# Beyond Position – Spatial Context for Mobile Information Retrieval Systems

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***Abstract*— Within context-aware mobile applications, location information usually plays a major role for information selection and adaptivity. In this paper, we explore the geospatial dimension between simple position-aware and fully context-aware information systems by examining in-depth the features of spatial context beyond mere position. We describe how these features can be used to create spatial queries in a mobile information retrieval system and further discuss the influence of spatial context to select and adapt the query results and its relation to mobile user's information needs.**

## I. Introduction

Spatial information retrieval and mobile information systems are driving factors behind most mobile applications. Since a major information need of mobile users is that for location-related, local information, many mobile applications provide information services to the mobile user depending on the current location. These range from simple you-are-here maps showing the current location over location-based multimedia applications [1], local search [2], driver information systems [3], or hiking guides for pedestrian users [4] to mobile GIS solutions. These systems use some of the user's current context to ease user interaction and the formulation of queries to the information system [5]. However, the location is only one feature of the overall user context, although it seems to remain the most important one.

The work on context-aware applications centers on the adaptation of mobile information systems to users' needs and tasks by sensing and adapting to a variety of user situations and contexts. The context can comprise a wide range of features necessary for the adaptation that characterize the situation of the user, the device, the application, etc. [6].

An area that has received less attention is the usage of an extended spatial context apart from mere position for mobile information retrieval systems. While it is true that location is only one aspect of the physical environment of a user [7] there is also more spatial context than simply location. While many systems understand location only as a coordinate, we argue for a broader understanding of spatial context in mobile retrieval systems. Apart from the direct position, a wide range of other spatial information can be available to an application to more precisely tailor it to its task.

## II. Spatial Context Information

When we imagine the user of a mobile navigation system, the current location is only one of a number of spatial context features. Mobile users are by definition not fixed at only one place and their the position itself might change rather often and quickly, invariably adding a temporal aspect to the context.

With movement comes direction and speed, but only if the movement is permanent. With direction, speed, and position comes a prediction of future position. Especially for pedestrian users, movement is often not permanent or consistent [8]. A prediction can still be possible in various time scales, using extrapolation [9] or more complex methods such as probability maps [10] to determine probable future locations.

[11] describe a system that uses additional spatial sensors in the form of a compass to implement a directed geo-pointer which can be used to select spatial information sources by pointing. Other sensors used are digital compasses in combination with accelerometers to gather orientation and tilting angle as in [12] to further augment the user's context information. Finally, [13] demonstrate how to use images of the environment to gather location and direction information by using the image itself as a query.

We can then split up the location aspect of a user's context into several spatial features:

- *Position* from, e.g., navigation satellite systems such as GPS or other techniques [14];
- *viewport* of a map visualization to define the extent of the current view;
- *speed* as both average and current as a derived value;
- *heading* as a derived value or provided by, e.g., a compass to determine the direction of travel or gaze [15];
- *current time and date* as temporal aspects for the current location and trip;
- *past track* of previous locations for, e.g., range estimations or coarse prediction of future locations;
- *elapsed duration* of a trip;
- *location of the departure point* of a trip;
- *spatial environment features* such as road networks, topology etc. which help in understanding user movements in this environment.

Several features aiming at the future, gained from, e.g., a navigation system could be available, both for cars, bikers

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or pedestrians, such as the *location of destination*, *route information* as a much more precise way of estimating the future positions, possibly enhanced with corridor information; *estimate on the route and on arrival time* [16]; and some more. If such information is not available, a *historization* over multiple trips could assist to match the current trip to previous ones to improve the prediction. Such information could further be used to help deduce the type of trip, i.e. whether it is a new or a well-known route for the user.

We have to understand these characteristics of the constantly changing spatial context, and further understand the influence it can have on information needs of mobile users, Then a query can be enriched with this query context to aid a retrieval system in better understanding and addressing the user's needs.

