ActiveCampus: Experiments in Community-Oriented Ubiquitous Computing

The ActiveCampus project explores wireless context-aware computing as a means to enhance the "learning community" experience of a large urban university.

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The continuing proliferation of handheld computing devices offers a new platform for mobile computing applications that could enrich our experience of the world around us. Yet many questions about realizing this vision remain open: What exactly are the applications? What kinds of interfaces will make them usable in dynamic, social settings? What design features in the devices themselves promote usability? What kind of infrastructure can best support the development and delivery of application services?

We have been investigating these questions at the University of California, San Diego, through the ActiveCampus Project (http://activecampus.ucsd.edu). The activities of campus life in a large urban university drive our research. The dynamics of these activities are undergoing significant sociological changes. For one thing, demographic shifts are bringing ever more students with different cultural backgrounds to the university. At the same time, more students are working and living off-campus. Such fundamental changes compromise the learning community that the campus setting is meant to nurture.

ActiveCampus explores technologies that can enrich the learning community in the midst of these changes. For example, virtual spaces have proved effective in sustaining communities among geographically dispersed members,[1] and context-aware applications such as E-Graffiti[2-3] and GeoNotes[4] allow users to leave electronic notes in physical community spaces.

Our research began with the null hypothesis that context-aware applications of ubiquitous computing technologies running on existing infrastructures and handheld devices, especially personal digital assistants, could enhance the learning community experience.

None of the technological components of this hypothesis is a given. Context-aware applications are novel and not well understood; even though PDAs offered the best all-around platform available for our purposes, current designs reflect the needs of mobile professionals maintaining calendars and contacts rather than students forming a learning community in a large campus environment.

We have tested two applications: ActiveClass supports classroom activities, such as asking questions during a lecture, and ActiveCampus Explorer supports context-aware activities, such as instant messaging and location-aware maps annotated with dynamic hyperlinked information. Even at this early stage in the development of wireless handheld computers and their applications, our experience with ActiveCampus reveals considerable promise, and the lessons learned suggest directions for further research in community-oriented computing.

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METHODOLOGY

The first step in our project was to develop a context-aware application infrastructure and an array of application services.[5] We then deployed two applications on HP Jornada PocketPC PDAs with 802.11b wireless networking.

We began with ActiveClass, a simple application designed to encourage student participation in large classroom settings.[6] We deployed ActiveClass in the 2002 Winter and Spring quarters on 350 PDAs given to the students enrolled in three classes: two sections of our second programming course (CSE 12) and one section of our third programming course (CSE 30).

For the CSE 30 class, we also introduced the ActiveCampus Explorer application.[5] We deployed this application again in Fall 2002 to the 300 freshmen entering UCSD's new residential college, Sixth College. We sponsored the Sixth College Explorientation, a three-day team challenge in which students used the PDAs and ActiveCampus Explorer to familiarize themselves with the campus.

We adopted an ecological approach[7-8] to evaluate the project experiments and experimental data. This approach denies the dichotimization of a setting's social and technical elements. It puts all people, artifacts, and practices on an equal analytical footing, thus permitting us to observe how the cooperative and competitive forces of the setting operated across these elements.

APPLICATIONS

E-Graffiti[2-3] and Geo-Notes[4] offered compelling context-aware applications that also indicated the importance of making self-sustainability a primary design goal. To support this goal, we adopted a lowest-common-denominator approach to application design for ActiveCampus. This approach assumes that increasing the number of users has more value than increasing the richness of application features.

In keeping with this approach, we followed several design rules:

- The applications made minimal demands on the infrastructure and end-user technologies. We gravitated to a standards-based client-server model and supported server-side applications on a standard Web server with MySQL and the PHP scripting language.
- The applications served basic HTML, ensuring that virtually any networked device can render content in a Web browser. Optionally, a SOAP Remote Procedure Call interface could support client-side tasks such as detecting and reporting location.
- Recognizing that community-oriented computing takes place in a milieu of activities, the applications minimized computational demands on the client.

