Interface, information & interaction:
An exploration of Mobile Augmented Reality present and future
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Cover image
The augmented-reality mode in Nokia City Lens overlays information about local businesses on top of a live camera view (Credit: Ariel Zambelich/Wired CC BY-NC 3.0 Source: http://www.wired.com/gadgetlab/2012/05/hands-on-nokia-city-lens-beta-augmented-reality-for-your-lumia-phone/)
Mobile Augmented Reality (MAR) is an emerging technology that will be made more accessible by the increased availability of high-speed broadband. This paper was written as part of a project exploring the use of mobile augmented reality as a tool for public engagement with scholarly and scientific activity.

In this paper we outline the current state of MAR technology from the overlapping perspectives of interface, information and interaction. Information in this paper is based on a review of industry and academic sources during April-July 2012.

First we examine MAR technology from an interface perspective, looking at the methods of triggering an augmentation experience (input) and methods of delivering an augmentation experience (output).

We then review MAR from an informational perspective, looking at content delivery media and prevailing use case categories, with a closer examination of specific case studies within the fields of science, education and the built environment.

Following on from this we look at MAR from an interaction perspective, offering a use case categorisation based on user agency rather than informational content.

We then categorize the kinds of software tools that can be used to create MAR experiences, and provide a listing of selected tools that are currently available.

Finally, we conclude with a discussion of current technological limitations and likely trends in the next three to five years of MAR development.

Readers interested in designing MAR experiences for science communication as well as other outcomes should find this document to be a useful starting point.
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1. **Interface**

To understand the possibilities of MAR from an interface perspective, it is helpful to consider the ways in which augmentations can be triggered (input) and expressed (output). It should be noted that input and output methods are not mutually exclusive.

Also, for the purposes of this paper we have taken the handheld computer (smartphone and tablet) as the sole interface device for the MAR experience. Emerging and potential interfaces such as eyeglasses and contact lenses will be addressed in the section on MAR futures.

1.1 **Type of augmentation trigger (input)**

Also called the method of registration, this is the means by which the interface device determines that an augmentation exists and should be delivered to the user. There are currently three ways to trigger the delivery of an augmentation using MAR:

1.1.1 **Vision**

With this method the interface device uses computer vision technology to “see” if any augmentations are in its field of view. The user frames an object or image in the device viewfinder, as if to take a picture. The camera then compares the object or image against a library of images that has been provided to the MAR application. If a match is found, the application will then deliver information that has been associated with the image.

Augmentation triggers that use computer vision fall in one of two sub-categories:

- **Fiducial marker**: An image consisting of a black frame with a distinct, high-contrast pattern inside, the earliest and most familiar example being a Quick Response (QR) code. These markers are usually attached to an augmentation target such as a building, billboard, poster or product.

![Figure 1: Example of a QR code (Credit: Mathieu Ploduce CC BY 2.0)](image-url)
• Markerless (natural feature tracking): Markerless tracking is the next evolution in computer vision for MAR applications. By mapping the corners and edges of natural features within the landscape – or in printed images – the camera is able to match the augmentation target with its corresponding reference image in the application database.

1.1.2 Location

With this method the interface device uses its location sensors to determine if any augmentations are nearby. The user enables Global Positioning System (GPS) sensing on the device, allowing the MAR application to search for augmentations that have been associated with GPS coordinates in the vicinity. Using other location and orientation sensors built into the device, including Wi-Fi, compass, accelerometer and gyroscope, the application can further determine a user’s position relative to an augmented point of interest (POI). Once the user is within the required proximity to the POI, and correctly oriented toward it, delivery of the associated augmentation is triggered.

It should be noted that GPS has an error margin of 10 metres, is easily disturbed by metallic objects and electromagnetic interference, and does not work indoors. As such, many newer MAR applications are moving away from location-based triggers – or using them in tandem with computer vision techniques to improve accuracy.

Figure 2: Example of a markerless image used to trigger an augmentation (source: ARLab)

Figure 3: Yelp’s augmented reality feature, Monocle (left) and an augmented view of Paris (Credit: Peter Morville CC BY 2.0)
1.1.3 Other sensors and data networks

Vision and location are currently the predominant methods of triggering MAR experiences, but other kinds of machine sensing have also been used. The iOS app Inception and its follow-up game Dimensions use “just about every sensor and gizmo” inside the interface device – including microphone, accelerometer, clock and camera – to monitor ambient noise and light levels, speed, time, date and other environmental factors, augmenting audio feedback in real time as these data points shift.

