Location-Based Services for Low-Income Communities in the California Central Valley

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ABSTRACT
We set out to investigate how location-based services (LBS) on mobile phones can possibly benefit low-income communities in the California Central Valley. Our overall approach is to integrate a theory of social learning and appropriation with the emerging technology probe needs assessment methodology, to unify the design, deployment and analysis of how such a service may co-evolve within and between three communities of practice: agricultural workers, non-profit staff members and LBS developers. As the first step, we interviewed non-profit staff members and volunteers to understand the everyday problems faced by these communities, after which we co-brainstormed three potential location-based services, including car-pooling. Next, we describe how the design of the car-pooling service prototype underwent three iterations so as to satisfy our technical and social requirements, especially semi-literate end-users. We then explored how we could study the longitudinal and *in situ* use of the service, after which we present the systems architecture of its implementation. We conclude by identifying appropriate wireless service providers and three promising avenues through which we can seed the probes.

Author Keywords
Car-pooling, Geographic Markup Language, GML, Global Positioning System, GPS, Illiterate users, Location-based services, Mobile phone, Needs assessment, Technology probe, Scalable Vector Graphics, SVG.

ACM Classification Keywords
H.5.2. - H.5.3: Information interfaces and presentation: User Interfaces, Group and Organization Interfaces.

INTRODUCTION
Location-based services (LBS) in the form of geospatial databases and Global Positioning System (GPS)-enabled mobile devices are beginning to permeate everyday life. By using geographic location information to enhance a rich variety of domains, including travel, shopping, entertainment and event information [1], LBSes can, for instance, behave appropriately depending on the user's current location. At the same time, mobile phones are increasingly adopted in developing regions as compared to computers for various reasons, including greater affordability and usability. They are widely perceived to be more acceptable by semi-literate and illiterate people, which often make up most of the population in underserved communities.

In this paper, we investigate how location-enabled mobile phones can be used by low-income communities in the California Central Valley. Our goal is to develop a technology probe for LBSes, which is intended to be used to study how social learning and appropriation of the LBS technology can possibly take place within the end-user communities.

LOCATION-BASED SERVICES
LBSes are networked services that are accessed via location-enabled devices, such as personal digital assistants (PDAs) and GPS-enabled mobile phones. LBSes leverage on real-time location information as provided by GPS satellites, or points of interest (POI) data as provided by a geographic information system (GIS), to enhance the quality of service provided to the end-user.

Immediate examples include the latest shuttle-tracking system to be implemented soon on the University of California, Berkeley campus [2], the law enforcement LBS adopted by the police in San Francisco to reduce and control crime in every city district [3], and the E911 federal mandate that requires all US wireless phone companies to offer improved location capabilities on their networks [4].

Previous LBSes in Developing Regions

More to the point, LBSes can be harnessed for the needs of developing regions. For example, faults in utility networks (e.g. electricity, water, telecommunications, etc.) can be reported to a central geospatial server, so that maintenance teams equipped with PDAs can be quickly dispatched to the fault locations in real-time. With the PDAs, maps, spreadsheets and other records can be accessed as needed [5]. Similarly, a GIS can integrate spatial data into the overall design and asset management of intermittent water distribution systems [6], so that policy-makers and engineers can use the GIS to project water demand levels (based on factors such as population density and expected population growth) broken down by geographic regions, so as to plan for anticipated changes in water demand. In China, national level systems like basic resource databases, as well as land, mineral and forest resource databases have been developed for flood forecasting and prevention, management of soil erosion, urban/township planning and land management [7]. For rural developing regions, precision agriculture is yet another instance of LBSes whose goal is to maximize total crop yield, while minimizing the expenditure and environmental impact of fertilizers [8].

PROJECT METHODOLOGY

In setting out to design LBSes for the California Central Valley, we are aware that LBSes are a novel technology which has not been widely deployed in this developing region. As such, it is necessary to adopt a human-centered design methodology in which users, as members in a larger community connected to one another via social ties, are introduced to LBSes. In the process of learning what they can use LBSes for, they can drive the adoption of LBSes by appropriating the technology for their own needs. Likewise, as LBS developers, our learning objective is to examine and facilitate this appropriation process as it unfolds, so as to continually engage with the end-users to better understand their needs and to design LBSes with them in a participatory fashion to tailor the technology for their local needs.

Theory of Social Learning and Appropriation

In Engestrom's theory of social learning and appropriation, which is derived from activity theory, his expansive learning cycle (Fig.1) comprises a foundation for a social and communicative theory of design [10]. It addresses the critical issue of considering the users as communities of practice defined by their particular sets of knowledge, tools, inter-relationships and social rules. Existing work and social practices undergo significant stress and breakdown each time a new technology is introduced into a community. The new technology can be totally appropriated and successfully deployed only if the community is willing and able to reflect upon these breakdowns, so as to change its practices to align itself to the new technology.

