Chapter 20

NAVIGATION TECHNIQUES IN AUGMENTED AND MIXED REALITY: CROSSING THE VIRTUALITY CONTINUUM

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1. Introduction

Exploring and surveying the world has been an important goal of humankind for thousands of years. Entering the 21st century, the Earth has almost been fully digitally mapped. Widespread deployment of GIS (Geographic Information Systems) technology and a tremendous increase of both satellite and street-level mapping over the last decade enables the public to view large portions of the world using computer applications such as Bing Maps[1] or Google Earth[2].

Mobile context-aware applications further enhance the exploration of spatial information, as users have now access to it while on the move. These applications can present a view of the spatial information that is personalised to the user's current context (*context-aware*), such as their physical location and personal interests. For example, a person visiting an unknown city can open a map application on her smartphone to instantly obtain a view of the surrounding points of interest.

Augmented Reality (AR) is one increasingly popular technology that supports the exploration of spatial information. AR merges virtual and real spaces and offers new tools for exploring and navigating through space [1]. AR navigation aims to enhance navigation in the real world or to provide techniques for viewpoint control for other tasks within an AR system.

AR navigation can be naively thought to have a high degree of similarity with real world navigation. However, the fusion of virtual information with the real environment opens a new range of possibilities, and also a significant number of challenges. For example, so-called *AR browsers* enable the presentation of large amounts of geo-located digital information (e.g. restaurants, bars, museums,

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[1] Bing Maps, Microsoft Corporation, http://www.bing.com/maps/
[2] Google Earth, Google Inc., http://earth.google.com

shops) over the real world through a GPS-based AR handheld platform (Figure 1). Nevertheless, efficiently exploring this massive information space and presenting it to the user in a simple way remains an important research topic.

Figure 1. AR navigation with the World-Wide Signpost application [2]. Image courtesy of Tobias Langlotz.

Similarly, finding the shortest path through a multi-floor building using a handheld AR navigation system needs to address specific problems related to the topology, geometry of the building, and the registration of virtual navigation information in the real world. Using a map, directional arrows or wireframe representation of the building are some potential techniques that can be used in this context.

Beyond these standard cases, AR also provides a more seamless way to *bridge* and access other worlds, like 3D Virtual Environments, 2D digital maps, or simply the real world. Accessing or *transitioning* into these worlds using efficient location and navigation cues is still an unresolved and challenging problem.

In this chapter we will introduce some of the benefits, issues and challenges around AR navigation by presenting previous work in this area, and proposing a general navigation framework, addressing future challenges and research topics. The work we present also applies to the broader field of Mixed Reality (MR), where real and virtual information are mixed without a precise definition of which space (virtual or real) is augmented and which space is augmenting.

In the next section, we will first present the general concept of human navigation and location through space. Then we will describe our general model of AR navigation (section 3) before illustrating related work derived from our model. We classify related work by the viewpoint of the user on the spatial information, either

considering AR as a primary (section 4) or a secondary (section 5) source of spatial information.

2. Navigation

Navigation is the task of moving within and around an environment, and combines both *travel* and *wayfinding* activities. With travel a user performs low-level motor activities in order to control her position and orientation within the environment. With wayfinding a user performs higher-level cognitive activities such as understanding her position within the environment, planning a path from the current position to another location, and updating a *mental map* of the environment. This last activity requires acquiring spatial knowledge and structuring it into a mental map [3][4].

Spatial knowledge can be acquired from various sources. Darken and Peterson [3] distinguish between *primary* and *secondary* sources. A primary source of spatial information is the environment itself. As we navigate the environment, we extract information from it which we use for navigational tasks. Secondary sources of spatial information are all other sources such as a map. In the case of a user who acquires information from a secondary source, we also distinguish whether she is immersed in the environment related to the information (*e.g.*, browsing a map of the surroundings) or not (*e.g.*, browsing a map while in a hotel room).

There is still no unique model to detail how spatial knowledge is structured into a mental map. The most established model is the Landmark, Route and Survey (LRS) model of Seigel and White [5], which was later refined by Goldin and Thorndyke [6]. The LRS model defines a classification of spatial knowledge and describes the sources from which the different classes of information can be acquired. *Landmark knowledge* represents the visual appearance of prominent cues and objects in the environment independently from each other. It develops by directly viewing the environment or through indirect exposure to it (*e.g.*, looking at photographs or videos). *Route* (or *procedural*) *knowledge* represents a point-by-point sequence of actions needed to travel a specific route. It provides information on the distance along the route, the turns and actions to be taken at each point in the sequence, and the ordering of landmarks. Route knowledge can be acquired by navigating the route. Finally, *survey knowledge* represents the relationships between landmarks and routes in the environment in a global coordinate system. Survey knowledge can be acquired either by repeated navigation in the environment or by looking at a map.

Lynch [7] classifies the elements of a mental map of a city into five types: *landmarks*, *paths* (or *routes*), *nodes*, *districts* and *edges*. Landmarks are fixed reference points external to the user. They can be either distant prominent elements or local details, and their key feature is singularity. Landmarks are used as clues for the structure of the environment. Paths are channels through which a person can travel. People tend to think of paths in terms of their start and end points. The other elements of the environment are structured along and in relation to the paths. Nodes are strategic points in the environment, typically the convergence of paths. People travel to and from nodes, and wayfinding decisions

are often made on nodes. Districts are individual medium-large areas of the environment. Edges are breaks in the continuity of the environment (*e.g.*, a river or a railway), which sometimes inhibit crossing them. The context in which the information is acquired also has an impact on how the information is represented. For example, pedestrians will see a highway as an edge, whereas car drivers will see it as a major path.

As we have seen, the source and the context used for acquiring information impacts on the type of information acquired. Primary sources support landmark and route knowledge, and only after repeated navigation survey knowledge starts developing. In contrast, secondary sources can speed up knowledge acquisition – yet with a loss in quality. For example, maps directly support survey knowledge, yet the knowledge acquired from them is inferior to that obtained from repeated route traversals. This is because knowledge acquired from maps tends to be orientation specific [3]. Goldin and Thondyke [6] show that watching a film of a route can provide substantial landmark and route knowledge.

In general, a user performing navigational tasks uses various types of spatial knowledge and reasons on multiple frames of reference. For example, Goldin and Thondyke [6] show that procedural knowledge supports egocentric tasks – such as estimating the orientation and route distance with respect to their own body – better than survey knowledge. In contrast, survey knowledge better supports exocentric tasks – such as estimating Euclidean distances or the relative position of generic points in the environment. One key element is therefore *resolving the transformation between the frame of reference of the spatial knowledge and the frame of reference of the task to be performed*. The smaller the distance between the two frames of reference, the lower the burden on the user who must mentally transform between the two.

3. Enhancing navigation through Augmented and Mixed Reality

Augmented Reality is inherently bound to the frame of reference of the real world scene being perceived. As discussed previously, it is therefore crucial to identify which tasks can be supported from the AR frames of reference.

For example, AR can be used to augment the physical environment in which users are embedded. Users can therefore explore the spatial information just as they would explore the streets and the buildings in the environment. Differently, AR can also be used to overlay a table with a detailed virtual 3D visualisation of a remote location. Users can physically walk around this visualisation, reach closer to it or move further from it. In general, it is crucial to identify which tasks can be supported from the AR frame of reference.

AR and MR can be complemented by other interfaces to better support a broader range of navigational tasks. Interface designers must also consider how to transition between the multiple interfaces. This section presents a generic navigation and transitional model. It details how we can navigate an AR or MR interface and how we can move between different types of interfaces within an MR interface.