As discussed further in the MAR futures section of this paper, the slow but steady growth of sensor networks embedded in the physical world (i.e., the ‘Internet of Things’) will also create opportunities for MAR experiences that are triggered by these data networks.

1.2 Type of augmentation expression (output)

These are the means by which the physical affordances of the interface device are used to deliver an augmentation experience to the user. Broadly speaking, these means of output fall into the one of the following three categories:

1.2.1 Visual

The display unit (screen) of the device is used in the manner of a camera viewfinder, with augmentations overlaid on the view of physical reality. These augmentations can take the form of text, video, 2D or 3D graphics and can be static or animated. The visual MAR experience conforms most closely to the historical definition of augmented reality and is still the prevailing means of output for most applications.

Figure 4: The MAR game Time Treasure uses 3D graphics superimposed over the user’s view of the physical world (Credit: Gary P. Hayes CC BY-NC-ND 2.0)
1.2.2 Auditory

The device’s speaker (or attached headphones) is used to deliver audio-based augmentations to the user. These augmentations may be paired with other categories of output, for example as the audio track of a video-based augmentation. They may also stand alone, as with the Inception and Dimension applications referenced above.

Figure 5: LocoRadio is a MAR audio browsing system that immerses the user within a shifting soundscape derived from a custom, geo-tagged audio database (Credit: MIT Media Lab)

1.2.3 Haptic

If the interface device contains a motor that enables vibration, as is common in most smartphones and some tablet computers, it can be used to deliver tactile augmentations to the user. Haptic feedback is less common in MAR than in other realms of augmented reality, though researchers have identified it as an area of possible growth⁵,⁶.

Figure 6: A haptic AR demo at TEDx Adelaide by Christian Sandor of the University of South Australia’s Magic Vision Lab, using a head-mounted display and haptic-feedback stylus called Phantom. (Credit: RIAUS and TEDx Adelaide)
2. **Information**

To understand the possibilities of MAR from an informational perspective, it is helpful to look at the different ways in which information can be conveyed (content media) and the most common contexts within which MAR is currently being used (use case categories).

### 2.1 Content media

Based on the handheld computer as the prevailing interface device, the following content media are currently available for delivering informational aspects of a MAR experience:

- text
- audio
- video
- 2D graphics (photos/illustrations)
- 3D graphics (static and animated)
- haptic feedback (vibration)

### 2.2 Use cases

The number of potential use cases for augmented reality continues to grow as the technology matures. Looking specifically at MAR, implementations of the technology can be found across the following categories:

- marketing
- games and entertainment
- navigation and wayfinding
- arts and culture
- health and science
- education
- built environment

As the authors of this paper have a primary research interest in MAR applications relating to the latter three categories, we shall examine representative use cases from each of these categories.

#### 2.2.1 Health and science

While non-mobile variations of augmented reality are readily found within the fields of health and biomedical science – for example to assist with visualisations in surgical settings – mobile implementations, particularly those aimed at the general public, have been slower to emerge. One application currently in development is HealthCare Alert, which uses GPS to notify users of public health threats in the immediate vicinity, including “contagious disease outbreaks, severe weather, radiation, auto break-in areas, contamination, polluted water and other health threats.” The application developers say that users will be able to “see” through walls and be aware of health threats nearby using HealthCare Alert’s augmented reality features. The app also allows users to add localized health threats to the database and view threats that other users have added, create a personalised risk profile, and subscribe to personalised reminders for preventative services.
Moving away from healthcare and into the realm of science communication, the MIGHTy project explores augmented reality as a tool for public engagement with scientific research. The project aims to expose people to research being done at different points along a relative scale of the universe, with an emphasis on nanotechnology. Two players wearing AR-enabled eyeglasses manipulate QR cubes in cooperation with each other, attempting to match pieces of information that will ‘unlock’ 3D animations of researchers talking about their work. While not technically a mobile implementation of augmented reality, the portable exhibit is nonetheless an interesting example of AR in the context of informal science communication.

2.2.2 Education

MAR has elicited a great deal of interest from the education sector, inside the classroom and beyond. Informal educational MAR apps include Star Walk and Star Chart, both of which use GPS positioning to superimpose an annotated astronomical map over the view of the night sky as seen through the viewfinder of user’s device.

