

# Augmented Reality 2.0

Dieter Schmalstieg, Tobias Langlotz  
Institute for Computer Graphics and Vision  
Graz University of Technology  
Graz, Austria  
{schmalstieg, langlotz}@icg.tugraz.at

Mark Billinghurst  
The HIT Lab NZ  
University of Canterbury  
Christchurch, New Zealand  
mark.billinghurst@hitlabnz.org

**Abstract.** Augmented Reality (AR) was first demonstrated in the 1960s, but only recently have technologies emerged that can be used to easily deploy AR applications to many users. Camera-equipped cell phones with significant processing power and graphics abilities provide an inexpensive and versatile platform for AR applications, while the social networking technology of Web 2.0 provides a large-scale infrastructure for collaboratively producing and distributing geo-referenced AR content. This combination of widely used mobile hardware and Web 2.0 software allows the development of a new type of AR platform that can be used on a global scale. In this paper we describe the Augmented Reality 2.0 concept and present existing work on mobile AR and web technologies that could be used to create AR 2.0 applications.

## 1. Introduction

*Augmented Reality* (AR) is an area of research that aims to enhance the real world by overlaying computer-generated data on top of it. Azuma [Azu97] identifies three key characteristics of AR systems: (1) mixing virtual images with the real world, (2) three-dimensional registration of digital data and (3) interactivity in real time. The first AR experience with these characteristics was developed over forty years ago [Sut68], but mainstream adoption has been limited by the available technologies.

Early Augmented Reality applications ran on stationary desktop computers and required the user to wear bulky head mounted displays (HMDs). Despite the ergonomic shortcomings with this configuration, there have been successful applications developed in certain domain areas, such as industrial assembly [Miz00], surgical training [Sie04] or gaming [Son09]. However the cost of these systems, and the technical expertise needed to use them has prevented widespread use. Despite this, monitor-based AR advertising applications by companies such as Total Immersion<sup>1</sup> and Metaio<sup>2</sup> are beginning to be available for non-expert users.

Recently, AR experiences have begun to be delivered on mobile phones. Researchers such as Möhring [Möh04] and Wagner [Wag08b] have shown how phones can be used for computer vision based AR tracking, while companies such as Layar<sup>3</sup> are deploying compass and GPS based mobile outdoor AR experiences. However, widespread use of AR-based mobile technology that allows “Anywhere Augmentation” away from the desktop has not yet been realized.

In this paper, we describe how recent developments in mobile and web technologies allow Augmented Reality applications to be deployed on a global scale and used by hundreds of thousands of people at the same time. We call this approach *Augmented Reality 2.0*, a combination of the terms *Augmented Reality* and *Web 2.0*. Although our focus is on mobile AR,

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<sup>1</sup> [www.t-immersion.com](http://www.t-immersion.com)

<sup>2</sup> [www.metaio.com](http://www.metaio.com)

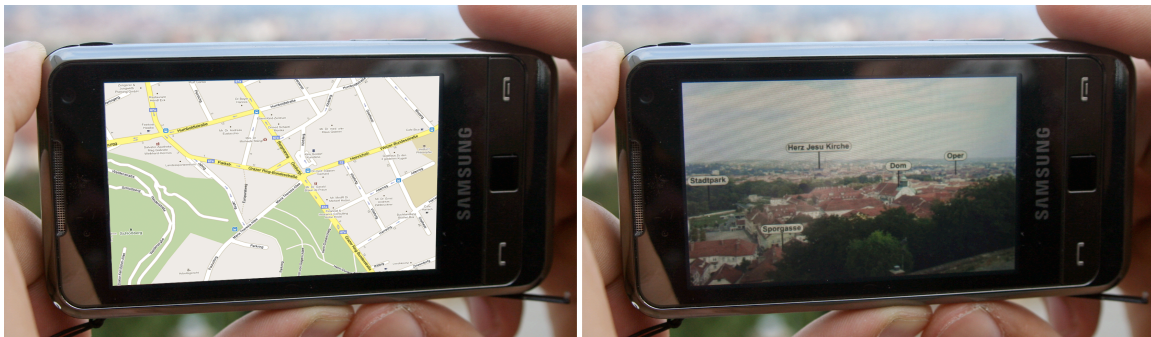
<sup>3</sup> <http://layar.com/>

we also realize that there will be continued developments in HMD and monitor based AR applications that will increase their ease of use and deployment.

Like mobile phone AR, Web 2.0 is itself a recent development. O'Reilly<sup>4</sup> mentions that the main difference between Web 1.0 and Web 2.0 technologies is that Web 2.0 enables end user creation of web content, and thereby encourages social networking. In contrast, the original web technology was mainly used for one-way information retrieval. Only few people made content, while most users accessed information without creating or modifying it. Web pages were mostly static and did not allow the users to interact with them or provide additional information.

The advent of Web 2.0 substantially changed the way people use the Internet. Instead of only retrieving content, users are engaged in creating and modifying web material. Web interfaces have become simplified to a point that even people with no technical skills could create content. This has opened the way for services based on user participation, like Flickr<sup>5</sup>, YouTube<sup>6</sup> and Facebook<sup>7</sup>, among others.

In a similar way, the goal of AR 2.0 is to provide widely deployable location-based mobile AR experiences that enhance creativity, collaboration, communication, information sharing and rely on user generated content. With an AR 2.0 platform a user should be able to move through the real world and see virtual overlays of related information appearing at locations of interest, and easily add their own content. Figure 1 shows how this might look.



**Figure 1: Contrary to traditional map displays (left), AR 2.0 will augment navigation information on top of the images captured by mobile phones (right). Users will also be able to create and update 3D registered content, creating a location-based social network.**  
(Image courtesy of Graz University of Technology)

This information overlay will be dynamically generated from a variety of sources and seamlessly fused together on the users handheld display. In addition, the user will be able to generate their own location-specific virtual content, that can then be uploaded to content servers and shared with others. Finally, the platform will provide support for social networking through synchronous and asynchronous context-sensitive data sharing. AR 2.0 as a user experience and networked medium has many parallel characteristics to Web 2.0 (See Table 1).