The user interface design avoids typing, which is tedious and distracts users from the learning environment we wanted to highlight. Interfaces had to be easy to grasp, even in a dynamic setting. Early results with E-Graffiti[2-3] had revealed the tendency to appropriate graffiti for messaging, despite its unsuitability, so we decided to support multiple applications within our framework and provide simple transitions between them.

System scalability is important. Testing on our 1-GHz server showed that it could handle 300 users. However, if everyone checked the instant-messaging buddy lists at the same instant, the server load could increase 30-fold. Consequently, we put a rate-limiter into the system's automatic push mechanisms to gracefully degrade quality of service. On each interaction, the server tells the client how long to wait before reloading a page or sending location data. Internal caching mechanisms avoid unnecessary requerying of the database.[5]

ActiveClass

We developed ActiveClass to fill a void that emerged with the adoption of large classrooms, which may accommodate hundreds of students with stadium seating, microphones, and LCD projectors. This environment does not address the social dynamics of a diverse group of students.

ActiveClass is a simple client-server application that enhances classroom participation via small mobile wireless devices. ActiveClass is intentionally minimal in both its function and requirements for integration into classroom practice: Minimal function permits students to use low-cost mobile devices; minimal integration requirements make it easy for professors to incorporate them into the teaching format.

Silent broadcast. The idea behind ActiveClass is simple. Students can use personal mobile wireless computing devices to ask questions anonymously through a text interface, to answer polls related to the questions, and to give the professor feedback on the class. The students and professor see lists of the questions and polls; students can vote for questions, encouraging the professor to give them precedence.

The modality is a silent, aggregated, broadcast conversation. The identity of the student asking a question is fully hidden from other students. Our original idea was to keep the student's identity hidden from the professor unless the student took deliberate action to reveal it.

Example scenario. Sim is a student in Professor G's CSE 12 class, the second programming course for computer science majors. The topic today is hash tables, and Sim is wondering, "Why doesn't the program need to search the whole table?"

Because nobody else seems to be lost, she doesn't want to raise her hand. She decides to ask her question through ActiveClass. With her stylus, Sim types the question on the keyboard that pops up on the PDA's display. The PDA's word completion suggestions reduce the effort of typing in long words.

The question is added to a list of questions for the class, and Sim soon notices that many students have voted for her question, which has risen to the top of the list, as Figure 1 shows.

Professor G looks at the top question and realizes several students have missed a key concept. He uses a recent homework problem to illustrate how the relationship between key and placement limits the search.

Sim is relieved to have her question answered. She goes to the ratings page, gives the teacher a 9, and clicks Just Right for the lecture's speed.

Professor G saves the day's questions for use in another section of the class as well as future curriculum development. Remembering the excellent hash table question, he goes to its "spy" page, which lists Sim as the author as well as the answers that other students entered for it. He notes Sim as a potential tutor for next term.

ActiveCampus Explorer

We drew on other applications of location-based technology to support community development with ActiveCampus Explorer.[9-12] The idea is to give campus users a mobile, wirelessly connected device that provides a kind of "x-ray glasses" for viewing the immediate vicinity—letting each user see through crowds and undistinguished buildings to reveal nearby friends, potential colleagues, departments, labs, and interesting events. This medium would reveal opportunities for serendipitous learning experiences that would otherwise go unnoticed on large university campuses.

Location-aware applications. Figure 2 shows a simple realization of this concept, appropriate for a handheld device like a PDA. In the top screenshot, the large area is a map of a person's immediate

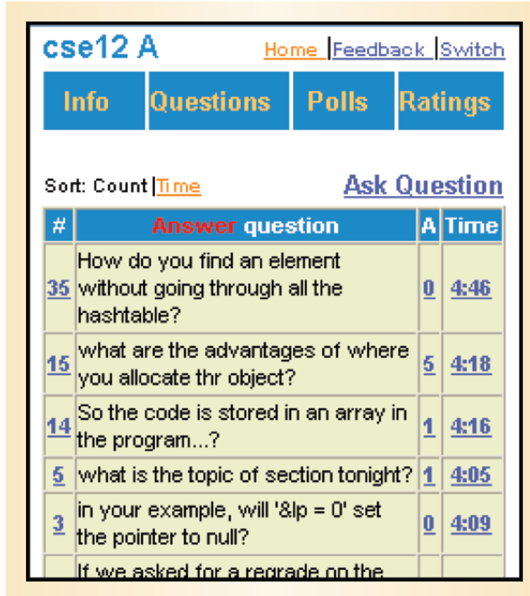

Figure 1. Question list sorted by polled vote count. A student votes on a question by clicking its vote count (far left column). Students can answer a question by clicking the count under the "A" column.

