Simplified Guided Visibility Sampling for Location Based Services

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1 ABSTRACT

Location plays an increasingly important role in many urban mobile computing and application scenarios. Location based information services for mobile phones and PDAs that provide their users with contextually relevant data - such as local yellow pages search or "where is"-services that guide users to the nearest pharmacy or restaurant - have become widely available on the market.

In this paper, we describe a system that enables novel interaction methods and user interfaces for future location based systems by introducing an additional context parameter beyond location: visibility. We argue that mobile application scenarios greatly benefit from knowledge about the visible environment around the user: Information that is related to objects, geographical features or buildings that are visible to the user may be contextually more relevant than information about objects that are not; interactive, ego-centric maps on mobile devices provide added value if they contain indications of the visibility of surrounding features, as has been shown by [Froehlich et al]; visibility information can even enable entirely new interaction metaphors on mobile devices equipped advanced sensors such as GPS and digital compass, as has been described by [Egenhofer] and [Simon et al].

Based on the guided visibility sampling algorithm [Wonka et al.] we have developed a high performance visibility computation service for handheld devices that gracefully degrades under high load.

2 INTRODUCTION

A number of future service scenarios are based on handheld or portable devices. These range from personal digital assistants (PDAs) and tablet PCs, to smart phones, all the way to low-end cell-phones. As these devices are portable, their actual location plays an increasingly important role in designing services for special applications.

2.1 Location based Services

Location Based Services (LBS) that provide mobile phone users with information related to their immediate environment have been offered by mobile network operators since the late 1990's. Typical examples of LBS offered today are direction finding services or yellow pages-like services (e.g. for finding the next pharmacy or nearby restaurants, see Figure below), mapping and traffic information services, as well as community-oriented applications that facilitate social interactions like chat or messaging by allowing their users to share their own location with other users.

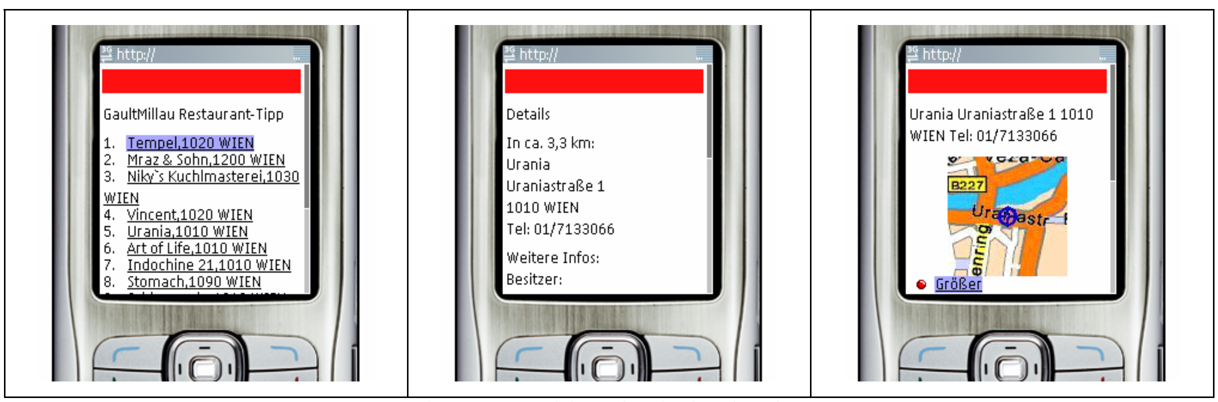

Figure 1: State-of-the-art location based service.

To estimate the position of the user, current LBS implementations typically take advantage of the fact that the location of the GSM cell tower a user is currently connected to is known to the network. Since the width of the area covered by a single cell tower may, however, range from a few hundred meters to several kilometers, this location estimate is rather coarse. Also, the necessity to perform a lookup in a central database that relates cell tower locations with geographical coordinates imposes scalability limitations in the network. Recently, it has become more common for state-of-the-art smartphones and PDAs to feature built-in GPS receivers. Regulatory initiatives that require network operators to provide position data for mobile phones in case of emergency calls, like the US E911 regulation or the European E112 counterpart, further stimulate this trend. Consequently, newer LBS implementations rely on GPS receivers to estimate user locations, leading to a considerably improved location granularity.

