Using Augmented Reality as a Medium to Assist Teaching in Higher Education

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Abstract

In this paper we describe the use of a high-level augmented reality (AR) interface for the construction of collaborative educational applications that can be used in practice to enhance current teaching methods. A combination of multimedia information including spatial three-dimensional models, images, textual information, video, animations and sound, can be superimposed in a student-friendly manner into the learning environment. In several case studies different learning scenarios have been carefully designed based on human-computer interaction principles so that meaningful virtual information is presented in an interactive and compelling way. Collaboration between the participants is achieved through use of a tangible AR interface that uses marker cards as well as an immersive AR environment which is based on software user interfaces (UIs) and hardware devices. The interactive AR interface has been piloted in the classroom at two UK universities in departments of Informatics and Information Science.

1 Introduction

Until the emergence of new technological innovations the most common teaching method has been the direct communication between students and teachers usually taking place in the classroom. Although current teaching methods work successfully, most higher education institutions are interested in introducing more productive methods for improving the learning experience and increasing the level of understanding of the students. The emergence of new technological innovations in computing technologies has provided the potential for improving them. For instance, the web-based Virtual Learning Environments (VLEs) that many universities have adopted for aiding the teaching process are characteristic for this. A recent study has shown that virtual learning applications can provide the tools to allow users to learn in a quick and happy mode by playing in virtual environments [PCY*06].

In particular, the introduction of Information and Communication Technologies (ICT) not only in schools but also in higher education institutions has been welcomed by students and educators worldwide. Most multimedia applications available for higher education purposes utilise teaching material in a number of formats including text, images, video, animations and sound. These tools usually build upon traditional teaching methods, making the subject matter more interesting and challenging for both the students and the lecturer. Consequently, any future systems and techniques must take into consideration the current trends and needs of the higher education sector which is adopting these new technologies fast.

Many universities are eager in exploiting new visualisation methods to improve the current teaching models and one of the most promising technologies that currently exist is augmented reality (AR). In technical terms, AR is an amalgamation of computer graphics, vision and multimedia, which enhance the user's perception of the real world through the addition of virtual information [ABB*01]. In AR the real environment must be harmonised (and synchronised) with the virtual in position and context to provide an understandable and meaningful view.

To improve student retention and participation in computing disciplines, Carter suggests that learning should be "more fun" [Car06], therefore one of the primary aims of this research is to increase the level of understanding of the students in complex learning issues through an effective use of engaging audio-visual augmentation, which should be "attractive and highly motivating to today's generation of media-conscious students" [MLC04], which is an educational goal in itself.

This paper is structured as follows. A discussion of work related to the use of AR in teaching is followed by the specification of the requirements for applying AR technology to learning in higher education. The following section introduces a theoretical framework for enhancing the learning cycle and style using AR. This is followed by a presentation of approaches for effectively designing teaching material in the context of AR scenarios for higher education. Furthermore, multimedia augmentation techniques are presented for enhancing traditional teaching methods. Several case studies exploring collaborative learning through the use of human computer interaction techniques are presented, followed by a preliminary evaluation together with our conclusions.

2 Education with AR in a Classroom Setting

Modern classrooms are frequently enhanced through the addition of new technologies, such as multitouch and computer gaming technologies [MDD09], and AR is one of these new technologies. Research has shown that learning does occur in virtual environments [Har06], and one of the earliest works in this area, applying AR to an educational context, is the 'Classroom of the Future' [Coo01], which conceptualises how it could be possible to enhance interaction between instructor and students by employing AR technologies. Another example is the higher education AR learning system for mathematics and geometry education Construct3D [KS02], which allows teachers and students to interact through various interactive scenarios in a collaborative environment. An alternative experimental education application demonstrates the AR enhanced teaching of undergraduate geography students about earth-sun [SH02]. In a similar AR application educators use AR to explain to students how specific parts of a computer could work in practice [FM03].

