Lessons in Deploying Public Ubiquitous Computing Systems: Experiences from the e-Campus Project

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Abstract

In this paper we reflect on our experiences of deploying ubiquitous computing systems in public spaces and present a series of lessons that we feel will be of benefit to researchers planning similar public deployments. We focus on our experiences gained from building and deploying three experimental public display systems as part of the e-Campus project. However, we believe the lessons are likely to be generally applicable to many different types of public ubicomp deployment.

1 Introduction

In this paper we reflect on our experiences of deploying ubiquitous computing systems in public spaces and present a series of lessons that we feel will be of benefit to researchers planning similar public deployments. We focus on our experiences gained from building and deploying three experimental public display systems as part of the e-Campus project. This project is exploring the creation of large scale networked displays that can form part of an interactive pervasive computing environment embedded in public physical spaces. The deployments vary in technology, location, scale and user community and have provided us with a rich set of experiences. Based on these experiences we present a series of lessons that are certainly applicable to researchers planning similar deployments of public displays and may also, we believe, generalize to many other public ubicomp deployments. Where appropriate we provide evidence of this by drawing on our experiences from other deployment-oriented projects such as GUIDE [1].

2 Deployments

2.1 Deployment 1: WMCSA 2004 Conference Signage

Our first deployment was a digital signage solution at the 6th IEEE Workshop on Mobile Computing Systems and Applications, WMCSA 2004. The WMCSA system consisted of four public displays stationed outside each of the entrances to the main auditorium and demo room. The displays provided a rolling display of information for delegates tailored to the display's location (proximity to ongoing conference activities) and the time of day. Each display was able to show information relevant to the talks being presented in the adjacent rooms, about activities in the wider locale, and navigation symbols directing delegates to refreshments at appropriate times of the day. The displays were interconnected via a local network, allowing us to synchronise content across the displays on a per content item basis.

One of the key issues we sought to explore with WMCSA was how to simplify the process of injecting content into the system and of mapping that content to displays. We did this by exploiting a separation of concerns: authors could create content items (images, web pages, RSS feeds and videos) and request these to be mapped dynamically to the network of displays using a constraint based scheduler. The content of the WMCSA system was therefore reduced to a set of scheduling requests. A scheduler associated with each display observed these requests and attempted to construct a timeline for the display that best matched the requested set of constraints. Where content was required to be synchronised across displays, a distributed agreement protocol was used to converge on a mutually agreeable time in each scheduler's timeline.

2.2 Deployment 2: Brewery Arts Centre Exhibition to Commemorate the 60th Anniversary of VE Day

The second installation took place at a local arts centre (The Brewery Arts Centre in Kendal, Cumbria) as part of their celebrations of the 60th Anniversary of VE Day. Specifically, the installation was one element of an interactive exhibition of local wartime memorabilia designed to raise awareness of life in the region during World War II. The installation consisted of four main components: a set of three large projected public displays (see figure 2), a video diary booth, a web based diary, and 'the Kirlian Table' (an interactive art exhibit created by a local arts collective). The public displays showed a series of news footage and radio broadcasts evocative of the era, interspersed with images captured from the interactive table surface and video diary entries. The video diary application enabled visitors of the exhibition to record their own war-related memories, that could then be accessed by visitors via a local web based content management system.