## III. Geographic Information Retrieval

Geographic information retrieval describes the identification, augmentation, and processing of geographical information from documents to provide semantic access to geo-referencing information sources. It further concerns the access towards this processed information by appropriate query interfaces [17]. It further employs the notion of ranking, which can sort query results based upon the relevance of the resulting documents to the query.

Within common information retrieval, as also employed by most Web search engines, the relevance is calculated by the textual or keyword similarity of the query to a document in the document base. Special index structures are established to efficiently retrieve the result documents [18]. For the geographic aspect, spatial index structures also provide spatial indexes and allow the calculation of spatial relevance [19], [20] by spatial features in both query and documents. Then, the relevance of each document and therefore the query results are computed by its relevance of the content and spatial features given the respective components of the query:

$$Relevance(q, doc) = Rel_{Content}(q_{content}, doc_{content}) \otimes Rel_{Spatial}(q_{spatial}, doc_{spatial})$$

Similarity then can not only be based on textual content similarity, but also on similarity on spatial features. Parameterizations of the system include first, a weighting of the components and their combination depending on the application need and second, the definition of the relevance functions based on containment, overlap, nearness etc. as outlined further below [20]. Location is understood as a geographical point or an extent in the real world or a named geographical place that describes the position of the user, an artefact or natural objects.

Following the early work on geographic information retrieval [21], we discuss several types of spatial queries, shown in Figure 2:

- *Point query* select results at a specific coordinate (a). This rather applies to an underlying continuum of data such as weather measurements, but not discrete items. For point-based data, usually containment or vicinity queries are necessary.

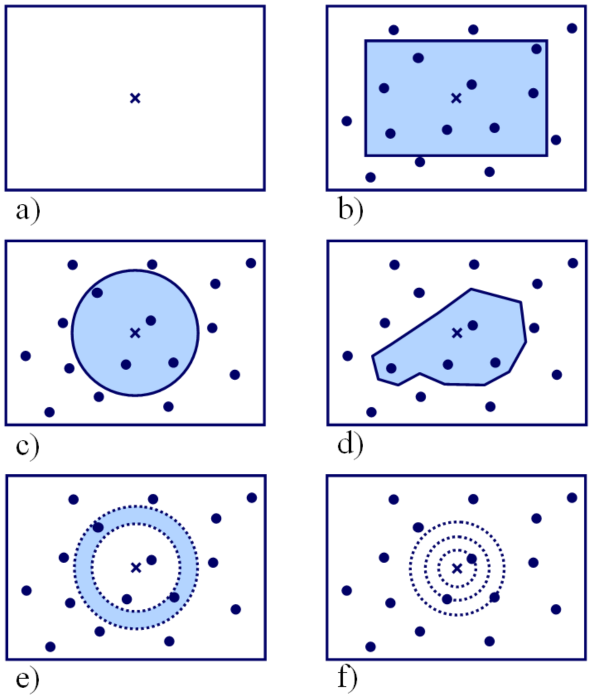


Fig. 1. Types of spatial queries based on position

- *Matching Point-in-polygon queries* apply this concept to area-based data as a form of containment, asking what items with a polygonal extent cover a certain coordinate for questions such as "what orthophotos cover this spot".
- *Region queries* select items inside a given polygonal region, with the most commonly used a bounding box (b), a bounding circle (c) or a polygon (d).
- *Distance and buffer zone queries* select items in a certain relational distance to a given structure, usually used as a vicinity search (e). They can further be used as a vicinity activation for active information provision [22], [4].
- *First-N or k-nearest-neighbors* [23] are a refinement of the distance query in that they select by distance. However, they do not select everything within a given distance, but only the first k items in order of increasing distance (f).
- *Path queries* select paths from a network structure based on constraints such as fastest route and other constraints.
- *Multimedia queries* are those that combine multiple sources to resolve a query and might combine multiple of the other types.