Other researchers have compared the use of AR and physical models in chemistry education [Che06], where results showed that some students liked to manipulate AR by rotating the markers to see different orientations of the virtual objects whereas others preferred to interact with physical models to get a feeling of physical contact. In another study, two modules, 'Solar System' and 'Plant System', were developed for mixed reality (MR) in the classroom, "providing support for classroom teaching and self-learning" [LCMLT07]. This study was influenced directly by its perceived usefulness, and indirectly through perceived ease of use and social influence, and preliminary results seemed to indicate the participants' intention to use MR for learning. Elswhere, researchers have studied the integration of physical objects that are computationally-augmented to support and encourage face-to-face interaction between disabled students and virtual objects [APK*09]. Here, initial results have indicated the importance of inclusion in novel technology-enhanced learning approaches for science education.

Collaborative AR allows participants to work in teams, experiment and interact with the superimposed virtual information in a natural way. In such environments, multiple users may access a shared space populated with digital information and thus maximizing the transfer of knowledge [Kau03]. A good example is the use of a real physical book for the development of a visually augmented reality book, however with drawbacks that include the affordances of the book resulting in book-like interaction by the users, which creates challenges in terms of technology deployment [GDB08]. Another collaborative approach for teachers and trainees is an AR system that simulates a web-based training and teaching environment for distance education and training. AR may be used successfully to provide assistance to the user necessary to carry out difficult procedures [SL03] or understand complex problems. Demonstration in lecture and seminar rooms is one of the most effective means of transferring knowledge to large groups of people [LMW*04].

The main advantage of AR over more traditional teaching methods is that learners can actually 'see' and 'listen to' supplementary digital information. Additionally, students can intuitively manipulate the virtual information, allowing them to repeat a specific part of the augmentation as many times as they want. One of the main aims of this research is to contribute in resolving the perceptual discontinuities [DNT01] initiated by scattered sources of information during the learning process. To better understand these discontinuities we have developed a prototype AR learning system focused on higher education with a particular interest in computing courses. The basic idea is an AR table-top learning environment that integrates the real teaching environment (i.e. lecture theatre) with virtual learning scenarios in a student-friendly and engaging manner. Tangible interfaces are the medium used to allow students examine and experiment with the virtual teaching material in a natural manner.

One of the most important aspects of learning is effective interaction and collaboration. The concept of collaboration appears to be widely accepted as a manner of encouraging learning to take place in the classroom. The educational goal for which collaboration is intended plays a significant role on the nature of collaboration [Brn98]. In cases where learning is the primary educational goal it is essential to investigate how students become capable of collaboration [BBTJ97]. It is highly believed that AR support for collaboration can be improved if there is awareness for the level of collaboration required. Past research has shown that virtual and augmented reality learning environments can provide assistance to learners to perform cooperative and collaborative studies [KS02; POVP04; LMW*04].

3 Learning in Augmented Reality

Apart from the subject content itself, pedagogical and psychological issues also need to be considered when designing a higher education learning system. The shared presence of virtual environments can enhance the opportunities for effective educational applications [HM97]. As an extension to VR systems, AR systems can be extremely effective in providing information to a user that deals with multiple tasks at the same time [KHS*00]. Previous studies [BHBS99] have shown that they can improve performance times when the training is conducted on real objects. Taking into consideration the fact that individual persons have different learning styles and different ways of communication it is very important that we design a system following a user-focused approach. Educators not only need to recognise a unique learning style but also recognise this correctly for the successful development of effective learning and teaching strategies. The potential benefits of AR applied to higher education include:

- multi-modal visualisation of difficult theoretical concepts
- practical exploration of the theory through tangible examples
- natural interaction with multimedia representations of teaching material
- effective collaboration and discussion amongst the participants

Multi-modal visualisation allows students to switch interactively between different visualisation media. Tangible AR interfaces can help students to explore the multi-dimensional augmentation of the teaching material in various levels of detail. Students could navigate through the augmented lecture data and therefore concentrate and study in detail any part of the lecture. It is also important to consider the technological issues when introducing AR into teaching and learning processes [LMW*04]. Ideally an educational AR system fulfils at least the following requirements:

- be simple and robust
- provide the learner with clear and concise information
- enable the educator to input information in a simple and effective manner
- enable easy interaction between learners and educators
- make complex procedures transparent to the learners and educators
- be cost effective and easily extensible.

A carefully planned and managed presentation of AR technology is also needed to avoid the teaching and learning environment being solely focused on technological issues rather than educational ones. This, together with the use of technological improvements, can direct higher education institutions to improve their teaching and learning processes.