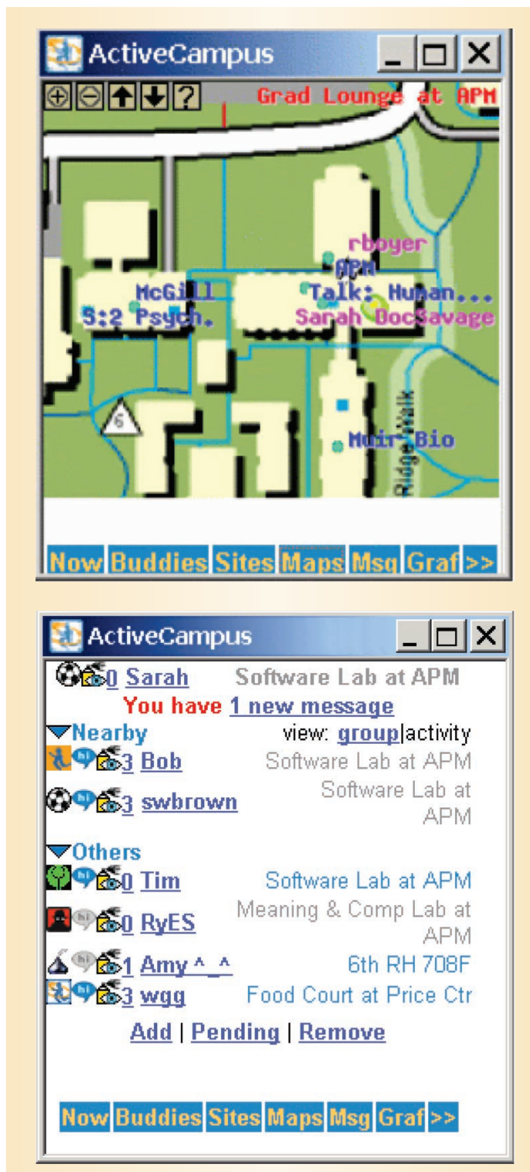

Figure 2. Map (top) and buddies (bottom) pages of ActiveCampus, shown on an HP 548 Jornada for "Sarah." Outdoor or indoor maps of the user's vicinity are overlaid with buddies, sites, and activity links.

The laptop "virtual student" could absorb any negative reactions to a question.

vicinity. Clicking one of the overlaid URL labels showing the location of nearby departments and friends brings up a Web page. A nearby colleague, formerly no more available for lunch than 100 others, is seen to be nearby and can be instantly messaged or found on foot. Any place or entity can be tagged with digital graffiti, supporting contextual, asynchronous discourse.

ActiveCampus currently detects location through the PDA's report of currently sensed 802.11b access points.[13] The reported signal strengths and known locations are used to infer the user's location by a least-squares fit. Users' point-and-click corrections of map locations are also saved with these reports, refining future location inferences.

Sample scenario. Sarah walks out of her introductory electrical engineering lecture, wondering where to find the engineering her father had told her about—building things that improved people's lives. Glancing at her PDA, Sarah sees that ActiveCampus shows a map of her vicinity, and she finds a link to a "talk" with "human" in the title (Figure 2, top). Clicking through, Sarah sees that a lecture on the human-machine interface is about to start in the engineering building, and she decides to attend.

After the lecture, Sarah drops by Professor Griswold's office, hoping to talk about the lecture, but he's not there. Looking at her PDA, she sees that Bob is nearby and active (Figure 2, bottom, shows both the location and message icons highlighted in blue). She's about to send him a one-click "Wanna eat?" message, when she notices that Professor Griswold is already at the Price Center food court. She uses the map to navigate over to the food court and find him.