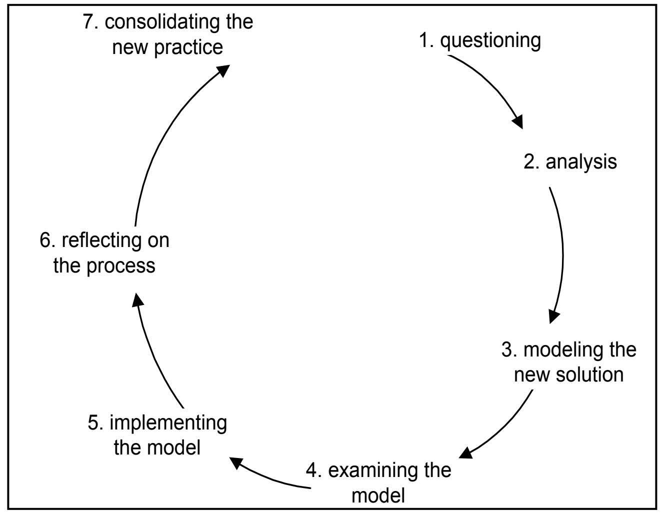

Figure 1. Learning cycle in Engeström's model.

The design implication is that learning models need to be integrated into technology design methodologies, so that the resulting technological artifacts support social learning and change. This issue is especially relevant in our case for two reasons. Firstly, LBSes are a novel technology that has not attained widespread usage. Secondly, and more importantly, attempts to improve the lives of underserved communities using technology have historically been perceived to be too technology-driven without taking the real needs and social considerations of the user community into account.

Technology Probe

In order to take the social learning and social practices surrounding our LBS into account, we have chosen to extend an emerging methodology known as the technology probe with the above theoretical framework. The technology probe is both a needs assessment methodology and an instrument to monitor how people use a novel technology [11-16]. A probe is most appropriate during the early stage of a project because, like a prototype, it is an incomplete artifact that is meant to be further refined. Unlike a prototype, however, a probe is not defined in terms of its functionality. Instead, a probe is primarily a tool that is used to collect data about the end-user community, including data related to their use of the new technology.

The technology probe is used to achieve three interdisciplinary goals, namely, the design goal, the social goal and the engineering goal [11]. For the design goal, the technology probe promotes participatory design by educating users about the technical capabilities of the technology, so as to inspire appropriate suggestions for new functionality through negotiations between designers and users. The probe is co-adaptive in the sense that the users are not only expected to adapt to the new object but also to adapt it for their own purposes, with assistance from the LBS developers. The social goal is about collecting data related to the user's daily life in a real-world setting and gaining the knowledge on how the user learns to use the new technology, on how he/she is aided by it, and on how he/she changes his/her social practices because of it. From an engineering perspective, the probe's goal is to test the technology under actual field conditions, as opposed to laboratory conditions.

By extending the technology probe methodology with a theory of social learning, we equip ourselves with a theoretical framework that unifies design, deployment and analysis under local conditions. We intend to design and implement a probe which is "aware" of what is going on around its user at the time and place of its usage; our LBS is therefore a "socially-aware" LBS. More specifically, our probe is a software application that we developed to run on a GPS-enabled mobile phone, with features to log the time, location and duration of various activities performed with the phone. Most importantly, it provides users with mobile Web access to the car-pooling LBS that we have developed for them. The objective is to expose end-users to the whole new idea of "location-based services" through the preliminary car-pooling service, which will form the basis for additional LBSes to be developed in consultation with the users. As a result, the probe acts as a boundary object that mediates social learning within and between three separate communities of practice, namely, the low-income constituents, the non-profit organizations and us as the designers and developers of the LBS (Fig.2).

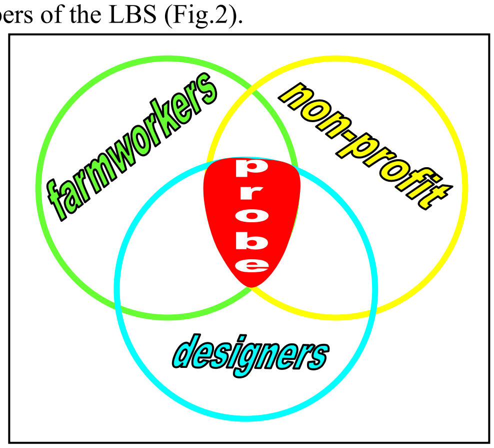

Figure 2. The technology probe as a boundary object that mediates social learning within and between three communities of practice.