3.1 Context and Transition

Our conceptual model encompasses and extends the navigation between an inner space (like AR) to a more generic approach, considering the navigation of multiple spaces and in-between spaces (*transition*). Our model considers space from a mathematical viewpoint, and navigation as motion in this space. In this section we explain our model and how it frames navigation in AR, MR or any composite (multiple spaces) scenarios. Readers can refer to [8] and [9] for more information about the model.
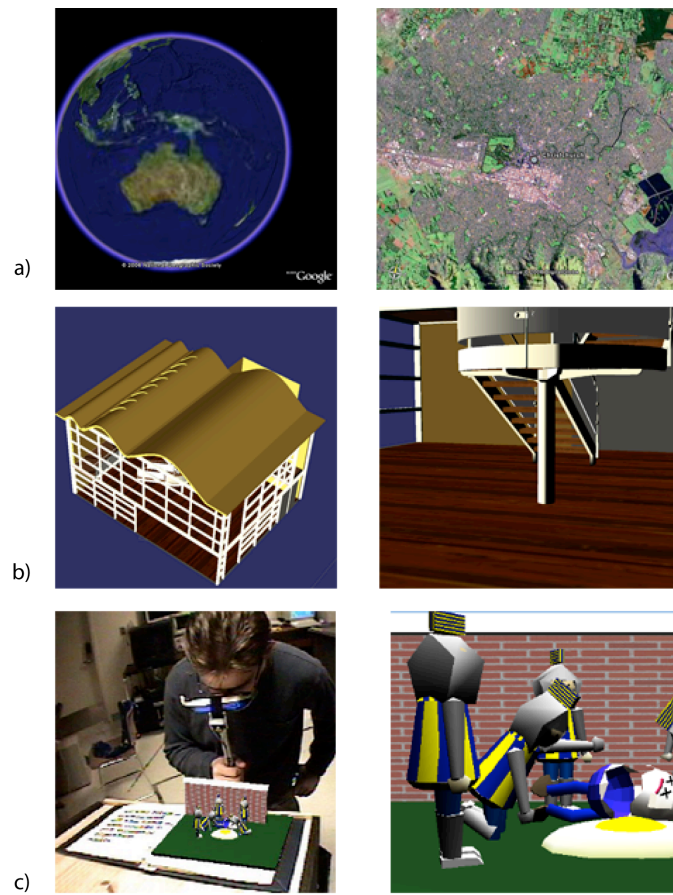
a)

b)

c)

Figure 2. Examples of different contexts: (a) different scales, (b) different viewpoints (c) different spaces.

First, we introduce the notion of *Context* related to an environment where users can collaborate and interact within (Figure 2). A context not only defines a *space* (e.g. AR, VR, Reality) but it can define a *scale* (e.g. macro, micro, nano, etc.), a *representation* (e.g. photorealistic, non-photorealistic, symbolic), and any other user parameters (such as *viewpoints* and *navigation mode*). Thus, a context is the collection of values of parameters relevant to the application. For example, one context may be defined as an AR space, on a 1:1 egocentric scale with cartoon rendering and a walking navigation metaphor.

In each context, the user has one (or multiple) *viewpoint(s)* related to the view of a task represented in this context (e.g. viewing a 3D virtual model of a future hospital building). The location of the viewpoint in or out of a task representation defines the egocentric or exocentric viewpoint (e.g. inside the building or "God's eye view" of the building). Different viewpoints can be spatially multiplexed (e.g. map, WIM, etc), so we consider the *focus view* as the primary view which has the user's attention at a certain time (the other views are defined as *secondary views*).
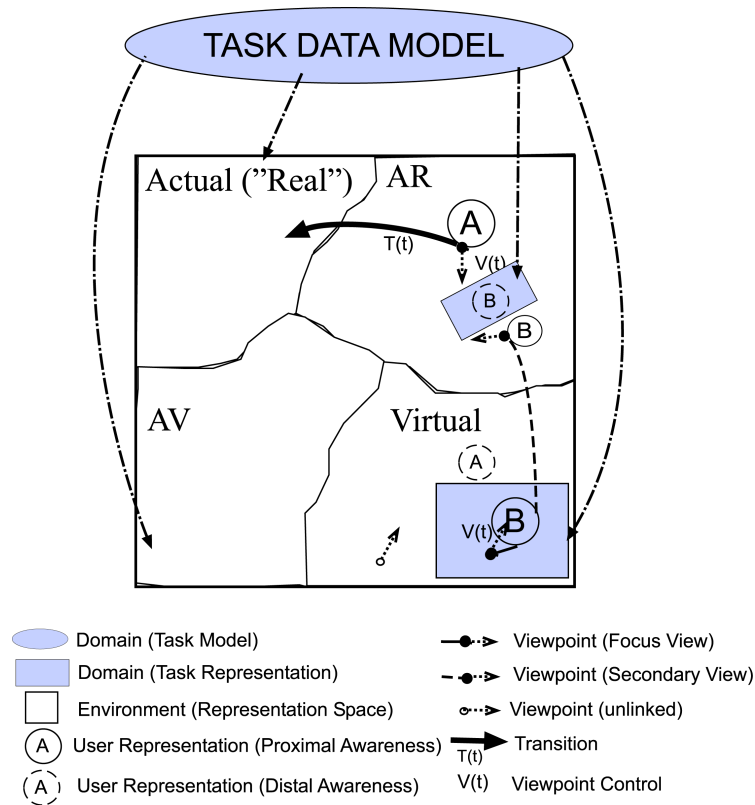

Figure 3. Transitional Collaborative Model (Contexts are associated here to the notion of Environments).

In a specific context, the user can navigate the environment, and thus has a *viewpoint control* defined by a motion function (navigation technique). To support collaboration and location awareness, we define a user representation (*embodiment*) in each context (*proximal embodiment*) and a proxy representation (*distal embodiment*). A user can navigate and manipulate content within a context but can also *transition* to other contexts (i.e. change in viewpoint, and possibly change in scale, representation and interaction). A *transitional interface* is an interaction technique supporting this concept. *Figure 3* summarizes our model.

3.2 Transitional Interface: Single-User and Multi-User

We identify two general cases based on the number of users: single-user or multi-users. Three main aspects should be considered for a transitional interface:

- What is a transition?
- How does a transition affect the user perceptually?
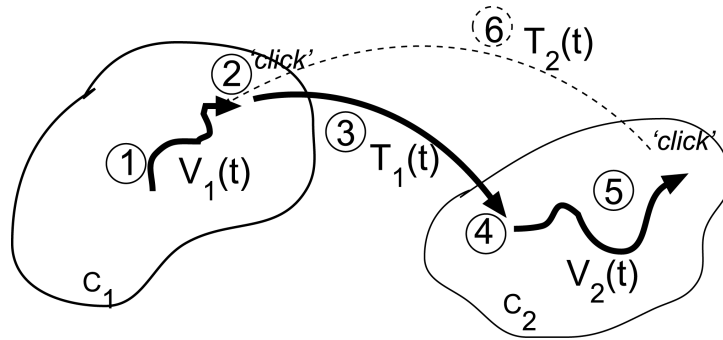- How does a transition affect interaction for the user?

Figure 4. Description of a Transitional Interface.

A transition between two contexts can be decomposed into a succession of different actions. *Figure 4* describes the steps of navigation and transition between different contexts:

1. The user moves in the first context based on a locomotion function $V(t)$.
2. The user can initiate a transition (e.g. click a position on a map)
3. The user is in a restricted mode where his view "moves" between the two contexts.
4. The user is reaching a new context.
5. The user can navigate in this new context based on a similar or new locomotion function $V(t)$.
6. The user can optionally come back to the first context, by using the same transition function (so we have the notion of `de-selection') or to another context. The user can therefore come back to his previous state on the other context (e.g. viewpoint) or can also be a new one.

Perceptual and Proprioceptive Factors

The transition function needs to take user perceptual factors into account. Recent work in this area has been limited to deliberately simple solutions: for example, a sudden switch between a view of the real world and a black VR background or perhaps a simple linear interpolation between the two viewpoint positions [10]. Bowman and Hodges [11] show that when using a teleportation mode between two different viewpoints, a user may feel disoriented, and cannot orient herself quickly in her new position. They also show that an application needs to favour a continuously smooth transitional motion (fading) rather than the discontinuous and fast approach of teleportation.

Thus, it is important to provide feedback to the user concerning the relationship between the two viewpoints. This is most often not merely smoothly interpolating between two viewpoints. It is rather a complex task that requires minimising the user's confusion during the transition while at the same time maximising the user's awareness of the fact that the context is changing. We hypothesize that these concepts need to be applied in the case of the transitional interface from a spatial and visual aspect.

The proprioception factor is thus critical. A user needs not only to be able to identify herself in the different contexts (such as by seeing a virtual hand in a VR space), but also during the transition. Furthermore, if the representation of the user is very different between contexts, she might feel disturbed when transitioning and be disoriented in the new context.

