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COMPUTING SCIENCE

How Paranoid Are You?: Issues in Location Information of Ambient Systems

Budi Arief, Joey Coleman and David Greathead

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The prevalence of location-informing devices such as smart phones brings a lot of benefits, such as the ability to find the right services nearby. Nonetheless, there are also concerns that such devices might infringe our privacy and breach security. This paper discusses both viewpoints by outlining how location information might be obtained, what the location information can be used for, as well as the issues and problems that might be faced when location information becomes available too readily or in too much detail. We illustrate these with a case study using an iPhone application that we developed, which allows users to track the last known location of their "contacts" (such as friends or family), and to specify the granularity level of the information they are willing to share with each of their contacts in return.

About the authors

Budi obtained his Bachelor of Computing Science with First Class Honours from Newcastle University in 1997. He had a one year placement (industrial training) during his undergraduate study with Mari Computer System Ltd. from 1995 to 1996. He went on to study for a PhD at Newcastle University with a scholarship from the School of Computing Science and an Overseas Research Studentship (ORS) from the British Council. He completed his PhD in July 2001 with a thesis entitled "A Framework for Supporting Automatic Simulation Generation from Design". He currently works as a Research Associate at the School of Computing Science. He had previously worked as a Research associate on the TrAmS, TRACKSS, Rodin and DIRC projects, as well as a Teaching Fellow between October 2008 and September 2010.

Joey earned a BSc (2001) in Applied Computer Science at Ryerson University in Toronto, Ontario. With that in hand he stayed on as a systems analyst in Ryerson's network services group. Following that he took a position at a post-dot.com startup as a software engineer and systems administrator. The technical problems encountered working on a large multi-threaded application sent him back to academia in search of better ways of dealing with concurrency. At Newcastle University he has since earned a MPhil (2005) and a PhD (2008) for work on semantics and formal methods. During his time at Newcastle he has been involved with several projects including the FP7 RODIN project, working on methodology, and was associated with the EPSRC DIRC project. He is currently involved with the EPSRC "Splitting (Software) Atoms Safely" project, working on atomicity in software development methods. His interests cover a broad range of topics in computer science, though the focus has been primarily on programming language semantics and the use of formal methods to model concurrent systems. Recent work has involved rely/guarantee reasoning and structural operational semantics.

Dr. David Greathead holds a BSc, MPhil and PhD in psychology. Between 2001 and 2010 he worked at the Centre for Software Reliability at the University of Newcastle, initially as part of the Interdisciplinary Research Collaboration on Dependability (the DIRC project). This involved working closely with computing science researchers, and in association with people from backgrounds such as sociology and statistics, as well as other psychologists. Between March and August 2010 he worked in Newcastle University's Culture Lab where he was involved on a project investigating assistive technology in the home. As part of this work he developed and carried out interviews as well as installing the monitoring systems in the homes of several of the participants. During this project he was also responsible for gaining ethical clearance for the study, recruiting participants, examining literature and all of the other tasks associated with this type of project. In September 2010, David moved to Northumbria University's PaCT Lab where he works on the TSB Assisted Living Platform Grant, "Freedom to Roam". This project involves similar work to the Culture Lab work and is aimed to combining existing technologies to help older people gain accesses to the services they need whether they are at home or outside.

Suggested keywords

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HOW PARANOID ARE YOU?: ISSUES IN LOCATION INFORMATION OF AMBIENT SYSTEMS

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ABSTRACT

The prevalence of location-informing devices such as smart phones brings a lot of benefits, such as the ability to find the right services nearby. Nonetheless, there are also concerns that such devices might infringe our privacy and breach security. This paper discusses both viewpoints by outlining how location information might be obtained, what the location information can be used for, as well as the issues and problems that might be faced when location information becomes available too readily or in too much detail. We illustrate these with a case study using an iPhone application that we developed, which allows users to track the last known location of their “contacts” (such as friends or family), and to specify the granularity level of the information they are willing to share with each of their contacts in return.

1. INTRODUCTION

The concept of Ambient Systems – quite often referred to as Ambient Intelligence [25] or Ubiquitous Computing [27] – has been around for over a decade now. In this report, we envisage situations where networked devices embedded in our environment provide context-aware services that can be personalised to meet our needs.

The European Commission Information and Communication Technology Advisory Group (ISTAG) scenarios document [11] provides a good illustration on what we might expect of this concept. The scenarios aimed to describe what it might be like for ordinary people to live with Ambient Intelligence in 2010, and they offer visions on what can (although need not) be realised in the future. There are four scenarios scripted in this document, these relate to:

- personal ambient communicator (for assisting a traveller while away from home)
- connecting people and expressing identities (by having an automated and intelligent software agent to represent a person and to assist in decision making process)
- traffic optimisation (through dynamic car sharing and intelligent transportation systems)
- social learning (allowing a group of people to learn together synchronously or asynchronously in real or virtual time and in a real or virtual place)

On top of the technological issues, that document also discusses socio-political and economic issues that need to be addressed in realising the scenarios.

