An Abstract Location Model for Mobile Games

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Abstract: A key task when building location-based experiences, such as mobile games, is to model locations and define how they are going to be triggered by the underlying technology. This is usually done by using the wireless sensing technology that is available on the desired target device, e.g. GPS, Wi-Fi, Cell ID, Infrared, Bluetooth, NFC, etc. – or a combination of those. This paper argues that it is beneficial to employ a location model that supports deriving locations from different positioning technologies through an abstract interface, so as to be more flexible for technical changes throughout the development phase and, with software patches becoming commonplace, also over the life-cycle of a project. This paper first elaborates on why an abstract notion of location is useful and then presents a concrete model.

1 Introduction to the Problem

When building location-based experiences, such as mobile games, it is important to understand the invisible wireless infrastructure that supports the design, as its performance will have a direct impact on the end-user experience [1]. This need for understanding is always closely related to the required positioning precision in the project at hands. Precision requirements for positioning technologies in location-based applications might vary between very high, e.g. for believable visual overlays in augmented reality applications [2], to very low, e.g. for determining a participant's approximate location based on his position in a cellular network [3]. With this variation of precision requirements between projects, there can be no universally valid positioning technology for location-based experiences that is a fit for every purpose. Rather, a suitable technology might have to be chosen for every new project.

1.1 Findings of Seminal Work

Seminal work for location-based experiences, such as the Georgia Tech Cyberguide or the Lancaster GUIDE, suggests that the precision requirements for such applications need not be seen too critical. The Cyberguide research concluded that *"absolute positioning information throughout an entire space is not so important"* and that *"it is far more useful to know what someone is looking at than to know someone's exact* *physical position and orientation"* [4]. Moreover, human factors entail that content does not necessarily need to be too closely tethered to the current location context. The requirement analysis of the Mercury project, a tour guide for historic sites in Greece, revealed that site visitors would frequently deviate from their current location context by either reviewing previously visited exhibits, planning their journeys ahead, or freely browsing the available material [5]. This view is also supported by the GUIDE project, which stated that designers of similar systems "*should be careful not to be over zealous when deciding to constrain the information or functionality provided by the system based on the current context"* [6]. Altogether, the relevant key findings of the seminal work in the context of the topic of this paper can be summarised as:

a) positioning technology does not have to be overly precise in order to effectively support a location-based experience

b) the context of the current location is often more important than absolute position coordinates

1.2 Relation to Mobile Games

In the domain of location-based mobile games we can observe similar patterns. Although some research prototypes, such as ARQuake [7], require highly precise and bespoke positioning technology, many other more market-ready mobile games maintain a much looser relationship between content and location context. Botfighters, for example, was one of the first commercial location-based games. It was a massively multiplayer online role-playing game that utilised the location-based aspect offered by mobile phones and combined them with Internet online-play. Players used the game website to design their robot game avatars and subsequently went outside on the streets with their off-the-shelf mobile phones to battle against other players' robot avatars. The game constantly scanned the virtual environment based on the player's physical position (acquired via operator-based positioning) and signalled players if their robot was near another robot, in which case those two opponents battled each other using text messages [8]. Botfighters was a commercial success in several countries. It demonstrated how a low-key mobile client with a very coarse grained location mechanism could still provide an engaging player experience by balancing lack of positioning accuracy with room for imagination.

Mogi [9], another commercial mobile game, used a similar architecture where players could play online and on the streets. Mogi was a collection game where players moved around with their mobile phones to hunt down, collect, and subsequently trade virtual items which were placed at locations all over Japan. The game used two ways of positioning: client-based cell ID and network-assisted A-GPS. As the latter was more precise, but also caused additional network charges for data-transfer, the game allowed players to freely switch between them, effectively making continuous cost/benefit decisions while playing. Mogi thus did not rely on the presence of a single positioning technology, but supported play with different levels of positioning granularity.