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<sup>4</sup> <http://www.oreillynet.com/pub/a/oreilly/tim/news/2005/09/30/what-is-web-20.html>

<sup>5</sup> <http://www.flickr.com/>

<sup>6</sup> <http://www.youtube.com/>

<sup>7</sup> <http://www.facebook.com/>

**Table 1: Comparison of Web 2.0 and AR 2.0 characteristics**

<b>Web 2.0 Characteristics</b>	<b>AR 2.0 Characteristics</b>
Large number of users and web sites (already true for Web 1.0)	Large-scale in number of users as well as working volume
No clearly visible separation between accessing local data and remote data	No clearly visible separation between visualizing local data or remote data
Applications running in a browser behave like local applications, encouraging the user to interact with them	Applications locally running on the device can transparently download modules or new features from remote servers
A huge amount of non technical people retrieve data and contribute or modify it as well	Users can create or update the AR content at specific locations
Information from different sources can be combined and create a new value-added application, in so-called <i>Mashups</i>	<i>Mashups</i> which access data from sources like traditional web services and combine them with AR content to display them in three-dimensional space

If AR applications are going to be deployed on a massive scale in an AR 2.0 approach, there are several key areas of technology that are needed:

- (1) A low-cost platform that combines AR display, tracking and processing
- (2) Mobility to realize AR in a global space
- (3) Backend infrastructure for distribution of AR content and applications
- (4) Easy to use authoring tools for creating AR content
- (5) Large-scale AR tracking solutions which work in real time

In the remainder of this chapter we first discuss the related work that provides the enabling technologies for AR 2.0. We then explain the use of AR for social networking, end-user authoring for AR 2.0, and finally present several case studies of early AR 2.0 applications.

## **2. Related Work**

AR 2.0 builds on earlier work in several areas, in particular research in mobile AR, social networking, and location-based services. In the late 1990s, the first experiments were conducted on presenting geo-referenced content in AR applications. The Touring Machine [Fei97] was the first mobile outdoor AR application and was used as a campus tour guide by showing virtual annotations on real university buildings. Although simple, this prototype showed the power of in-situ presentation of geo-referenced information.

Since then the increasing computing capability of personal mobile devices has made it possible to move AR systems from the backpack AR systems of the mid-nineties to Tablet PCs [New06], PDAs [Wag03] and then mobile phones [Möh04]. Nokia's MARA<sup>8</sup> project is an example of the Touring Machine idea ported to the mobile phone. Figure 2 shows sample systems in this evolution. Most recently, commercial applications such as Wikitude [Mob09] can show location-tagged AR content on a mobile phone in much the same way as the Touring Machine.

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<sup>8</sup> <http://research.nokia.com/research/projects/mara/>



**Figure 2: Evolution of Mobile AR Systems: Desktop Windows driven Tablet PC with weight about 1.2kg, ~1500 Dollar (left), PDA with external camera and limited communication capabilities (middle), Smartphone with built-in camera and various communication channels (GSM/3G and Wi-Fi) and low weight (100g), ~300 Dollar (right). (Image courtesy of Graz University of Technology)**

While the mobile AR hardware platform was changing, there was also progress being made on the software platforms. The emergence of the Web as a mass phenomenon prompted Spohrer to suggest the “WorldBoard” [Spo99], a combination of distributed online information systems and geo-referenced indexing. Information could be published in a traditional web form, but was indexed by geographic position rather than by a symbolic URL. The short-term goal of the WorldBoard was to allow users to post messages on every cubic meter of space humans might go to on the planet, while the long-term goal was to allow users to experience any information in any place, co-registered with reality.

Unfortunately, the WorldBoard vision was not fully realized, partly because key technologies such as community content creation tools were not mature enough. Later work, such as the Nexus project in Stuttgart [Hoh99], has similar concepts but targeted coarse geo-referenced information systems rather than Augmented Reality presentation.

Today, we see a new mass phenomenon, which has been dubbed Web 2.0. This is characterized by open communication, decentralization of authority, and the freedom to share and re-use Web content [Bar06]. It is also driven by collaboration between users and provides a platform offering open APIs and applications that can be combined in sophisticated applications integrating information from multiple sources [Ore08].

One of the key innovations that can be supported through Web 2.0 is social networking and crowd-sourced content. Without revolutionary changes, the availability of the web has reached a point that the voluntary joint effort of literally millions of users can produce databases of a size and quality that has previously been considered impossible. For example, Wikipedia<sup>9</sup> has already surpassed many traditional encyclopaedias in coverage and richness, and Flickr is one of the largest collections of digital images worldwide. As a side effect, it was found that simple keyword tagging is powerful enough to replace sophisticated semantic web techniques as an organizational principle. The open architecture of the Web 2.0 services allows everybody to enrich these experiences with *Mashups* (Information from different sources that can be combined to create a new value-added application), while advertising pays for the underlying infrastructure. It is important to note that all these results are based on simple existing technologies such as HTTP and *Asynchronous JavaScript and XML* (AJAX).

As part of the Web 2.0 movement, digital globe and map services have become very popular – Google Earth<sup>10</sup>, Google Maps<sup>11</sup> and Microsoft Virtual Earth<sup>12</sup> among others. While the primary

<sup>9</sup> <http://www.wikipedia.org/>

<sup>10</sup> <http://earth.google.de/>

source of data of these applications is produced by large enterprises at a high cost and level of effort, it is noteworthy that the results are still made freely available via the Web 2.0 ecosystem.

Using these map services, next generation web technologies may be used to link physical places, objects and people to digital content. This is often called Ambient Intelligence (AmI) [Aar01], a research field that explores the convergence of mobile, ubiquitous and intelligent systems (e.g. context-aware systems) and interaction with real objects. Another project is Deusto Sentient Graffiti [Deu09], which consists of an application that allows users to create annotations associated to real places using context and location data with Web 2.0 infrastructure. It aims to show the potential of Mashups, using the capabilities of mobile devices, Web 2.0 as a platform, ubiquitous computing web paradigms and social annotation of objects and places.

Deusto Sentient Graffiti is based on AJAX technology and using real objects to offer URL tags to XML virtual post-its. These post-its have multimedia content or a pointer to a web service and contextual attributes. Users of the system can move through an annotated environment, and browse and consume the available annotations according to the user's current context, profile and preferences. Servers store, index and match user annotations against the user's current context published.