DESIGN GOAL

In the initial design stage, we interviewed 20 individuals to learn about the everyday problems and needs of the low-income communities in the Central Valley. We supplemented our primary data by analyzing 3 survey datasets that are publicly available. From our findings, we generated 2 personas of the typical user to design for.

More significantly, we also made use of the above interview sessions to brainstorm, together with non-profit staff members who are familiar with the problems and demographics of our intended users, 3 potential LBSes that are likely to meet the needs of our target users. We settled on one of them (car-pooling) for our technology probe, which we subsequently designed and implemented, taking into consideration our technical and social (i.e. semi-literacy) limitations.

Interviews

We conducted semi-structured interviews with non-profit staff members of very active organizations in the California Central Valley, such as the Central Valley Partnership and the Civic Action Network. Most interviews were conducted face-to-face, either as a group or individually, while the remaining were conducted via telephone. Our interviewees work regularly with low-income communities in the Central Valley, whose economy is predominantly based on agriculture. In addition, a few of our interviewees included faculty and graduate student researchers who have been (or are currently still) directly involved in activities with the same or similar constituents. In all, we interviewed 20 individuals.

Our interviews were fruitful. Firstly, we gained a deeper insight into the everyday problems and needs of our target user group. The goals of the various non-profit organizations are wide-ranging, and aim to improve the quality of life, provide educational programs (e.g. English as a Second Language – ESL, and computer training), assist with residency permits and legal matters, organize cultural events, and promote respect and knowledge of all cultures and traditions, as well as raise civic participation among the low-income constituents.

Secondly, we discovered the "chicken-and-egg" problem inherent in the technology probe methodology which was not raised in previous papers [11-16] on the methodology, and represents a potentially new research direction for this methodology. On one hand, the probe is a means to educating users about the merits of the novel LBS technology, so that appropriate LBSes can be identified and developed with them. On the other hand, this means that a probe starts out relatively "unfinished," and hence is unlikely to be sufficiently compelling for users to interact with to the extent that they become well-informed about the LBS technology. The design implication, as we realized from our first few interviews, is that to facilitate meaningful social learning, our probe must provide a plausible LBS for a start even though its goal is to help determine the LBSes that should be implemented! As such, we used the last part of each subsequent interview to brainstorm possible LBSes. To familiarize our interviewees with the capabilities of LBSes, we provided them with a handout on 3 everyday scenarios involving LBSes, which we ask them to read before the interviews.

Thirdly, we learned how our target users currently gain access to information technology, and their computer skill levels. There are over 150 Community Technology Centers (CTCs) throughout the Central Valley [17]. These are public access points where low-income community members may access computers and the Internet for free. More significantly, these are the same locations where short and frequent (as often as everyday) computer-training workshops are held. We learned that the low-income constituents appear to be very interested and enthusiastic in improving their computer knowledge, particularly for software applications like Microsoft Office that are related to their employment prospects. A fair proportion of workshop attendees who show up for an Office application workshop do follow-up by attending subsequent workshops, so as to obtain training in the remaining applications in the Office suite. In addition, the workshops appear to have benefited the attendees, because some attendees felt the need to give back, and became volunteers who assist in conducting future workshops.

In contrast, cell-phone penetration appears to be much higher than personal computer ownership, although our interviewees could only provide anecdotal evidence to support this claim. This result also motivates us to design our LBS for the mobile phone, as opposed to PDA. More worrying, when we first learned that a great number of low-income constituents are immigrants (up to 50%) and may be undocumented, we searched the websites of several wireless providers webpages in California (e.g. Cingular, T-Mobile, Nextel) to determine the ease with which a calling plan could be purchased without legal immigration status. We found out that a social security number and a driver's license number are always required for the application process. Despite this obstacle, our interviewees reported that a large number of their clients use mobile phones, and expected them to have found a work-around via family calling plans, which require only one legal immigrant, such as a family member, a friend, or a neighbor to sign up. These plans allow for additional mobile phones with different phone numbers.

Surveys

To supplement the above primary data, we analyzed the the datasets from three surveys conducted at three different times by three different organizations. We also took advantage of the multiple datasets to compare their results for consistency.

The dataset with the largest sample was obtained from the Special Survey on Central Valley conducted in April 2002 by the Public Policy Institute of California (PPIC) & The Great Valley Center: 2,004 individuals, from 18 Central Valley Counties in four different sub-regions (North Valley, Sacramento Metro, North San Joaquin, and South San Joaquin), were contacted by telephone interviews [18]. In order to arrive at data and results pertaining to our target end-users, we gradually filtered the sample by selecting a desired characteristic at each step:

- low income people, with household income <$20,000 per year, filtering 347 individuals out of 2,004;
- Hispanic ethnicity, 113 out of 347;
- only Spanish speaking, 47 out of 113;
- living in rural areas, 2 out of 47.