As a classification of mobile queries, understood as queries issued from a mobile device, [24] defines three types:

- *non location related queries* for information without a location aspect, similar to usual search engines,
- *location aware queries* for information related to a certain location. These can be absolute queries with an absolute location reference in the form of "castle near Hanover" or relative queries which can be more broad and describe

relations such as ”camp site near river” which might again anchored to a region and are used to express co-location proximity, and
- *location dependent queries* or *location-based spatial queries* [25] for information relative to the current location of the user, such as ”what is here?” or ”where is the next restaurant? (from my current location)”. Only this query type is dependent upon and utilizes the current user location which is understood as the center of the area of interest and can usually be determined automatically.

We further denote *spatio-temporal queries* as those combining both spatial and temporal aspects of the data and *continuous queries* as repeating queries over time, including user motion. This is similar to work in moving objects databases (cf. [26]). This is for example used in the approach of so-called window queries. For repeating queries, an estimate on position and speed give the predicted position and can be used to minimize the amount of queries that has to be issued to retrieve results for the currently shown map display [9]. The paper also explains the theoretical and technical background for efficient retrieval by using efficient spatial indexing and access structures and matching query algorithms. Similarly, distance queries can be defined, e.g., a moving k-nearest neighbor query [27] which continually updates the list of nearest matching items. [28] describe an efficient method for processing time-parameterized spatial queries. They return result items along with their temporal validity, given a query moving with a known speed and direction. Similarly, projected locations are a prerequisite for hoarding [10] as a form of query where items are proactively cached under assumptions of future movement.

For selection of result items, spatial filters (cf. [29], [30]) are defined to determine the information relevant to a user. These filters rely on the position of the user, but do not take further spatial context into account.

- *Spatial proximity* defines distance metrics on simple euclidian distance,
- *Temporal proximity* defines distance by travel time, depending on the mode of transport,
- *Prediction* of likely future locations (as a density function), and
- *Visibility* performs a viewshed analysis on the user’s current location and determines by topology or buildup information the visibility of certain areas.
- *Field of view* is a filter to only select information directly in front of a user which considers additional heading information.
- *Viewport* filters are defined by map-based applications that show a user a certain part of the environment as a region query. The information presentation can use the usual rectangle bounding boxes, use 3D Bird’s eye views that lead to trapezoid polygon filters, or might use other transformations such as distance contractions or map projections.

## IV. Spatial-Context Queries

The extended spatial context of a user, especially route information, unlocks new types of queries that can build upon these features and allow to partly define user interests dependent on them. Apart from the common ”Where am I?” types of query, we can further define questions such as ”Where am I heading?” or ”Where will I be? And when?”. This focuses more on a context with a purposeful directed movement such as an automobile trip and not just an exploration of the surroundings.

We use the simple and well-exercised example of the search for gas stations in a car to demonstrate some ideas, since we can gain valuable insights from its discussion under the perspective of spatial context. Commonly, the scenario serves as an example for context-aware systems where the car senses its tank running low and starts displaying gas stations to the driver along with the alerts. Or maybe it even starts showing the stations before an actual alert would be issued. A common solution would be simply to start populating the current map with gas stations from the POI database and let the driver sort them out.

We can of course exploit the excellent visual and spatial cognitive aspects of human users and let them work out for themselves the nearest (dependent on metric) station, but if we consider the cognitive load and imagine to return rather precise answers than an unsorted list of results we need to understand the metrics of users and their expectations and then apply them to the data.

The question then becomes not to show all gas stations, but those reachable and preferably the nearest. We could define reachability by the left fuel range of the car and extend it with additional metrics [31]. The definition of nearest cannot be that of euclidean distance, since the driver is already committed to a driving direction. So unless the gas is running extremely low, the best choice would be those gas stations that would come up on the chosen route naturally, i.e., those with the least driving distance within the direction currently travelled. For this, we assume a destination of the trip and an established route. The distance metric is defined as follows. The distance to a point is the detour it would take from the established route, If several items lie directly on the route, preference would be given to those next on the route, i.e., the detour metric is adjusted by a distance, giving, for a route, a *directed distance*. In this case, we would gain a best-N query, having refined the metrics to best suit the current task.

