Between location awareness and aware locations: where to put the intelligence

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Abstract

Location awareness is a key ingredient to many applications of mobile devices. Devices with the ability to determine their own position in space can retrieve, filter or present information depending on this position. There are, however, different ways to look at this situation resulting in different distributions of computational resources. A strongly simplified description model will be introduced and a number of existing systems, from both research and industry, will be analyzed according to this model. With a view to scalability in ubiquitous computing worlds, we will examine the tradeoffs with respect to putting more computational effort and design wits into the environment and infrastructure or into the actual mobile device. Some of the ideas presented here were discussed in a paper at the first workshop on Artificial Intelligence in mobile devices, AIMS 2000[9].

Introduction

At the origin of this article was a number of discussions about a building navigation system for PalmOS handhelds called IRREAL[11, 2] at the time of its first public demonstration in 2000. This system only required minimal resources and no additional hardware on the handheld organizer. All it took was a 26K piece of software which could be beamed to every device.

Yet the software seemingly made the device location aware. There was no tracking system involved whatsoever, yet the device apparently knew not only where it was to a resolution of 2-3 meters, but also in which direction it was held (to a resolution of 30-45 degrees). This fact managed to astonish most people until they saw the strong infrared transmitters mounted to the walls around them. These transmitters constantly broadcast text and vector graphics data in a scheme similar to the one used in the Video Text[1] system. A browser program on the handheld collected this data, displayed it on the screen and allowed for interaction with it. The graphics could contain clickable elements and the user could interact with it in a way similar to web pages (or Video Text pages for that matter).

We used this setup at a trade show as a booth navigation system which would allow users to find exhibits and navigate to them, as well as retrieve exhibit descriptions and contact information for all items on display.

Now were those PalmOS handhelds location aware? Certainly not, because at no point they were able to determine their own position in the usual sense. Nevertheless they exposed a behavior that can be characterized as location awareness. In this situation it might be more appropriate to attribute the term awareness to the other side of the communication channel, namely the infrastructure or the environment. By placing infrared senders throughout the environment and broadcasting localized information from those senders we had created an environment that could be characterized as being device aware or locally adapted for the mobile device.

Location aware devices

Location awareness in the classical sense implies some means of tracking, be it GPS, radio bearing or conventional ultrasonic, magnetic or infrared tracking systems. Another approach is to place active or passive markers in the environment, such as ultrasonic or infrared senders, bar codes, cybercodes[18] or ARToolkit Markers[6], which are scanned by the mobile device. The main principle here is, that the device has information of some sort about its position in space. It can then retrieve, filter or present information appropriate to this position. This paradigm puts the mobile device in charge of a) determining its position and b) selecting, retrieving and displaying the appropriate information. For a classic example see [16].

There are better and worse examples of wide spread location aware devices, the most widespread of which probably are GPS based car navigation systems. They obviously vary their output depending on their measured position, direction and velocity in space. Other examples are location aware tourist guides based on GPS tracking and/or augmented reality output facilities (see [21, 15, 19, 13]). Within buildings, infrared markers are used to mark exhibits in museums, so a portable device can select fitting descriptions from its database or a server (see [5, 17]). Some of these systems struggle with the required amount of computing power or memory that is needed to do position determination, content selection and presentation and possibly even retrieval all on the mobile device. Another important factor for systems relying on a network of sorts is the availability of this network. For a good discussion of the tradeoffs regarding network connectivity see [12].

Device aware locations

A different approach is to keep the mobile device as simple as possible and make use of the fact that it can only receive information within a certain range. In this sense even a simple transistor radio is location aware to a certain degree, since it will only play radio stations nearby, resulting in localized news, weather forecasts and traffic reports, all even in the appropriate language (if we forget about international travel for a moment). On the more technological side many FM stations in Europe use their RDS[1] channel to scroll this same localized information across car radio displays. Although no GPS is involved, the traffic warnings are roughly localized for the area the car is driving through.

