Towards a Modular Network-Distributed Mixed-Reality Learning Space System

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Abstract. We propose a Modular Mixed-Reality Learning Space System (MRLSS) that relies on middleware tools and distributed mixed-reality technologies to support multi-modal communications between local, remote, and virtual *audience sets*. Each audience set occupies a *spatial module* represented throughout the system as a *cell* which is visually displayed on specifically aligned projection surfaces in each module. A module can host multiple cells and can be categorized based on scalability and technical advantage. For example, an *Individual Cell* (ICell) could contain a participant with only a web cam and audio. A *Classroom Cell* (CCell) could be a single classroom. A *Virtual Cell* (VCell) is a graphically rendered space with unique possibilities for interaction, experience, and exploration. A *Studio Cell* (SCell) is a specialized facility with advanced systems, services, and scalable spatial capabilities. A *University Cell* (UCell) can host multiple instances of an MRLSS, i.e. simultaneously host and combine more than one MRLSS.

1 Introduction

In *Planning for Neomillenial Learning Styles*, Dede suggests that 21st century students are well accustomed to "the growing prevalence of interfaces to virtual environments and augmented realities." He also notes that students are becoming well versed in new interactive media as well as becoming increasingly immersed in "media-based lifestyles." As a result, the student culture is changing and new styles of learning are emerging. "In the long run," Dede argues, "the mission and structure of higher education might change due to the influence of these new interactive media." [1]

In addition to changes in contemporary learning styles, advances in powerful computing platforms and high-throughput network infrastructures are enabling a broad range of computer-mediated communications(CMC) across data-rich interactive networks such as the Internet. The unique capabilities and popularity of these Information and Communication Technologies (ICTs) are driving major shifts in *how* the education process is orchestrated. Academic operations depend heavily on ICTs, particularly in areas related to accessing campus computer resources, developing course management systems, and managing distance learning courses.

Many traditional classrooms and learning spaces have also transformed in order to get "wired" for online access and to accommodate advanced presentational

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methods. The resulting systems have engendered a lively environment for practical innovations in the design and experimentation of advanced learning spaces while simultaneously supporting new pedagogical techniques. [2,3,4,5,6,7,8]

Like Dede, many educators recognize this technological shift as a valuable opportunity to leverage network-centric educational tools and computer-mediated experiences in order to manage and enhance the learning process. [9,7].

We introduce a conceptual framework for a scalable and modular Mixed Reality Learning Space System (MRLSS) and illustrate its unique design. The system is intended to engender modular and scalable presentational spaces that combine and align multiple viewing volumes into comprehensive spaces for learning, experience, and presentation.

The concepts and techniques associated with distributed mixed reality (MR) in presentational environments are central to the development of our proposed MRLSS system. For example, tessellated mixed reality boundaries (MRBs) are incorporated into the MRLSS using a scalable hexa-cellular layout and configuration scheme.

Three distinct viewing space categories, or *audience sets*, are identified: local, remote, and virtual. Each audience set has inherent tradeoffs in the context of the MRLSS and a major research goal is to identify and manipulate critical factors related to how learning outcomes change as critical presentational materials migrate across boundaries.

The primary education-related goal of this network-distributed system is to effectively synthesize key advantages of both traditional and network-centric pedagogical forms. Special attention is given to shaping the unique features of the MRLSS in order to accommodate the particular needs of neomillennial learners and educators.

2 Related Work

The MRLSS framework is intended to establish methods and standards for orchestrating the synchronous and poly-synchronous confluence of co-located learners, educators, and researchers into advanced learning spaces. The proposed framework is a synthesis of a variety of emerging concepts and technologies related to mixed reality, middleware-enabled open architecture, and synchronous collaborative platforms.

2.1 Mixed Reality

Beginning roughly in the early 1990's, the coupling of real-time 3D computer graphics capabilities with their associated displays and interface devices have inspired novel possibilities for enhanced mediated experiences. Some of these highly interactive experiences involve the merging of shared virtual environments with real-time processing of live video and audio streams. This technique is generally known as *mixed reality*.

The term "mixed reality" (MR) first appeared in the literature in 1994 when Milgram and Kishino published a taxonomy and continuum in order to identify an emerging subclass of virtual reality technology called Augmented Reality (AR). The authors identified MR as "...the merging of real and virtual worlds" such that "real world and virtual world objects are presented together within a single display" [10].