Some of the ideas presented in the ISTAG scenarios may sound far-fetched, but others have already been manifested in our daily lives through devices and gadgets that we carry around or are embedded in our environment. These include Personal Digital Assistants (PDAs), smart phones, Global Positioning System (GPS) devices, Radio Frequency Identification (RFID) tags [26], and smart sensors. In particular, the proliferation of smart phones – such as iPhones – somehow changes the landscape of ambient systems, in a sense that the concept becomes more readily available to the general public, not just to the computing elite.

Similarly, people with little or no technological awareness use complex devices on a daily basis within the area of Assistive Technology (AT) for older people, the infirm or the disabled. In this area, the use of various devices is driven by a need or desire to remain

independent whilst simultaneously remaining safe and well, rather than a desire to use the devices themselves. This technology could take the form of anything such as home monitoring systems, fall detectors, or interfaces to allow a person to control their environment when they would otherwise be unable to do so.

When we consider context-awareness, this quite often relates to location-based services. For example, when we are travelling in a city that we are not familiar with, we might want to find out how to get to our destination from our current location. This can be achieved through an application that utilises location information – obtained from a Global Positioning System (GPS) device, say¹ – and another application to work out the route such as Google Maps.

In this paper, we will delve further into location information, and consider various issues that might be encountered when using this kind of information. As part of our research, we are investigating how location information can be used on iPhones, and what human-related issues must be carefully taken into account.

2. LOCATION

Ambient systems tend to rely on location information in order to provide context-specific services. This could be anything from tracking a person's location while walking outside, to monitoring their movement from room to room within their home or even identifying their location within a specific room in order to aid them in performing certain tasks such as in the 'Ambient Kitchen' [10]. Full details on what we perceive as location information, how we obtain such information and what we can do with it are discussed in the Appendix.

Location information is very useful, but it also raises many issues – among others – concerning trust and privacy. In this section, we will highlight potential pitfalls in using this kind of information if it is not properly handled.

2.1. POTENTIAL PITFALLS

Location information gives rise to trust, privacy and safety issues. It is understandable that not everybody wants to have their current location known or to have the history of places they have visited recorded. Some of these issues boil down to:

- Who or what to trust
 - a) Logging. Potential problems could arise if Internet Service Providers (or other people with access) were to start logging this kind of tracking data. Different countries have different data protection laws and if these data were made available across borders, legal problems could arise. The idea of where the data would be stored also raises issues. There are different issues to consider, for example: whether the data is stored by a trusted third party (such as Google) or if there is peer-to-peer sharing of the data by the parties involved. This then raises questions of trust in that some people may trust the third party more than the people in their network while other people may trust their contacts more than a third party.
 - b) Separation of device and user. If the device begins to be treated as a kind of identity badge users may react differently to it. Some users might intentionally leave their device somewhere else to avoid being tracked. There are further considerations surrounding theft of the device. If a device was stolen the positive side is that it may be easier to track. However, if the devices are treated as identifying individuals in some way then there may be implications for people who have had their devices stolen

¹ Location information has become more accessible these days as GPS devices are commonly embedded in smart phones.

being implicated in criminal activity. This may be especially relevant if the device is stolen, present while a crime is committed and then returned without the knowledge of the owner.

- c) Location spoofing. A person may spoof their own location if they don't want to be known visiting certain places or have it spoofed by others to implicate them in some way. If data is captured at regular intervals, it may be possible to spoof your own data just by acting between the updates, i.e. appearing to remain motionless when you are in fact moving and returning to your location. As mentioned above a person could simply leave their device behind if they wanted to move undetected, or have a friend carry it for them in order that it looks like they were somewhere else. There is a recent news story where some children taking part in a study on their exercise levels managed to fool the researchers by attaching their pedometer to their pet dogs so that they appeared extremely active [3]. This kind of trick can obviously be used to carry out location spoofing too.
- Timeliness. The relevance of the information may depend on when the last update was (e.g. that you were in the office at 10am does not mean much at 9pm).
- Privacy. What you choose to allow others to know also allows them to build a profile about you, and by choosing to filter out particular properties of an anonymized data set they may be able to single out individuals, or small groups (of size k), from larger set of users. Thus, k -anonymity might be breached for a user in an anonymized data set if the searcher happens to know that there are very few people with particular properties and can correlate those properties in the data set [15].
- Data design for location information. Locations are "fuzzy". Because of this any application which utilises location information must not treat locations as absolute points but rather as probabilistic volumes.
- Reliability and accuracy of location information (and communication connection). Vertical movement within a building may be difficult to infer. It is possible that assumptions may be made by users regarding a person's location within a multi-storey building when actually the person is elsewhere within the building. It is also possible that a person may appear to remain motionless when actually they are moving up and down within a large building.
- Assuming some level of user trust, problems may arise if location data becomes important in critical situations. For example, if a system to allow location of an individual by emergency services arises and this data is erroneously trusted then the time taken to locate the user could actually be greater than if the system had not been in place at all.