The final key area of related work is social networking. Many mobile devices have adapted versions of web-based social networking applications such as Facebook for the Apple iPhone<sup>13</sup>. However, with mobile devices, social networking applications can also be developed based on the device location and other context cues.

There are many popular mobile social applications, which use these context cues. In Dodgeball [Dod09] users receive text messages of friends, and friends of a friend if they are within ten blocks of each other. The location-awareness is implemented by user's entering their location and time or using the IDs of cell towers. Plazes [Pla09] is a location/context-aware system that relies on the Internet infrastructure to serve information about services and nearby friends. Localization is based on GPS, and MAC addresses of networks and WiFi access points. Rumble [Rum09] helps mobile users locate nearby friends, or even strangers with the same interests and offers them access to location-related data. Jabberwocky [Jab09] performs repeated Bluetooth scans to create the sense of the "familiar stranger" in an urban community. Familiar strangers are people that are always nearby in an urban region but are acquaintances. Serendipity [Eag05] uses Bluetooth technology to facilitate interactions between physically proximate people through a centralized server. Through the identification of Bluetooth IDs and support of on-line profile matching, Serendipity identifies new people to become acquainted with.

As can be seen there has been related work developed in a number of areas, including social networking, location-based services, and mobile AR. However, there have been few examples of applications that combine all these areas. In the next section we discuss how this previous work can be integrated into a platform for developing AR 2.0 applications.

### **3. Augmented Reality for Social Networking**

A low-cost hardware platform for AR is important for realizing our vision of AR 2.0. Today's smartphones satisfy all basic requirements of a hardware platform for AR 2.0. They combine networking, a display, and graphics hardware capable of 3D rendering. Furthermore, smartphones offer enough computing power to track the device using the build-in camera, with the optional assistance of various other sensing technologies like GPS, WiFi triangulation and accelerometers. Smart phones are inexpensive as they are produced for a mass market and there are currently

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<sup>11</sup> <http://maps.google.de/>

<sup>12</sup> <http://www.microsoft.com/virtualearth/>

<sup>13</sup> <http://iphone.facebook.com/>

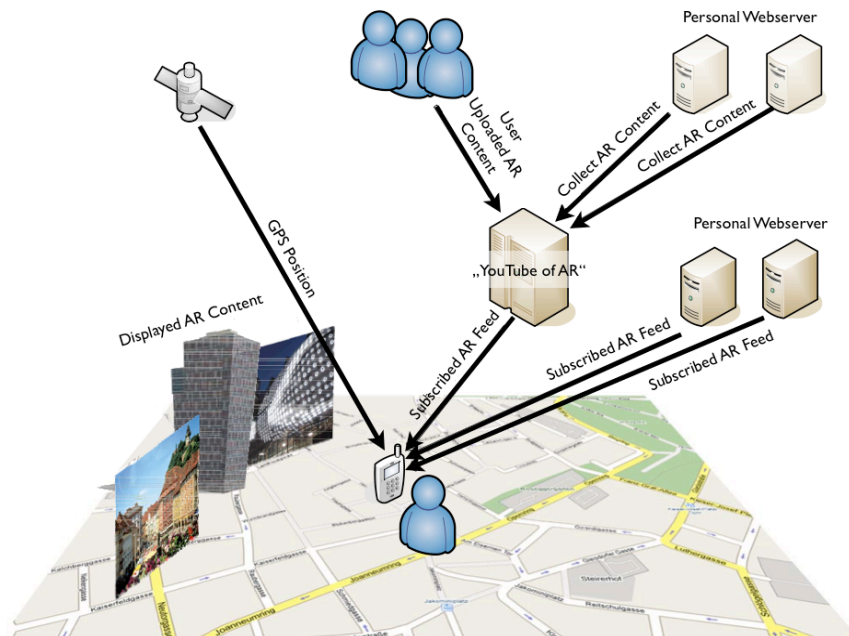
hundreds of millions sold per year. This momentum ensures a large-scale in terms of number of users and broad geographic coverage.

A further feature of smart phones over older mobiles phones is their capability to communicate over various channels. They use third-generation mobile phone communication technology (3G), which is optimized for data rather than voice traffic, while WiFi and Bluetooth complete the set of supported fast communication channels. This makes it possible to access the Internet using higher bandwidth to request additional content or program modules, and allows applications to remove the separation of local and remote data.

Spohrer's vision of "information in places" can be realized by using smart phones as the hardware platform and Web 2.0 as the backend infrastructure. Web 2.0 owes its success largely to open standards, which allow interested parties to easily partake in an economy of scale. Likewise, the success of AR 2.0 will require a federated approach and especially open formats for content description and content exchange.

An interesting common standard is the *Keyhole Markup Language* (KML), an open and extensible XML dialect utilized by Google Earth. It incorporates Placemarks which describe geo-referenced information, and also refers to other web standards for multimedia content. For example, 3D models (essential for AR) are described as COLLADA files, an XML-based 3D exchange format increasingly supported by digital content creation tools. However, while KML is an open format it still has a lot of properties that are proprietary to Google Earth. Thus it is only partially suitable for describing AR content, which could be referenced in many ways (geo-referenced, using barcodes, other AR tracking systems, etc.). Consequently, we suggest adopting ideas from KML into a new open format called *Augmented Reality Markup Language* (ARML), which describes the AR content and its spatial reference system.

As shown in Figure 3, a location-based AR application uses data and services remotely stored and served by web Mashups, visualized on the mobile device. Data and services offered to the user must be related to geospatial information corresponding to user location – using GPS, WiFi or a vision-based tracked scene, for example – and a geo-database web services. Content authoring can be performed using a desktop computer or directly on the mobile device while on location. Taking advantage of open APIs and Mashups, complex applications can be easily broken down into smaller components and leverage existing online services. Given appropriate sources of geo-referenced data, developers can focus on the user experience of AR 2.0 applications.