Many “guided tour” MAR applications use this same annotational model to provide educational content about earthbound geographical areas, augmenting sites of cultural and historical significance with relevant information about those sites. One such example is the DiscovAR Dunedin app, which augments the New Zealand city with more than 450 pieces of historical and contemporary information that users can explore.

Within the context of formal education there are both commercial and academic initiatives exploring potential applications of MAR. Commercially there are developers such as Melbourne-based Curiosity Lab, which creates locative and augmented reality games for curriculum-based learning. Their Identi-tee project sends students on a city-wide exploration of their own cultural and family history and culminates in the students developing their own MAR application and other digital artefacts using off-the-shelf software solutions. In this instance MAR is used not only as a vehicle to deliver and explore educational content, but also as a tool...
to “foster collaboration, build empathy, enhance ICT and communication skills.”

At the University of Canberra in Australia, the newly established ARStudio is a two-year project that will explore applications of augmented reality to “expand our concept of learning spaces, to create new dimensions in mobile learning and to increase connectedness of learners in multiple contexts.” At the studio’s inaugural AR Camp in June 2012, academics, teachers and students convened to discuss potential applications for AR in education. Examples included Chinese language acquisition, music education and development of ICT skills.

2.2.3 Built environment

There are numerous applications of MAR that incorporate the built environment. Common scenarios include cultural, industrial and architectural use cases.

As mentioned above, the “guided tour” model is a common cultural application of MAR. Continuing our examination of DiscovAR Dunedin, the experience incorporates many features common to the guided MAR tour: physical markers on points of interest (POIs) to indicate the presence of augmentations; navigational tools within the application itself to help users find their way to POIs; filters that allow for the discovery of POIs based on location and interest categories; and the ability to save and share content delivered by the application.

The content itself encompasses video, audio and still photographs, and uses the motif of architecture to tell the story of Dunedin from the 1840s to present day. As the authors of the application note, “In some places the past melds nicely with the present while in many places it is difficult to recognise your location the way it once was.” The authors refer to the negotiating of this dissonance as “the challenge of merging time and place” – which seems a valid assessment of such experiences.

Other cultural use cases include more conceptual and artistic applications such as the 110 Stories project. The project functions as a downloadable app that helps users in New York City orient their viewfinder to the former location of the fallen World Trade Center towers. The application then superimposes a hand-drawn silhouette of the towers over their original location in the New York City skyline and allows users to take a photograph of the composite scene. Users are then encouraged to add a personal comment and upload their annotated image to a public gallery, which is viewable at the project website.
Industrial and architectural applications of MAR include visualisations of underground and internal infrastructure such as pipes,\(^1\) as well as on-site visualisations of proposed architectural designs as a tool for aiding public participation in urban planning.\(^2\)

\(^1\) 

\(^2\)
3. Interaction

To understand the possibilities of MAR from an interaction perspective, it is helpful to consider the notion of user agency. MAR researcher Christine Perey has developed a helpful model in this regard, delineating three interaction-oriented use case categories for MAR applications: Guide, Create and Play.²⁰

Informed by Perey's work, we propose the following three use case categories as a useful model for examining the interaction possibilities of MAR: Consume, Create and Connect. As with many other aspects of MAR experiences, these categories are not mutually exclusive.

**Consume:** Experiences that are primarily one-way interactions, where the user's main role is to consume content delivered by the application (i.e. text, video, 3D animation). A limited amount of input may be solicited from the user, such as content filtering preferences. Use cases include applications like the Star Walk and Star Chart astronomy applications referenced above, as well as guided city tours (though many of these incorporate options for interactivity).

**Create:** Experiences that allow or require the user to take some action to engage with the experience, such as the ability to capture, annotate and share an augmented photograph in the 110 Stories project referenced above. This category is not limited to interactions that result in user-generated content; it may include affordances for sending emails, making phone calls, or taking other actions that engage the user with the experience.

**Connect:** Experiences that require the user to engage with one or more other people in real time as an essential element of the experience, such as the collaboration required between two players in the MIGHT-y nanotechnology exhibit. Users may be local or remote. As Perey notes in her Play version of this category, use cases are not limited to games but also include manufacturing, repair and even military scenarios.
4. Software tools

The MAR software landscape resembles something of a wild frontier at the moment. A number of industry bodies are working toward standards for interoperability, in much the same way that HTML and other standards have been adopted to ensure the ongoing functionality of the Web. At present much remains unstandardized however, meaning that there are many grey areas and overlaps when trying to categorize the tools available for MAR development.