There is even more potential in existing network infrastructures with a finer granularity than broadcast radio. One well known application are electronic museum guides that play different texts in their headphones depending on the room people are in. They receive their signal from infrared or weak radio transmitters that can only be received within the room in question, and thus provide localized information by their pure working principle. Cellular service providers are using the position of mobile phones (given by the radio cell in use) to charge their customers different rates depending on their being at home or away. Just like the museum description this is achieved without ever explicitly dealing with positions in space, yet seemingly makes the mobile phone location aware.

The location of awareness

Between these introductory examples there is a spectrum of location aware systems. The property of location awareness can be distributed between the device and the environment, each contributing its share. A classic example in the middle of the spectrum is the ParcTab[20], which does a certain amount of computation on the device, mainly display and interaction, but cannot function without an intelligent infrastructure.

A comparison of location aware systems

In order to describe the spectrum and existing systems within it, a simplified model for location aware behavior will be given. Positioning various systems on the one-dimensional scale from location aware devices to device aware locations is, of course, a very strong simplification. The discussion almost entirely leaves out the aspects of network reliability (by assuming perfect coverage), network structure (by assuming simple cell-based radio networks, such as GSM or WLAN) or protection of privacy. It focuses on the distribution of computationally intensive processes between the device and its environment.

[1] Radio Digital System

A simplified description model

There are several basic ingredients to the phenomenon of location awareness. In order for a device to be location aware, it needs to be mobile, i.e. be able to move between different locations. On the other side, different locations in the environment need to be distinguishable by the device. There needs to be some kind of position determination. The element of position determination is symbolized by the wind rose in figure 1. According to the result of this position determination, the device will exhibit different behavior. Usually this behavior is the generation or selection as well as the presentation of information specific to the location. The process of generation or selection is symbolized by the funnel in figure 1. It was put inside a cloud to symbolize the fact, that the nature of this processing will not be discussed in detail, i.e. remains in the clouds.

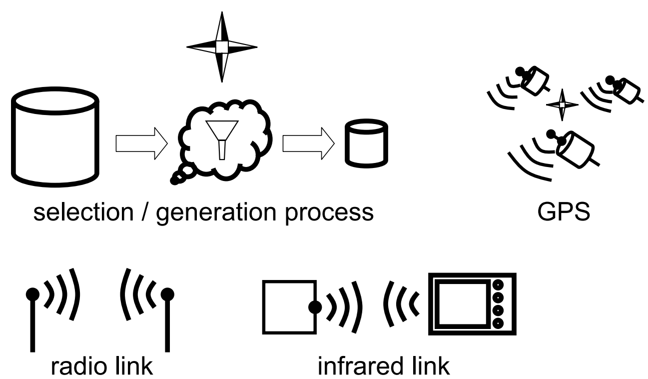

Figure 1: Components of a location aware system

The information might possibly need to be transmitted to the device, if it is selected or generated elsewhere, in which case also the position information needs to be transmitted elsewhere from the device. In figure 1 there are several symbols for transmission channels, namely optical (infrared) or radio. Some of these channels can also, by virtue of their working principle, be used for localization.

This model allows to categorize a number of existing location aware systems according to their specific constellation of these basic components. It makes vastly different systems with different purposes comparable with respect to their location awareness along the dimension described above and shows where the system´s intelligence is located.

A spectrum of existing systems

GPS car navigation

Probably the most widespread example of a location aware system are the widespread GPS car navigation systems. As far as data transfer and terrestrial communication are concerned, these systems are autonomous, since they carry all their data with them. This is symbolized in figure 2 by the box around all of the mobile components: A CD in the car holds all map data, usually of a whole country, and according to the GPS signal received and the target destination entered by the user, the system selects the right set of maps and arrows to display and issues the corresponding speech commands in order to guide the driver to her destination.