A study of the design process of a location-based mobile phone game called Love City, which was built at our lab in collaboration with external professional experience designers from a company called Active Ingredient, revealed that designers seek to understand location mechanisms to a degree that allows them to judge whether there would be enough locations for content in their design when using a particular location mechanism, and how the content would be triggered using that mechanism [10]. This thinking is directly related to the achievable granularity of locations over the target area, which differs between location mechanisms and also between different configurations of the same mechanism. Furthermore, such accuracy considerations need to be balanced against other project and end-user requirements.

In the case of the Love City project, user tests of a graphical smartphone prototype led to the conclusion that a change of the positioning technology from client-based (cell ID) to operator-based positioning would allow the game to be playable by a much wider audience. This triggered a major revision of the game which was ultimately played over SMS and used a subscription-based location-based service gateway for positioning. This change of location sensing technologies in the midst of the project could have potentially invalided all location mappings of in-game areas to network cells, as the location gateway was not reporting cell IDs (which were used for authoring game regions), but remapped this network internal metric back to the more common GPS-like coordinates in latitude/longitude. It was only through the production of a detailed, geo-referenced network plan, which assigned geospatial areas to measured cell IDs, that the extensive game region authoring of the smartphone prototype could be reused in the final version of Love City. Locations were then triggered by taking the incoming GPS-like coordinates from the location gateway and intersecting them with the self-constructed network plan to look up the corresponding cell IDs and their associated game regions. More details about this specific example application can be found in [11]. In essence, this developer experience of supporting different technologies through intersecting different metrics and area definitions stipulated the thinking behind the presented abstract location-model.

1.3 Motivation

This paper argues that the decision making process about the target location mechanism should initially be decoupled from technical thinking as much as possible, while still staying within the boundaries of the technically achievable. On the one hand this frees designers from constraints imposed onto them by premature technological decisions and allows them to better sketch their anticipated user experience, which is the prime concern [12]. On the other hand it is necessary to stay in close touch with the technical foundations that underpin such work, so as to be able to implement the final design on time and within budget. Hence, it is proposed to use a flexible and extensible abstract location model that supports deriving location information from a variety of different location sensors.

The proposed abstract location model differs from typical sensor fusion, e.g. as done by RADAR [13], or Place Lab [14], as it does not fuse different position readings into absolute position coordinates, but instead fuses the readings on an abstract notion of location (abstract as in the computer science sense). Section 2 provides some background on this idea, while section 3 presents the abstract location model itself.

2 Making Sense of Location

In the context of this paper, we separate the terms position and location, and argue that the terms should not be used interchangeably:

- A position specifies a point in a coordinate system and can be defined either in absolute or relative coordinates. (52.953412° latitude, -1.187508° longitude) is an example for an absolute position that is defined in the World Geodetic Coordinate System (WGS84), which is the standard for the Global Positioning System (GPS).

- A location is an opportunity to associate meaning. Locations are more humane in the sense that they are easier to grasp and talk about, but they might be ambiguous. The previously defined absolute GPS position could refer to a location called "office".

Thus, a location is a disembodied concept, whereas a position is a more tangible definition that is directly linked to its underlying metrics (e.g. GPS coordinates, GSM cell IDs, etc.). A similar distinction of related terms has previously been introduced to the computer supported cooperative work (CSCW) community by Harrison and Dourish, who distinguished between space and place [15]. They argued that people *"are located in 'space', but act in 'place'"* and that *"a place is generally a space with something added"*. This paper argues that this distinction should be used and appropriated for the design of location-based experiences. Designers of such experiences ultimately strive to provide meaningful locations to their users, i.e. they are designing for places in the sense of Harrison of Dourish.