Starting in the late 1990s, the Communications Research Group(CRG) at the University of Nottingham generated a number of projects and papers related to the applied use of collaborative virtual environments (CVEs). While investigating the shared dynamics across physical and synthetic spaces, the Communications Research Group conducted several experiments within the context of live performance and presentational environments.[11] One series of experiments known as "Inhabited Television" merged CVEs with broadcast television and a live theatre audience. [12,13,14,15,16,17]

One of the most unique research areas to emerge from the CRG was the introduction of the mixed reality boundary (MRB).

Tessalated Mixed-Reality Boundaries.

MRBs were proposed by Benford et al. as a novel approach for "creating transparent boundaries between physical and synthetic spaces."[18]

MRBs demonstrated that MR could be extended beyond just what happened within any given viewer-oriented display. "Thus, instead of being superimposed, two spaces are placed adjacent to one another and then stitched together by creating a 'window' between them." [18,19]

In an eRENA report entitled "Pushing Mixed Reality Boundaries", the authors note that "multiple boundaries might be used to join together many different physical and virtual spaces into a larger integrated structure called a tessellated mixed reality." [20].

The modular system presented in this paper incorporates the tesselated mixed reality technique using hexa-cellular arrangements of distributed mixed reality boundaries. This unique, scalable, design takes full advantage of the inherent mathematic properties of regular hexagons.

2.2 Network and Middleware Modeling

While describing a middleware infrastructure for building ubiquitous mixed-reality applications, Tokunaga et. al [21] state that two key requirements must be satisfied in order to effectively build ubiquitous mixed-reality applications: High-level abstraction to hide heterogeneity of multiple device requirements; and a middleware infrastructure to cope with environmental changes via automatic reconfiguration.

The infrastructure they present, MiRAGe, consists of a *multimedia framework*, a *communication infrastructure*, and an *application composer* that reportedly "hides all the complexities to build mixed reality applications for ubiquitous computing."

The MRLSS is targeted towards accommodating multiple instances of co-located heterogenous users. Unique capabilities of middleware (such as those identified by Tokunaga et. al) will be leveraged for managing and enabling necessary levels of abstraction for the system.

2.3 Designing High Performance Presentational Spaces for Learning and Engagement

Any real-time presentational event that has the power to attract a significant number of participants and/or spectators may benefit by incorporating unique models of networked mixed realities and multimedia into the event space. This is particularly true in research universities with high enrollment. Universities are founded on physical presentational spaces ranging from media-rich cubicles, to large lecture halls. Many universities have a main proscenium theatre with many other alternative performance spaces. Classrooms, however, typically occupy most of the "educational real estate".

Today traditional classrooms are typically equipped with several multi-media options. Collaborative multi-media forms that give advanced controls to individual users greatly increase the cost and complexity of presentational forms such as lectures and research meetings. Previous work related to concepts associated with the MRLSS focused primarily on very small groups in very small, focused, shared spaces. Five examples in particular make use of the *table* metaphor as a familiar gathering point for remotely sharing a space.

In *Extending Tabletops to Support Flexible Collaborative Interactions*, Rogers et. al, demonstrate an interactive tabletop, though all participants are in the same room and gathered around the table.[22]

In *The ARTHUR System: An Augmented Round Table*, Moeslund et. al employ augmented reality to present 3D objects and data onto another shared table concept while incorporating a wireless wand, tangible interfaces, and gesture-based hand and pointing commands within a collaborative context. [23,24]

Regenbrecht et. al, published two papers related to shared spaces that used mixed reality technology. In *MagicMeeting: A Collaborative Tangible Augmented Reality System*, [25] real meeting locations were augmented by incorporating an "Augmented Reality Meeting Table". Again, in *Using Augmented Virtuality for Remote Collaboration*, the cAR/PE! system demonstrated communications within a full virtual environment and generally centering the experience around a virtual table. Live video planes of participants at three different locations were arranged around a table. The cAR/PE! system also allowed for scaling the number of participants around the table. [26]

The National Institute of Standards and Technology (NIST), an agency of the US Department of Commerce, headed the NIST Smart Space Project. The Smart Space Project focused on "Human Information Interaction that transcends the desktop." The project was primarily targeted for US military uses [27]. However, an illustration of a commercial application entitled "Collaborative Design Space" was shown in a NIST presentation related to the project[28]. The example also incorporates the *table* metaphor similar to the cAR/PE project. The focal point, again, being positioned towards an abstracted *table* area for sharing aligned spaces and advanced services.

