Beyond Location Based – The Spatially Aware Mobile Phone

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Abstract. An increasing number of mobile phones feature embedded sensors such as GPS receivers, digital compasses or accelerometer-based tilt sensors. In this paper, we present an application framework for building spatially aware mobile applications – applications that visualize, process or exchange geo-spatial information – on mobile phones equipped with such sensors. The core component of the framework is a novel, platform-independent XML data exchange format that describes the geographic vicinity of the mobile device. The format enables a variety of new mobile interaction styles and user interface types – from traditional text-based local search and information interfaces to innovative real-time user interfaces like geo-pointers and smart compasses.

Keywords: Spatial information appliances, personal spatial assistants, location based services, geo-spatial information.

1. INTRODUCTION

Almost all information that exists is related to a certain place, area, or location: historical data may be related to buildings or streets; a timetable is related to a bus stop or train station; most content available on the World Wide Web is related to a place or region. In essence, information is almost always – at least to a certain extent – geographical. Web-based mapping applications like Google Maps, Yahoo Maps or Microsoft Windows Live Local, as well as geo browsing applications like Google Earth or NASA World Wind have recently raised the public awareness for the usefulness and the educational, as well as the entertainment value of geographical information.

Even though many mobile applications today offer comparable functionality – such as location-based search and mapping – few have succeeded in conveying a user experience nearly as rich and dynamic as their desktop counterparts. Interestingly, novel and compelling concepts for interacting with geo-spatial information on mobile devices have already been suggested years ago. Based on the technology of Geographic Information Systems, Egenhofer [1] predicted *Spatial Information Appliances* – portable tools for professional users and a public audience alike, relying on fundamentally different interaction metaphors: *Smart Compasses* that point users into the direction of certain points of interest, *Smart Horizons* that allow users to look beyond their real-world field of view or *Geo-Wands* – intelligent geographic pointers that allow users to identify geographic objects by pointing towards them.

Our work is motivated by the vision that mobile phones will soon serve as generic hard- and software platforms for a variety of spatial information appliances. The device features necessary to realize this vision are already becoming available: Embedded GPS receivers, digital compasses and accelerometer-based tilt sensors are found in an increasing number of handsets and can be expected to be even more widespread in the near future. What is still missing today is a common application framework: a toolkit that leverages mobile geo-spatial applications by enabling developers to experiment with new interaction metaphors and to prototype user interfaces that offer experiences beyond what is offered by today's applications.

In this paper, we present such a framework, which we developed based on requirements derived from a series of Wizard-of-Oz user tests [3]. The paper is structured as follows: Section 2 discusses related work and explains our concept of spatial awareness. Section 3 lists the technical requirements we derived from the user tests. Section 4 describes our proposed data exchange format that enables rapid prototyping and development of spatially aware mobile applications. Section 5 presents our framework implementation. Section 6 concludes with an outlook on future work.

2. THE SPATIALLY AWARE DEVICE

Several research projects have investigated mobile interaction with geo-spatial information: GeoNotes [2], Nexus [6], Urban Tapestries [4] or Riot [9], for example, are based on the common idea of attaching digital information to real-world places like a virtual post-it note or graffiti. A handheld device equipped with a location sensor (e.g. a GPS receiver) allows users to consume this location-based information or to actively participate as provider of information. Other projects have experimented with additional sensors beyond GPS: Wasinger et al, for example, presented a PDA-based application that uses GPS and a digital compass to realize Geo-Wand-like two-dimensional pointing functionality [12]. Similar ideas were applied by Mitchell et al [5] in the context of a mobile multiplayer game.

The common idea of creating a digital information space, interconnecting it with the real world through geographical references and using handheld devices as bridges between the real and the virtual space is consistent with our understanding of the spatial information appliance. However, we argue that the concept described by Egenhofer goes further: A spatial information appliance is not just a collection of sensors that measure basic geographical properties, which subsequently serve as search parameters in a spatial database query. Rather, we see spatial information appliances as smart, spatially aware personal geographical assistants: devices which themselves possess locally stored knowledge about the environment around them – its structure, its geometry and its visual appearance – and their own relative position and situation therein. This explicit knowledge enables them to support users in navigation and orientation tasks in real-time and to offer intuitive and compelling user experiences beyond what is offered by today's location-based services.