Before joining him at his table, Sarah gets in line to order some coffee. Looking down at her PDA, she sees that someone has posted a graffiti saying, "Roma has the best croissants on campus." She decides to add a croissant to her order.

ACTIVECLASS EXPERIMENTS

We introduced the ActiveCampus PDAs into an environment of considerable social, physical, and technological complexity. To address this complexity, we separated the classroom ecology into two aspects: a political aspect that addresses the relations between the professor and students, and a physical aspect that addresses the desks, artifacts, and classroom layout. These two aspects have qualitatively different effects on classroom practice, and they change at different rates.

This separation reflects the architectural concept of *shearing layers,* which Stewart Brand proposed as a way to address aspects of building design that change over time.[14] Shearing layers support "buildings that learn."

Political aspect

Both staff lecturers who volunteered for our study were highly sympathetic to students and motivated to try new technology that might enhance their learning experience.

The first lecturer had many concerns about ActiveClass. For example, he wanted to know which students asked questions, so we compromised on the original idea of providing students complete anonymity and instead gave the professor a "spy" feature that let him see who asked each question. He also thought it would be difficult to integrate ActiveClass into his routine because he would have to manage it during the class. We encouraged using a teaching assistant (TA) to monitor the session for appropriate use, allowing him to ignore the system until his usual breaks for questions.

He started calling his laptop "the virtual student." This metaphor had two benefits. For him, it meant that his laptop was just one more student asking questions. He would usually refer to the virtual student only after taking questions from students who had raised their hands, indicating a preference that students participate verbally. For the students, it created a peer that could relatively painlessly absorb any negative reactions to a question.

The students and TAs tended to use the ActiveClass question and answer features for communication. When we observed students sometimes using the Ask Question feature to answer questions, we added an Answer Question feature to the application (and later, a one-click answer-scoring feature that TAs used).

Once in place, students sometimes used the Answer Question feature to thank those providing helpful answers. The TA monitoring the session sometimes used it to answer questions that were off topic.

Finally, the professor used questions from the ActiveClass session to modify his presentation in other classes. He also posted them to the class's discussion board. Here, ActiveClass was impacting the boundaries of the classroom ecology.

A few data points convey ActiveClass's role in the classroom:

- About one-third of the students provided some kind of input (question, vote, and so forth) to ActiveClass on a regular basis.

- In CSE 12, the average number of questions asked per class session was eight, and the average number of votes cast was 40.
- In CSE 30, the lecturer's style was more interactive, and the numbers were slightly lower.
- Once we introduced the answer feature, essentially every question that was not directed specifically to the lecturer was answered by another student, with a maximum of eight different answers for a question.

Although the level of participation may seem low, we note that the lecturer took verbal questions in preference to ActiveClass questions, and he carried over good questions to his second section. By our judgment and the lecturer's, however, the level of participation was quite high. Moreover, the lecturer found the participation qualitatively different from CSE 12 sessions without ActiveClass. The lecturer began using ActiveClass in CSE 12 in the third week into the term. After the first use, he said:

> The most surprising aspect from today is seeing students ask questions that I don't recall ever being asked in prior versions of CSE 12. A few of these questions were especially insightful. I was very pleased to answer these questions that hadn't occurred to me, and the result is that all students were able to benefit.

His response also highlights that even students who don't use ActiveClass directly are potential beneficiaries.

Putting these observations together with our detailed session data from ActiveClass, we found that the anonymous materialization of questions in a public space affected the classroom ecology in several ways. It gave the students the ability to ask questions without revealing their identity to peers, resulting in a broader range of questions. This in turn gave the lecturer the ability to pick questions to answer (not people to ask questions), thus filtering the spoken discourse. Yet, the lecturer did not choose these questions in a vacuum—student voting influenced the filtering process. Finally, ActiveClass gave TAs and students the ability to answer questions, often questions the professor did not select.

Each "feature" of ActiveClass questions gave something different of value to two or more parties. Although anonymity may have motivated students to ask questions that they would not have asked otherwise, the lecturer liked this feature because it let him choose questions to answer rather than people to ask questions. Thus, ActiveClass improved the fitness of questions by moving the focus directly to the questions themselves. This level of fitness is not perfect, of course. For example, some experiences with ActiveClass suggest that the incomplete anonymity may inhibit some students.