All of these examples inform the concept proposed in this paper and set the stage for extending the table metaphor into a hexa-cellular arena theatre metaphor.

3 A Modular Mixed-Reality Learning Space System (MRLSS)

The conceptual basis of the MRLSS is built upon the unique properties of scalable interlocking regular hexagons. The hexa-cellular arrangement of mixed reality boundaries (shown via simulation in figures 1, 2 and 3) illustrate how the MRLSS can combine and align multiple instances of local, remote, and virtual audience sets into a shared, comprehensive, learning space. Each audience set occupies a theoretic "spatial module". If each spatial module conforms to a set of operational constraints (such as alignment of boundary cameras and projection surfaces), the hexa-cellular platform concept makes it theoretically simple to parse, switch, and interlock all participating spatial modules. Spatial modules can then be abstracted and represented throughout the system as unique "cells". Each spatial module in the system–depending on its network connection and structural properties–can interlock with one or more cells.

Fig. 1. Overhead view of a full studio simulation with three local/studio cells, a remote cell, and two virtual cells

Fig. 2. A Simulated Example of an MRLSS Modular Learning Space

3.1 MRLSS Cell Framework

MRLSS cells are hierarchically categorized based on the relative scale and technical advantage of each spatial module. This *cell framework* differentiates spatial modules for design purposes in order to isolate and accommodate inherent tradeoffs associated with distinct scenarios. For example, a single participant joining the MRLSS from a coffeehouse with only a web cam and audio headset has many more constraints and limitations than a university researcher presenting visualizations of large scientific data sets in a specialized studio space. A specialized

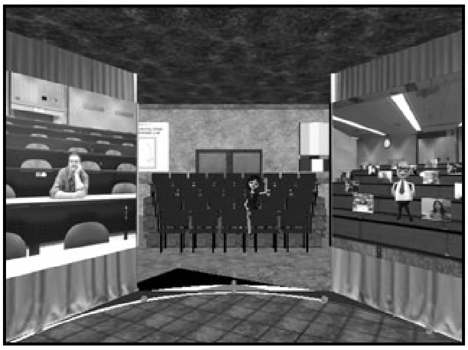

Fig. 3. Remote Module Point of View(front)

studio would naturally provide many more services including numerous technical and environmental controls.

An Individual Cell, or “ICell”, is characterized based on high levels of mobility and/or the use of only a single camera and visual display. An ICell joins the MRLSS via the VCell web interface (see below). ICells are represented as live video avatars in a VCell. Video from a web cam is displayed as a live texture on a geometric quad which is parented to a primary virtual camera. A secondary virtual camera (V-CAM) is positioned and parented facing the quad and tightly framing it for self-viewing and “switched” viewing so that other participants can get close-ups when necessary. The V-CAM can be disengaged from the quad and operated by the participant giving freedom to roam the virtual space and share its viewpoint. The V-CAM also has a 2D graphics overlay for pointing purposes and to display other 2D information.

Classroom-based modules, or “CCells”, are constructed in physical learning spaces using specifically anchored audio and video sources arranged to conform to the hexa-cellular platform. The CCell would require a fast intranet/internet connection, wireless access, power outlets, and at least one adjustable camera, semi-permanent projection surface and video projector. A *basic* CCell has only one boundary and is oriented towards taking full advantage of alignment limitations due to permanent, pre-existing, projection systems in typical contemporary classrooms. If the permanent configuration is too far off axis, it is re-classified as an ICell and routed into a VCell (see below). *Flexible* CCells would allow for positional adjustments to projectors and projection surfaces. This allows more freedom to tightly conform to the hexa-cellular platform. Advanced CCells would extend the basic CCell by adding adjacent “wing” MRBs to its primary boundary. Each wing boundary positioned to create a “half-hex” configuration.

A Virtual Cell (VCell) is a graphically rendered space with unique possibilities for interaction, experience, and exploration. (see Figure 4) The VCell includes the ability of ICell participants to login to the virtual cell using a desktop computer, laptop, or other mobile devices that are equipped to interface with the MRLSS (cellphones, PDAs, blackberry’s, iPods). VCells can host as many cells as the system is capable of processing and distributing in realtime. VCells also enable participants to simultaneously occupy more than one spatial module, i.e., a participant with a laptop in a CCell (a nested ICell) could also enter a VCell and, technically, "be" in three cells at the same time. The VCell is unique in that it enables participants to interactively explore advanced levels of content nested within the VCell as well as position themselves to optimally view presentations and participants that occupy other cells.