4 An Affordable Augmented Reality System

Different learning styles can be applied from a single classroom session to a whole degree programme [HJ00]. Traditional methods of presenting teaching material can satisfy student demands only to a certain degree. For example, when teaching computer graphics it is really difficult for students to understand the concept of 3D if only traditional methods (i.e. PowerPoint presentations, websites, etc) are used. A cost effective AR audio-visual presentation of virtual multimedia content can be utilised to exploit the potential benefits of using alternative technologies to improve current teaching methods. Using virtual multimedia content, students can see real-life 3D examples of the principles they are studying as well as interact with them in a natural way.

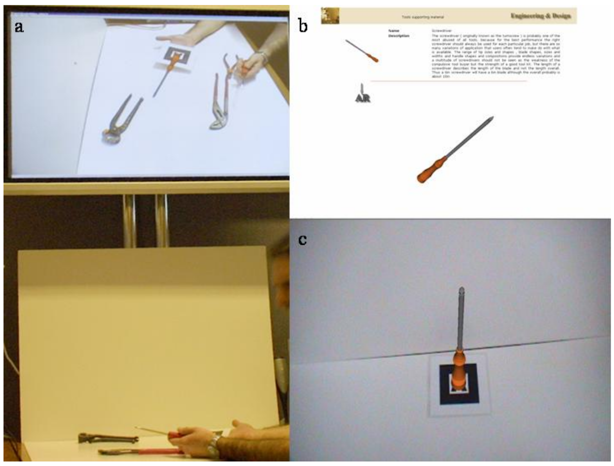

Figure 1: Operation of our AR system.

The majority of educational AR applications operate in indoor environments [FS99; SH02] and this is where this research work is focused. Registration between the real and virtual information is one of the most important issues of AR can be achieved either with the use of sensor devices or via computer vision techniques. Although, both techniques have proven advantages and disadvantages it seems that vision systems work much better in indoor environments while sensor-based systems are preferred for urban outdoor environments. In this paper, a vision-based AR learning solution has been adopted since the target environment is the classroom and it is much easier to control environmental parameters such as the lighting conditions. In addition, the cost of most of the technologies used in vision-based AR systems can be afforded by most higher education institutions – the cost of the system used here is a standard computer with a web camera (Figure 1).

5 Design of Teaching Material

To experimentally prove the feasibility of the higher education application, different teaching scenarios from different subject areas have been investigated and implemented. All scenarios are specifically engaged with the improvement of learning and teaching techniques in the fields of Informatics at the University of Sussex and Information Science at City University. The presented scenarios have the capabilities of providing a rewarding learning experience that is otherwise difficult to obtain. Although the system suggests ways of enhancing teaching methods currently applied in computing courses it has been designed in such a way that it can be easily adapted and applied to other educational domains. The design of the teaching material has to be formulated in a way that satisfies the AR requirements of learning in higher education proposed above. As a consequence, the end result of the teaching material must transfer practical, theoretical, functional and constructive knowledge to the students. The teacher's expertise and the adaptation capabilities of the students serve as a cornerstone in deciding which methodology and scenarios should be followed. Depending on the nature of the subject areas (i.e. science or arts) the educator will have to design the course accordingly. In this research, courses that belong to the computing area have been used as case-studies. The development of the teaching material itself is an off-line process and consists of the following three interrelated parts each of those are explained in detail below:

- a set of distinctive marker cards – this provides the link between the real and the digital information so it needs to be easily distinctive
- digital information – the digital information including pictures, 3D models, textual descriptions, video animations and auditory information
- educational tutorials – a number of predefined learning scenarios which combine theory and practice at the same time