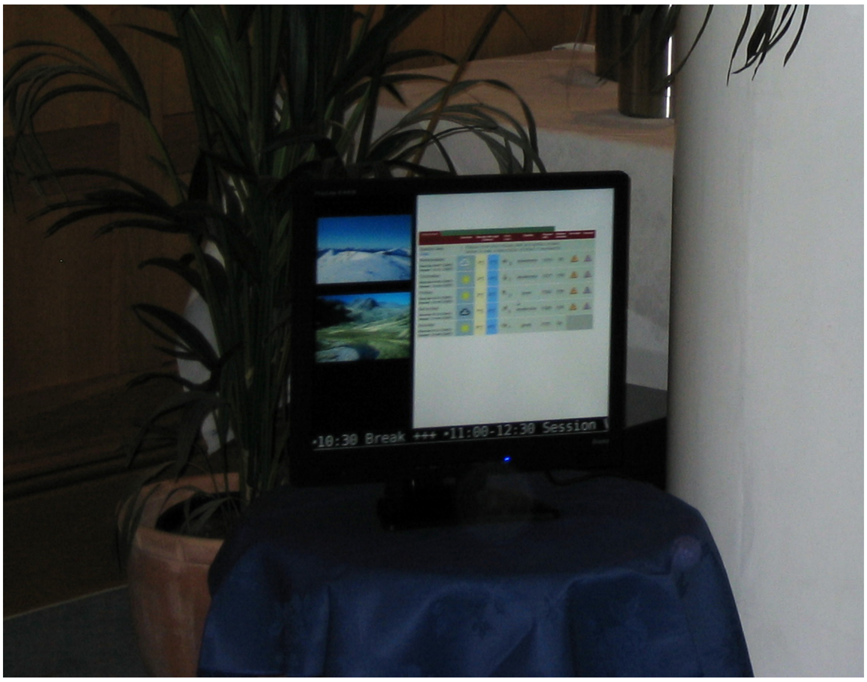

Figure 1: One of the WMCSA situated public displays. The display is showing a carousel of photos from the surrounding Lake District National Park, the current weather forecast, and an RSS ticker of the forthcoming talks.

Additionally, if consent had been given, diary entries were scheduled and displayed on the multi-screen projector public display system.

Prior to deployment individual parts of the Brewery system were developed and tested in isolation in one of our labs. Installation, integration and final testing of the components took place in the exhibition space over a period of 48 hours and were directly followed by the official opening night of the exhibition – a highly visible event.

The system remained active for a total of 14 days, i.e. for the entire duration of the exhibition. During the fortnight, 1723 visitors attended the exhibition. They were encouraged to leave feedback about the system using provided questionnaires. Additional information was collected through observations. Results suggest that generally visitors found the exhibition informative, innovative, interesting and appealing.

2.3 Deployment 3: The Underpass

The last in our series of deployments was installed in an underground bus station on campus (called 'the Underpass'). The aim of the installation was to enrich this 'interstitial non-space' by providing a mixture of information

Figure 2: Photograph of the Brewery gallery space during setup of the exhibition. The projected displays (showing test images) are in the background. The video diary booth is out of shot far left, the web kiosks are behind the photographer. Various elements of the 'evidence' exhibition are in place with irreplaceable items locked in a glass case, to the foreground.

and interactive content to people waiting for buses. In contrast to our other technology probes, the installation in the Underpass was intended to be a long term deployment, i.e. lasting at least for several months, possibly up to a few years. To fit the physical dimensions of the space, it was decided to deploy three large-scale projected displays that would be aligned side-by-side. We also wanted to be able to either use each of the projection surfaces independently or in combination as wide-screen displays of 2 or 3 displays.

¿From the start we aimed to employ a mixture of content, including artistic material, textual information and videos. Consequently the installation opened up with a piece of interactive art (called 'Metamorphosis', see figure 3) that consisted of a set of 3 videos that were to be shown side-by-side and were controlled by a Max/MSP[1] script. Metamorphosis was essentially self-contained and distributed across four dedicated Mac Mini machines. Three of these machines were responsible for rendering the videos. The fourth Mac Mini was in charge of controlling the playback according to events reported by external sensors that were triggered by passing traffic.

To support additional content besides Metamorphosis we deployed a PC with a multi-headed graphics card that allowed us to either render different pieces of content on each head or render content that spanned across two or more heads. An AV matrix switch[2] and an embedded AMX controller[3] were put in place to allow us to switch between content rendered on the PC and content rendered on the dedicated Mini Macs.