By examining the statistics for the low-income Hispanic subset, which contain only two 2 sample points out of the 2,004 total respondents, we learned that only 8-9% of the Hispanic respondents live in rural areas, while the largest percentage live in small cities or towns. Moreover, 42% of the phone interviews were conducted in Spanish and 58% in English. Finally, about 32% of the individuals are hired as farm-workers. The results of this drastically sparse subset are extremely inconsistent with the other two datasets, and appear to have arisen from the fact that *all* respondents for this survey were randomly selected from telephone listings. This finding is highly consistent with what we learned from our interviews about the difficulties faced by the non-profit staff and volunteers in contacting the low-income constituents, many of whom live in non-typical residences (see next paragraph) and are likely to be undocumented. More importantly, this finding implies that to achieve the engineering goal of field-testing the LBS probe, we will need to identify feasible channels through which we can reach our intended users.

An highly informative health-related survey "Suffering in Silence" was conducted by the Californian Institute for Rural Studies in seven communities (in the regions of Sacramento Valley, North Coast, San Joaquin Valley, Central Coast, South Coast, Desert) in 1999 and sponsored by the California Endowment [19]. The methodology adopted in this survey was completely different from the PPIC's: researchers visited 971 persons at their place of residence, because a "dwelling unit" may range from a house or apartment to a trailer, motor home, tool shed, garage, tent, vehicle or a temporary shelter. Health is a major problem facing our intended users: nearly 70% of the respondents lacked health insurance, with the lack of transportation being the major obstacle in gaining access to healthcare and health checks. There were other details from this survey that we used to construct personas of the target users (more below).

The Immigrant Voice Survey was conducted by the Central Valley Partnership in September 2003 [20]. 487

individuals, all foreign-born adults, were randomly interviewed door-to-door in three Central Valley towns (Cutler-Orosi, Firebaugh, Madera). The results from this survey are somewhat consistent with those from the "Suffering in Silence" survey, and were most valuable in informing us that most of the low-income constituents are not English-literate. There appears to be higher demand for English training over computer training. 81% of the respondents desire additional schooling, with 48% indicating English as a Second Language (ESL) as their more urgent priority over computer training. More disturbingly, Spanish literacy levels are low, as further detailed in the personas below. This was a major design constraint when we prototype the car-pooling LBS, also to be described below.

Overview of the California Central Valley

Based on the above interviews and surveys, the Central Valley is a vast region in the inner part of California, 400 miles long and up to 90 miles wide, from Redding, north of Sacramento, down to Bakersfield in the south. It is a largely rural area whose economy is mostly based on agriculture (2/3 of the total California's production, 1/6 of California's GDP), together with pottery and light industry [20,21]. The 18 Central Valley counties host a 5.5 million population, made up by a 30-40% of minorities among Hispanic, Latin, predominantly Mexican. Diversity in culture, ethnicity, language, etc. is one of the main characteristic of this region, where most communities are refugees and immigrants communities, often underserved.

Two Personas to Design For

A common technique in human-computer interaction is to create personas and/or profiles of the target users, in order to bear their goals, needs, and skills in mind throughout the design phase [22]. Personas help us as designers to avoid the "elastic" user, i.e. stretching the profile of the user beyond what they actually are, and to communicate our conception of the user among ourselves.

Our target end-users fall under two main classes, i.e. farm-workers and non-profit staff members, with their characteristics in Table 1.

We draw the reader's attention to the low-literacy design constraint. 63% of the farm-workers had six years or less of education in their home countries. Similarly, only 50% of them can read and write Spanish adequately. Most troubling, only a very small percentage, 4%, can read and write English. On the other hand, numeracy is generally good and farm-workers seem to be familiar with numbers and arithmetic, which our interviewees attributed to their need to maintain bank accounts and execute monetary transactions using cash.

		Farm-worker	Non-profit staff member
Demo-graphic and Socio-	Average age	34, 59% married	18-35
	Gender	64% male, 36% female	Mostly female
	Ethnicity	Latino, Hispanic, Mexican	Hispanic,Caucasian/ White (American)
	Income	7,500<$<9,999 (minimum wage job)	Sometimes volunteer, non-profit worker
	Legal status	possibly refugee or undocumented; mistrust of government	Legal resident
	Residence	small towns/rural areas	Small towns and cities
Skill levels	Education	63%, six years or less in home country	High school/ College/Master
	Spanish literacy	low level writing and reading (50%)	Average/High level
	English literacy	Low ability/inability, 96% of the interviews in Spanish	
	Numeracy	Good	
	IT literacy	Very low	Average

Table 1. Personas for the minimum-wage farm-worker and non-profit organization staff member.