**Figure 3: Data flow of end-user provided content in an Augmented Reality 2.0 scenario.  
(Image courtesy of Graz University of Technology)**

Specific AR data types can easily be integrated into the XML dialects, and hosted using standard web-based databases, accessible via HTTP. New types of Mashups, which are specifically designed to be consumed by AR clients, can be derived from a mixture of existing (conventional) content and content specifically created for AR. This will include visual objects, other multimedia data, application code and the feature database necessary for local tracking.

The selection of content by the user can be performed using either a push mechanism or a pull mechanism such as a webservice capable of accepting simple HTTP queries encoding the current location or area. This allows everybody with access to a server to provide geo-referenced AR content, either genuine or based on data accessed via mash-up. In addition, larger service providers (the “YouTube of AR”) can syndicate content provided by many users and organized through tagging. Such syndicated content-hosters would allow a wide audience to publish their material, and also provide easy access for the mainstream audience.

For consuming the AR content, we expect that an end-user device has subscribed to content feeds from a number of AR service providers, based on personal taste and recommendations from others. At a given location, the device sends a request containing its current position and other context information to all these service providers and receives an index of available content. The request can ask for all information in a user-defined radius around the current point of interest, or it could describe an area in an alternative form, for example all data along a route to a given destination. The exact details on which information to download and/or to present to the user and how the user interface lets the user control what he or she sees, is entirely up to the client. All of these approaches are possible without modifying the server side infrastructure.

For example, if an online service for image recognition from a large database of geo-referenced images is available, this service would act as a filter: The client device takes a picture and sends it to the recognition service, possibly assisted with GPS coordinates to reduce the search space. If the image is recognized successfully, the recognition service returns an exact position match, which can then be used by the client to query for content.

Another approach is the use of 2D barcode markers, such as DataMatrix<sup>14</sup> or QR-Code<sup>15</sup> (see Figure 4), which contain enough information to point to a specific web address of an AR content service. This can substitute the need for GPS or image recognition, and directly point to specific content rather than having to know a specific server feed or channel beforehand. It is also a suitable method for non geo-referenced content, for example downloading an AR game board game printed and advertised in a newspaper. If barcode markers are used, they can also initialize tracking, and thereby establish a common frame of reference (for a shared space of multiple users), while ongoing tracking can be based on natural features in the surroundings.



**Figure 4: QR-code based AR advertising application.**  
(Image courtesy of Graz University of Technology)

#### **4. Application Development and Authoring**

Although mobile devices provide a good hardware platform for AR experiences, there is still a need to create the content that is going to be viewed and also author the AR 2.0 application. Most web-based social services provide tools for easy content creation. However, there are no such tools yet for AR 2.0 experiences.

In developing AR 2.0 applications there are several aspects that must be considered; the application data, programming the mobile AR client interface and creating a representation of the real world. In this section we consider each of these aspects in turn.

Authoring in an Augmented Reality 2.0 ecosystem can be transformed from a monolithic problem into one that can be simultaneously addressed with a multitude of tools. Authoring activities range from genuine creation of new applications from ground up to simple Mashups with only minimal original contribution. The key factor is that standard file formats can be used at least for passive content. Work on actual content creation will likely be done primarily on the desktop, while layout may either be performed on the desktop (e.g., using a map of the area), or in-situ. For many instances of application logic, wizards can be created (for example, for AR Magic Books or a timeline-based self-running presentation), which makes the task accessible for end users with little programming experience. Complete integrated development environments for code-centric applications are also conceivable.

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<sup>14</sup> <http://datamatrix.kaywa.com>

<sup>15</sup> <http://www.denso-wave.com/qrcode/index-e.html>



#### 4.1 Application Data

As described in the previous section, AR 2.0 applications involve the aggregation of multiple data sources depending on users' needs. Combining multiple data sources through open APIs into a complex "Mashup" application makes it easier to create mobile social software:

- (1) Complex social network algorithms and huge databases can be processed on servers, offering light-weighted data and services to clients;
- (2) Mash-ups can use the benefit of existing social networking applications and other related applications to concentrate in designing features truly related to mobility, pervasiveness, location and context awareness;
- (3) APIs (like GoogleMaps<sup>16</sup>) and geo-databases can be used to create geospatial mash-ups, simplifying the development of location-aware social software;
- (4) User preferences and other data that might be used to infer context can be gathered from web sources and combined with mobile client acquired data.

A possible extension is the use of AJAX for live client-server collaboration. If the content is represented at the client side as a document object model, for example as an X3D compatible scene graph, then a client-server connection, e. g., based on XML and Javascript, can be used to shift the execution of parts of the application logic to the server. This avoids lengthy downloads, allows exploitation of the greater computational power of the server and facilitates multi-user applications. In many cases it should be possible to mask the latency of network transmission using the asynchronous, multi-threaded execution model of AJAX. Applications that are not just passive browser of AR information and that cannot be encoded with a simple approach such as Javascript, will have to be provided in binary form, forsaking platform independence. However, even platform-specific downloads are a large step forward towards the interoperability of AR applications compared to current approaches.

#### 4.2 In-Situ Reconstruction and Authoring

One of the most important aspects of AR 2.0 is how the representation of the real world is captured. This is necessary so that AR 2.0 content can be attached to real world locations and objects. Of course, simple configurations can be created from markers, and environments that are planar (such as a wall) or near-planar (such as a façade) can simply be photographed and then turned into tracking targets with an automated tool. We also assume that wide-area geo-referenced information sources, such as a database of streets and even textured 3D models of buildings, are available through large geo-data providers. Moreover, large collections of geo-referenced photos are already available through image services. However, this does not solve the immediate problem of creating 3D models of specific environments or registering user-generated content in such an environment.

Early work in in-situ authoring focused on placing virtual objects in the real scene and supported users through triangulation from different views [Bai01] or working plane constraints [Pie04]. Another approach, which allows the user to create AR applications in place, was presented in [Lee04]. Here the designer can interact with the virtual world by using a marker-based tangible interface. Another example is sketchand+ [Sei03] an AR collaboration tool geared towards urban planner and architects. The approach was to annotate design proposals with 3D sketches, text snippets and audio clips in order to communicate processes, design decisions and other spatial artefacts to peers.