The majority of the hardware was installed in a rack in a garage in the

[1]http://www.cycling74.com/products/maxmsp
[2]http://www.sierravideo.com/
[3]http://www.amx.com

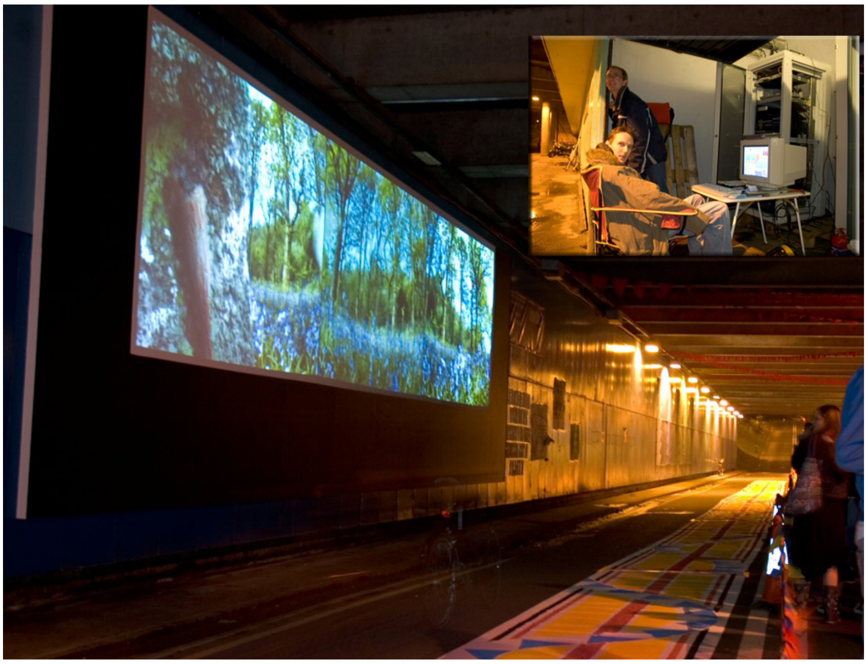

Figure 3: Photograph of the opening of the Metamorphosis installation using the public displays in the Underpass. Inset: members of .:thePooch:. arts collective keeping a close eye on the system console.

Underpass. Due to technical as well as health and safety considerations – we had to make sure not to blind the drivers of passing traffic – the projectors had to be mounted on the tunnel ceiling directly above the road with special lenses fitted to correct for keystoning etc. Deployment of the projection system therefore required a complete closure of the Underpass for several days to enable the installation and wiring to take place.

3 Lessons in Deploying Ubicomp in Public Spaces

Technology and Deployment

Over the years our group has amassed considerable experience in deploying mobile and ubiquitous computing applications (e.g. in the GUIDE project [1]). However, we were still surprised by the sheer volume of work involved in creating the deployments described in this paper. For example, the Brewery deployment required a team of almost a dozen people to create the system and to physically install it. After the installation, staff were needed more or less permanently on-site during the exhibition. For the Underpass deployment many months were spent on non-technical activities such as liaising with local transport companies and University bodies. Our first lesson is thus: *"never underestimate the effort involved in creating real deployments of systems"*. Indeed, even on the technical front we were surprised by the complexity of the AV installation we required. Hardware for the Underpass deployment occupies most of a full-height rack and includes specialized components such as an AMX controller that has its own full programming language and associated development tools that needed to be mastered.

Our second lesson is *"never underestimate the impact of environmental factors on a deployment"*. In both the Brewery and the Underpass installations we faced significant technical challenges. At the Brewery these principally related to the absence of adequate high speed network access and the non-technical nature of the staff manning the exhibition. However, other environmental factors also impacted on our deployment. For example, the Brewery tests its fire alarms weekly during which time they shut off all power to the room in which the exhibition was taking place.

In the Underpass the physical environment created enormous difficulties for our work – the Underpass itself is a cold, dark, damp, public space and is heavily polluted with diesel fumes. This meant, for example, that the projectors had to be housed in specially designed cases that could withstand the elements and physical damage while simultaneously providing adequate cooling for the projectors and filtration of the diesel fumes. To give some idea of the scale of the problems our first attempt at an install ran for less than one week before the filters in the projectors were so clogged with diesel that the projectors themselves overheated and shut down. This was despite the fact that the projectors were installed in custom designed housings with filters that were supposed to remove the diesel particles.