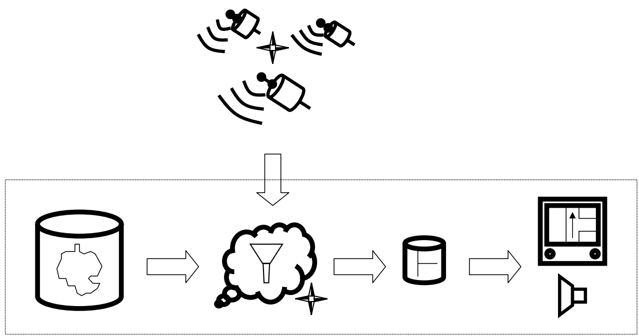

Figure 2: GPS car navigation system

GPS tourist guide

In recent research on location aware systems, mobile tourist guides are a popular subject. Examples include the projects ARREAL[19, 3], Deep Map[21], and MARS[15].

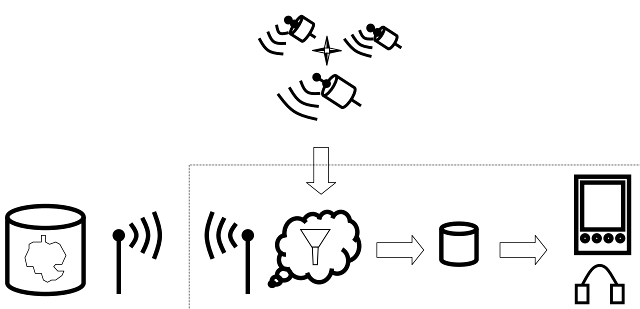

Figure 3: A mobile tourist guide such as Deep Map

These systems use GPS to determine the mobile user's position and request and present material from a comprehensive database according to their position.

Other systems, such as MIA[4] just transmit the GPS position to a central server which in turn sends back localized content. As we see, the amount of computation on the mobile device is minimized here, while in the Deep Map case, it was more balanced with computation on the server, i.e. in the infrastructure.

Cellular phone LBS

Another very popular type of location aware systems are what people call by the very general term LBS (location based services). What they mean are services on cellular phones that observe the phone user's location. Examples are a phone finder with which you can find your own phone on a map, when you have misplaced or lost it, a friend finder or finder for nearby restaurants or hotels. In Germany, the cellular provider O2 also charges different rates according to the user's being at home or out of their home zone. In terms of our description model, this is an example where the mobile device does nothing but display and take user input. Even the localization of the phone is done in the infrastructure, since the network keeps track of the cell with which the phone is communicating. The implication of this is a very lean and lightweight mobile device. The massive investment on the infrastructure side only pays off because of the very large number of mobile phone users.

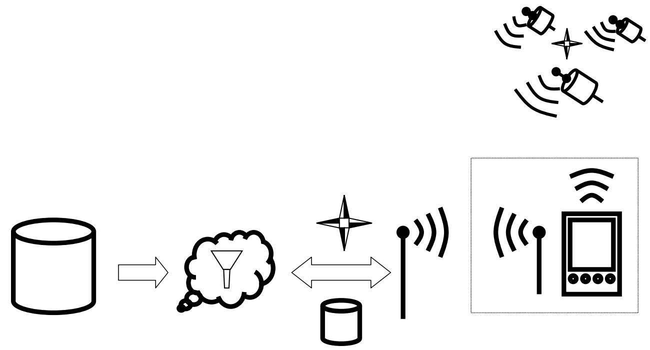

Figure 4: Setup of the MIA system

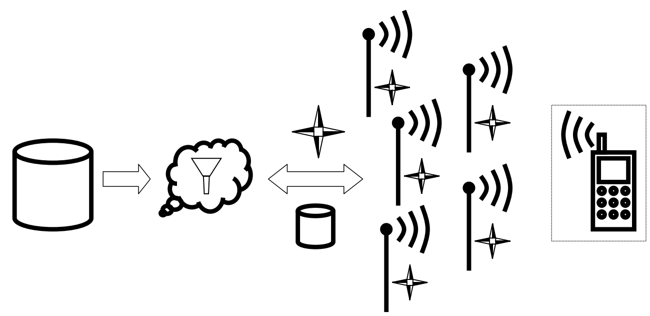

Figure 5: Cellular phone LBS

IR beacons

A few research projects as well as recent commercial PDA based Micro-LBS[8] use infrared beacons in order to determine the position of a mobile device. The classic example is the PDA-based museum guide Mobis[5], which keeps a database about all the exhibits in a museum or a trade fair on a PalmOS PDA and selects content from it according to the signal from IrDA beacons in the vicinity.