However, there is some semblance of order amidst the chaos. The majority of tools that are currently available fall into one (or more) of three categories: software development kit (SDK), browser, or content management system (CMS).

**SDK**: These are tools for creating stand-alone MAR applications. Often a mobile-specific SDK will be one option within a suite of AR SDKs offered by a particular developer. All of the major MAR browser developers offer SDKs that can create stand-alone MAR apps but which also operate as advanced content creation tools for their own browsers. Some SDKs allow for the use of GPS or computer vision triggers exclusively; a few use both. Free and licensed options exist. SDKs are primarily aimed at people with at least some software development experience – they are not a “plug and play” option.

**Browser**: MAR browsers serve a somewhat similar function to their internet counterparts (Internet Explorer, Firefox, etc.), in that they allow for the discovery and consumption of content specific to that medium. They differ significantly from web browsers in that content must be created for and published to each browser individually in order to be discoverable with that browser; there is no “AR web” that all MAR browsers can access universally.

Once installed on the interface device, the browser allows the user to view the MAR content that has been developed for and published to that browser. Content typically resides on discrete “layers” or “channels” – analogous to web sites – which are often grouped by category (dining, historic sites, etc.) to aid the user in finding content of interest.

In addition to the SDK option described above, browser companies typically offer tools such as APIs (application programming interfaces) that allow developers to publish content to the browser. Free and licensed options exist, and all major MAR browsers offer both GPS and computer vision as trigger mechanisms.

**Content Management System**: Similar to the “WYSIWYG” visual interface model that is now common for managing blogs and other websites, MAR CMSs offer a simple interface for the non-technical user to create and publish content to one or several of the major MAR browsers. Free and licensed options exist, and a mix of GPS and computer vision options are available.

Please see Appendix A for a representative list of currently supported MAR software tools and their features.
5. Mobile Augmented Reality limitations and futures

MAR is no longer in its infancy, but it is by no means mature. In this section we look at the limitations still facing the technology, and identify likely trends in the next 3-5 years of MAR development.

**Hardware:** While the smartphone – and to a lesser extent, the tablet – currently predominate as interface devices for MAR experiences, there are inherent limitations to these form factors. The small screen size of smartphones, the awkward positioning often required of the user, and the obtrusive nature of introducing a phone or tablet into a scenario can make for experiences that are less than compelling.

Future MAR interfaces are likely to include head-mounted displays such as eyeglasses and contact lenses, which create a more immersive, hands-free experience. While contact lenses may be more than five years away for the general public, eyeglasses seems to be much closer on the horizon. Indeed, while a fully-realized head-mounted MAR device such as recently proposed by Google’s Glass project is yet to exist, sunglasses maker Oakley is reportedly working on a prototype that can project information directly onto lenses. In the specialist realm, Zeal Optics is already selling a GPS-enabled ski goggle that gives skiers real-time information about speed, temperature, location, altitude, distance and other relevant environmental factors. And MAR contact lenses are more than science-fiction prognostication: scientists with military funding are currently working on a contact lens that acts as a 3D panoramic video display.

![Head-mounted MAR device and user interface, as imagined by Google](Credit: Google)
**Tracking methods**: As computer vision and 3D rendering technologies continue to improve, the industry will likely also continue its move toward vision-based tracking (and away from GPS) as a method of triggering and tracking augmentations. This has the potential to improve the indoor MAR experience in particular, as GPS does not work inside buildings. It also has the potential to improve the accuracy of MAR applications overall, which has particular relevance in industrial settings and also in regard to consumer perception of MAR as a reliable and useful technology.

**Standards**: While hardware and software development continues to advance, MAR still suffers from a lack of standards for interoperability. However, given the amount of activity around MAR standards development in the recent past it is likely that standards for cross-platform content development and delivery will emerge within the next 3-5 years. These standards will likely focus in particular on an open format for compressed 3D graphics as well as standards for presentation (output) and user interaction.

As the MAR environment becomes more standardized, it is likely that MAR-specific mobile browsers will be eclipsed by all-purpose mobile browsers that include MAR functionality.