The need to adapt and maintain our deployment leads us to our third and fourth lessons: *"deploy for maintainability and change"* and *"create and keep duplicate deployments in the lab"*. While the need for maintainability may sound obvious it is worth providing a concrete example of the trade-offs involved. The projectors in our Underpass installation are located above a road and maintaining them requires closing the road. During term time this is practically impossible and thus any failures of these components incur on average a 5 week downtime (terms are 10 weeks so long so in the worst case we can have the system out of commission for 10 weeks). With hindsight we should probably have mounted the projectors on a moving platform that could have been mechanically pulled clear of the road. At the time we deemed the extra expense to be unjustified, but this was probably bad judgement on our part. Creating duplicate deployments in the lab is obviously good practice but we have found that the temptation is to create a deployment in the lab and then to move this installation into the field. Based on our experiences we would recommend keeping a duplicate in the lab to ease testing of proposed maintenance procedures. We believe that in most cases the extra costs involved will be more than justified in terms of ease of testing and maintenance.

Our fifth and final lesson is *"anticipate and plan for regulatory compliance issues"*. In our deployments we encountered numerous regulations that, inevitably, governed our deployments of the systems. While some of these are absolutely standard (e.g. compliance with safety standards for electrical installations) others we had not anticipated. For example, the need to provide access to the displays (and the information thereon) for disabled people – creating a technology deployment that does not implicitly discriminate needs great care. As a second example, compliance with health and safety regulations when carrying out system maintenance has increased the time taken to carry out even apparently simple tasks.

Monitoring and Management

During the WMCSA deployment members of our team were also delegates at the workshop and were therefore on site all the time. Failures of the display system were therefore relatively easy to spot and rectify. As the deployment at the Brewery Arts Centre was scheduled to run for two weeks, we decided to try to monitor the system remotely, i.e. essentially by periodically checking the system's activities on the event channel and by monitoring logs obtained from individual components, both of which could be obtained by logging into the systems from a remote location. However, it quickly became obvious that even if all the components in our distributed system appeared to be perfectly healthy, the system might still not actually be functional as far as human observers were concerned. For example, the information we obtained did not include any clues about the health of the three projectors. Consequently, we received a number of phone calls during the first few days of the deployment about malfunctions of the system that turned out to be down to either the projectors overheating or one of the projector's bulbs having reached the end of its lifetime. In the end we had to revert to the monitoring approach we had used for WMCSA, i.e. to put people on site that were able to visually monitor the health of the system by looking at the output on the projected displays. The lesson we draw from this is: *"ensure that it is possible to remotely monitor the output of the system as it is perceived by the user"*. In our more recent deployments we have been very careful to provide adequate monitoring facilities, e.g. in the Underpass deployment by installing a set of cameras capturing the output of the displays, enabling members of the project to inspect the visible state of the system from remote locations.

The seventh lesson we learned is complementing the issue raised in the previous paragraph from a systems perspective. The lesson here is that *"it is important to provide tools and abstractions to enable inviduals to reason about the state of the system"*. One issue we encountered early on during the Brewery deployment was that it proved difficult to tell what item of content would be displayed next and how long it would take until, for example, a video diary entry would be displayed. Watching the projectors did not help as during each cycle of the schedule individual pieces of content would often be displayed more than once. Inspecting the system's output on the console and the event channel did not help either as the information provided did not contain data about the relative position of the piece of content currently being displayed with respect to other pieces of content. Complicating matters even more, the schedule also contained periods during which no content would be displayed to allow the projectors to cool down. Lacking appropriate monitoring tools that provide an abstract overview over the systems's status we found it very difficult to determine whether at a specific point in time the displays were scheduled to be blank or whether a fault had occurred in the system, causing the displays not to show any content.