Since all elements of location awareness have to be implemented on this relatively low power device, the available amount and quality of data remain limited. More recent versions, such as the eyeGuide system[8] account for this fact by using more powerful devices with much more memory, but use the same overall working principle.

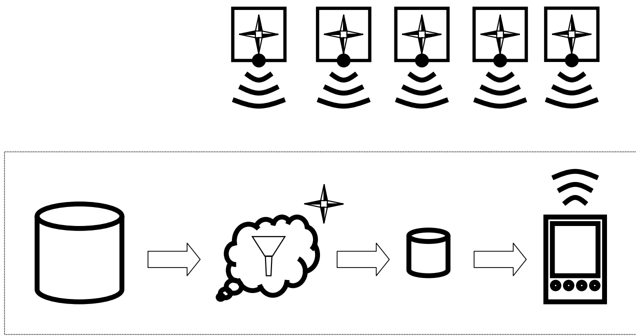

Figure 6: Mobis and eyeGuide

The HIPPIE prototype developed within the HIPS project used similar IR beacons for position determination, but a more powerful mobile device with a radio network connection. In this way, it could retrieve dynamic content from a rich database and modify its presentations according to the observed user behavior. The price for this was a more com-

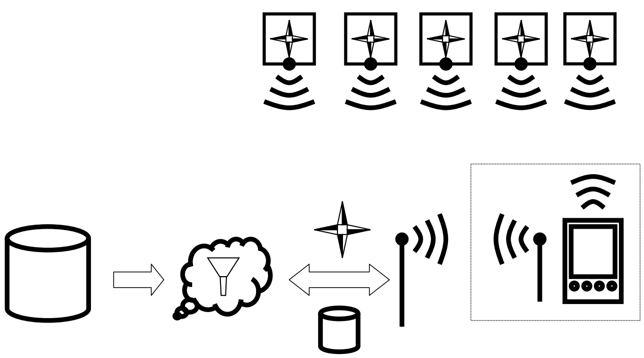

Figure 7: The HIPPIE museum guide

plex infrastructure carrying part of the computational load. This meant that the system was practically unsuitable for use by a wide audience at the time of its publication (in contrast to the two systems discussed before), because the subnotebooks and network cards used in HIPPIE were much more expensive and suffered from a much shorter battery life than the regular PDAs used in Mobis and EyeGuide.

Broadcast Networks

Finally, there is a group of systems using IR senders or radio cells not only for position determination, but also for the transmission of content. The classic here is the ParcTab[20] with a complete IR-cell-based network infrastructure, which allowed two way communication and localization by cell ID at the same time.

A more recent, if potentially less powerful version is the IR-REAL system[11, 2], which uses IR broadcast of a whole information space in order to allow limited interaction on the mobile device without sending back any information. In figure 8 a graphical route description is generated from a way network and the appropriate arrows are broadcast at the appropriate crossings and in the appropriate directions within a building. This allows very low power off-the-shelf mobile devices while it still preserves some of the properties of a fully interactive system. Also, since the mobile device doesn't transmit anything to the infrastructure, the user's whereabouts are hidden from the system and thus her privacy is perfectly protected.

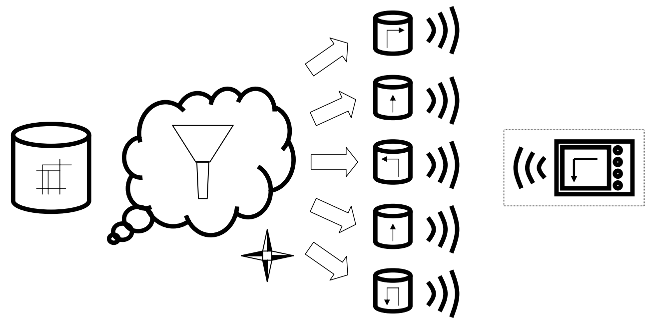

Figure 8: Infrared broadcast in IRREAL

A partially similar approach at a larger scale is taken by the Lancaster GUIDE system[12]. Broadcasting location specific content to an arbitrary number of clients within the cell and caching parts of the content on the device leads to a robust behavior with respect to the loss of network connectivity as well as to a low power consumption and good scalability.