5.1 Design of Distinct Marker Cards

The precise definition of the teaching material is of great importance in any learning and teaching environment. In addition, the way the material is presented to students plays a significant role. The purpose of using marker cards for presenting the teaching material was selected because it provides a tangible interface between the real and the synthetic information, while it gives an indication to students what each marker contains at the same time. Our system presents the virtual multimedia information on marker cards of various shapes and sizes [Lia05]. The teaching material, course notes, diagrams and video animations were decomposed into appropriate components and for each a single marker card was created. This set of meaningful marker cards was carefully designed to create a complete representation of the theoretical elements of the subject matter during teaching. Students are given a selection of marker cards associated with the teaching material so they can have a visual choice before the information is presented. Each marker contains a link to the learning components (i.e. 3D objects and scenes, textual information, pictures and diagrams, video animations and spatial sound), allowing students to experiment with different combinations. The use of marker cards allows learners to pick up and examine the superimposed information in an intuitive manner. The lecturer needs only to devise the learning strategy, which is to create the most appropriate learning scenarios. That is, the sequence in which they need to instruct the students to observe the markers and hence display the learning material in the AR environment. This can be achieved using a number of different ways. The lecturer can either manipulate the marker cards himself on a big table so that all students can enjoy an augmented presentation or leave the students to organise for themselves the sequence used in the teaching session. It may be that a combination of both methods could be more beneficiary for the students because they will be able to spend more time on the material they prefer or for which they need more assistance. This encourages students to become more interested in the subject because the teaching information is presented in an appealing way compared to more traditional methods.

5.2 Digital Information

The digitisation of the teaching material must have an educational flavour, as otherwise the virtual information will not have any effect when presented to students. To keep the complexity of the system low, only a few video animations were created and more emphasis was placed on the collection and generation of 3D objects, 3D sound, images and descriptive textual information. Most of the 3D models used were digitised using a technique known as Image-based Modelling (IBM). Although IBM techniques are not ideal for producing highly realistic models with detailed geometry, they have the advantage of rapidly generating 3D content. Alternative 3D content creation methods include laser scanning or manual modelling. The collection and digitisation of the static images was the most time-consuming task, as the information had to be organised in categories, followed by a thorough selection process to meet the requirements of the AR learning visualisation. Parts of relevant textbooks (i.e. from Multimedia and VR) were originally scanned and modified to make them suitable for classroom presentation. For storage, the TGA file format was selected as it provides an alpha channel that can be used to make images appear transparent. The textual descriptions were created in a text editor and stored in ASCII format. For generating the sound material, a standard microphone and an audio processing tool were employed.

5.3 Tutorial Generation

Aspen and Helm [AH04] proposed that a mixture of related approaches can be of substantial benefit to learners, resulting in effective commitment in a number of situations. The teaching material that we used was adapted from the official course material provided to the students in the classroom and digitised appropriately, aiming to address a wide range of students, including visually impaired students. The digitised information has been categorised into different types. Each one aims at introducing different sections of the teaching material to the students. The tutorials that have been implemented up to this point can be categorised into three parts: theoretical; practical; and assessment tutorials;

- Theoretical tutorials – only the most important aspects of the theory are described through visual and auditory means of augmentation. The theoretical tutorials are the easiest to design technologically as no interaction with the user is required. The instructor simply needs to present the appropriate information to the students. However, the toughest challenge is the representation of the information in an appropriate manner for understanding and learning. In some cases, the information that has been transformed from 2D to 3D can confuse the user instead of helping, which is caused by a phenomenon known as information overload.

- Practical tutorials – based on the theory, students have to use a specific set of marker cards to describe a simple but complete process (i.e. building a computer using hardware devices). The practical tutorials encourage students to explore and interact with audio-visual information. Students have to use natural means (the specific set of marker cards) to explore a complex process or system, such as understanding how a computer works and replacing a component of a computer (i.e. processor), or solving a 3D puzzle that consists of – in our experiments – six pieces (Figure 4).

- Assessment tutorials – 3D graphical representations of theoretical and practical issues are assessed in a semi-automatic manner. The assessment tutorials aim to provide a less stressful way to evaluate the learning ability of the students. In the simplest scenario, students are provided with an augmentation of a 3D object or scene and a related question is asked. In more complex scenarios, AR quizzes can present a sequence of questions and have the potential of creating an enjoyable method for assessing students. It is important to note that all of our tutorials were designed on an experimental basis and only the theoretical and practical tutorials were demonstrated to higher-education students. The assessment tutorials have not yet been applied in real teaching.

In the next section, two real-life examples of how AR learning scenarios can be applied in 'Informatics' and 'Information Science' are presented.