Content Creation and Management

Ubiquitous computing research is inherently concerned with applications and the user experience. Thus, the nature and quality of content presented by ubiquitous computing systems is of critical importance. Systems such as GUIDE [1], Can You See Me Now [4] and Uncle Roy All Around [7] have clearly demonstrated the benefits in user experience that are accrued from developing high-quality content for use in ubiquitous computing applications. For our e-Campus deployments the role of content was critical since for most users the content *is* the system. Whenever we didn't have content to display and turned off the displays people assumed the system was broken. Similarly, poor content reflected very badly on the system as a whole. Our eighth lesson drawn from our experiences with numerous projects is thus *"never underestimate the importance of content"*.

Generating compelling content is a non-trivial task and in our experience computer scientists lack the necessary expertise to produce such content (of course there are exceptions but these are few and far between). This is not simply a matter of artistic talent - producing content often requires specialized knowledge of tools and processes that are outside the remit of computer science. Furthermore, while many students and staff can justify working on systems infrastructure or user studies as part of their research, finding time to work on what is often (incorrectly) regarded as a luxury, i.e. content generation, is much more problematic. While there are lots of techniques that can be used to try and generate content with few resources (e.g. user contributed content, employing students etc.) even these techniques incur significant management overheads. In our deployments we have used content ranging from that developed by ourselves through user contributed video and text entries to professionally created performance pieces. Whichever approach is used our ninth lesson holds: *"ensure you have adequate resources set aside for content creation"*. We use resources in its broadest sense here to encompass both money and staff with the appropriate skill set.

In our deployments we were already mindful of the above lessons and thus ensured that we had made provision for content creation. However, we had not anticipated the difficulty we had managing the content once it had been created. For example, in the Brewery deployment we ended up with a multitude of versions of our diary entries. This reflected the need to convert the media into different encodings for the various parts of the system and the need to transfer the material off-site for previewing, approval and archiving. Our experiences have enabled us to identify a significant mismatch between the capabilities of existing Content Management Systems (CMS) (from both the broadcast media and the web communities) and the requirements of a CMS for pervasive computing environments. This leads us to our tenth lesson: *"managing content for pervasive computing is a major task for which existing tools are poorly suited"*. We also note that many of our problems in managing content in our deployments were related to the need to manage workflows associated with the content, e.g. this content must be archived and approved for display before being scheduled. Our eleventh lesson is thus *"with the need to manage content comes the need to manage workflows in mobile and pervasive environments"*.

Orchestrating Ubiquitous Computing Experiences

As computer scientists motivated by the ubicomp vision we have found ourselves often tempted to distribute the intelligence in the systems we build to as many low-level components as possible. Thus our system architectures typically appear as collections of fairly autonomous entities without an obvious central point of control – in the case of e-Campus these entities are displays and associated components. However, our experiences suggest that it is crucial that whatever the architecture chosen the system should be able to support the creation of carefully orchestrated (i.e. coordinated) "performances". Such performances define the user experience for a given period of time and support for these performances were a key requirement of both the Brewery and the Underpass deployments. Specifically, it is necessary in public deployments to be able to prescribe the exact user experience. Our twelfth lesson is thus: *"ensure that public deployments can support orchestrated performances"*. Related to this twelfth lesson is an associated requirement that these performances can be developed and tested off-line, i.e. away from the physical infrastructure and, crucially, in non-real time – enabling developers to step through or fast forward performances to tweak the experience of the users. In the Brewery and Underpass such facilities were crucial to enable us to test a days worth of content in a few minutes. This requirement translates into our next lesson: *"ensure that it is possible to develop orchestrated performances off-line and replay in non-real time"*.

One aspect of the types of performance we have been describing is that they typically span multiple components in the ubicomp deployment – in our case multiple displays. In our experience there was a need to provide transaction-like semantics for manipulating groups of displays. For example, we needed to be able to allocate content to a collection of displays and only display this content iff we could do so on all of the displays simultaneously. To ensure a satisfactory experience it was essential that this could be achieved without partial transitions becoming visible – essentially we required the properties of atomicity and isolation (or at least a variation on isolation that we term visual isolation [14]). Our fourteenth lesson is thus: *"ensure that users do not experience partial or inconsistent changes in system state"*. We suspect that this requirement to manipulate groups of ubicomp components and constrain the visibility of state changes generalizes beyond display networks such as e-Campus but this is an area of future research.