More recently, systems have been demonstrated that simplify the task of arranging virtual objects in 3D through constrained modelling. Wither et al. [Wit08] presented a system that uses a single point laser range finder to measure the object surface. Afterwards an annotation can be stuck to

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<sup>16</sup> <http://code.google.com/apis/maps/>

that object and automatically aligned to the surface of the object. A pure camera-based approach to specifying the location and orientation was demonstrated by the University of Cambridge [Rei06] [Rei07] by integrating an online model estimation framework to extract the 3D geometry of the real world and place annotations automatically with respect to it.

### 4.3 Client Application Development

There has been little previous research on client authoring tools for end-user AR 2.0 applications, although there are several existing authoring tools for building AR applications and for mobile phone applications that provide a useful starting point. These can be broadly organized into two types: 1) AR authoring tools for programmers, 2) AR authoring tools for non-programmers. These categories can be further organized into low-level tools which require coding/scripting skills, and higher-level application builder tools which use higher-level libraries or visual authoring techniques (see Table 2).

**Table 2. Types of desktop AR authoring tools**

	<b>Programmers</b>	<b>Non-programmers</b>
Low-level	ARToolkit[Kat99] arTag[Fia05]	DART[Mac04] ComposAR[Don08]
High-level	Studierstube[Sza98] osgART [Gra05]	AMIRE[Gri02] BuildAR[Bui09]

Low-level AR computer vision tracking libraries such as ARToolKit [Kat99] can be used to calculate camera position relative to physical markers. However, in order to develop a complete application more code needs to be added for 3D model loading, interaction techniques and other utility functions. High-level programming libraries such as Studierstube [Sza98] and osgART [Gra05] provide a complete system for developing AR applications. Studierstube includes all of the functions needed for building an AR application such as scene graph rendering, networking, window management and support for input devices, etc.

There is another set of authoring tools that have been developed for non-programmers. At the most basic level, tools such as BuildAR [Bui09] allow users to associate virtual models with visually tracked AR markers, but there is no support for object interaction or more complicated behaviours. A more complete system is DART [Mac04], the Designer's AR Toolkit. DART is a plug-in for the popular Macromedia Director software which allows non-programmers to create AR experiences using the low-level AR services provided by the Director Xtras and to integrate them with existing Director behaviours and concepts.

Although there are several tools for building desktop AR applications, there is less support for mobile AR. These tools can be summarised in table 3. At the low-level, the ARToolKit tracking library has been ported over to the Symbian operating system [Hen05] while the Studierstube tracker library [Wag08a] runs on multiple mobile platforms such as Symbian, iPhone and Windows Mobile.

**Table 3. Authoring tools for mobile phones**

	<b>Programmers</b>	<b>Non-programmers</b>
Low-level	Studierstube Tracker [Sch08] ARToolkit for Symbian [Hen05]	Python <sup>17</sup>
High-level	Studierstube ES [Sch08] M3GE <sup>18</sup>	FlashLite <sup>19</sup>

One of the few higher level programming libraries for mobile AR applications is the Studierstube ES [Sch08] (StbES) library. This is a C/C++ based application framework for developing AR applications for mobile devices. Studierstube ES provides support for 2D and 3D graphics, video capture, tracking, multimedia output, persistent storage and application authoring. For non-AR applications there are mobile 3D game engines such as the Java M3GE library that can be used for image loading, input, output, and general functions like AI, collision detection and other 3D rendering facilities.

For non-programmers, there is no mobile AR authoring tool but Python is available for rapid development of non-AR mobile applications. The Symbian version of Python<sup>20</sup> has support for 2D and 3D graphics, camera input, file handling, networking and many other functions for rapidly prototyping mobile applications. Users can develop python scripts on their desktop and then run them on their phone using a native interpreter. Other high-level visual design tools are available to author mobile graphics applications. The most popular is FlashLite<sup>21</sup>, a version of the Adobe Flash Player that has been specifically designed for use on mobile phones. With this a developer can use a combination of visual authoring and ActionScript scripting to build interactive phone applications.

Developing an AR 2.0 authoring tool for non-programmers is an active area of research, but as can be seen there are a number of options for developing AR 2.0 applications using existing low-level and high-level tools.

As it can be seen, there are currently no ideal tools for authoring AR 2.0 applications. This is an active area of research. However, there are methods that can be used for content aggregation, rapid prototyping and in-situ authoring. Over time these will progress from being low-level developer libraries to tools that can be easily used by non-programmers.

## **5. Case Studies**

Although large-scale deployment of AR 2.0 applications has not occurred, there have been several mobile AR experiences that display features that are needed in such applications. In this section we report on several mobile AR case studies that teach important lessons for developing complete AR 2.0 applications.

### **5.1 Mobile AR Advertising**

For AR 2.0 applications one of the challenges is how to deliver AR experiences to mobile devices on a massive scale. Traditionally AR applications have been preinstalled on devices or just distributed to a small number of users. However, recently researchers have begun to explore

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<sup>17</sup> [http://www.forum.nokia.com/Resources\\_and\\_Information/Tools/Runtimees/Python\\_for\\_S60/](http://www.forum.nokia.com/Resources_and_Information/Tools/Runtimees/Python_for_S60/)

<sup>18</sup> <https://m3ge.dev.java.net/>

<sup>19</sup> <http://www.adobe.com/products/flashlite/>

<sup>20</sup> <http://www.forum.nokia.com/python>

<sup>21</sup> <http://www.adobe.com/products/flashlite/>

mobile AR advertising experiences that need to be widely distributed and so address the AR 2.0 deployment challenge.

In 2007 the HIT Lab NZ delivered the world's first mobile AR advertising campaign. Working in collaboration with Saatchi and Saatchi<sup>22</sup> and the Hyperfactory<sup>23</sup>, they developed a marketing campaign for the Wellington Zoo in Wellington, New Zealand. For three days in a local city paper an advertisement was printed with a number that a code could be texted to (see Figure 5, left). When the reader sent a text message to the number they were sent back a small 200K application that they could run on their mobile phone. When the application was running they could point their mobile phone at the printed advertisement and see a virtual zoo animal, such as a cheetah, popping out of the newspaper page (see Figure 5). This appeared overlaid on a live video view from the phone camera. To achieve this, a mobile AR application was written using the Symbian port of ARToolKit [Hen05], which combined a 3D model loader with marker-based tracking.