6 Case Studies

6.1 AR in Informatics Teaching

First of all, it is important to ascertain whether augmented reality technology can be effective in aiding education and learning. This part of the pilot study focused on this issue having the following hypothesis: Augmented reality can be effectively combined with traditional methods to help students understand complex concepts and operations during practical laboratories. Based on studies that suggest that multimedia augmentation provides a more effective way of presenting teaching material compared to traditional methods [LPLW02], an interactive scenario was designed and demonstrated to two courses. The first was a foundation-level course called 'Introduction to Information Technology', and the other one was a postgraduate course, called 'Virtual Environments'. The audience in 'Introduction to Information Technology' course consisted of 15 foundation students while 'Virtual Environments' had a cohort of 5 postgraduate students. In both courses, qualitative responses were collected from the students based on the 'thinking aloud' technique [DFAB04].

6.1.1 Tutorials

The first step in the sequence of the lecture material described the basic hardware components of a computer system and only the most significant components were presented including the motherboard, RAM, CD-ROM, DVD-ROM, hard disk, fan etc. To present a more engaging way of learning, 3D representations of the hardware were combined with human-computer interaction techniques. Students were able to examine the virtual information naturally. They could either use a head-mounted display (HMD) or a standard display monitor to view the virtual information. Each type of visualisation display has advantages and disadvantages since a HMD-based augmentation provides more immersion but may cause nausea and motion sickness and increases the overall cost of the application. On the other hand, monitor-based augmentation is much cheaper and it is more suitable for collaboration but provides less immersion.

Figure 2: Student examining a 3D representation of an Intel CPU.

The application of AR in learning can be demonstrated through the use of a practical tutorial called the virtual computer. The aim of this tutorial was to combine traditional methods (i.e. PowerPoint presentation) with AR technologies to illustrate how a real computer looks like in reality. Students and lecturer gathered around a table on which the interior of a computer was overlaid. Based on the course's syllabus, augmented guidance was provided to the students using meaningful textual annotations in two ways: as references or as instructions. References (also called labels) were used to augment the most characteristic hardware devices whereas instructions were provided to act as an additional electronic guide for students (Figure 2).

To emphasise the 3D representations of the computer's parts the lecturer could isolate only the 3D models so that students were more focused and able to perform basic interactions on them such as rotations, translations and scaling operations.

Figure 3: Web3D-based VR presentation with metadata and AR-based presentation.

For the 'Virtual Environments' course, a second tutorial was designed and presented which allowed users to interact with 3D Web content (Web3D) using virtual and augmented reality. This allowed the exploration of the potential benefits of Web3D and AR technologies in education and learning. Multimedia content could be viewed locally or over the Internet, as well as in a tabletop AR environment (Figure 3).

To better manipulate the 3D model, sensor devices, such as 3D mouse were integrated within the system. The advantage of using a 3D mouse is that it usually provides button menus together with a puck allowing six degrees of freedom interaction with 3D information, which makes for a more efficient interface than the keyboard.

6.1.2 Evaluation

The two educational scenarios were designed to investigate the effectiveness and presentation of multimedia augmented reality. The operation of the system was presented to the laboratory and students in both courses were asked to comment on the effectiveness of the system and whether it should be used as an additional tool for teaching the courses. Two different configurations were used, one for collaborative learning using standard monitor displays and another one using HMDs.

As far as the user feedback is concerned, all students agreed the presented technology is very promising and should be applied in the classroom. However, the feedback received for individual aspects (i.e. visualisation and interaction) varied within the different groups of students (undergraduate and postgraduate). Specifically, the undergraduate students were impressed with the ease of use, the flexibility and the capabilities of the learning interface. In terms of visualisation, they preferred the monitor-based augmentation compared to the HMD-based augmentation which they found distracting and difficult to use. They commented that the monitor-based augmentation can help to increase collaborative learning and enhanced interaction and engagement with the subject matter. On the other hand, the postgraduate students found it extremely useful to be able to 'see' and 'interact' with related multimedia information in three-dimensions using the HMD-based augmentation. Especially in the case of computer components where they could examine a number of 3D representations concerning not only the specific hardware components but also learn by the virtual multimedia scenarios how a computer works. One particular student pointed out that the use of AR technology is the best means of teaching the 'Virtual Environments' course since it makes it easier to understand the underlying theories and concepts for three-dimensions.

In addition, all students agreed that the physical interaction of multimedia information provides an exciting means of collaboration between the lecturer and the students. However, almost all students criticised the fact that only a few scenarios had been implemented.