3. REQUIREMENTS

Embedded sensors are obviously one essential precondition for enabling spatially-aware applications. A second fundamental prerequisite is a data exchange format that captures and encodes geographical knowledge about the environment. In order to support more usable interfaces to geo-spatial information around the user, the format must model the environment in accordance with the user's perception of space. It must also take into account the special characteristics of mobile devices, i.e. it must be suitable for processing on computationally limited hardware and it must support a wide variety of different user interface styles, since mobile devices differ in terms of screen size, form factor and feature set (e.g. no sensors vs. embedded GPS and compass).

In an informal user study, we have tested and compared mock-up user interfaces for different types of spatial information appliances [3]. The results of the study revealed the following three important findings:

- While the traditional map representation still ranked among the most popular forms of user interfaces, ego-centric representations, such as the Geo-Wand or simplistic textual lists of nearby points of interest, were also rated as highly usable and intuitive.
- Users appreciated an explicit indication about the visibility of nearby features and points of interest.
- Orientation-awareness in three dimensions, rather than only in two, was appreciated. This is in accordance with findings presented e.g. by Rakkolainen and Vainio [8].

Within our work, we derived the following five technical requirements for a geographical data exchange format for spatial information appliances: *generality*, *user-centeredness*, *cross-platform scalability*, *simplicity* and *compactness*.

*Generality***.** The data format should be application-agnostic. Geographic XML formats such as the Geography Markup Language (GML [7]) are based on a Cartesian map metaphor. As our user tests have shown, intuitive spatially aware mobile applications can also be based on distinctively different interaction metaphors. While it is probably not entirely possible to define a data format without a particular user interface scenario in mind, the format should at least allow for a variety of possible solutions beyond maps.

User-centeredness. The metaphors used by the format should conform to the way users perceive their environment. As mentioned, three-dimensional representation has been identified as relevant in this context [8]. A closely related concept that has been found to be of importance in our user studies, and which is lacking an explicit representation in traditional maps or vector geometry formats is *visibility*: We therefore argue that knowledge of the visibility of geographic features from a certain point of view is crucial for enabling spatially aware applications. Computing the visibility from a 3D geometry model is a computationally highly intensive task and difficult to realize on mobile devices with low processing power. The format should therefore contain explicit information about the visibility of features or at least pre-process the data so that visibility computation is simplified.

Fig. 1. Possible LVis GUI concepts.

Cross-platform scalability. On the one hand, the data format should be explicit: Client devices with low computational power and limited graphical output capabilities should be able produce immediate output without the need for complex arithmetic calculations, e.g. by transforming it to a meaningful text. On the other hand, the format should be rich and detailed: High-end devices should be able to create a more compelling, richer user experience at the expense of higher processing overhead. In particular, the format should carry true structural information about the environment, so that the client can react to data from embedded sensors in real-time, without the need to re-query the application server. For example, the client might be able to re-compute distances, headings or the visibility of certain points of interest locally, as the user moves through the environment.

In order to illustrate the range of scenarios the data format might be required to support, Figure 1 shows concept illustrations of four user interface designs we have tested in our user study. Each design assumes different device capabilities and sensor equipment: In the most basic case (shown top left) only the location of the device is known and no particular computational power is available. In this case, only basic textual output is produced. The upper right image shows a basic *Smart Compass* interface that indicates nearby points of interest by arrows on an ego-centric compass rose. This or a similar scenario might be realized on a device with built-in compass and GPS. The lower left image denotes the principle of the *Geo-Wand*, which might be realized on a device equipped with differential GPS and compass [10]. Finally, the lower right image shows a concept for a more sophisticated user interface: Using a combination of differential GPS, compass and a 2-axis tilt sensor, a simplified augmented reality (AR) user interface might be envisioned, where labels are superimposed over the phone's live camera image to indicate points of interest on the screen.

Simplicity. The concepts and metaphors used by the format to model the environment should be simple and easy to understand. This is predominantly a technical requirement, since it reduces the entry barrier for application developers previously not involved with geographic applications, or who have little expertise in geographical or graphical vector formats like SVG.

Compactness. Last but not least, the format should be as compact as possible, so that airtime use and response time are minimized.