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The last essential element was the lecturer's tolerance for "unapproved" uses of the PDAs, such as instant messaging and game playing. Both lecturers felt responsible for creating an environment that held the students' attention and thus tolerated such activities as long as they didn't distract other students. The PDA's small display and quiet pen-based input were beneficial in this regard.

This group practice was not born whole but emerged through "experiments" by the lecturers, students, TAs, and researchers. Like Brand's shearing layers, variations on practice could be achieved at differing rates depending on the medium. By exploiting features such as Ask Question to answer a question, students could attempt and learn from innovation with a minute's effort, whereas integrating new practices into ActiveClass's implementation would take a few days. Changing the classroom itself can take years.

Physical aspect

The classroom's physical setting constrained how students could use their PDAs. For example, the desks were designed to barely accommodate standard-sized notebook paper and to slope slightly downward toward the student, which works for handwriting in a small space but is not convenient when using a PDA.

Like paper, a PDA requires line-of-sight access for reading and interacting, but its viewing angle is more limited. Further, using the pen on the small screen, which is crammed with clickable features, requires precision. Accordingly, students incorporated various PDA "postures" into their practices, mostly to keep their PDAs nearby while giving primacy to paper for taking notes. A popular tactic was to place the device on top of the paper on the desk. However, the PDA partially occluded the paper and so had to be moved frequently. Students would also use a leg as a second platform, or they would use their free hand to hold the PDA in the air.

For many students, note taking forms a bridge between the lecture and out-of-class practice. Because ActiveClass is physically detached from a student's notebook and contains content not found there, it was not deeply connected to note-taking practice. Students asked, "How can I use this to

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study?" In response, we added an archiving feature to ActiveClass that allows users to view previous sessions.

Students had to accommodate the technological faults of a new application, a new generation of networked PDAs, and the campus's wireless network. Ultimately, many students found it inconvenient to manage additional objects and chose not to use their PDAs.

We know that the lecturers and students found ActiveClass beneficial enough to sustain its use. One-third of the students voluntarily used it on a regular basis, and the lecturers both said that they would use it again.

But did ActiveClass measurably aid learning? This initial experiment cannot answer the learning question. First, as a case study, we did not control for selection bias. Second, at the study's inception, we did not know how ActiveClass might be able to help. We can now hypothesize that it can broaden the learning discourse, and we can look for changes in learning outcomes at the extremes. For example, are more students pursuing independent research later in their studies, or are fewer students dropping classes? Such learning outcomes would not necessarily be apparent in measures such as test scores.

ACTIVECAMPUS EXPLORER EXPERIMENTS

The results from ActiveCampus Explorer differ significantly from the ActiveClass results, shedding light on the importance of the social, physical, and technical setting in using handhelds. Because students use ActiveCampus Explorer at unpredictable and inaccessible times and places, we currently lack detailed observation of practices with it. However, we do have aggregate data that the system collected as well as data from our own experiences with it.

Experience

Our own experience with ActiveCampus Explorer has been quite positive. However, we achieved these results in part by refusing to let physical and technical obstacles deter us.

The part of Sarah's scenario with Professor Griswold actually happened. Other typical experiences included waiting for a colleague to pop up on your buddy list at his office and only then heading over to meet him.

Physical and technical obstacles

As with ActiveClass, there are considerable barriers to the successful use of ActiveCampus Explorer on wireless PDAs, but the causes are somewhat different. Use is less politically charged, but the less structured, more dynamic environment in which ActiveCampus Explorer must operate poses its own challenges.

PDA design. Wireless PDAs have limited battery life, typically less than four hours with wireless connectivity. A student could easily be away from a reliable power source for 16 hours.

It isn't easy to configure PDAs to conserve power by cyclically waking and sleeping. Often a running application or the networking itself will keep the PDA awake.