3. CASE STUDY: IPHONE

In order to examine some of the technical and human issues surrounding location information of ambient systems we propose a case study. Here we consider an application based on our definition of geophysical type of location (see the Appendix). Using the GPS data obtainable through the iPhone, users' locations could be tracked by anyone running our application. This information would then be uploaded to a server and shared to other users allowing real time location data to be displayed on each contact or friend. This way, every user could find out where their contacts are at any given time.

Users will be given the option to set the level of granularity they wish to make known to their contacts. It would be possible to assign different locations with areas of different size. For example, 'office' may refer to a specific building or an area of a town. If the office is on a university campus, the term 'office' could refer to the whole campus. It is expected that

different vicinities would be of different size with 'home' and 'office' being a lot smaller than 'town' for example.

Another way in which users may wish to configure their location application is by allowing different people access to different levels of granularity. For example, a user might want their partner to have very detailed information about where they are (perhaps within a few metres) while they may want their friends to be simply aware of whether the user is in 'office' or 'home'. The way they could do this would be by having different vicinity sizes for different people. Loose contacts may just be informed of which city the user is in or even which area of the country.

The vicinity information would be computed at the server level and then vicinity information sent out to the clients. In this way, less trusted clients never receive data about an individual at a finer level of granularity than the individual in question desires.

We would be interested in many aspects of this research. These being:

- Examining trust issues surrounding use of this type of tool. In particular, which vicinity sizes people choose to show to others. Are coarse vicinities the default choice for most people or are they content to show fine-grained information to all of their contacts?
- Does the 'cost' of setting up vicinities prevent users from defining these vicinities and who has access to them as much as they would wish? Do people bother to set up two or three different definitions of 'office' for different groups? Do they prevent some people from seeing some vicinities at all?
- How do users interact with the system? How often do they run the application and for how long?
- Do users utilise the application in order to facilitate social interaction. E.g. 'I saw you were close by so I thought I would say hello'.
- Can location data be spoofed to fool the server and therefore other users that an individual is elsewhere?
- Privacy is obviously a potential area of concern with this study. What if someone wants to hide their location from a friend? Perhaps Lester wants to buy a surprise present for his wife Carolyn, but Lester knows that when he walks in a certain area Carolyn would realise where he is and spoil the surprise. Lester thinks about this and switches off the application only to make matters worse as Carolyn now thinks either something unfortunate has happened to Lester, or that he is doing something he wishes to hide from Carolyn for less admirable reasons.
- Many people do not always carry their phone with them at all times. This behaviour would clearly muddy the data. Perhaps the application should only upload data when motion is detected on the device. Otherwise the device is assumed to be in the same place it was when it last moved. This may also reduce the impact on battery life.
- Do people assume that the data is accurate with regard to location and time? The less accurate the data, the less people will trust it. What if four out of five users have accurate data but the fifth does not? Is all of the data regarded as being inaccurate or just that of the problem user? Is the inaccuracy even noticed by the users?
- Do people actually use the system? If not is there some particular reason they do not use it? Battery life? Lack of device multitasking? Anonymity? No trust in data? Frequency of updates?

3.1. IMPLEMENTATION OF TRAMS CLOCK APPLICATION

For our case study, we implemented an iPhone application called “TrAmS Clock” – borrowing from the idea of “Weasley Clock” in Harry Potter [20]. In a sense, this application is rather similar to the “Whereabouts Clock” application [9], or even the “Google Latitude” application [13] mentioned in the Appendix, but in our application, we provide an extra layer of abstraction with regard to the location (instead of the exact location, friends can only tell whether we are “at home” or “in the office”, for example); the ability for the user to define the granularity of the information to be conveyed to their friends (for example, “in the city” vs. “at home”); as well as the fully mobile nature of the application, i.e. we can check our friends’ or family’s location from anywhere using the iPhone (instead of being tied to a specific place in the home).

Our TrAmS Clock application is a client-server system where location information (supplied by the client) is stored and managed in the server, and the server provides automatic abstraction (or translation) of the information requested by the client based on the granularity or privacy level appropriate for this client.