### A. Spatial Filter

Using the spatial context features described before allows for improved spatial query filters. Focusing first on available *route* information, we arrive at a set of extended filters as shown in Figure 2.

Using the proximity search, we first define three variants. One is the *search at departure* (a) to search around the start of the route which adds nothing new. Second is *search on route* (b) and third, we can define a *search at destination* (c) to search for items at the destination of a route which can

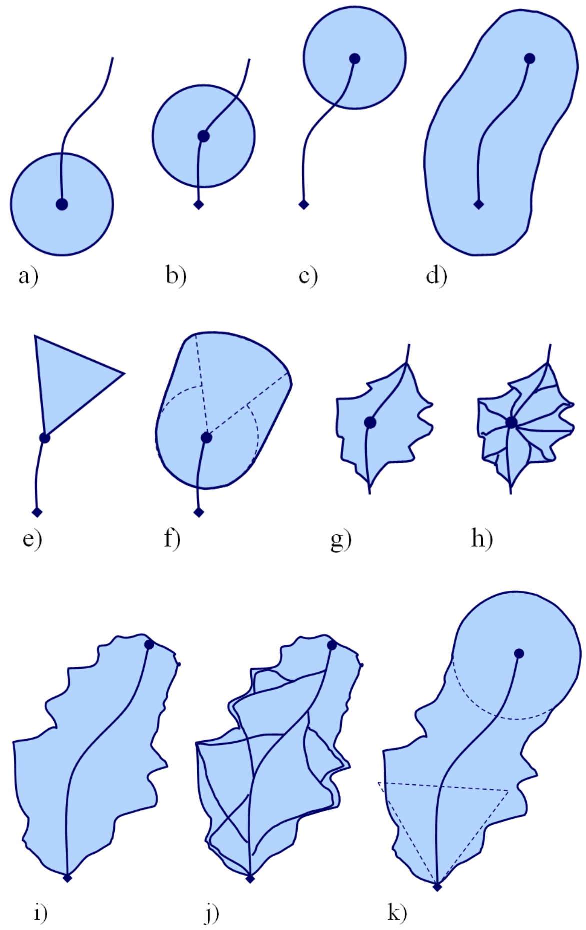


Fig. 2. Spatial filters for mobile users depending upon area of interest

be used to query hotels, restaurants or similar that would be of use when the user arrives. A *search along a route* defines an equidistant corridor around the route (d) and is basically the sum of all proximity searches (b) while moving along the route and can be used to select places that would be encountered during the trip. Furthermore, such a selection allows for proactive information provision [32]. Since users travelling in one direction usually do not want to turn, we define a *search along direction* (e) similar to the *prediction* filter with a directed distance metric which primarily shows items in the direction of travel. Combined with the route and the proximity filter (f), it would give preference to items ahead of the user but also showing places that were just passed.

Similar to the temporal proximity filter (g) that defines the distance from a point by travel time on a road network (h), we propose a *detour minimization* (i) as a query with a detour where we again take the route information into account. The distance metric would be defined by the additional effort it takes for a route to include a point as a stopover. This is not the direct travel distance from the route as would be achieved by repeatedly applying a road network distance (h) on all points of the route. Instead, this is a filter that relies on full route information available. We would include such items that are reachable within a certain threshold by a detour. This area would be defined not by direct travel distance, but by those points that are part of a detour route with a certain amount of additional travel time, defining a route distance based on road connectivity as defined by all possible routes within a certain distance, thus minimizing necessary detour to reach those points (j with only selected routes shown). This filter would calculate the overall distance for a new route from the current position via the stopover to the destination. This defines the expected detour of a user in a more natural way while still moving towards the destination.

We can identify the presented different query types and distance metrics as primitives. A combined spatial footprint for queries can be built (k) depending on the application scenario and on the available data as to route, speed, range and time.