However, with the multitude of different positioning technologies that could be used for a project, the definition of space needs to be a bit more flexible. In particular it needs to provide support for defining locations on all the different metrics that are associated with the respective technologies, e.g. absolute coordinates for GPS, cell ID for GSM, or access point MAC addresses for Wi-Fi, to name only a few. When building location-based experiences, the location is the notion that matters in the design, and the location-based content is the "something" that gets added to provide for human interaction. This situated content allows people to interact with the system and thus allows turning the disembodied concept of location into a place that (hopefully) matters to them. This idea may seem unsurprising at first sight, as *location* is already part of the term *location*-based. But it appears on second sight that many of today's location-based experiences are actually much more concerned about position (i.e. geo-space, as in GPS coordinates) than they are about location in this abstract sense.

Previous work in the field of location-based applications researched on a similar route. Hightower argued [16] that many contextual applications require such a symbolic notation as they *"want to reason about 'place' instead of or in addition to coordinates"*. The outlook of his PhD thesis [17], which presented a framework for sensor fusion that was adopted by Intel's Place Lab project, concluded that further work should be undertaken in this direction. Although the Place Lab project [14] mainly continued along the route of sensor fusion and related engineering tasks, they also devised a study about automatically learning and recognising places that people visit [18], based on traces of Wi-Fi and GSM cell ID data from mobile devices. Similarly, Ashbrook and Starner [19] presented a system that clustered traces of GPS data to automatically find *"meaningful locations"* from participants' movements in a post-event analysis, and the Reno study presented a social location sharing application that collected meaningful locations at runtime [20].

Harrison and Dourish provided a much needed separation between space and place from a sociological, or human factors, perspective, as they argued that humans appropriate their spaces to eventually turn them into places. They describe the relationship between space and place as: *"Space is the opportunity; place is the understood reality"*. The typical example in this context is the difference between a house and a home, and what these terms mean to an individual: a home is cherished place that is also a house, but not every house is a home. Dourish proposes that the evolution from space to place is something that can only be designed *for*, as it is the humans that have to trigger this transition by accepting a location as a place that matters to them. As a design principle that facilitates this transition, Dourish advocates supporting human appropriation of space, i.e. to be flexible about its structure [21] (page 91).

3 Abstract Location Model

To facilitate human appropriation of space in the design of location-based experiences, it is proposed to subdivide space into a metric level (position) and an abstract level (location). In this dualism, the abstract location is stripped from any metrics. Therefore, an abstract location is simply an empty hook which can be associated with meaning, i.e. content, definitions of regions (areas in a coordinate system), and meta-data. In theory a location is thus independent from any spatial representation[1]. In practice it is, of course, dependent on some form of embodiment to provide an opportunity for interaction and must thus be associated with both content and regions to frame the action.

	Metric Level	Abstract Level	Interactional Level
Term	**Position** (Space)	**Location** (Space)	**Place**
Example	GPS coordinates, GSM cell ID, Wi-Fi fingerprint	"House"; an empty shell; needs to be filled with meaning, i.e. content and regions in our case.	"Home"; a location with associated semantics
Usage	Define regions in space according to a particular metric	Links the metric level with the interactional level	Point of interaction with end user

Table 1: Position, Location, Place

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[1] 3D artists will find this abstraction similar to the concept of "null objects" in Softimage or "locators" in Maya

Table 1 puts the term abstract location in the context of space (as in position) and place. Attributes of locations could be definitions of regions in space, e.g. geospatial or other coordinates, content, i.e. digital media assets, or meta-information such as name, notes or tags. The advantage of this model is that the notion of location provides an abstraction of the interactional level – that is the anticipated user-experience – from any particular sensor technology that is tied to a particular metric of space. Of course, in practice, this model still requires a connection to a sensor system, but this connection is now more flexible and allows for an easy reconfiguration or extension with other technologies. At runtime, incoming position data gets processed on the metric level and subsequently triggers different locations on the abstract level.

