CONTEXT-AWARE PROCESSING OF CONTINUOUS LOCATION-DEPENDENT QUERIES IN INDOOR ENVIRONMENTS

Report from the STSM stay

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I. INTRODUCTION

Location-based services have attracted extensive research attention, as the development of these services is expected to have a significant impact for end users and also a high economic value. These services offer customized access to information by taking into account the location of the mobile users. More generally, context-aware systems exploit several elements in the context (location, time, activity, surrounding people and devices, etc.) to further customize the user's experience.

Context-aware indoor services strongly rely on location information to adapt to context changes. Therefore, a good integration of indoor spaces and context-aware systems requires the development of dynamic and flexible spatial models that will help to provide appropriate services to mobile users acting in the environment. Location-dependent queries, needed in context-aware systems, may be affected by any change of the locations of objects that are involved in the query. Location-dependent queries may be static or dynamic according to whether or not the initial query point is in a static location. Similarly, a location-dependent query can be applied on static or dynamic data, depending on whether the target objects are moving or not. For example, if a user wants to find out his/her friends within a range of 100 meters while navigating a shopping centre, this answer will depend on both the user's current position and the location of the nearest friends. This type of query is particularly challenging because the mobile user and the interesting entities for the query (i.e., the friends of the user) are both moving. Although many different types of location-dependent queries exist, a main focus is put on the following (due to their importance):

1. *Navigation queries* encompass all queries that directly help users to find points of interest by providing them with navigational information while optimizing some criteria such as the total distance or travel time. Examples of such queries are: (i) discovering the optimal path to the nearest points of interest (e.g., place, feature, etc.), (ii) planning a path to the destination, (iii) routing a user towards a moving target, etc.
2. *Range queries* are used to find and retrieve information about objects or places within a user-specified range or area. They provide an important navigation support by continuously updating relevant details according to users' movements.
3. (*k*) *nearest neighbour (NN) queries* search for the (*k*) closest qualifying objects to the moving user with respect to his or her current position. In contrast with range queries, (*k*) NN queries are range-independent. The user initiates a request by specifying some characteristics about objects of interest so that the closest object whose specifications meet these characteristics is retrieved (e.g., the closest available colour printer or the nearest friend).

Efficient management of static and dynamic data is a key issue for processing these queries since the result of a query is only valid for a particular location of the query issuer and the objects of interest. Thus, as the answer to a query may be valid only for a short time, the queries must be processed as *continuous* queries, meaning that the system should automatically keep the answers up-to-date efficiently (until the query is explicitly cancelled by the user). However, continuously updating the answers to the queries may imply a significant communication overhead and an additional processing cost at the server side. Moreover, although many research studies have discussed location-dependent queries and location-based services, very few works have addressed the problem of incorporating context dimensions, mainly those related to *user-centric* and *environmental* context that may completely affect the answer to a query even if the locations of the query issuer and other involved objects have not changed.

II. OBJECTIVE OF THE STSM

The aim of this short term scientific mission was to study location- and context-aware services and queries in indoor environments, with a special focus on the aforementioned queries. A unique combination of challenges arises, as the proposal must be able to process different kinds of location-dependent (navigation, range, and nearest neighbour) queries, in a continuous and efficient manner, and taking into account additional context information and the time-dependent and hierarchical layout of the indoor environment.

In a previous work developed by the STSM grantee [1], a context-dependent multi-granular spatial model that embeds different levels of granularity has been proposed. It represents: (i) all the features that populate the environment, where a feature can refer to either a person (i.e., a mobile user or any other interesting social entity located in the vicinity) or an object of interest (sensors, exits, tables, continuous phenomena such as a fire, etc.); (ii) their spatial properties (e.g., location and extent); and (iii) the behaviours that emerge from them (i.e., how objects can interact and communicate within the environment).

The proposed research plan takes into account the following steps:

- Reconsider and validate the proposed indoor spatial model, especially the adoption of a hierarchical spatial data model, with respect to its usefulness in location-aware queries and services; for instance, discussing a hierarchical path search approach for navigation queries as well as a hierarchical network expansion algorithm used for range queries.
- Design a generic query processing architecture that is used to execute several kinds of continuous location-dependent queries in indoor environments.
- Study and design solutions to specifically support continuous range and navigation queries for mobile users and on static/mobile data.
- Discuss the possibility to perform a distributed query processing approach by integrating the indoor model with a decentralized solution [5].
- Analysing efficiency and scalability of conducted works when dealing with location-aware continuous queries.