Worse, PDAs predominantly have dynamic RAM storage, so if the main and backup batteries die, the PDA's settings must be restored. A restore requires time and some savvy. In addition, the wireless networking can hang permanently if the PDA hits a dead zone while being moved between hotspots, requiring a reset to restore connectivity.

Finally, of course, using the stylus to enter (nonstandard) text messages is tedious.

Software infrastructure. Although using HTML achieves instant ubiquity, it incurs a significant loss in true push interactivity from the server. We use periodic refreshing to minimize this problem, but issuing alarms and the like is difficult at best. Consequently, mobile users must "keep an eye" on the PDA for the arrival of ActiveCampus Explorer messages, notices about interesting graffiti, and so on.

Graffiti issues. Digital graffiti did not appear on maps nor did it notify taggers of activity on their graffiti. This made graffiti less visible than sites and users. Further, ActiveCampus Explorer has no provision for deleting or hiding unwanted graffiti, so graffiti sites became cluttered.

Physical constraints. With a software infrastructure that makes it difficult to reliably wake a PDA periodically and push alarms to a user, it is best to keep the PDA on and either within view or at least handy. Most men have good solutions in loose shirt and pant pockets, but women's clothing typically lacks these conveniences.

Placing a PDA on a flat table often puts it at an angle that makes the screen hard to read. Indeed, people sometimes prop up their PDA with the edge of a book or a pencil. We are now experimenting with alternative solutions to the physical placement problem, such as attaching the PDA to a clipboard.

Aggregate usage characteristics

Because we had research questions concerning the requirements for self-sustaining behavior and other emergent properties, we performed aggregated, anonymized analyses of our server data for ActiveCampus Explorer "launches" from April 2002 through March 2003. The first was in conjunction with one of the ActiveClass groups; the second was for the Sixth College Explorientation.

The launches were meant to create a structured, supportive context for students to use ActiveCampus Explorer. These events were useful both for generating data quickly in a semicontrolled setting and for providing the opportunity to bootstrap a virtually mediated community—or at least to get a sense of how such a community might behave. In both launch sessions, the students were encouraged to try each feature—that is, the maps, buddy system, instant messaging, and graffiti system.

Measures of use based on the number of transactions gave excessive weight to a few heavy users. We instead examined how many distinct people created content for each feature. Figure 3 shows the number of distinct individuals who created each type of content during each month. The peaks in April and September 2002 correspond to the two launches.

Generally, use decays at an exponential rate from month to month until it stabilizes around 25 users. About one-third of these are members of the ActiveCampus project. We attribute these disappointing results to the ecological deterrents described earlier.

An underlying assumption of ActiveCampus is that location does matter. Our analysis of the message sender and receiver locations was limited to the 1,597 messages for which the automatic geolocation system had located both sending and receiving PDAs within the previous 100 seconds. There are many reasons for not currently geolocating, including the user's choice to hide location information.

Next, we compared each sender-receiver pair's average distance at the time of messaging to their average distance in general. Figure 4 shows this relationship. Each point in the chart represents a pair of users who have exchanged messages. The mean message distance is the mean distance between the pair when one of them sent a message to the other and their locations were both known. The mean geolocation distance is the mean distance between the user pair when their locations were both known, regardless of message activity. For 473 out of 539 pairs, the distance when messaging was less than the average distance, demonstrating that the short messaging distance is not just an artifact from the limitations of the geolocation system. For 311 pairs, the average messaging distance was less than 50 feet.

This tendency held up when we excluded project members and the Explorientation from the analysis.