On top of the above demographics, the personas' goals can be listed as:

- Employment (in some areas, only seasonal jobs are often offered);
- Affordable housing as a solution to overcrowded living conditions;
- Education for Hispanic students (e.g. ESL, computer usage, scholarships);
- Health care (insurance, free health checks);
- Transportation (improving the very poor public transportation system, driving licenses);
- Justice (legalization, residency, amnesty).

Potential Location-Based Services

The two most common barriers to education and participation in community activities are lack of time and transportation [20], due to a host of reasons: public transport is very poor or totally absent; undocumented immigrants cannot obtain a driving license; low-income households cannot afford the costs associated with car ownership; most farm-workers have very little time to spare in their workdays and they do not want to waste it waiting at the bus stop for a bus that may not come.

We came up with the idea of implementing a car-pooling LBS after brainstorming with our interviewees. This LBS aims to address the above transportation problems faced regularly by the target users. On top of making more workplaces accessible to them, this LBS is also intended to improve their access to essential services like health and education.

We brainstormed two further potential LBSes, which are event notification (such as free health checks, training workshops, job offers) and price comparison. The former service enables non-profit staff members to disseminate information about upcoming events to a larger number of their constituents, who are difficult to reach by more conventional and other electronic means. The latter service enables users to reap cost savings, because we were told that they organize regular shopping trips to urban centers to purchase their groceries.

Since we had to decide on a preliminary LBS to develop to address the "chicken-and-egg" problem associated with the technology probe methodology, we settled on the car-pooling LBS because transportation appears to be the most pressing problem. In addition, the efficacy of event notification is limited in the absence of transportation. Similarly, the price comparison LBS has to be shelved due to the difficulties involved in obtaining consent from a critical mass of retail chains to access and aggregate their price lists electronically.

The Car Pooling Service

By car-pooling, we envision a "get a lift/give a lift" service, in which both the passenger and driver benefit: the passenger gets a (even instant) lift while the driver shares the cost of gasoline with others [23]. Moreover, the driver obtains the legal right to use the car-pool lane, which is extremely beneficial for computing to and from work. The New York Times journalist R. Cohen reports on December 14, 2003 that "in Virginia, many drivers eager to gain access to High Occupancy Vehicle lanes cruise commuter bus stops where people wait in line for a lift into Washington, picking up about 10,000 riders each day, a custom so popular that officials have increased parking-lot capacity at major bus stops" [24]. This factual detail illustrates the growing popularity of car-pooling, and more importantly, that people in the United States do not seem to be overly concerned about personal safety issues related to picking up strangers.

Nevertheless, in our car-pooling service, we continue to take safety into our design consideration because crime is a problem in some areas of the Central Valley. Our solution is to have a rating scheme for each passenger, which is similar to a "credit history" assigned to him/her by previous drivers who had given him/her a ride in the past. It may be also possible to add in the future the name of the persons who recommended that passenger, because people can better trust one friend's bad rating than three good ratings from unacquainted drivers. From our interviews with non-profit staff members, it appears that there is a demand for car-pooling because of the need to travel within a community, neighbourhood, or even the vicinity of churches, schools and Community Technology Centers, where people may already been acquainted.

We developed a location-based carpooling service that runs on a GPS-enabled cellphone. At any time, to schedule a trip ahead of time or at the spur of the moment, the driver and the passenger can access the system and enter their planned destination, date, time and place of departure. When the driver has entered his travel details he will be shown the profiles of pre-registered passengers who have matching itineraries and need a lift, thanks to a server that matches the driver's itinerary with the passengers' requests. It is the driver who decides with which passengers he wants to provide a ride, and he is responsible for calling the passengers directly to make the confirmation. We designed the workflow in this manner for two reasons. Firstly, we wanted to provide as much control in the decision process as possible to the driver, who bears the risk of fetching untrusted passengers. Secondly, as much of the confirmation process is carried out via a telephone conversation, as opposed to the LBS user-interface, because the latter remains difficult for semi-literate users to use.

User Interface

The most challenging issue has been designing for semi-literate end-users, using non-textual means of representing information visually as far as possible. We adopted solutions like graphical icons, numeric displays and input interaction techniques, consistency of screen displays and color as recommended in [9] for the design of the car-pooling LBS.