Managing User Expectations

During the course of our deployments we experienced several problems that were a direct result of our failure to properly manage user expectations. Three examples illustrate the problem. First, we found that once the system was operational for a short period people assumed it would continue to be operational for the foreseeable future. In most of our deployments we needed test periods where information was displayed on the actual displays in-situ but the system itself was still under development. This testing period caused significant confusion in the minds of the public. Secondly, once the system was operational we failed to adequately communicate our access polices hence people either didn't contribute content because they didn't realize they could or they asked for inappropriate content to be displayed. Finally, we note that blank displays implicitly create an expectation of content to come (or more worryingly the perception of a broken system). This is one area in which projections on surfaces already present in the environment have a significant advantage over conventional displays. Our fifteenth lesson is therefore *"in any public ubiquitous computing deployment it is crucial to manage user expectations"*.

Related to the issue of user expectations we note that a specific feature of work on public displays is that the research output is, almost by definition, visible to members of the public. As a result press and public interest is high. Our sixteenth lesson is a word of caution, *"prepare yourself, your team and your work for public scrutiny"*. In practice this manifested itself for us in terms of numerous press interviews and the need to respond to a Freedom of Information Act request (this is a piece of UK legislation that enables members of the public to request information from any public body – in our case this was a request for the details of our spending on the Underpass deployment). In the end all of the information we provided was used in a very positive fashion by the recipients which was most gratifying.

4 Related Work on Display Deployments (possible sidebar)

In this section we briefly review related work on public displays to place our deployments in context. The largest deployments to date can be found within the commercial sector. These systems provide information and advertising specifically tailored to local audiences in public spaces, such as airports, train stations and shopping centres. Such deployments are usually supported by commercial signage software and hardware such as Sony's Ziris system. This system offers customers web-based tools for editing content and schedules (Ziris Create), solutions for transferring content and schedules to possibly remote sites (either using FTP or interfacing to an existing content distribution network) (Ziris Transfer), playout solutions using either proprietary hardware and software or standard PCs (Ziris View), and web-based tools for management, monitoring and reporting (Ziris Manage). Around 300 Ziris-based displays have recently been deployed to a small number of stores of a UK supermarket chain as a part of a six-month trial of the system. Displays in each store source content from a feed of 10-20 different channels of revolving content.

We are also currently witnessing a growing number of displays deployed for entertainment reasons. The BBC's "Big Screens" [4] are examples of this type of deployment. These daylight-viewable screens provide a display surface of twenty-five square metres and are currently installed in central locations in six major cities in the United Kingdom. The screens provide a rich set of media that is partly adapted to and contributed by the local community they are installed in. While the BBC has always encouraged contributions of content to the big screens, e.g. of media produced by visual artists, experiments are currently under way to enable the general public to interact with the screens and to provide content. At this moment in time, people are able to send messages the screens using their mobile phones, and to participate in interactive collaborative games that are based on crowd movement in front of the screens.

Finally, there are a large number of experimental deployments of public display systems to investigate specific research questions [13, 9, 10, 2, 12, 11, 8, 15]. Most deployments in this context tend to be rather small in scale and not very long lived. However, a small number of projects [6, 3] have been subjected to larger-scale longitudinal studies. [3] describes the results of a deployment of a small number of displays in a research lab over total a period of 14 months. In [5, 6] fellow members of the e-Campus project outline their experiences gained during the iterative design and a longitudinal deployment of Hermes, a digital doorplate system.

[4] `http://www.bbc.co.uk/bigscreens`

5 Conclusion

In this paper we have presented a series of sixteen lessons that we believe will be valuable to researchers deploying ubicomp systems in public spaces. These lessons are based on our specific experiences of deploying three public display systems as part of the e-Campus project. However, we believe the lessons are likely to be generally applicable to many different types of public ubicomp deployment.

We are currently embarking on a major new set of deployments of our display system. These range from equipping all of the offices in our Department with digital doorplates through to a second multi-projector install in the foyer of our campus theater. We are using the lessons we have described in this paper to help ease the process of creating these new deployments.

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