6.2 AR for Teaching Multimedia

A second pilot was conducted in a postgraduate course called 'Multimedia'. As before, the experimental demonstration of the AR technology was qualitatively evaluated. The course cohort consisted of 10 students including 5 male and 5 female. Since the use of AR technology as a learning tool was determined to be helpful the second stage of the research was to explore some aspects of it in more detail. The hypothesis consisted of three parts: augmentation of audio-visual information is more effective than other multimedia mediums and it can aid the learning process; interaction in AR is more effective than other means and will speed up the learning process; and current learning can be enhanced through the use of AR.

6.2.1 Tutorials

Figure 4: Collaborative AR learning game: unsolved AR puzzle pieces with the complete solution (left) and solved AR puzzle (right).

Collaboration in classroom situations is largely determined by the students' roles [KS02] so the lecturer is responsible for controlling the sequence of the demonstration using the AR interface environment. The AR Puzzle application designed for this study was used to present geographical information in an attractive manner that would make learners more interested in geography. As an example scenario the topology of the university's campus was presented in an interactive 3D puzzle. At the beginning of the game, students were provided with a set of marker cards. Each card corresponded to a different 3D component of the campus. Students were able to examine the components of the puzzle interactively in a natural way. Furthermore, they could experiment with different topology combinations by placing the pieces of the puzzle next to each other (Figure 4).

Students could collaborate in natural ways by swapping the cards around and utilising all types of communication that humans use when collaborating in real life (i.e. verbal, gesture, etc). This is one of the most significant advantages of the AR system over other educational and learning technologies. It offers students a selection of different interaction techniques ranging from natural interactions to software and hardware interactions.

6.2.2 Evaluation

The feedback received from the participants can be categorised into three types including: visualisation experience; interaction and movement; and usefulness in learning. In respect to the visualisation experience, most students agreed that the enhancement of AR was responsive, helpful with user-friendly interface. The visualisation experience as a whole was very useful and can be ranked as very good since the 3D models were very realistic. Some students argued that the tangible interface is very effective because it is possible to examine 3D objects from any angle in a natural manner. Three students mentioned that 3D perception in a classroom is much better than 2D because it helps to visualise the atmosphere in a better way and looks closer to reality.

As far as interaction and movement is concerned, students were impressed with the tangibility of the AR technology and the ability to naturally manipulate the learning material (i.e. navigating into a new place in 3D to wayfind from one position to another). Most of them mentioned that interaction seems to be very easy a very enjoyable and one said that it is "the most interactive interface that I have experienced in the classroom". One stated that it is much better to interact with 3D objects in AR rather than interacting using the mouse and keyboard. Another student said that it is better than traditional methods since it is closer to reality.

The general feedback received was that AR is a useful tool for learning not only in multimedia but also in other courses of computer science and informatics. Most students were impressed with the capabilities of AR and liked using it for exploration and learning. In particular one said "by far the most interesting lecture I have ever had and made me want to explore more and more". Another liked the fact that they can zoom-in and explore particular features. One student mentioned that it would be good to have the whole course using AR but this would probably require a lot of time in the generation of tutorials. Finally, two students said that it is complicated and need some time to adapt to it so they proposed to do some training before using it.

7 Conclusions

In this paper we have presented an interactive, low-cost AR educational environment. The innovation of the system is that it can provide students with a multimedia augmentation of teaching material in a compelling and engaging way. Students can collaborate with the learning environment using either a physical interface (i.e. marker cards) or hardware devices (i.e. keyboard, mouse, 3D mouse) and software user interfaces (i.e. graphical user interfaces).

The technology has been trialled in three different academic departments of different UK universities. Our initial evaluation suggests that AR technology is a promising and stimulating tool for learning and that it can be effective when used in parallel with traditional methods.

The current focus of the research is on implementing more robust educational scenarios and evaluating the operation of the system as well as the learning scenarios through extensive user studies One of the greatest advantages of the presented system is that it can be used as a platform for creating other learning applications in other higher education fields such as computer graphics (as mentioned in section 4 of this paper), biology, chemistry, physics, archaeology, geology, geography etc. Although AR has been around for a while now, only recently have researchers started designed and implementing experimental applications including entertainment, medicine, construction, collaborative design, military, archaeology and many others. However, many issues related to technology remain to be improved as well as wide-ranging user studies within universities must be completed before AR learning environments can become a standard component of higher education.

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