Fig. 3 and 4 respectively show the sequence of screen shots the passenger and the driver will go through when accessing our car pooling service: they were rapidly prototyped using W3C Amaya, an open-source What You See Is What You Get (WYSIWYG) SVG editor, in the form of SVG files and then displayed by our adaptation of the OpenSVG viewer.

In Fig. 3 the person searching for a ride from a nearby car enters the passenger's section by pressing 2 on his/her cellphone keyboard. All buttons/functions in every screen page are accompanied by a number that corresponds to the telephone key to be pressed to go on along the sequence. This procedure is expected to be particularly familiar and easy to use by low literate people. In the second page the passenger will enter his departure/pick-up place (A) and destination (B): he will be sent to a map where he simply positions a cursor on the desired places. When back to the second page, after entering his pick-up date and time, he will save the information that will be received by a server. The sequence of operations ends after that and the passenger will get a confirmation message for the recorded request.

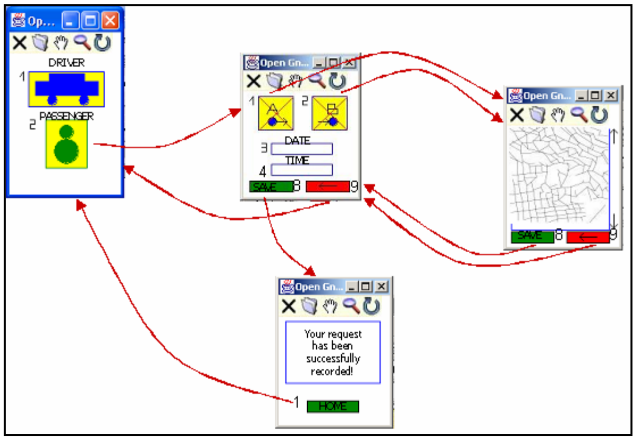

Figure 3. Passenger's storyboard.

Similarly, a person looking for a passenger to share gasoline cost or to gain access to the fast car pool lane in the freeway will press the 1 key on his/her cellphone for the driver's section (Fig. 4): he/she will enter the same information the passenger is also asked to enter, such as departure place and time, and then by pressing the "Search" button (number 8) he/she will search for available passengers by viewing a list of the people who requested a ride that matches with his/her own details. It is then possible to view the profile and the ride details of every person in the list by pressing the number linked to every name. The profile screen page contains all the useful information for the driver to approve or disapprove the passenger, such as pick-up address, date and time and the credit rating (%) that the passenger has gained in the past. In case the driver doesn't know where the exact pick-up address is located, he/she can view it on a map by pressing number 3. The driver can finally reject (red face icon) or accept (green face icon) to pick up that passenger.

The green and red colors have been employed consistently in all the screen pages to respectively convey an "OK" message (such as Save, Search, Home) and a "Stop" message (such as Back, Reject).

We expect such a simple user interface to be understandable also by illiterate people, especially thanks to the icons that enhance the meaning of every button in every page (such as men's shapes, smiling face, arrows).

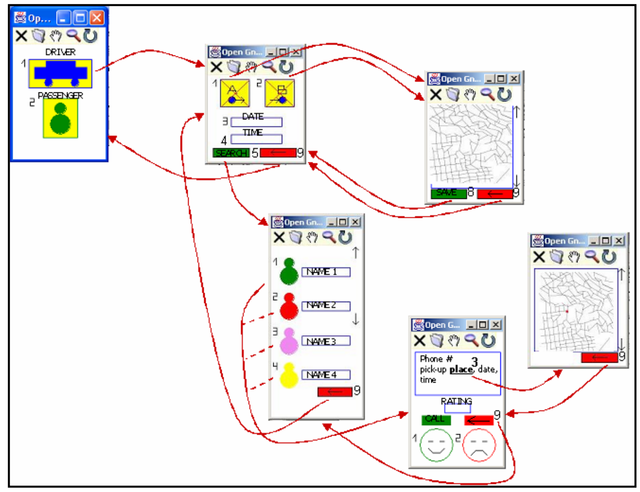

Figure 4. Driver's storyboard.

Iterative Prototyping

The car-pooling LBS, which comprises multiple Web pages accessible via a location-enabled mobile phone, underwent three prototyping iterations at both low- and high-fidelity. Protoyping proved to be extremely useful and critical for checking that the Web pages were complete (in terms of the functionality that we wanted to implement) and comply with all the technical and social constraints that we faced. By having our storyboard of the user interface undergo three iterations, we could check that all possible interaction sequences were covered. We were also able to minimize the number of layers in the interaction tree to reduce the time required to perform each task, especially when it takes time to transmit each Web page across the wireless network. Another constraint came from the small screen estate (128 pixels × 140 pixels). Finally, with the storyboards, other members of the design team could critique and gauge that the user interface is appropriate for semi-literate users.