There are five levels of location information granularity defined here: **exact** (i.e. the actual latitude and longitude), **vicinity** (user-defined locations such as “office”, “home”, “in town” – these are based on latitude, longitude, as well as radius information specified by the user), **region** (city- or town-based area, such as “Newcastle”, “London”), **country**, and **none** (where the location information is hidden). Each user can choose what level they wish to grant for each of their contacts, and the levels defined between each pair of users are not necessarily symmetrical.

The Server side: web service

The server side of the TrAmS Clock application is conceptually simple: it is just the combination of a database which stores the reported locations of the clients and an HTTP interface to allow both reporting of a client's location and requests for the location of other clients.

The database needs to store three types of information: user details, reported locations, and metadata about sharing preferences. User details include a login string, the user's name, and a password. Reported locations are a reference to the reporting user, the time at which the location was received, and the geophysical coordinates of the location with precision ranges. The metadata is, structurally, just key-value pairs which are associated with a user reference and their meaning is interpreted by the software (both client and server). Examples of metadata are a user's preference as to what level of detail for their location that another user will receive, and definitions of the vicinities in which a user's locations may fall.

The HTTP interface to the server was designed to be as simple as possible, using only HTTP GET and HTTP POST commands. This choice allows for the possible development of many different clients without the need to develop specific and complex client libraries for each target platform. This is because all of the platforms initially considered as possible targets for the client application are equipped with an HTTP library.

The interface includes commands for:

- reporting a user's current location
- requesting the most recent location of another user or set of users
- following and unfollowing other users
- defining and deleting vicinity definitions

- setting the level of detail at which other users will receive your location information
- searching for other users

Each of these commands is accessed by a specific URL format, most of which take parameters.

There is a privacy issue which must be addressed by the server software, based around what location information is sent in response to a request. To give a specific example, consider the case where user **A** requests the most recent location of user **B**. Initial versions of the server just returned the most recent set of full coordinates and the time at which user **B** last reported their location. This has clear privacy issues, however. First, it depends on the client software to obscure detail if user **B** has given user **A** less than exact permissions, and this is something a rogue client may not do. Second, giving the time at which the location was reported may expose user **A** in some circumstances. For example, there are the obvious cases of reporting a user as being somewhere when he or she ought to be somewhere else. There are more subtle cases, however, where someone watching a user's status can infer that the user has been in the same place for too long, thus exposing an errand –such as purchasing a gift at a shop while doing other errands– which the user would otherwise prefer to keep secret.

In light of this, the server now processes the location information before sending it to the client. We put in place a way of abstracting the geophysical coordinates, either to a user-defined vicinity or to geopolitical boundaries (such as cities or countries). The former is determined algorithmically by checking if the reported location is within a given radius of the defining point of the vicinity. The latter sends the geophysical location to a reverse mapping service on the internet and parses the returned data. We are careful to send nothing but geophysical location when using the reverse mapping service; this way the owner of that server may only infer that there was a user at the given location, but it will not be possible to infer who or when.

We have also considered abstracting away from precise times to phrases like "yesterday" or "a few hours ago", but this has not yet been implemented.

The Client side: iPhone application

The TrAmS Clock iPhone application (or “app” for short) was designed to be relatively easy to use, and this is reflected in its simple user interface (mostly table-based views). The first screen that a user will see after loading the app is shown in Figure 1 below.



Figure 1: TrAmS Clock's Welcome Screen

There are three main types of activities that can be performed on the client side:

- Updating location

The first thing that a user might want to do is to inform the server of their current location. Users can do a manual (single) update of their location by clicking on the “Location Data” button (see Figure 1). This will allow the app to obtain the location information of the device (in particular latitude and longitude) using Apple’s **CoreLocation** framework [1], and then send these raw data to the server. The server does the necessary filtering and abstraction to make sure that only the right level of information is shown to each user.

It is also possible for users to periodically update the server (as long as the app is still running – this is due to the restriction by Apple on running background processes on iPhones with operating system versions prior to iOS 4.0). They can do this by clicking on the “Start Auto Update” button. How frequent the update will happen is specified in the “Settings” part of the app.

- Dealing with contacts/friends

This is where most of the actions take place. Users can check where their friends are/were, add friends to their list, and specify the privacy level for each friend – i.e. the granularity level of their location information.