3.1 Reproducible ID-Strings

Unique and reproducible identifiers for locations are the basis for the proposed model to work in practice. This allows for a flexible mapping of digital content to locations that can be defined using various metrics. Regardless of the chosen technology, any measured sensor data needs to be referenced by unique ID-strings to allow for database storage and unambiguous mapping. Additionally, these identifiers must also be quickly reproducible on the target mobile device from the incoming sensor data to allow for triggering of content based on the current location context. In my model, each location is identified by a unique string of text (which acts as the database primary key), and also carries an optional human readable name. A location can be associated with any number of region definitions that define the location using any metric that is suitable for the underlying technology. The current design supports the definition of location data (regions) in GPS, Wi-Fi and GSM networks. The model is easily extensible through an abstract region interface. Like locations, regions are also uniquely identified by an ID-string and have a name.

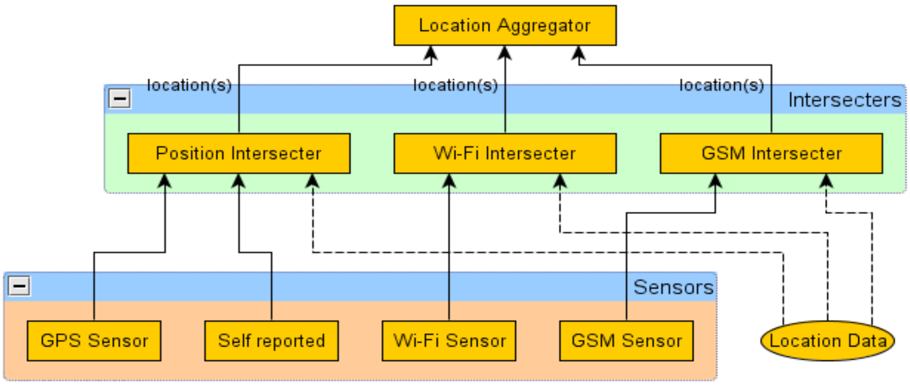

Figure 1: Abstract Location Model

The following section provides an overview of the flow of data through the abstract location model as depicted in figure 1, and section 3.3 proposes ways to define reproducible ID-Strings for different technologies.

3.2 Flow of Data through the Model

The flow of data from the device sensors, through the model to the location-based application is depicted in figure 1. The model abstracts the notion of location from the underlying sensors by introducing a layer of intersecters. These are functions that turn sensor readings into location events by intersecting the incoming sensor data with predefined location data, i.e. definitions of regions on the metric level.

Support for GPS positioning is indispensable for a general location model and the “GPS Sensor” in combination with the “Position Intersecter” provides just that. This intersecter could also be used to generate location-events based on a user self-reporting their position on an interactive map interface [22]. The “Wi-Fi Sensor” scans the wireless network and outputs a list of nearby access points and other metrics like their signal strengths. This data is then analysed by the “Wi-Fi Intersecter” which triggers a location if its corresponding trigger condition is met. Likewise, “GSM Sensor” and “GSM Intersecter” allow checking for locations that are defined based on the current cell ID.

The application developer decides which position sensors should be used by instantiating the appropriate sensor and intersecter classes, filling them with location-data, and wiring the objects together according to the model; this could also potentially take into account the user’s preferences. Because the application developer has access to the object instances, he can also directly access the raw sensor data, such as absolute GPS coordinates, if so desired.

At runtime, all location events triggered by the different intersecters are collected by the “Location Aggregator”, which is the main interface for the application. If several sensors cause their associated intersecter functions to trigger location events, then all of them are passed on to the location aggregator without any filtering. Thus, the proposed model does not make any attempt to mitigate, or hide, ambiguity problems which might arise from different sensors reporting conflicting locations; this issue is deliberately left to be dealt with in the respective application logic. The aforementioned Mercury project [5] reported that its developers employed a hierarchical ordering of sensors for Infrared, GPS, and Wi-Fi, which they ordered according to anticipated positioning accuracy and service reliability. At runtime, the system would try to obtain a user location by querying the available sensing technologies one after another. This means that if the Infrared sensor already yielded a location, no other sensor would be queried; otherwise GPS and Wi-Fi would be queried subsequently. If none of the sensors yielded a location, the user’s last known location would be retained. Such pragmatic decisions to deal with multiple position sensors will arguably be good enough for many applications, but more advanced techniques could also be implemented with this location model, if required.