Identified Issues

Brown *et al.* [12] mention the importance of information representation during a mixed-space collaboration. This was also mentioned by Zhang *et al.* [13] in a multi-scale application. Coherence must be maintained between the different representations chosen for the application content within the different contexts. Respecting logical spatial relationships, pictorial similarity, articulated dimensionality or topology of the object representations are important criteria. Consequently, we can list the different issues that have been identified:

- *Which interaction techniques are used to initiate a transition?*
- *Which transition function is used to maintain a seamless spatial and visual representation between the two contexts?*
- *How can a sense of proprioception be maintained during the transition?*
- *How can the user come back to the previous context? Does the user need to move back to the same location?*
- *How can the application content be coherently maintained between contexts?*
- *How can coherence of the proprioception/presence be maintained between contexts?*
- *How can coherence be maintained in the interaction between contexts?*

In the case of a collaborative application, awareness of other people needs to be provided to the users. In the literature [14], the common parameters cited are:

- *Who (presence, identity of users),*
- *What (their intentions, feedback of their actions),*
- *Where (location, gaze, view feedback).*

A user is generally embodied as a virtual model replicating her behaviour – an avatar [15]. A transitional collaborative interface needs to also provide similar awareness components: between users in a same context (*proximal embodiment*), between users in different contexts (*distal embodiment*), and also during a transition step.
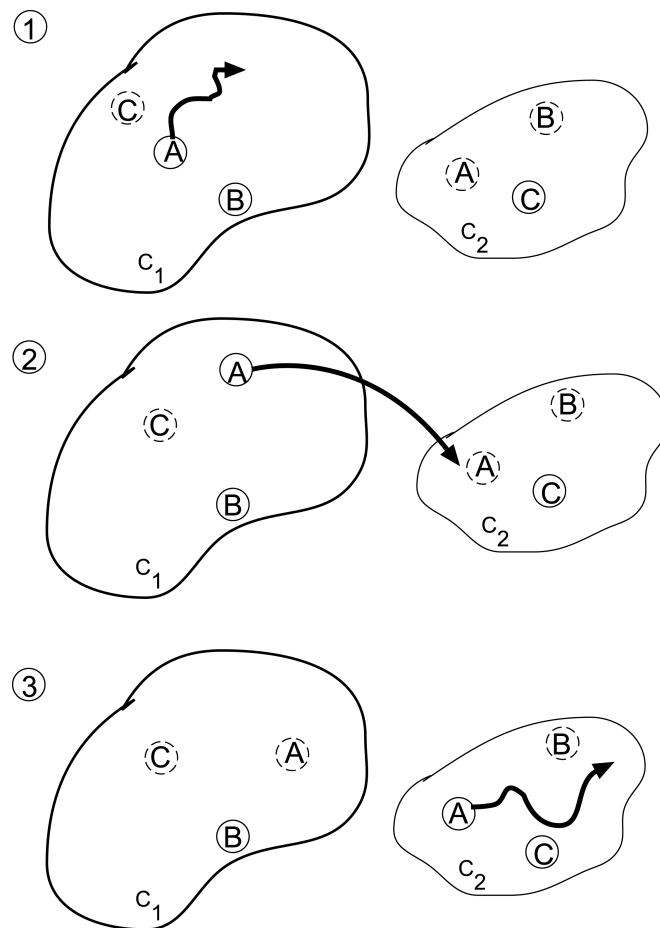
Figure 5. Steps of a user transitioning in a collaborative transitional application (solid circles represent proximal embodiment, dotted circles, distal embodiment)

Figure 5 illustrates a representative example of transitioning in a collaborative transitional application. In this scenario we have three users: user *A* and user *B* are in context 1 (c_1), while user *C* is in context 2 (c_2). We need to maintain awareness cues between users in the same context (user *A* and user *B*), but also a distal embodiment for users in different contexts (user *A* and user *B* for user *C*, user *C* for user *A* and user *B*).

When user *A* is transitioning between contexts (step 2), other users need to be aware of the transition stage. When the transition is complete, the distal and direct awareness for user *A* has changed, user *B* now has a distal embodiment of user *A* while user *C* has a proximal embodiment.

We can also list the different new issues identified for the multi-user scenario:

- *How to maintain awareness for other users while a user is transitioning between contexts? (from the start, during and at the end of the transition)*
- *How to illustrate which context the user is transitioning to and from?*
- *How to modify the proximal embodiment to a distal embodiment of a user transitioning?*
- *How to maintain co-context and cross-context awareness (co-presence, cross-presence)?*
- *How to maintain co-context and cross-context information sharing?*
- *How to maintain co-context and cross-context interaction?*

Our conceptual model supports the human requirements of accessing different representations and different frames of reference in order to perform different types of navigational tasks. Designers of AR navigation systems have the possibility to create advanced systems, considering AR not as the unique context but rather as a component that can enhance a navigation system made up of multiple contexts.
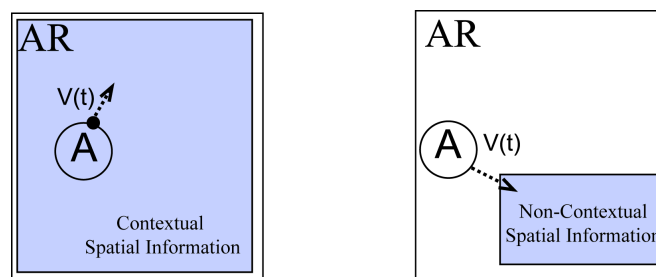

Figure 6. A user (A) using AR as a primary (left) or secondary (right) source of spatial information.

Depending on how AR is used to enhance the system, we distinguish between AR as a primary source or a secondary source of spatial information (Figure 6). In the first case, AR is applied to *augment the environment in which the user is immersed*. In the second case, AR is used to *control a vantage point over a set of spatial information*. In the following sections, we describe first how AR can be used as a primary source and subsequently how it can be used as a secondary source.

4. AR as a primary source of spatial information

By fusing the real environment with digital information, AR can be used as a primary source of spatial information. Invisible information becomes visible by superimposing it on physical entities. As the user navigates the environment, digital geo-referenced information augments his or her perception of it.

In this section we discuss the ways in which AR can be used to support navigation. We also analyse the techniques typically used to cope with two limitations of AR – distant or occluded augmentations, and off-screen augmentations. Finally, we look at which other interfaces are usually combined with AR and the types of tasks they are intended to support.

To date, most of the work on AR as a primary source of spatial information has been performed either on wearable setups or on handheld devices. This section will look at the work on both types of platform.

4.1 Supporting navigation with AR

AR can support both exploratory and goal-oriented navigation. Examples of support for exploratory navigation are annotations that provide information regarding the nearby buildings or the surrounding streets. Such annotations do not explicitly provide wayfinding instructions but they support users in understanding the environment. In contrast, an example of supporting goal-oriented navigation is an arrow or a path superimposed on the street to inform the user about the turns to take. In this case AR supports the user by explicitly embedding wayfinding instructions in the physical environment.

4.1.1 Exploratory navigation

AR supports exploratory navigation through annotations in the environment. The environment becomes an anchor for geo-referenced hypermedia databases. Users can browse the information by physically navigating the environment and looking at the various annotated objects.

One pioneering work in this field is the Touring Machine by Feiner *et al.* [16]. This allowed users to browse a geo-referenced hypermedia database related to the Columbia University campus. Users can navigate the campus and interact with the digital content overlaid on the physical buildings. Physical buildings are labelled with virtual information shown through a head-worn display. The authors intentionally label whole buildings and not smaller building features: this high-

grain labelling means that tracker inaccuracies do not affect the usability of the application.
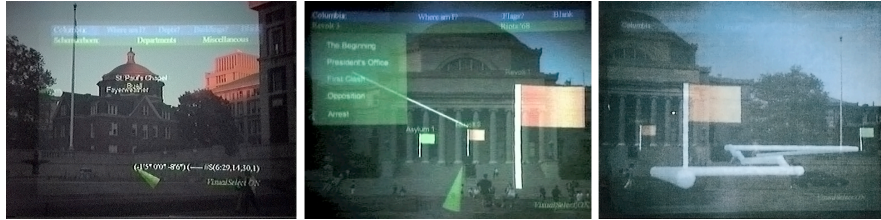

Figure 7. Exploratory (left and middle) and goal-oriented (right) navigation support in the Touring Machine [17]. Images courtesy of Tobias Höllerer. © 1997–2003, S. Feiner, T. Höllerer, E. Gagas, D. Hallaway, T. Terauchi, S. Güven, and B. MacIntyre, Columbia University.