SOCIAL GOAL

As the anthropologist R. Hames remarked, *"All behaviors have a spatial dimension. How does spatial variation relate to behaviors and the sociodemographic attributes of individuals? "* [25]. The social goal of our LBS technology probe is therefore to collect data that will enable us to analyze how the users' behavior relate to location, on top of social learning and appropriation of the LBS within and across their respective communities of practice. Such information enables us to construct models of user behavior in natural environments, and evaluate the longitudinal usage of LBS *in situ* [12].

For a start, we have decided that the probe needs to log variables like the number of daily accesses to the carpooling LBS, the time and place where the service is accessed, the "click-throughs" with which the user interacts with the service, and the durations and parties to whom telephone calls are made to.

ENGINEERING GOAL

To reiterate, the engineering goal is to test the system under actual field conditions, as opposed to laboratory settings. In this section, we describe the generic LBS architecture that we have implemented, point out plausible channels through which we can seed the probes to field-test them in the Central Valley, and evaluate several wireless service providers in California in terms of their infrastructural support for our LBSes.

Client-side Architecture

On the client side, we wanted to support as wide a range of client devices as possible, while not sacrificing the usability of the user-interface. Scalable Vector Graphics (SVG) is a markup language that allows two-dimensional vector graphics and graphical applications to be expressed in eXtensible Markup Language (XML) and rendered by a SVG-compliant viewer. We chose to implement most of the user-interface in SVG for these reasons:

- *SVG Tiny*, which is a lowest common denominator subset of SVG that is specifically targeted at highly resource-constrained devices, including mobile phones. A SVG Tiny viewer is therefore a client application that is sufficiently lightweight for mobile phones.
- *Expressiveness*. SVG Tiny enables graphical elements like vector shapes, images, text, fonts and animation to be easily described and exchanged over the network as plain text. The emphasis on a graphical user-interface is critical since our users are mostly illiterate.
- *Interactivity*. SVG Tiny supports interactivity to some extent through events and hyperlinks. Integrating both input and output in the same SVG document provides a network protocol-independent mechanism for generating the user-interface on the server side, transmitting it to the client over the network via HTTP, rendering it uniformly across heterogeneous client platforms, accepting user input on the client device and relaying the user's input back to the server. Through HTTP and hyperlinks, a SVG user-interface eliminates the need to devise separate network protocols for message passing between clients and servers for each LBS that we plan to build on top of this architecture.
- *Availability*. Freeware and commercial SVG viewers for mobile phones are available for the Symbian (Bitflash, Zoomon), Pocket PC (BitFlash, CSIRO) and Java (Gentle Player, OpenSVG) platforms. The increasing availability of mobile SVG viewers makes it possible for us to draw test users from a growing pool once we begin pilot studies. Moreover, some of these viewers (e.g. OpenSVG) are highly appropriate for LBSes, because they contain built-in support for the user to manipulate a graphical map display, via controls such as zoom-in/zoom-out and panning, which is expected in map-navigation interfaces and enhances usability.
- *Rapid prototyping*. Freeware and commercial visual editors for SVG exist, including Adobe Illustrator, Amaya, BitFlash Brilliance, Corel Draw!, and Jasc WebDraw. Some like Brilliance are useful because they validate that saved files comply with the SVG Tiny standard. Others like Illustrator enable event support to be added to graphical elements.

In practice, we made use of the OpenSVG Viewer that was implemented in Java and publicly available at www.sourceforge.net, because it has the smallest memory footprint among the open-source SVG viewers that we could find, and has the least common denominator requirement in the form of the Java 1.1 platform. We found its run-time performance to be less than satisfactory, and based on our previous experiences with Java, believe that only a viewer implemented in native-code can deliver the required performance. We are in the process of procuring commercial SVG viewers for our pilot deployments.

Server-side Architecture

On the server side, we made use of a quasi-release version of a server application from MarkLogic.com, which, among other modules, comprises a HTTP daemon module to host HTTP requests from mobile clients and an XQuery-compliant XML database engine (XQE) module. XQuery is a language that enables queries and operations on data represented in XML to be expressed. We found it more advantageous to use this server to host our geographic data, as opposed to a dedicated geographic database engine, for these reasons:

- In a very short time, we were able to convert the U.S. Census Bureau's TIGER/LINE geographic data, which comes in flat file format, to hierarchical XML using XQueries and eXtensible Stylesheet Language (XSL) transformations. This approach makes it easy to integrate additional maps from multiple (possibly heterogeneous) sources into our geographic database.
- The final data structure after the above transformation is a Geographic Markup Language (GML) document that is structured as an R-tree, the same data structure used in many custom geographic database engines. XQE query performance on this structure then rivals that of dedicated geographic database engines.
- GML is an XML language that allows geographic-related features to be attached to geographic entities such as roads, and Points of Interests. Whereas custom database engines have a fixed set of features, with XQE we can quickly add new annotations, metadata or queries, so as to enable rich spatial querying.