**Expanded definition of MAR**: As MAR technology matures it is likely that the very definition of the technology will expand, moving away from exclusively audio-visual experiences to incorporate tactile feedback. However, it may be more than 3-5 years before this mode of interaction moves beyond simple vibrational feedback and into the more expressive realm of “feeling each tiny hair” of a spider in MAR pop-up book, as imagined by AR researcher Helen Papagiannis.
6. Conclusion

There are many facets to the MAR experience, including considerations of interface, informational content and user interaction. Each of these aspects could be explored in greater depth – for example, is the built environment also an interface element in guided tours? Are there optimal or innovative ways to organize and present information using MAR? Has the technology finally matured to the point where we might soon see more compelling applications and interactions – a MAR ‘killer app’? (And what are the usability issues that have hampered the industry to date in this regard?)

We hope this brief technical overview provides a clear picture of the current state of the art of MAR technology, and a useful starting point for the consideration of more theoretical questions such as those suggested above.
# Appendix A: Mobile Augmented Reality (MAR) development tools

<table>
<thead>
<tr>
<th>Software</th>
<th>OS</th>
<th>Cost</th>
<th>Trigger method</th>
<th>Notes</th>
<th>URL</th>
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<tbody>
<tr>
<td><strong>Software Development Kit (SDK)</strong></td>
<td></td>
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<tr>
<td>D’Fusion Studio</td>
<td>Android</td>
<td>free</td>
<td>GPS vision (markerless)</td>
<td>Claims to have a suite of SDKs, including mobile, but the all-in-one 'Studio’ is the only available download.</td>
<td><a href="http://www.t-immersion.com/">http://www.t-immersion.com/</a></td>
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<td></td>
<td>iOS</td>
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<td>Vuforia</td>
<td>Android</td>
<td>free</td>
<td>vision (markerless)</td>
<td>Produced by Qualcomm</td>
<td><a href="https://ar.qualcomm.at/qdevnet/">https://ar.qualcomm.at/qdevnet/</a></td>
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<tr>
<td></td>
<td>iOS</td>
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<tr>
<td>Metaio Mobile</td>
<td>Android</td>
<td>free and paid</td>
<td>vision (markerless) GPS</td>
<td>Has a suite of SDKs for mobile, PC, web and other applications; also has simplified Creator and Junaio plug-in options.</td>
<td><a href="http://www.metaio.com/software/mobile-sdk/">http://www.metaio.com/software/mobile-sdk/</a></td>
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<td></td>
<td>iOS</td>
<td></td>
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<tr>
<td>Mixare</td>
<td>Android</td>
<td>free</td>
<td>GPS</td>
<td>Is a browser app itself, but also extendable to create custom apps based on a PDI model.</td>
<td><a href="http://www.mixare.org/">http://www.mixare.org/</a></td>
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<td>iOS</td>
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<td>Wikitude</td>
<td>Android</td>
<td>paid</td>
<td>GPS</td>
<td>SDK is separate from browser product (below)</td>
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<td>iOS</td>
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<td>ARToolWorks</td>
<td>Android</td>
<td>paid</td>
<td>vision</td>
<td>Based on ARToolKit; suite of SDKs including mobile.</td>
<td><a href="http://www.artoolworks.com/">http://www.artoolworks.com/</a></td>
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<td></td>
<td>iOS</td>
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<td>Layar Player</td>
<td>iOS</td>
<td>free and paid</td>
<td>vision</td>
<td>For the creation of Layar layers that can be embedded in stand-alone mobile apps.</td>
<td><a href="http://www.layar.com/player/">http://www.layar.com/player/</a></td>
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<td></td>
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<tr>
<td>Mixare</td>
<td>iOS</td>
<td>free</td>
<td>GPS</td>
<td>Very unclear what this app actually is, or how it's extendable. Not recommended for non-technical users</td>
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<td>Layar</td>
<td>Android</td>
<td>free and paid</td>
<td>GPS vision</td>
<td>Content can be created with Layar APIs or 3rd-party CMS tools (below).</td>
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<td>GPS vision (cannot combine methods in a single channel)</td>
<td>Content can be created with Junaio APIs or 3rd-party CMS tools (below).</td>
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<tr>
<td>Aurasma</td>
<td>Android</td>
<td>free</td>
<td>GPS vision</td>
<td>Content can be created as Aurasma layer; kernel can be embedded in existing app, or used to create skinned stand-alone app.</td>
<td><a href="http://www.aurasma.com/">http://www.aurasma.com/</a></td>
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<tr>
<td>Wikitude</td>
<td>Android</td>
<td>unclear</td>
<td>GPS</td>
<td>Content is created using Wikitude’s ARchitect framework or 3rd party CMS tools (below).</td>
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<td>Argon</td>
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<td>Hoppala</td>
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Figures

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