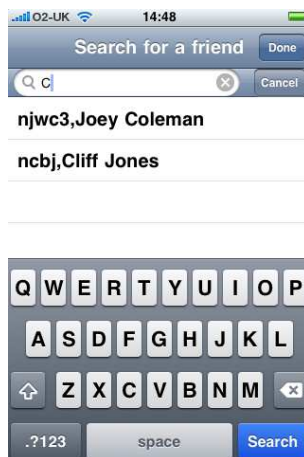
(a)



(b)



(c)



(d)



(e)



(f)

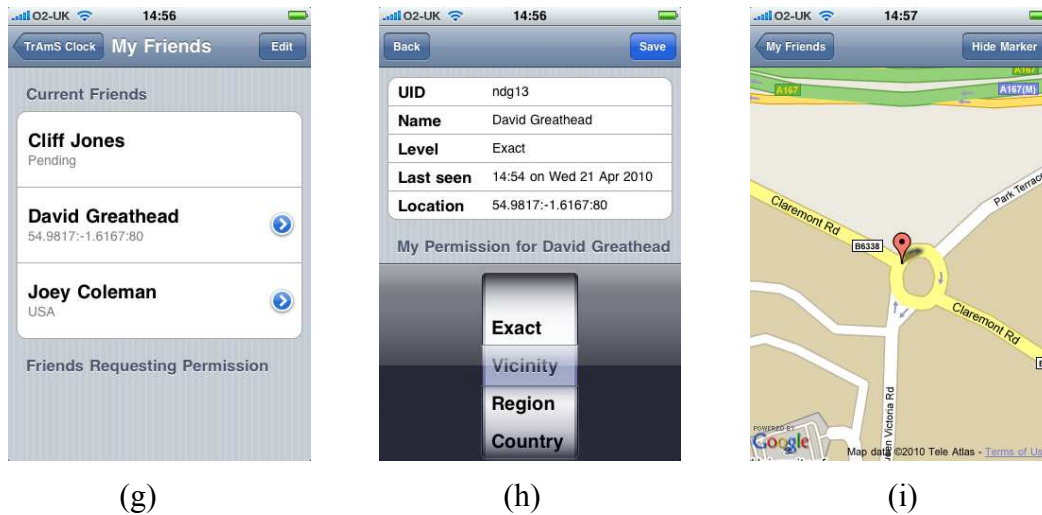


Figure 2: Viewing, adding, setting privacy level, and checking location of a friend

Figure 2 above shows the screen captures of some of the steps that can be taken in organising a friends list, as well as in finding out the details about the last known location of a friend. Here a user can view their friends – including pending requests from new friends (a). They can also remove or add friends (b). When adding a friend, a user can do a search based on the friend’s name or ID – in this example, “Cliff Jones” is used (c and d). The user can also specify the privacy level they are granting for this friend (e). At this stage, the user cannot see the new friend’s location as the request is still pending; this friend needs to grant permission – i.e. specifying the privacy level – for the user first (f). On the other side of the coin, the user can grant permission to a friend’s request. In this case, they are allowing “David Greathead” to see their *vicinity* location, whereas David had already specified (through his request) that the user can see David’s *exact* location (g and h). Clicking the blue arrow button next to David’s name in (g) allows the user to see a GoogleMap of David’s last known location (i).

Note: the process of setting up users is handled separately on the server side.

- Modifying application’s settings

This feature allows the user to change some of the app’s parameters, as well as to specify their vicinity settings (Figure 3 a, b, c).



Figure 3: User settings

A user can add new vicinity locations or delete any that are not required anymore. Each vicinity location contains latitude and longitude information as the centre of the area, as

well as the radius of this area. There is no guarantee that the information entered by the user is true, they can easily “tag” an area as their “office”, even though it is actually a pub, for example.

3.2. POTENTIAL PROBLEMS WITH THE IPHONE STUDY

Some pragmatic problems may well feature with this study. Unless a way is found to allow the application to run in the background, users would need to have the application running in the foreground on the iPhone². This would clearly result in very little long term use of the application in a general setting. For the purposes of an exploratory study it may be possible to gain some data but users would likely need to be reminded to leave the application running and resist the urge to 'play with their new toy' instead. If this problem is not resolved with the iPhone and a larger study is undertaken, it is recommended that another type of smart phone, which does allow multitasking be used in preference to the iPhone, or that a multiplatform approach be taken to allow for more widespread testing without the cost of purchasing large numbers of iPhones.

If the application can be run in a multitasking mode but there is a significant impact on battery life then users may simply opt not to use the application in order to preserve their battery life.

An application that provides context-sensitive information would also be open to misuse and abuse. To an extreme, it could be used as an excellent tool for terrorists who wished to coordinate an attack of some kind, for example. Therefore, careful consideration should be taken when implementing such an application.

4. FUTURE WORK

The next step in this research would be to carry out a larger scale test on various platforms in order that real user opinion could be gathered. On top of iPhones, other smartphone platform such as Google's Android [12] or Symbian platform [21], which recently became open source, should also be considered. At this point, some of the issues raised above (such as multi-tasking) could be examined in more detail and answers found to some of these questions. This will also allow bigger trials to be conducted, which is important in assessing the usefulness of the application, as well as in validating any hypotheses associated with this kind of application.