### B. Area Selection and Refinement

Additional information in navigation systems usually can be selected by the user, but is then displayed for the whole visible map, independent of zoom or direction. Thus mostly, the information displayed on the map is the same for the whole map view, regardless of current heading. One way where this is resolved automatically is a bird's eye view which only displays the map and following the information in the current direction of travel. These examples show that sometimes not necessarily the selection, but the presentation of information is a crucial factor in a mobile information system. In an automobile, for example, a speed-based zoom factor may be appropriate while for pedestrian users the density and granularity could be considered more prominent to achieve a clear and concise, yet comprehensive overview.

There are situations where no reliable prediction about future movement can be made such as a pedestrian user window-shopping in a small urban area. These cases would require a fallback to proximity or map view queries. For other scenarios such as a hiking guide application, the display of points of interest along the route is important, but also the display of further distanced items to maybe motivate a detour or a more explorative hike. The map scale also has account for achievable positioning accuracy and speed and direction uncertainty, so that the scale of a map, the retrieved information, and the speed and mode of movement have to be considered for proper presentation. Techniques such as Halo or Wedge [33] may be used to still hint at important off-screen locations without having to leave the current scale factor of the view.

Within a car environment, initial systems already use eye tracking to determine the current focus of a driver and detect sleepiness or area of attention. Using such a system, one could combine the spatial context of the car with the spatial context of the driver or other passengers to be able to answer questions such as “What is that landmark over there?” by combining the different frames of reference [34] and select information along the driver's gaze. Conversely, directional information can also be relayed to the user by several indicators within the car [35]

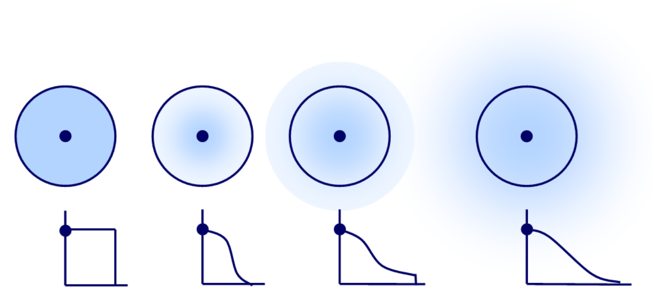

Fig. 3. Vicinity query with relevance ranking function

without the need for a map display. This is similar to landmark navigation where distinctive features of the environment are used as navigational hints according to the direction of the user.

### C. Spatial Ranking

Another way of looking at the filter footprints is as a density function. Instead of a binary exclusion filter, the distance metrics can be used to define a gradual distance-based relevance value. In combination with a ranking from the non-spatial features of the underlying data with respect to a query, items can be ranked by a combined spatial and textual ranking and be displayed accordingly. Thus, especially relevant items at a further distance could still be included when nearer items are not as relevant.

The combination of the various filters can be used to influence the ranking. The selection of various filters already defines a preference of certain spatial data, the weighted combination can further aid in showing more relevant items to the user. Different ranking functions can provide different meanings for nearness and capture varying degrees of matching between query footprint and data [36]. Figure 3 shows a simple exemplary distance ranking for a proximity search. The ranking can be used for a dynamic cutoff of results, simulating a region filter (a) or only ranking within the filter area (b). An extent about the filter area is possible to include farther away relevant results, with a dynamic distance-metric falling from the filter area to define a gradual falloff of spatial relevance which is cut off for limited lookahead (c) or an exponential decay (d). Combined with the content relevance, this allows highly relevant items further away to still be considered relevant to a query. In situations where the mobile user only has a limited attention to spare for the search results, only a selection of the most relevant results would be shown. The relevance metric can be used to influence this selection to more accurately capture the user's intention and construct a best-N query.