2.2 Visibility from a region in space

Visibility is a core problem of three dimensional computer graphics: visibility computations are necessary for a number of tasks such as occlusion culling, shadow generation, image-based rendering, inside-outside classifications, motion planning, and navigation. While visibility from a single viewpoint can be calculated quite easily, many applications require the potentially visible set (PVS) for a region in space, which is a much more complicated problem. Although a number of excellent from-region visibility algorithms exist, most of them are only applicable to a limited range of scenes, require complex computations, and sometimes significant amounts of memory. For this reason, sampling-based solutions have become very popular for practical applications due to their robustness, general applicability, and ease of implementation.

Although exact solutions for computing visibility from a region in space have been rare [Duguet and Drettakis; Durand], recently two new algorithms have been published [Nirenstein et al.; Bittner] and subsequently improved [Haumont et al.; Mora et al.]. Both of these algorithms are exact and work for general scenes, but due to the complexity of the underlying problem, and the numerical robustness of the implementation can lead to issues that may degrade their solution to be not perfectly exact anymore.

Based on this experience our research group, together with some scientific partners has developed a new, sampling based algorithm that has a vastly superior performance, and although it is not exact, the quality and correctness of the computed visibility solution in some cases exceeds the results of the so-called exact algorithms due to the numerical stability of the new method [Wonka et al.].

3 USING VISIBILITY IN LOCATION BASED SERVICES

The use of a visibility-based query mechanism offers two key benefits over traditional querying, as applied by todays LBS: First, information can be tailored considerably better to the user's context, since points of interest that are visible (for example places in the same street as the user) are most likely more relevant than those that are hidden (e.g. places two blocks away), even if they are closer to the user with regard to their bee-line distance. Second, visiblity-based querying enables new types of geo-spatial user interfaces on mobile phones equipped with orientation sensors such as compass and tilt sensors, as they are currently becoming available on the market.

3.1 Information Relevance

Unlike desktop GIS (geographic information systems) that typically present geo-spatial information on a map on the screen, mobile geo-spatial information systems and location based applications relate geo-spatial information to the user's immediate real-world environment; the user is physically immersed in the geographical region associated with the search space. [Gardiner et al] suggested that the spatial query operations currently offered by spatial databases – such as bounding queries or a fixed radius around a center location – are inadequate under these circumstances. They have concluded that a reference frame based on the user's *field of view* is more appropriate in the case of mobile spatial querying.

Furthermore, a user study conducted by [Froehlich et al] that compared different types of user interfaces for geo-spatial data access has confirmed that visibility plays an important role in the users' understanding of which points of interest are more relevant than others. An explicit indication of the visibility of nearby geographical features was particularly appreciated in textual user interfaces (which are still the most common presentation format for state-of-the-art LBS) and map-based presentations. We therefore argue that visible points of interest can indeed be considered more relevant for location based services, even if they are further away than other, hidden points of interest.

3.2 Orientation-Aware Location Based Mobile Interaction

Mobile phones equipped with navigation-related features like integrated GPS or digital compass have recently become more commonly available on the market. The growing proliferation of such devices not only promises to drive the demand for geo-spatial applications and location-based applications; it can also enable entirely new ways of how users interact with geo-spatial information in the near future: For example, visibility querying based on GPS- and compass-data from a mobile phone essentially allows users to identify geographic objects by pointing towards them (see Figure 2).

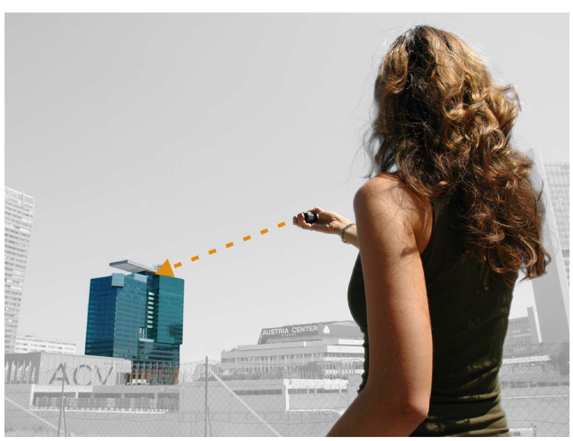

Figure 2: Visibility-facilitated mobile interaction: The Geo-Pointer – accessing geo-spatial information by pointing.

