from September 11th, 2011 to October 22nd, 2011).

2. A hierarchical and context-dependent indoor data model

The approach developed is a major extension of our preliminary work reported in [1], and introduces a multi-granular spatial representation of an indoor environment that can be integrated into a context-aware system architecture. Moreover, this model represents: (i) all the features that populate the environment, (ii) their spatial properties, and (iii) the behaviours or actions that emerge from them. The model is hierarchically organised and can be viewed as a tree structure in which location information is represented at different levels of abstraction. This hierarchical design is very flexible since it supports a large spectrum of applications that can be developed at different levels of abstraction, and alleviates performance and scalability issues in location-dependent query processing. In addition, time-dependent functions that compute the network distance and the travel time are introduced at the fine-grained level. This helps to compute time-dependent optimal paths and to pre-process distances at higher levels to facilitate hierarchical path searches. Furthermore, a classification of user profiles is presented in order to perform an offline filtering of the multi-level graph, thus reducing the amount of data that need to be processed in real-time for each query and supporting the retrieval of more accurate answers based on user profiles.

3. Continuous Query Processing Architecture

A generic architecture used for the continuous processing of several types of location-dependent queries in indoor environments has been proposed. In our environment, we consider managing: (i) mobile persons, each of them carrying a mobile device that allows computing the current location and communicating with other entities, and (ii) objects of interest that contribute to enrich the context of the query. Those are managed by a set of fixed servers (i.e., computers). Each of them is in charge of: (1) maintaining a part (i.e., within a certain geographic area) of the hierarchical spatial graph that represents the environment, (2) managing data and communicating with objects located within its area, and (3) executing queries or parts of queries whose data are locally available.

Two main components that contribute to the processing of continuous location-dependent queries are: (1) a Route manager in charge of determining the best candidate routes for navigation-related queries based on user-defined preferences and context data; and (2) a Query execution engine that repeatedly (i.e., while the request is not cancelled by the user) performs the following tasks: (i) update simple queries with locations of relevant
objects and with the new set of relevant routes, if needed, (ii) execute standard queries, (iii) join the results to standard queries, and finally (iv) present the answer to the user.

4. Query language for navigation-related queries in indoor environments

In order to improve query expressiveness, a query grammar is used to express those queries. This grammar has been extended from a previous work [4] to support navigation queries (of key importance in context-aware indoor navigation systems) and to incorporate some other preferences and semantics in the query model. For example, it includes additional operators (e.g., all-routes) and constraints (e.g., stop-vertices) inspired by [3]. The concept of location granule proposed in [4] is adopted. A location granule identifies a set of fine-grained geographic locations (e.g., geometric coordinates of vertices in the fine-grained graph) under a common name. This is completely consistent with the aforementioned hierarchical data model. The use of location granules allows formulating queries using the location terminology required by the user (e.g., vertices at the fine-grained level, rooms, floors, buildings, etc.). Some motivating examples of location-dependent queries are illustrated in [2], which show the power of the query grammar proposed.

5. Processing of Continuous Navigation Queries

Our approach for hierarchical path search is based on a bottom-up technique that uses two levels of abstraction, that is, a fine-grained layer at the first level and either an exit or a location hierarchy at the second level of abstraction. It starts the search from the user-specified level of granularity (depending on the location granule specified in the request and which contains the initial query point) to the highest level of abstraction to find the optimal route at an abstract level. Refinement processes are then done, when needed, to find the exact location of the target object. This is embodied by four main steps: (1) find the optimal path within the initial granule containing the start node until reaching the nearest exit; (2) search at the abstract level for the optimal path from the exit of the initial granule to the granule containing the target object; (3) find the optimal path within the last granule to the target object starting from the corresponding entrance of the granule; and (4) start the continuous processing of the query to keep track of the reference and target objects and to update the previous tree accordingly.

6. Processing of Continuous Range Queries

In a range query, a maximum distance threshold is specified instead of a target object. All qualifying objects located within this radius are retrieved. Our approach consists in hierarchically expanding all routes whose network distance from the source node is less than or equal to the specified radius. The algorithm performs a hierarchical network expansion once for the first iteration and keeps all visited nodes that compose the range around the reference object. An incremental search approach is also required in order to efficiently execute continuous range queries. This implies either expanding new sub-trees from boundary nodes (i.e., leaves) or eliminating some of them if the new network distance exceeds the specified threshold.

7. On-going Research

A successful integration of indoor spaces and context-aware systems requires the study and development of a dynamic and flexible spatial model that supports the continuous processing of location-dependent queries applied to moving objects acting in these environments. The research developed so far might be still enriched by the integration of a decentralized solution for the processing of location-dependent queries, and thus validating the proposed model. Furthermore, analysing the efficiency and scalability of the solutions proposed to deal with continuous location-dependent queries is still required. A part of this research summary is described in more detail in a recently submitted paper [2]. We would like to thank the MOVE (COST Action IC0903) STSM committee for giving us the chance to participate in this extremely interesting experience.

References