One advantage of digital technology is that annotations can be personalized and filtered based on the user's needs and interests. Further, the annotations can present dynamic content and the physical anchors can have a mutable position.

Julier *et al.* [18] developed the Battlefield Augmented Reality System (BARS) focused on supporting situation awareness for soldiers, and informing them about the location of personnel, vehicles and other occluded objects in the soldiers' view. In BARS, AR is used for three reasons: the urban environment is inherently 3D, accessing secondary sources of information requires the soldiers to switch attention from the environment, and the information to be displayed is often dynamic (*e.g.*, the position of snipers). Julier *et al.* [19] also discuss methods for reducing information overload by filtering the visual information based on the mission, the soldier's goal and physical proximity.

The MARA project by Kähäri and Murphy [20] implements the first sensor-based AR system running on a mobile phone. MARA provides annotations related to the points of interest in the surroundings of a mobile user. Points of interest are marked with squares and their distance is written as a text label. Clicking a button on the phone while pointing the camera towards a point of interest shows further information about the point. A similar concept is implemented by the many AR browsers recently appeared in the smartphone market (*e.g.*, Junaio[3]). AR browsers are typically applications that retrieve geo-referenced content from online databases and present it to a mobile user on their phone through an AR interface (see also Figure 1).

4.1.2 Goal-oriented navigation

AR supports goal-oriented navigation by visualizing the path from one location to another directly in the frame of reference of the physical environment. An advantage of digital technology is that paths can be personalised on the fly.

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[3] Junaio Augmented Reality browser: http://www.junaio.com

A pioneering work in the field is Tinmith [21] where a user explicitly defines a desired path as a finite sequence of waypoints. Tinmith then shows the position of the next waypoint through a head-worn display. A diamond-shaped cursor is overlaid on the physical location of the waypoint. The waypoints are also labelled with textual information. More recently, Reitmayr and Schmalstieg [22] show an AR system for outdoor navigation in a tourist scenario. Once the user selects a desired target location the system calculates a series of waypoints from the current location to the target. All waypoints are visualized as cylinders in the environment connected to each other by arrows (*Figure 8*, left). The authors use a 3D model of the city to correctly calculate occlusions between the rendered path and the physical environment. The system also supports three types of collaborative navigation between users. A user can decide to *follow* another user, to *guide* her or to *meet* her halfway between their current positions. The application also implements a browsing modality for exploratory navigation.

Figure 8. Goal-oriented navigation support in AR, outdoors [22] (left) and indoors [23] (right). Image courtesy of Gerhard Reitmayr and Daniel Wagner.

Reitmayr and Schmalstieg [24] also use the same wearable setup for a system called Signpost that supports indoor goal-oriented navigation, by using a directional arrow that shows the directions to the next waypoint. Wagner and Schmalstieg [23] pioneered handheld indoor navigation systems based on AR and implemented the Signpost system on a personal digital assistant. Similar to the wearable interface, the handheld interface also uses arrows to indicate the direction of a next waypoint.

4.2 Occluded and distant augmentations

Annotations are merged with live images from a video camera. AR is therefore bound to the frame of reference of the video camera. The augmentations are constrained to the field of view of the camera and restricted to the viewpoints that are physically reachable by it. In most cases, these viewpoints coincide with the locations physically reachable by the user herself. The amount of information visible from the viewpoint of the camera can be insufficient due to occlusions or large distances between the camera and the information.

4.2.1 Depth and occlusion cues

Various navigation systems employ transparency and x-ray vision to communicate depth and occlusion of annotations. Livingston *et al.* [25] conducted an experiment to evaluate various transparency cues to communicate multiple levels of occlusion. They found that a ground plane seems to be the most powerful cue. Yet, in the absence of a ground plane users are accurate in understanding occlusions when occluding objects are rendered in wireframe and in filled with a semi-transparent colour with decreasing opacity and intensity the further they are from the user. Bane and Höllerer [26] discuss a technique for x-ray vision in a mobile context. A tunnel metaphor is used to browse the rooms of a building from the outside. Semantics of the building are used, so that a user can select the rooms one by one rather than using a continuous cursor. A wireframe rendering of the tunnel provides cues about the depth of the various rooms. Avery *et al.* [27] show a similar x-ray vision technique that employs transparency and cut-outs to communicate multiple layers of occlusion. More recently, the authors also add a rendering of the edges of the occluding objects [28] to better communicate depth relations.

Another approach is to warp or transform virtual information interactively in order to make it more legible. For example, Bane and Höllerer [26] allow selected objects to be enlarged. This zooming technique causes the AR registration to be no longer valid because the object becomes much larger than it should be in the camera view. Yet, as the user's task is the exploration of a specific object, this solution provides a much closer view on it.

Güven and Feiner [29] discuss three methods to ease the browsing of distant and occluded hypermedia objects in MARS. A *tilting* technique tilts all the virtual content upwards in order to see hidden objects. A *lifting* technique translates a virtual representation of the environment up from the ground. This makes it possible to view otherwise occluded objects. A *shifting* technique moves far objects closer to the user to explore them from a shorter distance. These techniques also break the AR registration, yet they allow for a much closer look at information that cannot be browsed with conventional AR. The authors conducted a formal evaluation of the tilting and lifting techniques compared to a transparency-based technique, and they found that they were slower than the transparency-based interface but were more accurate.

Sandor *et al.* [30] suggest using a 3D model of the city to virtually melt the closest buildings to show the occluded content behind them. Aside from the content directly visible in the camera view, the remaining content is rendered from the textured virtual models.

4.3 Off-screen augmentations

Information can be outside the field of view of the camera and not directly visible in the augmented visualization. AR systems therefore often integrate special interface elements that hint at the location of off-screen augmentations.

4.3.1 Graphic overlays

Graphic overlays can hint at the direction of off-screen augmentations. Such overlays are typically bi-dimensional and therefore operate in a frame of reference different from the three-dimensional frame of AR. These overlays hint at the direction in which a user should turn to bring the augmentation into view.

In the Touring Machine [16], a conical compass pointer is overlaid on the AR view and always points towards a selected label. A visualization element in Tinmith also hints at the location of off-screen waypoints [30]. When the waypoint is not in view, a diamond-shaped cursor appears on the left or the right side of the screen, showing the user the way to turn their head to bring the waypoint into view. AR browsers often employ radar-shaped like overlays to show the horizontal orientation of all the surrounding annotations.

The Context Compass [31] uses a more complex graphic overlay, that shows the horizontal orientation of annotations with respect to the user. It is a linear indicator of orientation: icons in the centre of the overlay represent annotations currently visible by the user, whereas icons to the side of the overlay represent annotations outside the field of view of the user. The Context Compass is designed to have minimal impact on the screen space while providing key context information.

4.3.2 AR graphics

AR graphics can also be used to hint at off-screen annotations. In this case, the hints are three-dimensional and embedded in the frame of reference of AR.

Biocca *et al.* [31] present the *attention funnel*, an AR visualization element shaped as a tunnel which guides the attention of a user towards a specific object in the environment. The authors evaluate the technique in a head-worn setup, comparing it against visual highlighting (a 3D bounding box) and a verbal description of the object. Results show that the attention funnel reduces visual search time and mental workload. However, the interface also provides visual clutter, so the user should be able to disable the tunnel when needed, or the transparency of the tunnel can be increased as the view direction approaches the direction of the object.

Schinke *et al.* [32] uses 3D arrows to hint at off-screen annotations. The authors conduct a comparative evaluation of their 3D arrows versus a radar-shaped like graphic overlay. Participants were asked to memorize the direction of all annotations from the visualization without turning their body. The evaluation showed that 3D arrows outperformed the radar overlay and users were more accurate in estimating the physical direction of off-screen annotations.

4.4 Combining AR with other interfaces

As different interfaces and frames of reference are needed for various tasks, AR is often combined with other non-AR interface elements to support tasks that are more easily performed outside the AR frame of reference. In this section we will detail both *what* interfaces are combined with AR, and *how* they are combined with AR. Interfaces are sometimes separated spatially. In this case a certain screen space is allocated to each interface, or a separate device is provided for accessing the non-AR interface. In other cases the interfaces are separated temporally by animations and transitions that allow moving between AR and the other interfaces.