Tradeoffs for mobile AI

If a decentralized paradigm is applied to location aware mobile computing devices, the benefits are twofold: A simple mobile device with location awareness provided by its locally adapted environment can be much more lightweight and requires no tracking hardware or position calculation. On the other hand, by shifting the task of localization to the environment side, we can afford (in comparison) almost unlimited computing power and memory. By simply providing adapted information in all the different places and letting the mobile device display whatever it is able to receive, we effectively make it appear location aware while it can be kept very weak in terms of computational power, and thus generally very lightweight and cheap. The AI part which in many cases is required to generate localized information is shifted from the mobile device to the infrastructure where it is much easier to provide the computational resources for it.

This schema, of course, will only pay off if there are more than a few users, since the investment on the infrastructure side can easily surpass savings on the mobile side. In addition there is another tradeoff to consider: While adapted environments generally make for very simple mobile devices, they also limit the amount of accessible data. This means that the number and complexity of services is limited by the environment instead of the individual device. While the requirements for mobile computing power and memory are kept low, the required communication bandwidth might actually increase, since instead of a few bytes for position information, all the localized data has to be transmitted. A partial way around this are the broadcast networks mentioned above, which allow an arbitrary number of clients to be connetcted simultaneously.

We believe that in the future a major challenge will be to provide localized services with the devices and infrastructures already in place. A mobile phone with the ability to 'know' whether it is used in its owner's house or with the capacity to provide a list of nearby restaurants or ATMs might as well offer a textual or acoustic description of touristic sights in its direct vicinity. It can just as well warn about traffic jams in the immediate neighborhood. This functionality requires no additional investment from the user, but provides a huge potential for localized services to infrastructure carriers.

They in turn won't be able to handle localization and adaptation on any larger scale without applying AI techniques to some extent. Examples include the automated generation of location- and user-adapted presentations, such as individual maps and text or route descriptions. Manual authoring of this kind of location specific content will quickly exceed existing resources and budgets.

Other key issues for future research

After analyzing the different distributions of computational resources in the above systems, it is clear that there is always a tradeoff between computational power, memory space and communication bandwidth. Saving in one of these aspects usually implies higher cost in one of the others.

Resource adaptivity

With this tradeoff in mind, one promising field of research is the automatic adaptation of mobile systems to a changing availability of resources. While true resource adaptive behavior is hard to achieve in some cases, a certain degree of adaptation to foreseeably scarce resources is part of good system designs.

Simple examples for resource adaptive behavior are the prefetching and caching of information while network bandwidth is available, as presented in [14], or the generation of complex presentations, while a device is otherwise idle. More complex examples are resource adaptivity built in to transmission protocols (e.g., [2]) or generation processes (as described in [7]). With a view to the description model described here, adaptivity might even go as far as to employ different constellations according to resource availability.

Environment management

Environments containing large numbers of mobile and location aware devices can exhibit different levels of intelligence. In situations, where all or part of the location aware services are provided by the environment, environment management (as introduced in [10]) becomes an important issue. In analogy to a window manager managing windows, icons, menus and the like, an environment manager can orchestrate devices within their environment. It can provide interaction metaphors for devices in the environment as well as coordinated interaction between several devices of possibly different device classes. One of the key questions here is whether such an environment manager will still have to work in a centralized way or can be distributed over many machines in the environment.

Acknowledgements

This article started out as a workshop paper and was initially just meant as a trigger for discussion about the distribution of resources. It originally compared two systems, but upon the recommendation of a reviewer, was extended to cover a whole scale of examples. Discussions at the workshop[9] as well as more reviews for the journal version added more examples, focus and clarity, and brought the article into its current shape. We'd like to thank all anonymous reviewers for their valuable contributions to this article.

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