The actual definition of distance can be dependent on both user and task [37] and further change with varying magnitudes as user's perception and concepts of nearness can change by task or distance. As we showed earlier, nearness can also be used in the sense of directional distance. User interests may also depend on the current spatial context and – within certain bounds – be used to automatically construct a query. In certain scenarios, only items in front of the user might be interesting while points of interest behind the user should only still be shown within a very short distance. Since users might be interested in places they just passed, the requirement may also be a vicinity around the user combined with prediction query. The mode of interaction, whether searching or exploring, might further influence the ranking. Finally, the ranking can also be driven by the data itself. Certain classes of content queries have associated implicit spatial context with them. A search for gas stations would rather be the next one within the detour minimization while a search for cinemas or similar entertainment might hint that uses mean places at their destination.

With these spatial ranking functions integrated into the query engine of a search engine, query formulation could be eased by the automatic integration of the relevant spatial context features and the respective spatial filters. Then the user context can be more easily matched with available data to retrieve more relevant results. An example is shown in Figure 4. A driver is approaching from the south along the blue route to a destination in the city. The light blue area indicates a spatial filter corresponding to the route and its destination. It is drawn along the route due to the underlying road network, but expands in the vicinity of the destination to encompass large parts of the destination city. Still, the spatial ranking mainly chooses those results near to route and destination which are shown in a brighter orange. More distanced and less relevant items are shown with less opacity. In a final user interface, the map view might select different areas or zoom factors. The presentation of result items should then also consider the current view and the amount of relevant information on it.

## V. Conclusion

Searching for spatial information out of a spatial context opens many possibilities for information systems. We have proposed a broader understanding of user's spatial context and have shown how it could affect and improve spatial queries in mobile information systems. We have discussed the characteristics of spatial queries in a mobile context, and detailed selected spatial filters and relevance ranking methods. Using route-based and temporal distance metrics, we have shown how they can in combination lead to queries that can improve the support for user's spatial information needs and enhance the user's information horizon.

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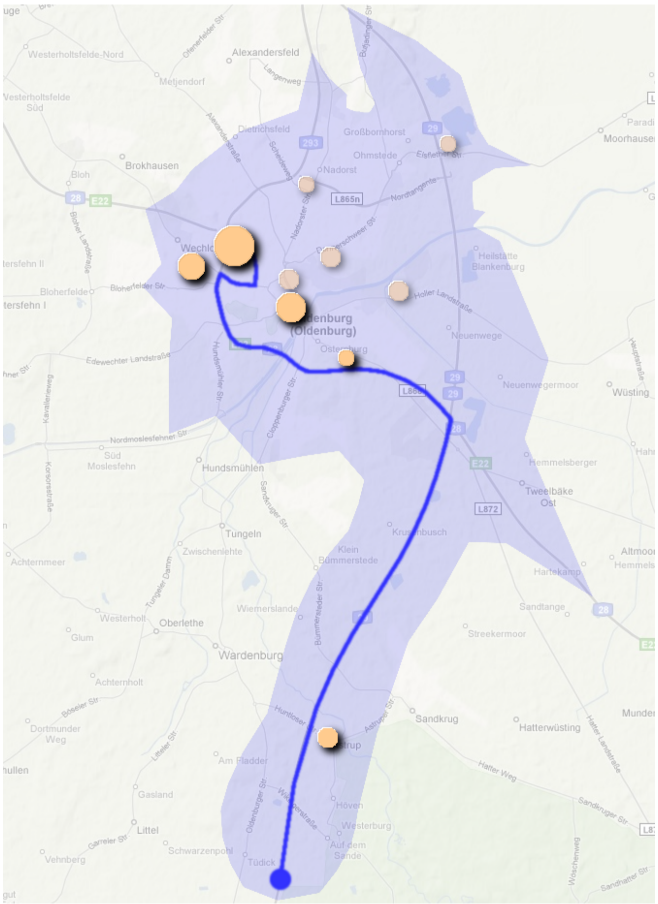


Fig. 4. Exemple query with spatially ranked result set

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