4.4.1 Web browser

One simple addition to a mobile AR system is a web browser. AR can be used as an interface to select the content of a geo-referenced hypermedia by looking (or pointing a handheld device) towards points of interest. A web browser can then be used as an interface for viewing multimedia content in a web page.

In the Touring Machine [16][17], the wearable setup is used in combination with a handheld device which provides contextual information as a web page. The AR context is used for intuitive selection of the labels, by simply looking at the corresponding physical building in the campus through the head-worn display. Users were provided with further information about the labels in a web page on the handheld device. Most AR browsers also adopt this approach. The environment is augmented with annotations and selecting an annotation often opens a web page or a textual description that provides further details.

4.4.2 Maps

Many AR systems for navigation also allow browsing a map of the environment. MARS, for example, provides a map view on a separate handheld device [17] that can be brought into view whenever needed. The AR and map contexts are synchronised, so that an object selected in one context is also automatically highlighted in the other. On handheld devices, Signpost [23] provides a semi-transparent map overlay that is superimposed on the AR view on request. Graphic overlays were also employed in Tinmith [34] to show a 2D outlook of the user and the objects in the environment from a top-down frame of reference. AR browsers also usually provide a map view that users can select from the application's menu.

MARA [20] also integrates a map view centred and oriented accordingly to the user's position and orientation. It uses the phone's orientation to move between representations: when the phone lies flat the map view is shown; when the phone is tilted upwards the AR view becomes visible.

In a recent work [33], Mulloni *et al.* look at a transitional interface that moves between AR and map views. In their case, the transition is achieved by smoothly moving between the viewpoint of the camera and a top-down viewpoint. They compare this transitional interface with a graphic overlay that hints at off-screen objects – similar to the Context Compass [34]. They evaluate the interface on a set

of spatial search tasks: finding a highlighted café, finding a café with a given name and finding the closest café. They found that task performance with the graphic overlay is better than with the transitional interface if the system highlights the target object. In contrast, task performance with the transitional interface scales better with increasing task complexity. In real-world applications this suggests that hinting at off-screen objects is sufficient if the system knows what the user is looking for (*e.g.*, as a result of a search query). For exploratory browsing, transitioning from AR to a map interface improves task performance.
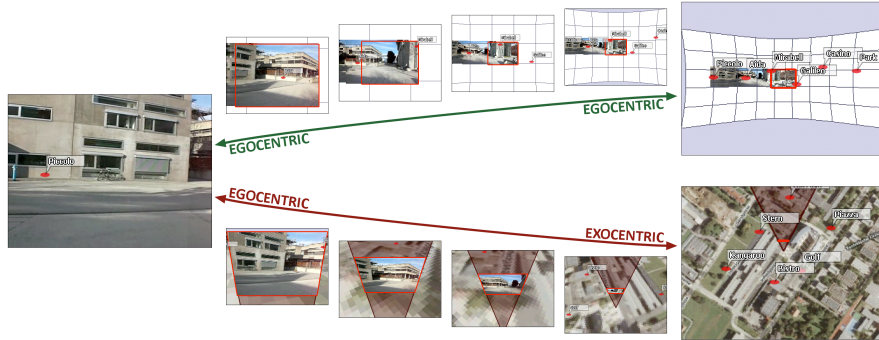

Figure 9. Smoothly moving between an AR view, and a map or a panoramic view [33].

4.4.3 Worlds in Miniature

Some AR navigation systems provide a World in Miniature (WIM) view [35], which extends the 2D map to the third dimension and represents a 3D miniaturized version of the surrounding environment.

Bell *et al.* [36] combine AR with a World-in-Miniature (WIM) to support situation awareness (*Figure 10*). The WIM acts as a miniature bird's eye view on the environment in which the user is immersed. Head tilting triggers the movement between WIM and AR views: tilting the head down magnifies the WIM, whereas tilting it up minimizes it. The view angle on the WIM is also updated accordingly to the head movements. Looking slightly downwards shows a bird's eye view on the model while looking straight down provides a top-down view. The position of the user is highlighted within the WIM. Finally, the representations in AR and in the WIM are tightly connected to each other. Labels are shared between the WIM and AR views. Objects can be selected either in the WIM or in AR to show further information. Bane and Höllerer [26] use a similar approach to provide a preview of a selected room in a building. Users of their system can exploit AR and x-ray vision to explore the rooms of a nearby building. Once they identify a room of interest they can trigger a "Rooms in Miniature" interface, providing an exocentric view on a virtual model of the selected room. To avoid loss of context, the room is smoothly animated from its real-world position to the virtual position.
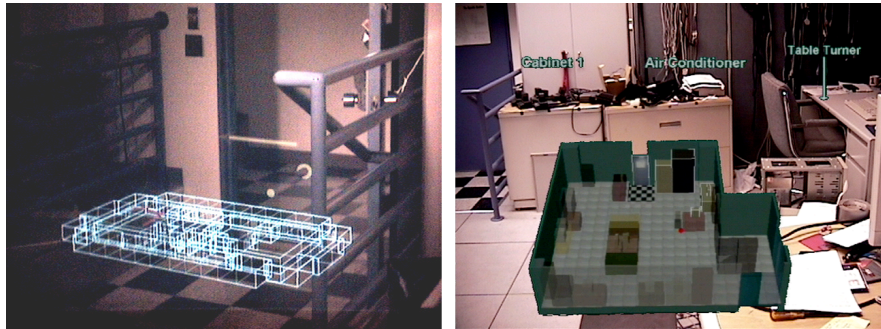
Figure 10. Supporting overview on the environment by moving between AR and World-in-Miniature representations. Images courtesy of Tobias Höllerer. © 2001–2002, T. Höllerer, D. Hallaway, N. Tinna, S. Feiner, B. Bell, Columbia University.

Höllerer *et al.* [37] use a WIM representation that transitions between AR and WIM views depending on the quality of the tracking. When the tracking is sufficiently accurate annotations and route arrows are superimposed on the environment. When the tracking accuracy degrades, the interface smoothly transitions to a WIM view. An avatar representation is used to indicate the current position of the user in the WIM. Rather than inaccurately placing the augmentations – which could potentially confuse users – the authors transition the system to a WIM interface that is more robust to tracking inaccuracies.

Reitmayr and Schmalstieg [24] also support their indoor navigation system with a WIM. In this case the WIM is virtually located on an arm-worn pad. Users can therefore access the WIM view at any time by lifting their arm into view. Further, users can click on a room in the WIM to select it as the target location for navigation. Path, and current target locations are all highlighted on the WIM. In this case, the WIM is used as an exocentric view to select target destinations in the real environment.

4.4.4 Distorted camera views

Maps and WIMs allow the user to gain an exocentric view on the surrounding environment. In contrast, some work proposes virtually modifying the field of view of the camera while maintaining an egocentric view on the environment.

Sandor *et al.* [30] uses a 3D virtual model of the environment to provide a distorted view of the surroundings with a much larger field of view. In recent work [33], Mulloni *et al.* virtually change the field of view of the AR camera by exploiting an online-generated panorama. As for the transition to the 2D map, evaluations show that when search tasks require an overview on the information, transitioning to a virtual wide-angle lens improves task performance.

Finally, some AR navigation systems combine AR and VR. Virtual Reality can be useful to support users in browsing an environment that is not available. The situated documentaries [38] use 360° omni-directional images to immerse the users in such an environment. When viewing these images, the interface switches from AR to VR. In the VR interface the omni-directional images are mapped to a virtual sphere that surrounds the head-worn display. The user can thus physically turn their head in order to explore the image.

Virtual Environments (VEs) can also support collaboration between users immersed in the environment and users that do not have physical access to the environment. Piekarski *et al.* [39] explore interconnecting AR and VR representations to support collaboration in military settings. The system supports collaboration between the outdoor users and a base station equipped with a PC. Users at the base station can visualize the battlefield environment in a VE. The VE can be freely explored or watched from the exact position and orientation of one of the outdoor users. Users of the base station can support the awareness of outdoor users from advantageous virtual viewpoints and outdoor users can update the elements in the virtual environment based on their experience of the real environment. MARS [17] also supports collaboration between outdoor and indoor users with two different interfaces. On a desktop PC indoor users can access 2D and 3D visualizations of the environment as multiple windows on the screen. Indoor users can also access a tabletop AR view. A head-worn display allows browsing a virtual model of the campus augmented on a physical table. Virtual objects can be added, modified and highlighted by both indoor and outdoor users. All users can see the modifications. Finally, paths can be drawn in the environment to support collaborative navigation.