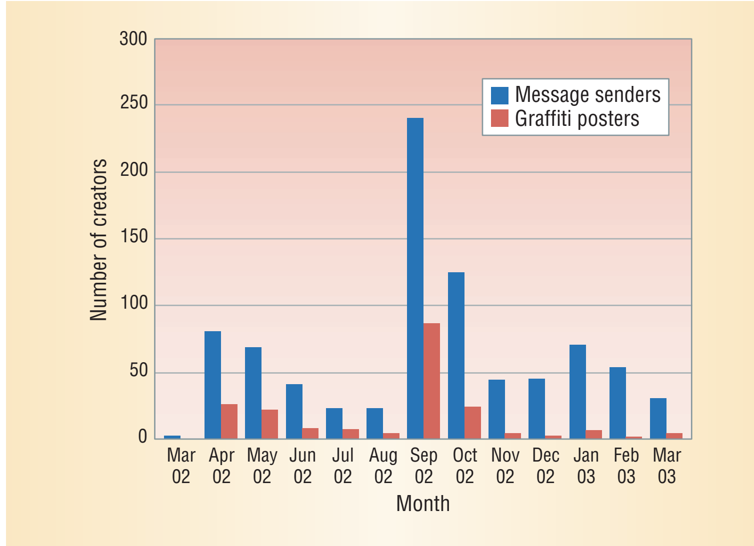

Figure 3. Message senders and graffiti posters for ActiveCampus Explorer. The peaks in April and September 2002 correspond to the two launches.

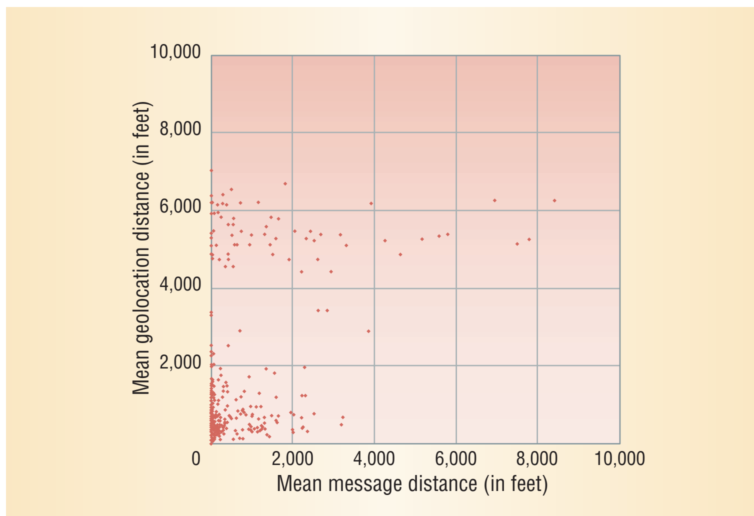

Figure 4. Geolocation and message distances for ActiveCampus Explorer sender-receiver message pairs. Each point in the chart represents a pair of users who have exchanged messages.

In short, relative location as a context does seem to matter in community-oriented computing. With so many messages sent at a short distance, it is possible that the pairs saw each other in the same room and used instant messaging as a communications back channel. They may also have known that they should be in class together.

Finally, we examined privacy issues. Just one percent of users changed their default privacy settings to hide location from buddies; 8.2 percent exposed their presence and location to nonbuddies; 0.3 percent more exposed just presence. In short, users seem unconcerned about location privacy with friends. A modest percentage will even share their location with nonbuddies, perhaps as a way to meet people.

With the structure a classroom setting provides, a simple application like ActiveClass can create new participation modalities, broadening discourse in a public space by materializing anonymous questions. The many services available through a location-aware application like ActiveCampus Explorer demonstrate the potential for creating impromptu community experiences in a large physical environment.

Yet many technological barriers to implementation remain. Mundane issues such as battery life, data loss, and connectivity make using these applications difficult. These issues will likely be resolved soon, but they illustrate the sensitivity of technical innovation to material circumstances. The office and business travel environments in which PDAs have flourished do not present these challenges to the same extent as the educational community.

The one-way nature of existing communication standards presents another challenge. SOAP RPC retains HTTP's "pull" semantics and so does not fix this problem. We are now developing a native ActiveCampus Explorer client that uses off-the-shelf XML-based instant-messaging frameworks for managing a "push" connection to the client.

The social barriers to handheld computing are also significant. As computing moves into public spaces, the issues of regulating access, acceptable usage, and resource sharing remain open. ActiveClass puts the power of negotiation into the application itself. It's unclear if we can extend this idea to ActiveCampus Explorer.

Our results show that students at UC San Diego are willing to share location with buddies and even nonbuddies for location-aware social computing. In addition, they are more likely to message each other when they are in close proximity to one another. This tantalizing observation suggests that relative location is a relevant factor in community-oriented computing. ■

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