**Figure 5: Wellington Zoo Mobile AR campaign: Printed AR Advertisement (left), Virtual Zoo Animal Appearing (right). (Image courtesy of the HIT Lab NZ)**

Although the AR application being delivered was very simple (just a single static model), there were challenges in being able to freely distribute a mobile AR advertisement outside of the lab environment. In this case the application was built for Nokia N-series mobile phones running the Symbian operating system, such as the N95 and N72 phones, etc. This meant that code on the application server needed to detect the type of phone that the text message came from. If the phone was not an N-series phone then the AR application was not sent since it could not be run. Instead a picture was sent back showing what the AR application would have looked like if the phone could have run it. There were also different versions of the application that needed to be developed depending on the N-series phone model that was being used. If the text message was sent from a Nokia phone then there was a specific executable sent to the mobile phone depending on the model of phone it was.

In addition there were challenges in creating the AR content. The initial virtual models delivered were designed for desktop applications. Significant work needed to be done to reduce them down to the size that they could be rendered in real time on the mobile phone.

Despite the work involved, the advertising campaign was a success. Attendance at the zoo increased, there was a large amount of press generated and Saatchi and Saatchi won several advertising awards for the innovative use of leading edge technology. Since that time several more campaigns have explored different aspects of AR marketing. In all cases the most challenging aspects have been the content creation and application distribution, not the application programming.

<sup>22</sup> <http://www.saatchi.com/worldwide/index.asp>

<sup>23</sup> <http://www.thehyperfactory.co.nz/>

Although not a complete AR 2.0 application, this simple application shows both the impact that mobile AR applications can have and also the challenges that must be addressed in terms of content creation and application distribution.

## 5.2 Content Delivery

One of the key challenges of AR 2.0 applications is how to provide location-based delivery of software and services. For example, when a person is visiting a new city location they may want to be able to automatically download AR tags of building names and virtual comments that other visitors have left at that location.

Mobile service providers typically use 3G or GPRS to deliver content to the handset. However, this is often expensive (especially with service providers that charge for data transfer) and the 3G service isn't location-specific.

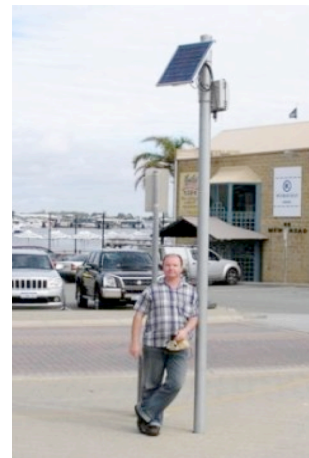
Researchers at the Australasian CRC for Interaction Design (ACID)<sup>24</sup> have been exploring an alternative delivery method that could be useful for AR 2.0 applications. The first version of this is an embedded device supporting transfer of digital content to and from nearby mobile phones. Called the InfoPoint, this is a small Linux computer connected to wired networking and Bluetooth hardware that can detect when mobile phones are within range and then use Bluetooth to automatically push content on the phone. In this way location-specific applications or data (such as text, image, audio and video files) can be delivered to phones at no cost to the end user, exploiting the use of the mobiles as 'third screens' [Gog06]. The design intention behind InfoPoint is to manage and deliver situated content for mobile phone users without the need for custom software.

The InfoPoint access hardware was tested in a heritage trail tourist application in the Fishing Boat Harbour in Fremantle, Perth in 2008. This was an adaptation of a guidebook prototype that supported the upload and download of situated content by mobile phone users running custom software. The prototype used LightBlue to support Bluetooth features (OBEX) that avoided the need for users to install client software [Che05, Sch06]. The unit was solar-powered, sealed for protection against the coastal climate and mounted on a traffic pole (see Figure 6). It also included a web interface for Fremantle Council to remotely manage content and review logs.

When users with Bluetooth enabled mobile phones walked within 30 meters they were asked if they would like to receive historic information about the site. If they accepted, they received an mp3 file with an audio dramatization of a letter written by a Captain D.B. Shaw in 1892 describing Fremantle as 'the worst damn hole I ever saw.'

The system was tested over several months during which the InfoPoint detected an average of 600 distinct phones each day. The installation highlighted issues related to long-term real-world deployments. Only around 5% of users accepted the offer to receive the digital content, showing reluctance on the part of users to download unsolicited content. There were also major variations found in Bluetooth interfaces between mobile phone models and wide variations in familiarity with Bluetooth-based interaction, with a strong generational bias.

As can be seen, the InfoPoint prototype delivers rich media content to visitors' mobile phones, providing a platform for research into mobile experiences and interactions, user-generated content and system architectures. In the future the platform can be used to understand mobile phone



**Figure 6: InfoPoint Hardware.**  
(Image courtesy of ACID)

<sup>24</sup> <http://www.interactiondesign.com.au/>

users' experiences of situated content, and to explore interfaces for managing this content, with a longer term aim of exploring options for user-generated situated content.

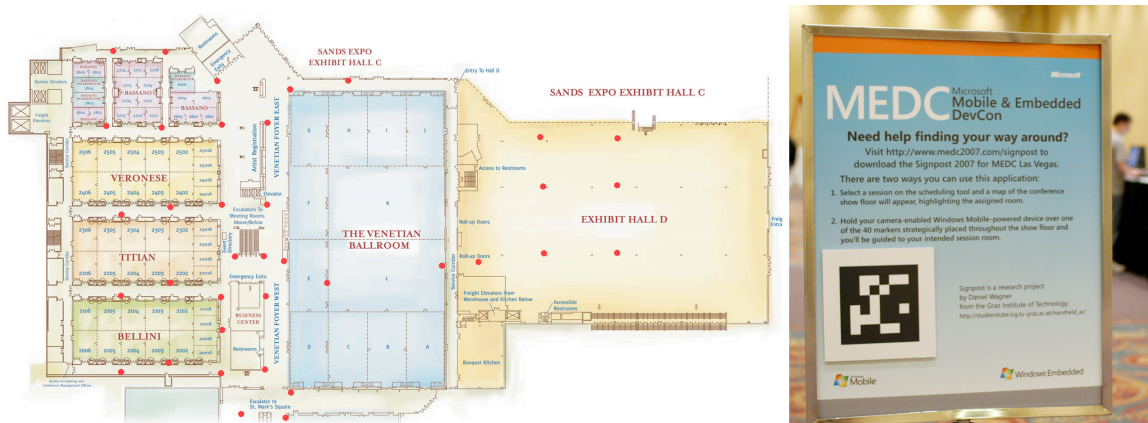
### 5.3 Signpost

Signpost is an indoor navigation system, which takes advantage of associating locations with markers, thereby providing an inexpensive, building-wide guide executing solely on the end user's camera-enabled mobile phone. While previous work on barcode-based location tracking, such as applications requiring 2D-barcodes (e.g. QR Codes), rely on non real-time "snapshot" processing, our approach continuously scans an environment in search for navigation hints. The navigation therefore scales from sparse, strategically placed fiducial markers to continuous navigation in 3D with AR overlays.