5. AR as a secondary source of spatial information

The previous section presents the use of AR in the context of a spatial fusion between real and virtual space in an egocentric viewpoint environment. Another approach is to consider restricting part of the real environment to a limited space, and representing virtual spatial information that can be observed with an exocentric viewpoint.

Using a table (overlaid with a virtual map), a room (augmented with a 3D virtual map that floats above the ground) or real spatial source of information like a real map are some of the most widely used approaches. In this case, the physical space is acting only as a frame of reference to position and contain the virtual information. The spatial knowledge is generally dissociated from the location of the users, presenting, for example, cartography from a different building, landscape or city.

As the exocentric viewpoint restricts the spatial knowledge, different research works have explored the access to the other spatial contexts of information such as a virtual reality world or superposing multiple spaces of information in the real

world (e.g. projecting on a wall). We describe in this section some of the major work done in both of these areas.

5.1 Virtual Map in the Physical Space

The first category of augmentation is to consider the existence of a physical source of spatial information like a printed map. The printed map generally furnishes a high-resolution version of contextual information, which can be enhanced with live, dynamic, and focused virtual information. Navigation and interaction with the content is generally supported through a tangible user interface or gesture interaction. The map also provides a shared and common tangible artefact for collaboration, supporting communication or physical annotations.

Different AR display technologies have been explored for this purpose. We can cite three major approaches for viewing the AR content: projection-based, HMD-based/screen-based or handheld devices.

5.1.1 Projection-Based AR Maps

Reitmayr *et al.* [40] present a projection-based system coupled with a camera, allowing tracking of different physical elements over a map. A user of their application is able to select different region of interest with a tangible user interface or handheld device (see *Figure 11*).

Figure 11. An Augmented Map using Projection technology and supporting tracking of physical objects. Image Courtesy of Gerhard Reitmayr [40].

5.1.2 HMD and Screen-Based AR Maps

Different projects explore the use of HMD-based or screen-based AR to show 3D information directly above the map. Hedley *et al.* [41] developed a collaborative

HMD-setup where users can overlay a printed map with different type of 3D GIS datasets (e.g topology, soil) by manipulating and positioning encoded tangible markers over the map. A similar idea is explored by Bobrich [42] using a paddle interface to query information on the map. Asai *et al.* [43] introduce a screen-based solution for lunar surface navigation using a pad to control navigation and displaying elevation information above the map. Jung [44] proposes a similar system for military applications.

Tangible User Interface methods are often used for interacting with an augmented map. Moore and Regenbrecht [45] push the boundaries of the concept further, using a physical cube with a virtual map wrapped around it. Interaction and navigation are supported through different natural gestures with the cube (e.g. rotating on the left face to go west). Using a different approach, Martedi *et al.* consider the materiality of the map as a support for interaction, introducing some initial ideas for interacting with a *foldable augmented map* [46].

Only a few works have used a room space as a frame reference for navigating virtual information. Kiyokawa *et al.* [47] explore this concept with the MR Square system where multiple users can see and observe a 3D virtual landscape displayed floating in the centre of a room and naturally navigate through it by physically moving around the landscape.

5.1.3 Handheld-Based AR Maps

Finally, a handheld device can provide a lens view over an existing map, the device acting as a focus (and individual) viewpoint to navigate the map [48]. For example, Olwal presents the LUMAR system [49], using a cell phone as a way to present 3D information above a floor map.

Figure 12. The MapLens application: augmenting a physical map with a handheld AR view [50].

Rohs *et al.* [51] present a comparative study between a standard 2D virtual map on handheld vs. an augmented map. Their results demonstrate the superiority of the augmented approach for exploration of the map. Similarly, Morrison *et al.* [50] (*Figure 12*) found that an augmented map, in contrast to a virtual 2D map, facilitates place making and collaborative problem solving in a team-based outdoor game.

5.2 Multiple Contexts and Transitional Interface

Extending spatial information using additional contexts can be realized with two main approaches: *spatially* (showing more viewpoints from the view of the user) or *temporally* (switching successively between different viewpoints). Below we present some of the contributions based on both of these methods.

5.2.1 Spatially Multiplexed Contexts

One of the seminal works using a projection-based system is the BUILD-IT system [52], developed for collaborative navigation and interaction with a floor map of a building. The authors develop different techniques for navigating with the map and changing viewpoint (using a tangible user interface), including both an augmented exocentric view of a building, and a 3D VR egocentric view.

The concept is extended in 3D through the SCAPE system [53] which combines both an egocentric viewpoint (projected on a wall) and an exocentric viewpoint (projected on a table) with a Head-Mounted Projection Display (HMPD) to display the spatial information. Navigation is supported in both contexts: physically moving in the room to change locally the viewpoint, and moving a token on a table to change exocentric viewpoint location or displace the egocentric viewpoint.

Navigation can also be considered for different users navigating in two different contexts. The MARS system [17] illustrates this concept, where an indoor user has only an exocentric view on a 3D virtual map. Another example is the 3D Live! System [54] that demonstrates how a user with a VR egocentric viewpoint can move in a virtual space whilst a second with a user with an AR exocentric viewpoint can navigate the same virtual scene, seeing the distal embodiment of the first user (polygonal model reconstructed with a visual hull technique).

Relatively few works empirically evaluate multiple-context navigation. A noticeable work is [55] comparing the impact of different modalities as navigation cues for an egocentric HMD-based AR context and an exocentric projection-based AR context for a cooperative navigational task. The results point out that using visual guidance cues (such as the representation of a virtual hand for indicating directions to a mobile user) is more efficient than audio cues (only). Grasset *et al.* [8] evaluate cooperative navigation for a mixed-reality space collaboration between a VR egocentric user and a secondary user in different spatial conditions (AR exocentric, VR exocentric). The study shows that combining VR egocentric navigation with AR exocentric navigation benefits from using an adapted distal

embodiment of the egocentric user (for the exocentric user) to increase location awareness. Additionally, the usefulness of an AR approach (see *Figure 13*) depends on whether the application can take full potential of gestural and tangible interaction in the real world and also on the choice of the display to support the navigation.
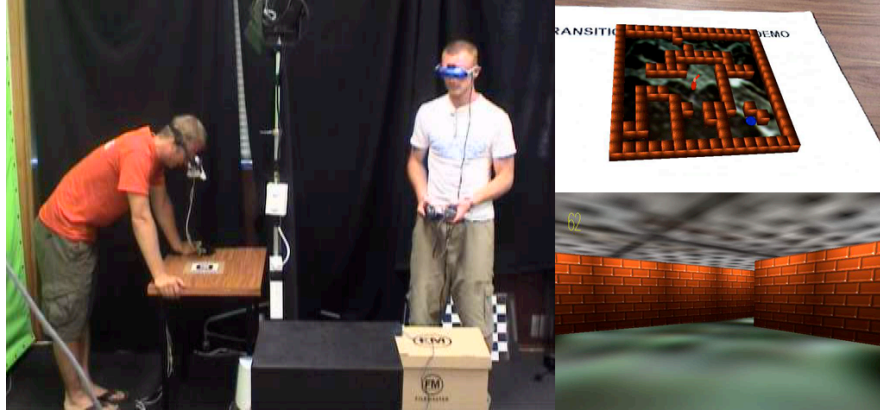

Figure 13. Left: Navigation in a Mixed-Reality collaboration, left user has an AR exocentric viewpoint, the right user has a VR egocentric viewpoint. Right: AR and VR view.

5.2.2 Time-Multiplexed Contexts

A time-multiplexed AR navigation system was introduced by Billinghurst *et al.* with the MagicBook Application [56]. This is an interface for navigating between different contexts (AR egocentric, VR exocentric or real world) which also supports transitions between these different contexts (viewpoint interpolation). Using a novel type of handheld device, the system allows the user to trigger the transition step and accesses different virtual worlds, each of them associated with a page of a book.