4 FAST COMPUTATION OF THE VISIBILITY FROM A REGION

In a service scenario where a huge number of requests for the complete visibility information from various handheld devices need to be computed by a small number of servers, the computational cost for computing this information by simple means can become prohibitive. In order to handle this situation, we took the forward sampling step of guided visibility samping as a basis for server based visibility computation. The server maintains a database of the 3D-geometry of the city or region in which the service is offered. Whenever a handheld device needs information about the visibility of objects in its vicinity, its location is transmitted to the server, and the server responds with a set of object ids for those objects which are visible from the location of the handheld device, or in a service based approach with all location based services associated with the visible objects.

The forward sampling step of guided visibility sampling is based on starting with a number of random visibility samples, and then extending the set of visible objects, by sampling in the vicinity of them, i.e. the initial samples act as seeds in a flood-fill like sampling process.

In order to speed up the main operation in this sampling approach, namely the intersection of visibility rays with the object database, a pre-calculated kd-tree is built. Although this is a potentially time-consuming operation, it only needs to be performed once for the geometry database, and the resulting k-d tree can be stored. The k-d tree has the additional benefit of being rather memory-efficient, as its size grows with O(N log N) in the number of objects in the geometry database.

For a cost-efficient service, it is necessary to process a huge number of request in a relatively short time. Due to the nature of the underlying algorithm our implementation can handle a single visibility computation within a data set of millions of triangles within a small fraction of a second. In addition to this impressive performance, the service is scaleable in two more directions: parallelization and service quality. Since the database underneath this kind of service is only used in a read-only fashion for the visibility computation, the algorithm can be trivially parallelized for multi-core systems with nearly linear speedup in the number of CPUs, and the geometric data set can be partitioned onto multiple servers, each of which is responsible for a different region. Another way to speed up the performance of the server is by degrading service quality. Although each single request can be handled in a small fraction of a second, it is even possible to restrict the processing time for each query. As guided visibility sampling finds most of the visible objects within the early parts of the computation, any restriction will only affect a small portion of the overall result. Thus even when the service time is limited the most important visible objects will be found by our algorithm.

5 RESULTS

We implemented our server to automatically adjust its quality of service based on its load. Whenever its service queue is filling up, it is gradually reducing the processing time per query so that it can empty the queue. When the queue is empty it increases the processing time per query again. In order to evaluate the quality of service, we determined the percentage of visible triangles found (when compared to the total number of visible triangles) as a function of the processing time per service request. We performed this test for 100 000 service requests on current PC hardware and plotted the result. The data set that was used for the test represented the city of St. Pölten. Figure 2 shows the results of this evaluation. Clearly, the algorithm finds more visible triangles the longer the processing time per request, and the correct result is only available asymptotically. However, after only about 60 milliseconds, already 90% of all visible triangles are found, and after 150 milliseconds, 95% of all visible triangles are found. Additionally, the triangles are found with a probability proporitonal to their apparent size from the view point, so even after only a few milliseconds the triangles that are found to be visible cover nearly all of the visible objects. Note also, that within the service application a typical object with an associated service, e.g. a house in the city, consists of more than one, typically at least 10 triangles, and if only one of these triangles is found, the location based services associated with this object can be offered.

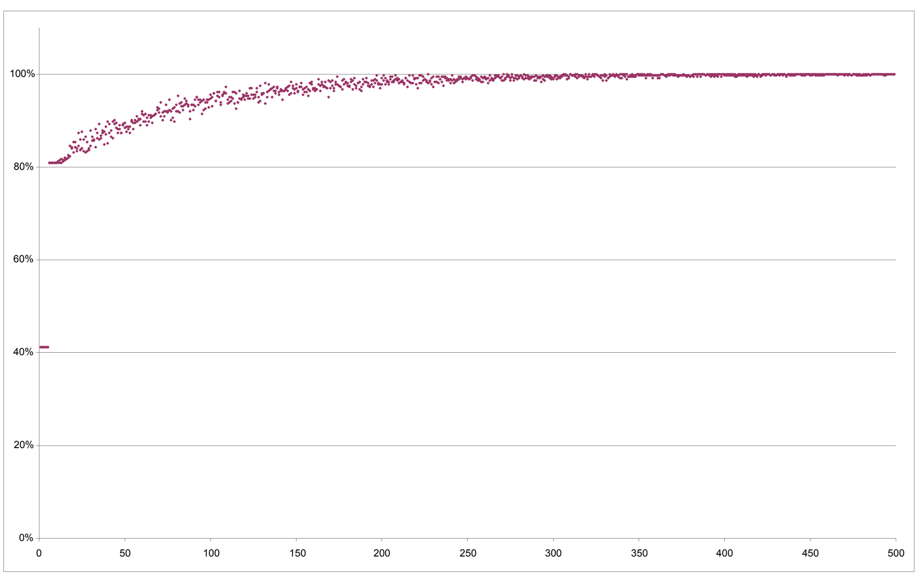

Figure 3: Percent of all visible Triangles found versus time in milliseconds. Although the correct result is only available asymptotically, after only 150 milliseconds 95% of all visible triangles are returned. Note also that even after only 5 milliseconds, most of the visually important triangles have been found, see Figure 8 for more details.