It is also beneficial to look at working with support for older people. Location data, in particular time spent in certain locations and motion whilst there could be of particular use. The system could alert a carer if (for example) the user appears to have been motionless in a particular place for a certain amount of time. It may be normal to be still whilst sitting in the living room but not at the foot of the stairs. Events such as unexpectedly rapid movement could also be flagged, again especially when moving down the stairs.

Similarly, other work carried out at Newcastle University's Culture Lab involved developing specific devices for individuals with dementia and associated problems with wandering outside and becoming lost [18]. This system allowed carers to find people who had become lost discreetly and without involving the emergency services. It would be relatively straightforward to take the software developed in the current study and use it for a similar application.

In addition to this, there is also a potential application to give parents peace of mind when their children are outside. It is becoming increasingly common that children are carrying their

² At the time of implementation of our application, iPhone 4 was not available. It is claimed that iPhone 4 can support multi-tasking, but we have not had the opportunity to try it out ourselves.

own mobile telephones and their parents can call them if needed. An interesting avenue of research would be to use the location technology for this and investigate how parents would use this location data to monitor their children when they are away from home.

5. CONCLUSIONS

This work has opened several avenues for further research to investigate how people interact with the increased availability of rich location information. There are various very useful applications based on location information that can be developed, and these can have a great deal of effect on our daily life. They can assist us (for example in supporting independent living for older people); change how we behave and interact with others (for example by using this kind of application as a social networking tool); or they might cause us problems (for example getting burgled because we naively announced that we are not at home).

With the rise of popularity and prevalence of location-information-capable devices – in particular, smart phones – it is clear that we need to be careful in designing and implementing applications utilising this kind of information. Privacy issues are obviously one of the biggest concerns that need to be addressed. The reactions to the privacy problems on Facebook [7][8] suggest that users are becoming more aware about this danger (and rightly so!), so the designers and developers of any ambient application need to make sure that they do not breach privacy rules and regulations. Usability is another very important factor to consider. We might have built a very valuable application, but if it is not usable, nobody will take it up and the application might be deemed as a failure.

There is still a lot of work to be done, both from the developers' point of view, as well as from the users'. Perhaps some standards or guidelines that developers need to follow – along with advice and education materials that users can understand – can help in making location information useful in our daily live without sacrificing other facets of our live such as privacy or trust.

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APPENDIX

A.1. WHAT DO WE MEAN BY LOCATION?

A location is a property held by a thing –physical or virtual– that indicates where it is to be found or accessed. Location can change over time and this gives rise to the notion of mobility; a thing’s location is always transient to some degree.

We define three primary types of location:

- Geophysical:

This type of location matches the traditional use of the term, referring to a point (or area/volume) in physical space. Typically this is reduced to a set of coordinates giving a fixed point (i.e. 55°N 1°E), but it can also be specified in relation to some other location (centre of Newcastle).

Actual physical objects –devices, people, places– can and must have a unique geographical location. Non-physical things such as websites, however, do not necessarily have any meaningful geophysical location, though they may be associated with one or many geophysical locations depending on their nature.

- Network:

A network location is a piece of information which can allow access to something on a network; telephone numbers, IP addresses, hostnames, and email addresses are all examples of this. People and places do not directly have network locations, rather, network locations refer to a device, and can only directly refer to a device. A device can have multiple network locations, depending on both how many different networks it can connect to and on the particular configuration of the device. People can (indirectly) have many network locations which are theirs, depending on the method which is used to access the location.

- Contextual:

Contextual location is a far less concrete type of location than the two preceding and is potentially dependent on them. The notion of this sort of location is to define it in terms of the available resources. Resources may, for example, include network access, projectors, physical space, and even people (either specifically, i.e. Prof. Jones, or generally, i.e. secretarial support). The intent is to allow us to define abstract locations such as a kitchen (typically implying access to a sink, counter space, utensils, and so on) or even Newcastle University as a whole.

All of these three types of location are affected by a few common secondary attributes:

- Accuracy/Precision:

This deals with both how correct the location is and how complete or detailed the location is. For example, consider the geophysical location of the authors’ workplace: claiming the location as in the UK is accurate, but not precise; claiming the location as the Tower Bridge in London is (relatively) precise, but certainly not accurate; and claiming the location as Claremont Tower, Newcastle University is both accurate and (relatively) precise.

In terms of network locations, precision relates both to ensuring that a location is sufficient for communication with the target device, and also about whether the location is a complete enumeration of all of the possible network addresses for that device.

Precision for contextual locations is primarily concerned with the enumeration of all of the available resources; an accurate contextual location is just one which does not falsely report the availability of any resource.