This innovative concept has been evaluated in [57], considering transition for a single-user and different type of transition techniques (e.g. using a MagicLens metaphor to select a location in a new context, see *Figure 14*). In their paper, the authors demonstrate that participants easily understood the metaphor, but the design of the navigation and transition techniques for the contexts where highly connected. An importance observation was related to the perception of the presence in the contexts: The AR context had really low perceived presence, concluding that proposing navigation between multiple contexts reduces the perceptual discrepancy between them (in this latter case the perception was leaning towards "everything is VR").

Figure 14. A time-multiplexed transitional interface.

6. Conclusion and Future Directions

In this chapter, we presented an overview of navigation techniques in AR and MR. We introduced a model for navigation in AR/MR and a generalization of the problem to multiple spaces and contexts. Finally, we categorised previous work based on whether AR is used as a primary or a secondary source of spatial information. As shown by the broad list of previous work, AR can support various spatial tasks and cover various application areas. Yet, a number of future research directions for AR navigation are still open: we present a few of them below.

Augmented Reality Navigation relies heavily on registration and tracking. While it was not the focus of this chapter, the need for temporally and spatially accurate tracking and a correct registration is primordial to support a usable and efficient navigation in AR. Taking into consideration the current inaccuracy of tracking technologies and registration algorithms is one of the first potential research direction in this area. Developing navigation techniques that model the inaccuracy of the system and integrate it into a navigation model (*uncertainty model*) to adapt the presentation of visual guidance information is one potential approach, as shown by Höllerer *et al.* [37].

In addition, there is no tracking system sufficiently robust and reliable to work in a large range of spatial locations such as in an office, a whole building and outdoors. This implies the need to develop different navigation modalities as a function of the tracking availability. Creating adapted and adaptive models, navigation patterns and tools will help to develop more systematic integration of multiple tracking technologies and facilitate navigation in and between these different locations.

Another major aspect of AR navigation is its dependency on the existence of a spatial model per se, thus including the different objects of the real and virtual environment. Significant progress is currently being made on reconstructing and acquiring real environments (i.e. position, geometry and topology of real artefacts), but the possible challenges induced by error in this process or the scalability of the system (city, country) can potentially lead to more hybrid navigation models (i.e. using different representations of the real environment in different areas).

Other types of visual interfaces can be combined with AR and can complement it. For example, several other interfaces are employed in location-based services (based for example on 2D maps, 3D maps and 360° panoramic images) and could be integrated with AR to build more flexible navigation systems. Furthermore, other modalities can also be explored in addition to visual information, such as audio navigation or haptic guidance. More longitudinal and empirical studies of the viability of these concepts need to be conducted.

In general, the role of AR for supporting navigation is still not fully clear. More experimental work will be needed in the future to identify which navigation tasks are best supported by AR interfaces and which are not. Furthermore, as we are now observing a tremendous increase of digital devices, social applications and spatial information, defining more advanced models to support natural transition between the context of tools simultaneously used by the public will also need further user studies.

Information spaces (*e.g.*, *cyberspace*[4], *hypermedia*[5], Internet) and contexts (*e.g.*, AR, VR, real world) that were once disconnected are now slowly converging towards a unified model. Concepts such as context and transition are now paramount, as users who are embedded in the information space need moving from one context to another. AR will surely play a major role in this model, offering us a solid and direct connection to the physical world that we still navigate in our everyday life.

References

[1]   R. Azuma, "A Survey of Augmented Reality," *Presence*, vol. 6, no. 4, pp. 355-385, 1997.

[2]   T. Langlotz, D. Wagner, A. Mulloni, and D. Schmalstieg, "Online Creation of Panoramic Augmented Reality Annotations on Mobile Phones," *IEEE Pervasive Computing*, 2010.

[3]   R. P. Darken, B. Peterson, and B. S. Orientation, "Spatial Orientation, Wayfinding, and Representation," *In K. M. Stanney (Ed.), Handbook of Virtual Environments: Design, Implementation, and Applications*, p. 493--518, 2001.

[4]   D. A. Bowman, E. Kruijff, and J. LaViola, *3D User Interfaces: Theory and Practice*, 1st ed. Addison Wesley, 2004.

[5]   A. W. Siegel and S. H. White, "The development of spatial representations of large-scale environments," *Advances in Child Development and Behavior*, vol. 10, pp. 9-55, 1975.

[6]   S. E. Goldin and P. W. Thorndyke, *Spatial Learning and Reasoning Skill.* 1981.

[7]   K. Lynch, *The Image of the City*. The MIT Press, 1960.

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[4] http://en.wikipedia.org/wiki/Cyberspace
[5] http://en.wikipedia.org/wiki/Hypermedia

[8]   R. Grasset, P. Lamb, and M. Billinghurst, "Evaluation of Mixed-Space Collaboration," in *Proceedings of the 4th IEEE/ACM International Symposium on Mixed and Augmented Reality*, Washington, DC, USA, 2005, p. 90–99.

[9]   R. Grasset, J. Looser, and M. Billinghurst, "Transitional interface: concept, issues and framework," in *Proceedings of the 5th IEEE and ACM International Symposium on Mixed and Augmented Reality*, Washington, DC, USA, 2006, p. 231–232.

[10]   K. Kiyokawa, M. Billinghurst, S. E. Hayes, A. Gupta, Y. Sannohe, and H. Kato, "Communication Behaviors of Co-Located Users in Collaborative AR Interfaces," in *Mixed and Augmented Reality, IEEE / ACM International Symposium on*, Los Alamitos, CA, USA, 2002, vol. 0, p. 139.

[11]   D. A. Bowman and L. F. Hodges, "An evaluation of techniques for grabbing and manipulating remote objects in immersive virtual environments," in *Proceedings of the 1997 symposium on Interactive 3D graphics*, New York, NY, USA, 1997, p. 35–ff.

[12]   B. Brown, I. MacColl, M. Chalmers, A. Galani, C. Randell, and A. Steed, "Lessons from the lighthouse: collaboration in a shared mixed reality system," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, New York, NY, USA, 2003, p. 577–584.

[13]   X. Zhang and G. W. Furnas, "Social interactions in multiscale CVEs," in *Proceedings of the 4th international conference on Collaborative virtual environments*, New York, NY, USA, 2002, p. 31–38.

[14]   C. Gutwin and S. Greenberg, "A Descriptive Framework of Workspace Awareness for Real-Time Groupware," *Computer Supported Cooperative Work*, vol. 11, p. 411–446, Nov. 2002.

[15]   S. Benford, J. Bowers, L. E. Fahlén, C. Greenhalgh, and D. Snowdon, "User embodiment in collaborative virtual environments," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, New York, NY, USA, 1995, p. 242–249.

[16]   S. Feiner, B. MacIntyre, T. Hollerer, and A. Webster, "A touring machine: prototyping 3D mobile augmented reality systems for exploring the urban environment," in *Digest of Papers. First International Symposium on Wearable Computers*, Cambridge, MA, USA, pp. 74-81.

[17]   T. Höllerer, S. Feiner, T. Terauchi, G. Rashid, and D. Hallaway, "Exploring MARS: developing indoor and outdoor user interfaces to a mobile augmented reality system," *Computers & Graphics*, vol. 23, no. 6, pp. 779-785, Dec. 1999.

[18]   S. Julier, Y. Baillot, M. Lanzagorta, D. Brown, and L. Rosenblum, "BARS: Battlefield Augmented Reality System," *In NATO Symposium on Information Processing Techniques for Military Systems*, p. 9--11, 2000.

[19]   S. Julier et al., "Information filtering for mobile augmented reality," in *Proceedings IEEE and ACM International Symposium on Augmented Reality (ISAR 2000)*, Munich, Germany, pp. 3-11.

[20]   M. Kähäri and D. J. Murphy, "MARA - Sensor Based Augmented Reality System for Mobile Imaging," 2006.

[21]   B. Thomas, V. Demczuk, W. Piekarski, D. Hepworth, and B. Gunther, "A wearable computer system with augmented reality to support terrestrial

navigation," in *Digest of Papers. Second International Symposium on Wearable Computers (Cat. No.98EX215)*, Pittsburgh, PA, USA, pp. 168-171.

[22] G. Reitmayr and D. Schmalstieg, "Scalable Techniques for Collaborative Outdoor Augmented Reality," in *ISMAR*, 2004.