When the HTTP daemon module receives a HTTP request, say, from a mobile client with a SVG Tiny viewer installed, the daemon interprets the request, and if it is something more complex than a hyperlink access, such as an XQuery, the daemon forwards the query to the XQE. The result is subsequently returned to the client through the HTTP daemon as an SVG document. This SVG document is generated on-the-fly according to the following steps:

- Boundary computation. Boundaries are computed to determine which features to return for a query. Every feature has a pair of (x,y) coordinates, which are used to compute a bounding box for the respective feature. Similarly, a location (e.g. the user's current location) can be associated with a query, and its bounding box can be computed by taking a square centered at this location.
- Feature retrieval. Each feature in the GML document is scanned, such that features are included in the result set only if the feature's bounding box intersects the bounding box associated with the query's geographic scope. By the end of this step, we have the query's results in the form of GML tuples.
- Map styling. SVG elements like lines, shapes and colors are generated based on the above result set, so that there is graphical content for a mobile SVG viewer to render. Stylesheets are applied so that the look of the resulting SVG can be separated from the SVG content creation.

By locating most application logic on the server, we can easily upgrade it or fix bugs without having to circulate new code to the users, which we expect to be challenging for them to install.

Probe Deployment

Even as we implement the carpooling LBS, we needed to identify possible avenues through which we can seed our LBS technology probe. We learned from the above Central Valley Digital Network 2003 survey that there are over 150 CTCs in 8 counties of the Central Valley, namely, Merced, San Joaquim, Stanislaus, Sutter, Tulare, West Fresno, Yolo and Yuba. Similarly, from the above Immigrant Voice Survey 2003, we learned that school (54%) and church (29%) meetings are the most predominant forms of civic participation. In fact, 83% of the 487 individuals surveyed attend church services regularly. We believe that these three avenues are promising means of getting in touch with the low-income constituents of the Central Valley, especially when we have previously discussed how some of them are difficult to reach due to their undocumented status. While we have not made a decision among these three options, we believe that CTCs yield an additional advantage in that the presence of volunteers at CTCs is conducive towards social learning, particularly with their first-hand experience of how the target users acquire technological know-how.

Quality of Service Assessment

On top of exploring possible social avenues to seed the LBS technology probes, we need to ascertain that the technical infrastructure for these avenues meet a minimum quality of service requirements. We checked out the geographic coverage of wireless access plans offered by Verizon, Cingular, AT&T, Sprint, T-Mobile and Nextel, and determined that Verizon, Cingular and Nextel appear to be the most appropriate provider for our needs, due to the most extensive coverage of the Central Valley region. All the three carriers provide enough data bandwidth for our needs. However, Nextel is the only one that has already shipped both GPS and Java technology-enabled phones, supporting location-enabled applications and services [26]. This is a crucial constraint for our LBS and the reason why Nextel is likely to be the best provider choice.

CONCLUSION AND FUTURE WORK

In this paper, we had set out to investigate how location-based services on mobile phones can be used to improve the lives of low-income communities in the California Central Valley. The central thrust of our approach is to integrate the framework of Engestrom's social learning theory into the emerging technology probe needs assessment methodology, so as to unify the design, deployment and analysis of social learning and appropriation both within and between three communities of practice: agricultural workers, non-profit staff members and developers of the location-based services.

We communicated with 20 non-profit staff members, volunteers and researchers to learn first-hand about the Central Valley, and supplemented our findings with online papers. Based on these findings, we constructed two personas to guide our design of the location-based services, and more importantly, to avoid the problem of the "elastic" user. We also made use of these sessions to brainstorm, in consultation with the non-profit staff, three possible location-based services: car-pooling, event notification and price comparison.

Next, we underwent three iterations of low- and high-fidelity prototyping of the carpooling location-based service, so as to ensure that the design meets our tight technical and social (especially semi-literacy) constraints. We also determined the variables that we needed to log, in order to better understand the longitudinal and *in situ* use of the service, after which we designed the client- and server-side systems architecture of the service. Finally, we identified community technology centers, schools and churches as three promising avenues through which we can seed the probes and Nextel as the most suitable wireless provider for our location-based service.

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