Pose tracking-based on fiducial markers is a well-established mechanism in AR. Unlike natural feature tracking it is highly robust and works well under varying lighting conditions. Furthermore, efficient algorithms for detecting and estimating the pose of these markers exist, making the approach highly suitable for devices with minimal processing capabilities such as mobile phones. Although marker tracking systems can do 6 degree-of-freedom (DOF) pose estimation, in Signpost we typically use only 3DOF to reduce the effort in creating a building model (map), thus making the system more practical. Full 6DOF tracking can still be used for advanced interaction mechanisms. Deploying our system to a new location consists of three steps: (1) creating a map and database of marker locations, (2) deploying markers on-site and (3) finally making the software available to potential users.

The mobile phone software activates the phone's built-in camera and continuously scans for markers at video frame rate. Since the phone is not a dedicated appliance, it was important to achieve a performance allowing the phone to remain highly responsive without disrupting regular cellular services.

Based on the technology presented in the previous section, we created a location-based conference guide, Signpost, which was deployed at several large trade conferences with thousands of attendees. The application is designed to work typically with sparse tracking to limit deployed markers to a manageable number. The left image in Figure 7 shows the location of 37 markers that were installed at the conference site in the Venetian Hotel Las Vegas, an area of roughly 100x200m.



**Figure 7. Marker placement for Signpost 2007 at the MEDC 2007 conference in an area of roughly 100x200 meters. Red dots mark locations of posters with instructions and markers (left). Poster with instructions and marker for tracking (right). (Image courtesy of Graz University of Technology)**

While the 6DOF tracking can deliver centimetre-level accuracy when markers are tracked, presenting only 2D location on a map reduces accuracy requirements considerably. This was

found important as conference organizers have to consider the logistics of deploying and inspecting marker placement. The most efficient way that was developed after consulting conference organizers was to stick markers onto poster stands which can be quickly deployed on-site at pre-planned locations (see Figure 7). The poster stand also attracts attention and provides details on how to download the application from the local Wi-Fi network.

The core function of Signpost is its combination of a conference calendar and a navigation system. The conference calendar can be browsed using various filters such as per-day, per-session or full-text indexing. Live RSS updates from the Wi-Fi network make sure the latest changes are reflected in the schedule. All calendar entries are linked to locations, so that the navigation module can compute the fastest route from the current location (sampled from the last seen marker) to the desired lecture hall. The results are displayed on a map that can be freely navigated by panning, rotating and zooming relative to a marker or using phone hotkeys.

For large events in venues with multiple levels or buildings, a single map is no longer sufficient. Signpost therefore supports multiple maps linked to a 3D overview, or alternatively an interactive 3D representation of the building showing the global geographic relationship of the current location and the target location (see Figure 8).



**Figure 8. Switching between maps (left), 3D view of the building with the current user's location (middle), Built-in AR mini-game (right). (Image courtesy of Graz University of Technology)**

A built-in Augmented Reality mini-game challenges users with a treasure hunt. In this game, each marker in the environment holds a specific 3D game object such as a company logo (see right image in Figure 8). The game objects only appear in the AR video view. A user managing to collect all game objects may register for a prize drawing or win a conference hat.

## 6. Next Steps

In this chapter we have described the concept of the AR 2.0 platform and have also discussed some early case studies that show technology that could be used to develop that platform. However before AR 2.0 applications become commonplace there are an important number of next steps that must take place. In particular important work needs to be conducted in the following areas, among others; Localization and Registration, Application Development, and User Evaluation.

### 6.1 Localization and Registration

In order to provide compelling AR 2.0 applications there is a need for research on better methods for outdoor localization and registration. Early AR systems developed for outdoor use relied on GPS for position measurements and magnetic compasses and inertial sensors for orientation [Fei97, Hoe99, Bai01, Tho98, Pie01]. Recent examples, such as Nokia's MARA project [Gre06] and Wikitude [Mob09] work on mobile phones and exploit the embedded sensors, including GPS, accelerometers and a compass. However, GPS is only typically accurate to about 10 meters, creating large registration errors for virtual objects and its reliability significantly deteriorates in urban environments due to shadowing from buildings. Indoors, the

GPS signal is usually unavailable. Similarly, inertial sensors are prone to drift and magnetic sensors are disturbed by local magnetic fields encountered in urban environments.

Computer vision techniques can be used to overcome these limitations. These directly rely on the image to be augmented, so the placements of virtual images can be accurate up to the pixel. The camera pose is estimated by matching image features and minimizing the re-projection error of these features in the image. This is an active area of research. The University of Cambridge has demonstrated a fast edge-based 3D tracking algorithm [Dru99] and successfully applied it to Augmented Reality in [Kle03] and [Kle04]. EPFL developed a feature-point-based system that matches points with reference images and also tracks feature points over time to prevent drift and jitter [Vac03].

The recent developments of feature point descriptors such as SIFT [Low04] or SURF [Bay06a] allow for fast matching of the captured image against a set of reference images. EPFL also developed an approach called Ferns that is computationally more efficient but requires more memory [Ozu07]. These techniques can be used for accurate, autonomous and robust initialization. These techniques have been tried in localization methods by matching captured images against databases of geo-referenced images [Siv03, Nis06, Mob09b]. Some authors demonstrated that techniques from this category perform relatively well with large datasets of city landmarks [Phi07, Phi08]. However, these approaches require large amounts of memory, and are not feasible on mobile devices.