III. ACTIVITIES AND ACHIEVEMENTS DURING THE STSM

The effective time of the STSM has been six weeks (from 11 September to 22 October, 2011). During the first week, we had the opportunity to present our research works to each other and to exchange ideas about the objectives, which has led to establish a concrete research plan as described above. In addition, I delivered a seminar entitled "A Fine-grained Spatial Model for Indoor Context-Aware Navigation Systems" at the Department of Computer Science and Systems Engineering of the University of Zaragoza on September 16, 2011. The following five weeks have been dedicated to deeply study the abovementioned steps and to deal with the issues described in the first section. A brief summary of each of these aspects is presented below.

1. *Extending the indoor model by incorporating time-dependency and by handling user profiles:*

The approach proposed in a previous work [1] is a multi-granular context-dependent model that represents an indoor environment with three complementary layers: (i) the spatial layer is a multi-level graph defining the hierarchical structure of the model; (ii) the feature layer integrates persons and objects of interest; and (iii) the action layer represents actions that are either predefined and triggered automatically by the system in form of informative, context-aware messages, or generated by a given feature acting in the environment. As an extension of this model, 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 search. Moreover, 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.

2. *Query processing architecture applied on moving objects:*

A general 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 others, and (ii) objects of interest that contribute to enrich the context of the query and are used by the user to provide his/her preferences and constraints. 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:

- A *Route manager* is in charge of determining the best candidate routes for navigation-related queries based on user-defined preferences and *context* data (e.g., information about user profiles, descriptions of objects of interest, etc.).

- A *Query execution engine* repeatedly (i.e., while the request is not cancelled by the user) performs the following tasks: (1) update simple queries with locations of relevant objects and with the new set of relevant routes, if needed, (2) execute standard queries, (3) join the results to standard queries, and finally (4) present the answer to the user.

3. *Query language for navigation-related queries in indoor environments:*

For clarity, an SQL-like syntax is used to express the queries. The query language grammar considered to express the queries has been adapted from a previous work [4], and extended to support navigation queries (of key importance in the context of indoor navigation) 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]. We adopt the concept of *location granule* proposed in [4]. A location granule identifies a set of fine-grained geographic locations (e.g., geometric coordinates of vertices in the base graph) under a common name. This parameter is completely consistent with the hierarchical spatial graph proposed. The use of location granules allows formulating queries with a location resolution and terminology which is appropriate for the intended application.

4. *Processing of Continuous Navigation Queries:*

Our approach for hierarchical path search is based on a bottom-up technique that uses four levels of abstraction (i.e., fine-grained, room, floor, and building) and 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 three main steps: (1) find the optimal path within the initial *granule* (i.e., cluster of nodes representing a room, for instance) containing the start node to the nearest *exit*; (2) search at the abstract levels 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 granule's exit.

An incremental search-based algorithm is proposed for the continuous processing of the hierarchical path search, which transforms the previous search tree to an updated tree depending on objects' progression and changes in the environment. The algorithm maintains some basic concepts of the popular A* algorithm and is particularly based on two variants of A*: Fringe-retrieving A* (FRA*) [6] and Hierarchical Path-finding A* (HPA*) [2].

5. *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 of 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.

IV. CONCLUSION

The STSM experience has given me the opportunity to learn about location-dependent query processing, and has already started a fruitful collaboration. We are preparing a paper (currently 17 pages) for submission to a relevant journal/conference, which describes the outcome of the achievements performed during this STSM. It has also given me the chance to have many fruitful discussions with Prof. Ilarri and to learn from him new concepts and techniques regarding the distributed processing of location-dependent queries. There are still some issues that we need to consider regarding the possibility to perform a distributed query processing approach by integrating the indoor model into the decentralized solution proposed by the host institution. Furthermore, analysing the efficiency and scalability of the solutions proposed to deal with continuous location-dependent queries is still required.

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