- **Timeliness:**

The timeliness of location data refers to meta-data recording details such as when the location was observed, when the location is valid, and so on. Timeliness information allows us to reason about the change of location information over time — this is necessary as people and devices tend to move around.

- **Provenance:**

This refers to the source of the location information and answers the question “where did the information come from?”. This sort of meta-data can be used to determine the degree to which we might rely on the information, or perhaps provide credit/blame for the information itself.

A.2. HOW IS LOCATION INFORMATION OBTAINED?

There are three main ways of obtaining location information using mobile devices: using the signal broadcast from GPS satellites; using signals broadcast from cellular towers; and using a database of known WiFi hotspot locations. These three mechanisms can be combined: many modern smartphones use a combination of GPS and cellular signals, and some combine all three.

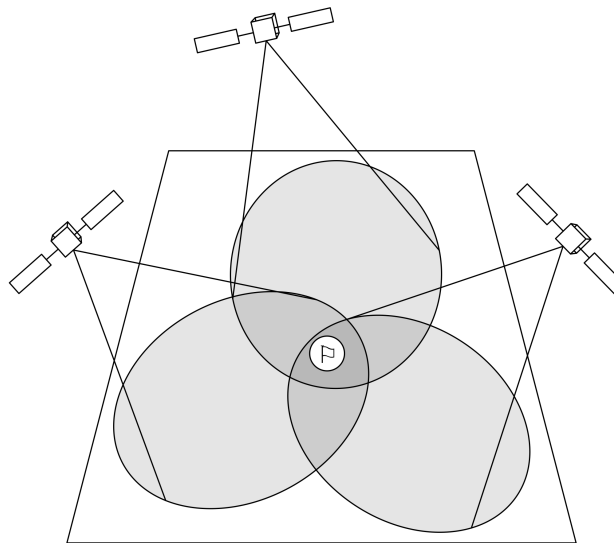


Figure 4: Determining location using triangulation

A location is determined from GPS signals via a type of triangulation. Figure 4 gives a simplified version of this: a device situated at the flag can determine that it is in the intersection of the three circles because it can receive a signal from the three satellites. (The simplification is that the calculation actually involves volumes rather than the areas as shown.) The device can identify which satellites it is receiving signals from as well as the actual location of the satellite (as the signal contains the satellite’s ephemeris data). The delay between the transmission of the GPS signal and the time it is received gives the distance from that satellite and the receiver. Each additional satellite signal narrows the possible space in which the receiver could be situated.

The GPS system has the advantage that it can be used anywhere in the world and that its operation is independent of any network connection. It is the only electronic system in

common use which has this property, and it is the only system we mention which provides altitude information. For a GPS device to determine its location accurately, however, it must be used outside as the GPS broadcast signal is easily blocked inside buildings.

Cellular triangulation is the most common way of obtaining location information in use on cellular devices. Where the GPS system requires the device to calculate its location, the cellular positioning system calculates the position of the device within the cellular system itself. This allows any mobile device to query the cellular network for its location. The accuracy of cellular triangulation is limited by the degree of network coverage in the area where the mobile device is; precision comes down to the area of overlap between all of the network base stations that are in range of the mobile device.

One distinct advantage of cellular triangulation over GPS is that it will work anywhere there is network coverage, including indoors. Its functionality is limited to regions where there actually is network coverage, which excludes large areas of the world.

WiFi triangulation works in a similar way as cellular triangulation; the mobile device records all of the hardware addresses of the WiFi hotspots which are in range, then sends a query to a location service giving the collected addresses. The service queries its own records to determine if it knows where those addresses have been seen, then returns a location to the mobile device based on that data.

This mechanism does typically require an internet connection to access the location service and due to the issues regarding the reliability and availability of WiFi hotspots, is the least reliable of the three mechanisms listed thus far. It does tend to be more precise than cellular triangulation, however, due to the relatively short range of WiFi hotspots.

These three mechanisms operate within overlapping ranges of precision. The GPS satellite system has the potential to be the most precise, giving location data to within less than 10 metres. It can also be the least precise, due to signal noise or inability of the device to lock on to satellites, giving data accurate only to tens or hundreds of kilometres. Cellular triangulation can match GPS for precision (ignoring altitude), but its outer bound is much lower as cellular signals are relatively low-power and the range from a given cellular tower is short. WiFi signals have a shorter range than cellular towers, but suffer from potential errors and timeliness issues in the location database.

So far we have discussed some of the available mechanisms for getting location info about the active device, i.e. the location of the mobile device that we might be holding in hand. We might also want to get location information about something else, say, the location of a nearby service, or of someone that we know. The mechanisms for this break down into two broad categories: examining the local environment directly; and asking a third party.