Both sources of information, image matching and geo-location sensors, represent a promising area of research but the final goal should be to develop systems combining both sources. Reitmayr developed one of the first handheld augmented reality devices that rely on a combination of edge-based tracking, inertial sensors and GPS to perform robust and accurate 3D tracking in outdoor conditions [Rei06, Rei07]. More recently, [Tak08] uses the SURF local descriptor and fast computation of near-neighbour using kd-trees to match images. Running feature extraction and matching on the client-side against a local database of features determined by the current GPS estimate allowed real-time performance. Schall et al. showed a system that compensated the error of a digital compass and inertia sensors using a vision based panorama tracker [Sch09] presented in [Wag10]

One of the main problems is that mobile phones have limited processing power, while computer vision algorithms typically perform heavy computations. Hence we require improved computer vision tracking algorithms for AR. In 2003 the ARToolKit library was ported to Windows CE [Wag03] and creating the first self-contained AR application on an off-the-shelf embedded device. This evolved into the ARToolKitPlus [Wag07] and heavily optimized Studierstube Tracker [Wag08a] libraries. Most recently the first natural feature tracking solution running at frame rate on mobile phones was developed. Wagner et al. [Wag08b] modified the SIFT [Low04] and Ferns [Ozu07] approaches and created the first real-time 6 Degrees-of-Freedom natural feature tracking system running on mobile phones.

## 6.2 AR 2.0 Application Development Areas

Once AR 2.0 hardware and software platform technology has been developed there is future work that can be conducted in exploring possible application areas. Some of the possible application areas include the following:

**Personal city exploration:** Users can create and browse recommendations, comments and hints about tourist places, restaurants, bars and shops and leave personal, user-generated content created by tourists and citizens for others in the community. This would form an ideal test-bed for the usefulness of the interfaces for selecting and creating content, and system scalability.

**Urban sub-culture:** Providing tools for young people to express themselves creatively, such as virtual graffiti, where the mobile phone can be used as a spray can, city tagging with exciting



media, or video and image diaries that are related to a certain location. In this way a virtual dimension is added to street art. It can also be used to mark cool locations and organise events.

**Culture information:** Professional content can be experienced for cultural highlights and sight-seeing spots in the city. Cultural objects can be enriched by virtual media that explains its origin and significance for the city. The accurate overlay of digital 3D reconstructions or adequately historical images can simulate a view into the past. Users can contribute with their annotations, post comments or recommendations.

**Urban planning:** Planned, virtual architecture can be viewed within the real environment of the city. This provides a completely novel way in which architects and urban planners can visualise and examine their visions. The same data can be kept open for the public to give interested citizens the chance to comment on planned constructions.

**Urban maintenance:** People responsible for maintenance of the city infrastructure can retrieve important status information on site, coordinate with other staff members and create and anchor their own situation assessment and status reports. Here AR makes it possible to accurately mark critical spots or objects and provide valuable annotations for an efficient and flawless handling of maintenance or emergency cases.

### 6.3 User Evaluation

An important part of AR 2.0 development will be to evaluate prototype interfaces and provide guidance to on-going application development. Evaluation methods for handheld augmented reality applications are only beginning to emerge. Early examples are the evaluation of AR Tennis [Hen06] and the Virtual AR Guide [Wag06b] applications. However, those tests were performed with only small user groups in very formal test setups. In the future there will be a need to move beyond the state of the art by developing novel methods for evaluating AR user interfaces designed for large-scale use and social networking applications with many simultaneous users.

Most of the published AR research has been on enabling technologies (tracking or displays, etc), or on experimental prototype applications, but there has been little user evaluation of AR interfaces [Dun07]. For example, in 2005 Swann et al. [Swa05] produced a literature survey reviewing all of the AR research papers from leading journals and conferences and they found that less than 8% had any formal user evaluation as part of them. Thus there is a need for examples of user evaluations of AR applications and development of new methods for AR user evaluation. The HIT Lab NZ has since then developed a report reviewing all of the known AR user studies to the end of 2008, again identifying key gaps in the research literature [Dun08]. One of the areas with smallest amount of research is on evaluation of collaborative systems with only 10 out of total of 161 AR papers with user evaluations focusing on collaborative applications, or just 6% of all known AR user studies.

There is research that needs to be conducted in the evaluation of the social network and collaborative communities facilitated by the AR 2.0 platform. Numerous papers have been published on the evaluation of social networks, the effectiveness of social networking visualization tools [Hen07, Tur05], social network user interfaces [Riv96], impact on collaboration [McD03, Don99] and user behaviour in social networks [Acq06, Vie04], among other topics. However, there has been little previous work on user studies of location-based social networking, such as [Bur04], and no work on the evaluation of augmented reality for location-based collaboration. Many of the evaluations of social networks have been focused on qualitative methods such as user surveys and interviews, and not quantitative measures. There is a need to conduct research in evaluation of augmented reality for location-based collaboration and also develop new evaluation methodologies that can be used by the broader research community for these types of user studies.

## 7. Conclusions

In this chapter we have described the concept of AR 2.0 and showed that Augmented Reality technology has developed to the point that it can be widely deployed on handheld devices and consumer-level hardware. Furthermore, we showed how the Web 2.0 infrastructure and tools allow user-generated content to be created and shared with social networking communities. Taken together these recent developments allow us to create location-based AR experiences that can be enjoyed on a global scale.

Early case studies show the potential for using mobile phones for experiencing AR content, for widespread deployment of AR applications and for experiencing AR real world navigation tasks. However, these studies have also identified important issues that need to be addressed in terms of the user experience, installing applications and tracking user location.

In the future, before AR 2.0 applications become commonplace, there are important research issues that must be solved in terms of device localization and registration, building demonstration applications, and conducting user evaluation.

## 8. Acknowledgements

This work was sponsored partially by the Austrian Science Fund FWF under grant no. Y193 and grant no. W1209, the Christian Doppler Laboratory for Handheld Augmented Reality as well as the EU funded project MARCUS (FP7-PEOPLE-IRSES-2008-230831). The authors would like to thank Istvan Barakonyi for contributing many important ideas.

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