In the following section, we present the *Local Visibility Model – LVis* in short (pronounced “Elvis”) – our proposed XML data format for spatially aware mobile applications, which satisfies the five requirements listed above.

4. LOCAL VISIBILITY MODEL

The Local Visibility Model represents a simplified, ego-centric geometric model of the local environment around a geographic position. Unlike a typical map, the LVis describes the structure of the environment in three dimensions, rather than only in two. Unlike other geographic encoding formats, it also contains implicit information about the visibility of geographic features. Since the LVis is XML-based and relies on standard units and measurements (i.e. meters and decimal degrees) meaningful textual output can be produced by simply styling the XML accordingly. Due to the fact that the LVis uses a polar coordinate notation, user interfaces that would normally require transformations from Cartesian to polar coordinate space (such as Smart Compasses or Geo-Wands) can be realized with considerably reduced effort.

4.1 LVis XML Syntax

The LVis distinguishes two types of spatial entities: *content* and *geometry*. The *content* of the LVis is formed by a collection of geographic markers. Each marker indicates an arbitrary location of interest and describes it with application-specific meta-data. Compared to a map, the function of a marker corresponds to that of an icon drawn on the map, e.g. to indicate a certain landmark. Since the LVis uses polar coordinates, each marker location is defined by its distance (in meters) and its heading and elevation angle (in decimal degrees) relative to the LVis center position. Only markers that are visible from the LVis center position are contained in the LVis.

The LVis *geometry* model describes the geometry of geographic features in the area around the LVis center. Our design goal was to keep modeling concepts and data structures as simple as possible. In particular, it should be possible to derive meaningful and user-understandable textual output by simply applying a transformation to the XML code (e.g. using XSLT). This approach restricted us from relying on traditional vector geometry formats, where geometry is typically described using polygons or geometric primitives in Cartesian 2D or 3D space. These formats require complex processing to produce visual output and are not human-readable as such.

In order to satisfy the conflicting requirements of describing the surrounding environment geometry sufficiently detailed and yet in a simple format that can be interpreted with an absolute minimum of processing, we decided to model the environment based on a *billboard* metaphor: Each geographic feature, such as a building, is approximated by a flat, rectangular wall, facing towards the LVis center. In essence, the LVis geometry model can be thought of as a 360-degrees panoramic “cardboard cutout” version of the vicinity, much like a movie set where the environment is not made up of solid buildings, but instead of building facades. Each billboard is defined by the distance, the heading and elevation angle of its center point relative to the LVis center, its width and height and application-specific descriptive meta-data. A textual description of the environment (e.g. “There is an office building to the North-East in 250 meters”) can therefore be produced without complex arithmetic computations or coordinate transformations.

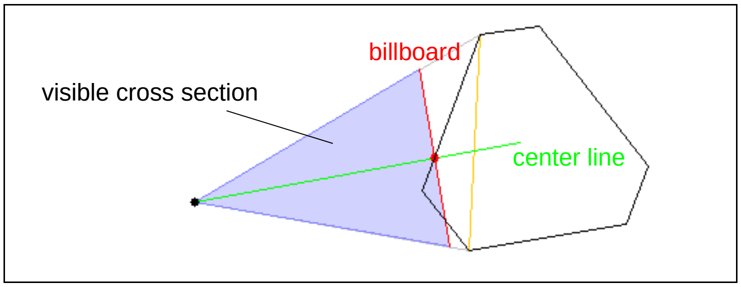

Fig. 2. LVis billboard approximation (top-down view).

Figure 2 illustrates the principle of how an LVis billboard is computed: The illustration shows a top-down view of an arbitrary building. First, the visible cross section of the building, seen from the LVis center, is determined. The billboard is computed by intersecting the cross section's center line with the building shape and computing a normal to the center line.

5. FRAMEWORK IMPLEMENTATION

Our current application framework consists of a Java library that implements the functionality needed to determine the visible content markers, as well as the billboards for fully or partially visible buildings. The framework relies on a 2.5D environment block model, i.e. each building must be represented by a 2D building footprint shape and a single height parameter per building. The library also contains GUI components for visualizing the computation results.