3.3 Defining Location Data

This section proposes ways to define containment regions to trigger locations for a selection of currently common positioning technologies and has been written with database-storage and realtime performance on mobile devices in mind. All region definitions provide unique ID-Strings which are either directly built from the incoming sensor data (e.g. as possible with cell ID), or are the result of a matching function.

Location Data for the "Position Intersecter" supports vector- and raster-based region definitions in absolute real world coordinates (WGS84).

The vector-based region definition uses a few basic bounding shapes: 2D polygon, circle, box and sphere. The polygon defines a closed area on the surface of the earth in latitude and longitude coordinates. For polygons and circles, altitude is disregarded as it is assumed that participants will usually dwell on the earth's surface, but the box or sphere shapes might be used for those cases where elevation data is meaningful. In either case, a vector-based location will be triggered if the tested geospatial coordinate is contained within the associated vector shape.

The raster-based region definitions are two-dimensional look-up tables encoded in geo-referenced bitmap images. This allows defining locations by colouring areas in images, as proposed by Flintham [23]. Each location has an associated colour-value which can be freely used in the image. The following steps are then needed to trigger a raster-based location:

1) test if the coordinate intersects the area of the geo-coded raster image

2) find out which pixel in the image it intersects and get its colour value

3) use the colour value to look up which location it belongs to

Location Data for the "Wi-Fi Intersecter" is non-geospatial, which means that its measured values do not inherently contain a notion of the geographic area to which they are thought to relate – but they can still be representative for that area. Regions in Wi-Fi network space have to be defined using the measurements that are available from "Wi-Fi Sensor", namely: BSSID (the unique MAC address of the access point), SSID (the non-unique name of the access point), RSSI (the received signal strength indication), encryption information (off, WEP, WPA, etc.), mode of the discovered Wi-Fi device (infrastructure, ad-hoc), and possibly others.

A very basic location definition would apply a 1:1 mapping between measured characteristics and locations, e.g. a location could be triggered whenever a specific BSSID is discovered. However, due to the fluctuating nature of the Wi-Fi environment, where access points might disappear at any time, this might not be a very stable definition. Location data for the "Wi-Fi Intersecter" should therefore utilise a composite of measurements, e.g. a list of BSSIDs per location or something more elaborate like a Wi-Fi fingerprint location mechanism [24].

Location Data for the "GSM Intersecter" is also non-geospatial. Similar to Wi-Fi, locations in GSM network space have to be defined using the metrics that are available, most notably: MCC (the Mobile Country Code), MNC (the Mobile Network Code), LAC (the Location Area Code), and CI (the Cell Identity). These four measurements need to be combined in order to form a unique cell ID. It is then possible to assign locations to regions of one or more cell IDs.

4 Conclusions and Future Work

Although GPS is becoming omnipresent on mobile devices – and is certainly a very good choice if the service is available – there are still devices, places and use cases where GPS cannot be applied. Consequently, definitions of locations for locations-based experiences and mobile game must be supported in GPS coordinates, and also in other metrics.

An abstract definition of locations provides the required flexibility while designing, as it decouples the interactional level from the metric level and frees thought from GPS-only coordinates. The presented location model has been implemented and used in a location-based experience for cyclists called the "Sillitoe Trail", which was based on the life and work of Nottingham author Alan Sillitoe [25] and which was authored by one of our Master students.

Care must be taken to consider the end-users' expectations when designing location systems with GPS-like devices, as users might expect these services to behave like GPS navigation systems, and could be disappointed if they discover that this is not the case.

We believe that the presented abstract location would be beneficial to other developers and have hence decided to release a reference implementation [26].

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