In order to investigate the performance further, we examined a few typical queries. An example of such a query can be seen in figure 4, which shows the map of a city with the marked location of a typical query. All visible triangles are drawn in green, all invisible triangles are drawn in red. As the actual number of visible triangles is a very small portion of all triangles in the database only a tiny fraction of the drawn map is marked in green. More detailed views of the same situation are shown in figure 5 and 6.

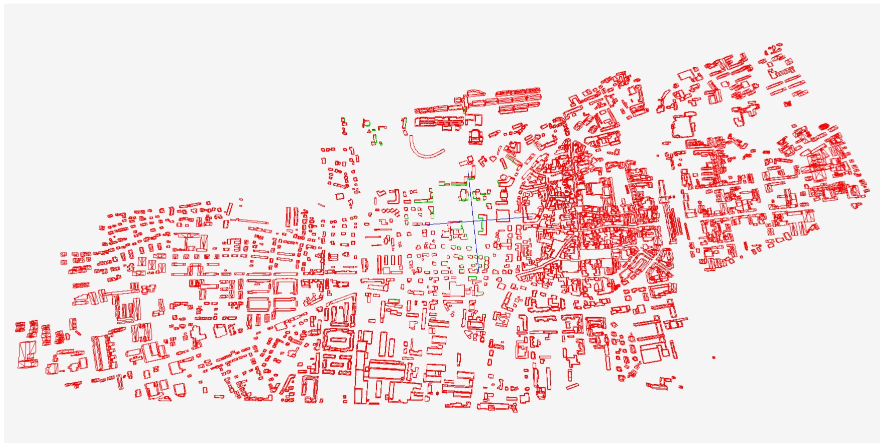

Figure 4: Map of a city with a marked location based service query point and the query result of all triangles found to be visible drawn in green.

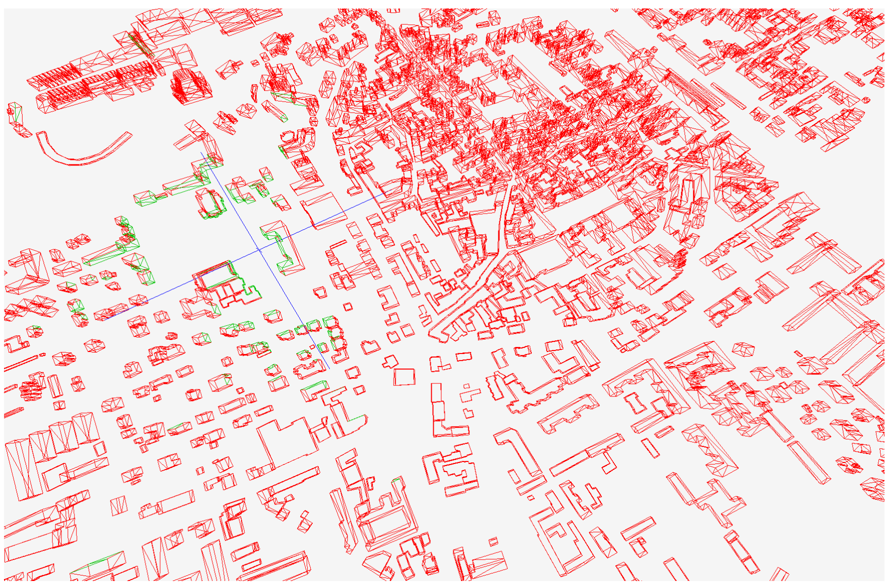

Figure 5: Enlarged view of the map in figure 4.