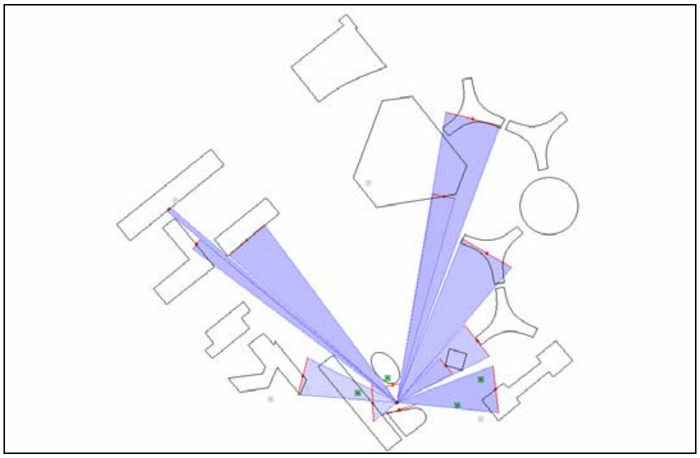

Fig. 3. LVis computation result (top down view).

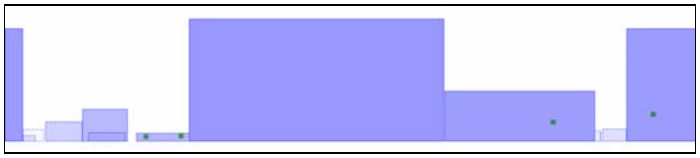

Fig. 4. LVis computation (panoramic view).

The environment model used with our trial setup consists of sample data covering an area of roughly 1x1 km around our office premises (an architecturally rather unusual business district in the North of Vienna, Austria). As content, we defined several points of interest, e.g. nearby shops, restaurants or public transport facilities. The data model is stored in a PostgreSQL/PostGIS database.

Figures 3 and 4 show the result of an example LVis computation performed by our implementation: Figure 3 shows the computed LVis in a top-down view; Figure 4 shows a 360 degrees panoramic visualization of the output. The visible content markers are shown as small dark rectangular dots. To make the billboards easier to recognize in the top-down view, a “viewing beam” extends from the LVis center to each billboard, with beams of lighter color indicating higher billboards. In the panoramic view, rectangles of lighter color represent more distant billboards.

Fig. 5. Outdoor function trials (Notebook and phone).

First function trials were carried out with the framework running locally on a Notebook, connected to a Bluetooth GPS receiver, as shown in the left image in Figure 5. Further trials were carried out with handheld test devices: Figure 5, right, shows a mobile phone (connected to the same Bluetooth GPS) with an example *Smart Compass* interface. For this trial, the framework was integrated with an open source web server, allowing the mobile device to communicate with the framework using over-the-air HTTP requests.

6. FUTURE WORK

The focus of our current and upcoming activities lies on application prototyping and further user testing. Since mobile devices with a full set of sensors are not yet readily available on the market, we are also working on a custom sensor hardware module for our experiments. The module will combine differential GPS, a compass and a 2-axis tilt sensor in a self-contained Bluetooth unit.

Based on the sensor hardware, we plan to realize several applications scenarios and evaluate them in a series of user tests. The scenarios include those depicted in Figure 1 and a scenario where users actively participate in generating location-based information, i.e. where the LVis is locally manipulated and re-submitted to the application server. While we have so far investigated the theoretical performance and accuracy that can be achieved by our system [10], the tests will reveal the practical limits that occur under real world conditions.

Also, the tests will further clarify whether the modeling concepts used in the LVis are effective in supporting more usable mobile interfaces to geo-spatial information. Insights in how people use our prototype applications are expected to influence and guide the further evolution of the LVis XML format. Modeling of hidden features and an assessment of the billboard metaphor's suitability for non-urban environment are among the topics that will be addressed:

Hidden features. In its current version, the LVis does not contain information about geographical features that are not directly visible from the user's current position. As has been found in our user trials, it is desirable to have this information available for many application scenarios. We expect the user tests to deliver valuable insights into how fully and partially hidden features can be efficiently modeled in accordance with users' perception of space.

Non-urban terrain. While the billboard metaphor has so far proven useful for modeling urban environment, it is unclear whether the same metaphor can also applied to geographic features in rural terrain. Tests will show whether it is reasonable to model topographical features like mountains or hills using billboards, or whether an alternative model should be applied.

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