A VCell is very flexible in that it can be constructed as a classroom, a laboratory, or a simulation of an ancient theatre. Specialized areas within the VCell can be constructed to support multiple visualizations of interactive data sets as well as collections of posters and pre-recorded video displayed on geometry. Previous course content, representative class projects, or collections of seminal research can be spatially archived and accessed within the VCell–perhaps inspiring exploratory visual adventures in research.

Fig. 4. A "cell wall" feed of a Module looking into a virtual audience set. This set has a 3D animated character and ICells projected on geometry.

A Studio Cell (SCell) is a specialized facility with advanced systems, services, and scalable spatial capabilities that can support modifications to the hexa-cellular platform. SCells are ideal for heavily used learning spaces that may accommodate a wide range of educational content, unique experiences, and special events. The recommendation is that an SCell conform to the hexa-cellular design by architecturally synthesizing it into a specialized arena theatre space. For example, a *full arena* SCell would be capable of hosting up to six additional spatial modules. A *standard* SCell splits the difference spatially between viewing volumes by supporting three local audience sets (offset along 120 degree angles) and three other non-local spatial modules (see Figure 1). Advanced Studio Cells could be constructed out along a hexagonal grid beyond the central SCell. This could potentially enable the creation of complex hexagonal mazes of persistent, interlocking, cell communities.

A University Cell (UCell) can host multiple instances of an MRLSS, i.e. simultaneously host and combine more than one learning space system. Content and course management systems used at universities could interface with the MRLSS for accessing dynamic and time-critical information. Collaborative projects between academic and scientific communities could be fostered to develop shared spaces and remotely view large, sensitive, data sets.

An Alternative Cell (ACell) can be any number of non-standard MRLSS configurations. For example, some classrooms have permanent projection surfaces that are positioned or sized in ways that make it impossible for the spatial module to visually conform to the hexa-cellular platform. In that case, the ACell must somehow adapt in order to effectively participate. Other forms of ACells may be specialized modules such as full body motion capture volumes, advanced haptic studios, scientific instrumentation labs, live performance spaces, interactive movie/gaming theaters, or even coffee shops with persistent connections to public MRLSS meeting spaces.

By the very nature of the hexa-cellular design, there is no established "center" to the MRLSS. Therefore cell centrism must be negotiated by the participants as to who and where the presentational focus is set. Given the inherent flexibility of VCells and SCells, central focus might orient around one of these types. In a VCell-centric scenario, the emphasis is on the virtual content. In a SCell-centric scenario, the real spaces is centric and other cells gather around the real space. Both have inherent strengths and weaknesses. In a non-centric MRLSS event, many interesting and distributed configurations could be generated–though presentational focus may be sacrificed.

4 Network Structure and Middleware

One of the primary challenges for the proposed MRLSS system will be developing an effective method for the synchronous orchestration of a wide variety of high-bandwidth, real-time, net-centric media objects. We propose a middleware-based collection of show control services or a "show engine" that can be operated, monitored, and controlled by cell-operators through a web portal.

In terms of network traffic, the initial prototype will employ and examine service-oriented designs based on a traffic-per-node or "per cell" basis. Video quality will primarily determine the actual amount of traffic and subsequent system behaviors. H.323 video traffic, for example, will generate low mb/s, whereas HDTV will generate traffic in the gb/s range. The MRLSS assumes a matrix of sites with multiple, heterogenous, data sources. Therefore, in the general case, traffic can increase significantly depending on the number of nodes. However, the use of advanced technologies and algorithms could potentially solve this issue.

In order to address the contextual challenges related to cell interoperability, service tier prototypes will be investigated for identifying, scaling, and filtering real-time media.

5 Discussion

The proposed MRLSS with its projection and camera-based scheme emphasizes conformity to common standards for projection display systems and their associated peripherals–such as screens, lamps, and lenses.

By leveraging the power and flexibility of emerging computer graphics techniques and network computing, traditional time/space constraints between viewer and viewed may soon dissolve within the boundaries of distributed, real-time, modular presentational spaces.

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