Examining the local environment directly corresponds to simply looking around. Short-range wireless communication protocols such as Bluetooth and WiFi can be used for this. The former can scan for nearby devices and, once found, can query those devices to see what they offer. The latter can provide a “landing page” which requires the user to log in before accessing the internet proper. On this landing page it is possible to advertise services which are available in the vicinity of that WiFi hotspot.

A.3. WHAT CAN WE DO WITH LOCATION INFORMATION?

There are many things that we can do with location information, but in general, four main application areas considered are: direction from A to B, find out what is nearby, let others know where I am (tracking), and local information broadcast. These are discussed in more detail here:

- Direction from A to B (topology)

a) Navigation system

The most ubiquitous (if not the most obvious) usage of location information is in assisting people to get from one place to another by using satellite navigation system (sat nav). This is particularly popular in the form of an automotive navigation system, such as TomTom [23]. Even though this type of application is very useful, it is not 100% error free. There have been cases where drivers are reported getting stranded in a river, or getting stuck under a bridge, or even precariously hanging over a cliff's edge just because they are following the instructions given by their sat nav system [5].

b) Student induction scenario

One of the case studies in the Rodin project [19] investigated the construction of an ambient campus application that can assist newly arriving students to carry out their induction activities. These activities range from simple tasks such as finding out who a student's tutor is, locating his/her office, to a location-sensitive automated agent to carry out the registration process (for example, certain registration processes might be conducted when the student is in a specific location on campus, such as the student union or in the reception area of a school/department) [14].

- Find out what is nearby

a) Resource discovery

Various applications are already available out there to assist their users in finding out where nearby resources (such as ATMs, taxi ranks, pubs, or hospital) are. These are usually linked to a map application that provides a (walking or driving) route from where the user is currently located to the target resource.

b) Tendering

Usually people like to get the best deal when there are several shops selling an item they want. In this case, we can imagine a scenario where someone who wants to buy an item, say a washing machine, arrives at the city centre and turns on an application to find the best deal for such item from shops nearby. In turn, the shops can provide various tendering promotions to attract shoppers to come to their shops.

c) Augmented reality scenario

There are several applications that provide Augmented Reality (AR) features, such as Acrossair's iPhone application that allows Londoners to find the nearest tube station from their current location using the functionalities provided by the phone's camera, accelerometer and GPS systems [2]. Nokia's Point & Find system [16] allows its users to point their phone's camera at a landmark or a barcode to obtain information about place or object of interest without the need of typing.

- Let others know where I am (tracking)

a) Where are my friends and social networking

In 2009 Google launched its "Latitude" service [13], which allows people to share their location information (represented as a dot or circle on a Google Map) with their friends. With regard to privacy issues, a user is given three options: to update their location with actual GPS information; to set their whereabouts to a fixed location; or to hide their location information from (certain) friends. Nokia also provides similar service through their "Ovi Contacts" [17], whereby users can announce their "presence" (availability/status and location), and they can chat using the integrated messenger service. Even Facebook recently launched its location-based service called

“Places”, which allows its members to share information of their location – obtained using GPS on their smartphones – while on the move [6].

b) Weasley Clock

This is based on the magical device described in the Harry Potter books, which allows the Weasley family to know where other members of the family are (e.g. “at school”, “at work”, “travelling”, “in mortal peril”) [20]. This is quite a popular type of application, and there are several systems out there implementing this. One example is the “Whereabouts Clock” [9], in which a device in a home (e.g. in the family’s kitchen) can show the location of family members in coarse-grained categories (“home”, “work”, “school”, “elsewhere”), as well as displaying any messages sent by the family members to the device.

c) Dynamic call forwarding

Proximity information –it is possible to detect when a mobile phone is present using Bluetooth, for instance– can be used to forward a telephone number to a nearby landline telephone. When the mobile phone is no longer detected at a location then that call forwarding setup reverts to the mobile phone (or, if the phone is detected elsewhere, the forwarding is diverted to the new location).

d) Emergency services and reconnaissance

Another potential application is for detecting the possible presence of people trapped in rubble by using location triangulation of their mobile devices. This is based on the notion that the people are likely to be near their devices.

- Local information broadcast

a) Direct advertising targeted at people who are in or near to a particular location. This could even be coupled with supermarket “loyalty scheme”, whereby a user’s shopping habit can be used to advertise relevant offers directly to them. Of course there are many privacy issues involved here, and some people might prefer not to use this kind of service.

b) Location specific public notices. The police have been trialling broadcast of information relevant to specific areas, for example, reminding people to take care on their way home after a night out or warning shoppers not to leave valuables in their cars while shopping [22]. On the other side of the coin, some people might inadvertently leave themselves vulnerable to being robbed by announcing in a social networking site that they are not at home at the moment [4].

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