[23] D. Wagner and D. Schmalstieg, "First steps towards handheld augmented reality," in *Seventh IEEE International Symposium on Wearable Computers, 2003. Proceedings.*, White Plains, NY, USA, pp. 127-135.

[24] G. Reitmayr and D. Schmalstieg, "Location based applications for mobile augmented reality," in *Proceedings of the 4th Australian user interface conference on User interfaces 2003*, 2003, pp. 65-73.

[25] M. A. Livingston et al., "Resolving Multiple Occluded Layers in Augmented Reality," in *Mixed and Augmented Reality, IEEE / ACM International Symposium on*, Los Alamitos, CA, USA, 2003, vol. 0, p. 56.

[26] R. Bane and T. Hollerer, "Interactive Tools for Virtual X-Ray Vision in Mobile Augmented Reality," in *Proceedings of the 3rd IEEE/ACM International Symposium on Mixed and Augmented Reality*, Washington, DC, USA, 2004, p. 231–239.

[27] B. Avery, B. H. Thomas, and W. Piekarski, "User evaluation of see-through vision for mobile outdoor augmented reality," in *Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*, Washington, DC, USA, 2008, p. 69–72.

[28] B. Avery, C. Sandor, and B. H. Thomas, "Improving Spatial Perception for Augmented Reality X-Ray Vision," in *2009 IEEE Virtual Reality Conference*, Lafayette, LA, 2009, pp. 79-82.

[29] S. Guven and S. Feiner, "Visualizing and navigating complex situated hypermedia in augmented and virtual reality," in *2006 IEEE/ACM International Symposium on Mixed and Augmented Reality*, Santa Barbara, CA, USA, 2006, pp. 155-158.

[30] C. Sandor et al., "Egocentric space-distorting visualizations for rapid environment exploration in mobile mixed reality," in *Proceedings of the 2009 8th IEEE International Symposium on Mixed and Augmented Reality*, Washington, DC, USA, 2009, p. 211–212.

[31] F. Biocca, A. Tang, C. Owen, and F. Xiao, "Attention funnel: omnidirectional 3D cursor for mobile augmented reality platforms," in *Proceedings of the SIGCHI conference on Human Factors in computing systems*, New York, NY, USA, 2006, p. 1115–1122.

[32] T. Schinke, N. Henze, and S. Boll, "Visualization of off-screen objects in mobile augmented reality," in *Proceedings of the 12th international conference on Human computer interaction with mobile devices and services*, New York, NY, USA, 2010, p. 313–316.

[33] A. Mulloni, A. Dünser, and D. Schmalstieg, "Zooming interfaces for augmented reality browsers," in *Proceedings of the 12th international conference on Human computer interaction with mobile devices and services*, New York, NY, USA, 2010, p. 161–170.

[34] J. Lehikoinen and R. Suomela, "Accessing Context in Wearable Computers," *Personal and Ubiquitous Computing*, vol. 6, p. 64–74, 2002.

[35] R. Stoakley, M. J. Conway, and R. Pausch, "Virtual reality on a WIM: interactive worlds in miniature," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, New York, NY, USA, 1995, p. 265–272.

[36] B. Bell, T. Höllerer, and S. Feiner, "An annotated situation-awareness aid for augmented reality," in *Proceedings of the 15th annual ACM symposium on User interface software and technology*, New York, NY, USA, 2002, p. 213–216.

[37] T. Höllerer, D. Hallaway, N. Tinna, and S. Feiner, "Steps Toward Accommodating Variable Position Tracking Accuracy in a Mobile Augmented Reality System," in *In Proceedings of AIMS 2001: Second Int. Workshop on Artificial Intelligence in Mobile Systems*, 2001, vol. 1, p. 31--37.

[38] T. Hollerer, S. Feiner, and J. Pavlik, "Situated documentaries: embedding multimedia presentations in the real world," in *Digest of Papers. Third International Symposium on Wearable Computers*, San Francisco, CA, USA, pp. 79-86.

[39] W. Piekarski, B. Gunther, and B. Thomas, "Integrating virtual and augmented realities in an outdoor application," in *Proceedings 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR'99)*, San Francisco, CA, USA, pp. 45-54.

[40] G. Reitmayr, E. Eade, and T. Drummond, "Localisation and Interaction for Augmented Maps," in *Proceedings of the 4th IEEE/ACM International Symposium on Mixed and Augmented Reality*, Washington, DC, USA, 2005, p. 120–129.

[41] N. R. Hedley, M. Billinghurst, L. Postner, R. May, and H. Kato, "Explorations in the use of augmented reality for geographic visualization," *Presence: Teleoperators and Virtual Environments*, vol. 11, p. 119–133, Apr. 2002.

[42] J. Bobrich, "An Immersive Environment Based on Paper Maps," in *Proceedings of ICC 2003*, Durban, South Africa, 2003.

[43] K. Asai, T. Kondo, H. Kobayashi, and A. Mizuki, "A Geographic Surface Browsing Tool Using Map-Based Augmented Reality," in *Visualisation, International Conference on*, Los Alamitos, CA, USA, 2008, vol. 0, pp. 93-98.

[44] K. Jung, S. Lee, S. Jeong, and B.-U. Choi, "Virtual Tactical Map with Tangible Augmented Reality Interface," in *Computer Science and Software Engineering, International Conference on*, Los Alamitos, CA, USA, 2008, vol. 2, pp. 1170-1173.

[45] A. Moore and H. Regenbrecht, "The tangible augmented street map," in *Proceedings of the 2005 international conference on Augmented tele-existence*, New York, NY, USA, 2005, p. 249–250.

[46] S. Martedi, H. Uchiyama, G. Enriquez, H. Saito, T. Miyashita, and T. Hara, "Foldable augmented maps," in *Mixed and Augmented Reality (ISMAR), 2010 9th IEEE International Symposium on*, 2010, pp. 65-72.

[47] K. Kiyokawa, M. Niimi, T. Ebina, and H. Ohno, "MR2 (MR Square): A Mixed-Reality Meeting Room," in *Augmented Reality, International Symposium on*, Los Alamitos, CA, USA, 2001, vol. 0, p. 169.

[48]   V. Paelke and M. Sester, "Augmented paper maps: Exploring the design space of a mixed reality system," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 65, no. 3, pp. 256-265, May. 2010.

[49]   A. Olwal and A. Henrys, "LUMAR: A Hybrid Spatial Display System for 2D and 3D Handheld Augmented Reality," in *Artificial Reality and Telexistence, 17th International Conference on*, 2007, pp. 63-70.

[50]   A. Morrison et al., "Like bees around the hive: a comparative study of a mobile augmented reality map," in *Proceedings of the 27th international conference on Human factors in computing systems*, New York, NY, USA, 2009, p. 1889–1898.

[51]   M. Rohs, J. Schöning, M. Raubal, G. Essl, and A. Krüger, "Map navigation with mobile devices: virtual versus physical movement with and without visual context," in *Proceedings of the 9th international conference on Multimodal interfaces*, New York, NY, USA, 2007, p. 146–153.

[52]   M. Fjeld, M. Fjeld, M. Bichsel, and M. Rauterberg, "BUILD-IT: an intuitive design tool based on direct object manipulation," 1998.

[53]   H. Hua, L. D. Brown, C. Gao, and N. Ahuja, "A new collaborative infrastructure: SCAPE," in *IEEE Virtual Reality, 2003. Proceedings.*, Los Angeles, CA, USA, pp. 171-179.

[54]   S. Prince et al., "3-D live: real time interaction for mixed reality," in *Proceedings of the 2002 ACM conference on Computer supported cooperative work*, New York, NY, USA, 2002, p. 364–371.

[55]   A. Stafford, B. H. Thomas, and W. Piekarski, "Comparison of techniques for mixed-space collaborative navigation," in *Proceedings of the Tenth Australasian Conference on User Interfaces-Volume 93*, 2009, p. 61–70.

[56]   M. Billinghurst, H. Kato, and I. Poupyrev, "The MagicBook: a transitional AR interface," *Computers & Graphics*, vol. 25, no. 5, pp. 745-753, Oct. 2001.

[57]   R. Grasset, A. Duenser, and M. Billinghurst, "Moving Between Contexts - A User Evaluation of a Transitional Interface," in *ICAT*, 2008.