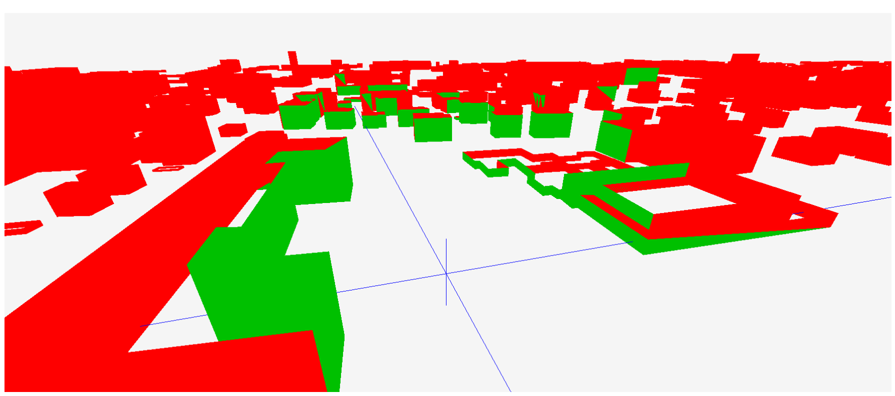

Figure 6: Solid rendering of the query result.

Figures 7 and 8 show the visibility query result as seen from the query point after asymptotic convergence and after 5 milliseconds. Obviously an exact visibility solution requires that all visible triangles have been identified (or drawn in green color) and this is the asymptotically converged result in figure 7. But figure 8 shows, that after a processing time of only 5 milliseconds, the overwhelming majority of visible triangles have been identified, and moreover for each building (i.e. object) that is visible at least one visible triangle has been found. Thus in this case, any object based visibility service will deliver the correct result after only 5 milliseconds. We therefore estimate, that the chance of missing a visible object approaches zero after only a few tens of milliseconds.

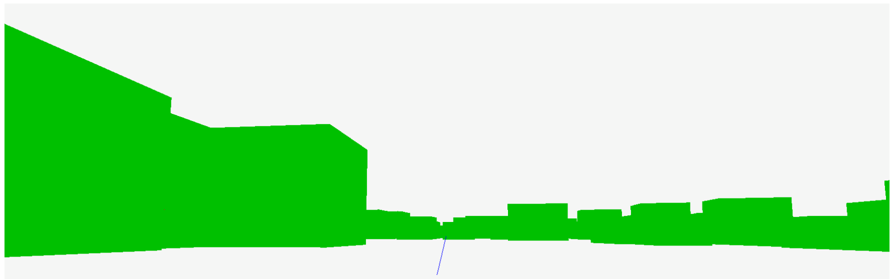

Figure 7: Perfect service response of a visibility query, as seen from the query point: all visible triangles are marked in green. Our method returns this result only asymptotically.

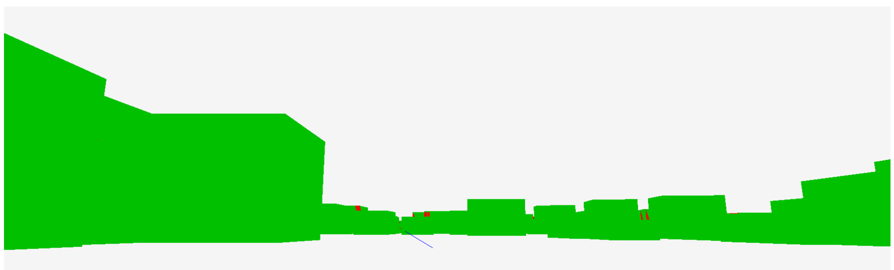

Figure 8: Service response **after only 5 milliseconds** of processing time as seen from the query point: only a very small number of the visual important visible triangles have not been marked as visible (e.g. appear red), but all service relevant objects have been identified.

6 CONCLUSION AND FUTURE WORK

We have demonstrated a viable solution for computing visibility information that is useable in location based services. Due to the high performance of the method, typical visibility queries can be serviced in a few tens of milliseconds on simple PC hardware. The method has been shown to be scaleable in its service quality, and easily parallelizable for arbitrary service volume. The visibility information that is generated can be used to refine existing services in order to offer visibility-facilitated mobile interaction metaphors such as the Geo-Pointer. A possible improvement of the algorithm for this type of service can be achieved by using the information about the association of triangles to objects to avoid sampling triangles that belong to objects that have already be found to be visible. At a conservative estimate this improvement will speed up the algorithm by another factor of 2. In this cooperation between the ftw Research Center and the VRVis Research Center which are both partly funded by the K+ program, we plan to follow up on this research by actually implementing some useful sample services that are based on visibility information.

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