

The Shared Imagination: Creative Collaboration in Augmented Virtuality

Charles E. Hughes

University of Central Florida
School of Computer Science
& Media Convergence Laboratory
ceh@cs.ucf.edu

Christopher B. Stapleton

University of Central Florida
Media Convergence Laboratory
& School of Film and Digital Media
chris@mcl.ucf.edu

Abstract

In creative collaboration, the primary focus of participants is creating “what if” scenarios that must be jointly imagined. Collaboration in strictly Physical Reality (PR) is constrained because of the limitations the real world places on shared imagination. As dynamic as Virtual Reality (VR) environments can be, subtle human-to-human interaction is severely limited in these totally synthetic environments, which provide such poor support for the physical expression of passion and personality. Augmented Reality (AR) can add virtual assets to the physical world, yet creative interaction cries out to escape the context of the physical world. With interpersonal imaginative interaction, Augmented Virtuality (AV), the augmentation of a virtual setting with real objects, provides a means to merge a richly layered, multi-modal, 3D real experience into a virtual environment. This class of Mixed Reality (MR), which represents a reversal of the more common AR concept, provides a change in paradigm that offers unique opportunities and novel tools for collaboration, the impact of which we will explore in this paper.

The Mixed Simulation “Demo Dome,” an innovative application of MR Head Mounted Displays (HMD) and unidirectional retro-reflective material, provides the next generation of immersive environment, one that is an easily deployable means of multi-modal AV collaboration. The technology associated with this environment will be discussed, along with the Mixed Reality Software Suite (MRSS), a system that supports the creation and delivery of nonlinear interactive experiences within such a dome. Examples of the use of this system and concept in team performance training, emergency planning, collaborative design, experience modeling, scientific virtualization and entertainment will be presented.

1 Introduction

1.1 Creative Collaboration and Mixed Reality

The Creative process is able to exist entirely in the imagination. However, once we introduce collaboration to the process, we must mitigate the limitation of Physical Reality (PR) in order to share inspirations. Traditionally this is achieved by augmenting the exchange with dialogue, drawings in the sand, marker board scribbling or rigid models to achieve a group consensus. An alternative is Virtual Reality (VR), a disembodied experience in a purely synthetic world. However, the goal of VR is to dominate the senses, taking its users to a place totally disconnected from the real world. Creative collaboration requires a more seamless exchange of both, representing a dynamic, interpersonal and passionate exchange that is difficult to represent synthetically. With many applications, there are aspects that just don't work well as virtual objects. Mixed Reality (MR) runs the full spectrum from the real to the virtual (Milgram & Kishino, 1994) with two commonly discussed discrete points along this range, Augmented Reality (AR) and Augmented Virtuality (AV). AR refers to the condition where users are situated in a real setting with synthetic objects added to the real landscape. AV refers to the condition where the setting is virtual, with real objects (typically at least the human users) situated in this virtual landscape. One of the most important aspects of MR experiences is that people can maintain their real identity; it is this personal identity that leads to social interaction.

Figure 1 shows examples of PR, DinoDigs at the Orlando Science Center, AR, Sea Creatures (Hughes, Smith, Stapleton & Hughes, 2004), AV, an experience using the MR Demo Dome, and VR, a VR version of Timeportal demonstrated as an AR experience at SIGGRAPH 2003. Note that the Sea Creatures AR experience has an embedded VR experience in the upper right-hand corner. This is an out-the-window view from an underwater virtual rover that the user can control to navigate through the Cretaceous waters that augment DinoDigs.



Figure 1: Milgram’s continuum with examples from MCL projects

By understanding that the full spectrum of Mixed Reality is a continuum between virtual and real and not just discrete points in that interval (PR, AR, AV, VR), one has the power to select the right mixtures of real and virtual to achieve a given application’s purposes. In creative collaboration, when most of the subject matter is speculative and out-of-the-box, nearly everything is of a virtual nature, except for the unique collaborators, who are very real. By including the human participants, AV is able to incorporate interpersonal tangible gestures, drawing and verbal expression, colored by each interactor’s unique personality of appearance and reactive behavior that is paramount in gaining a sincere and trusting relationship within the sensitive nature of creative exchange.

The development of a functional “Shared Imagination” creative, collaborative AV environment relies on the particular application of the technology and social awareness of various groups applying the concept. This paper explores the first generation prototype being employed to begin testing and evaluating creative team collaboration in context. This prototype and subsequent evaluations will inform the design and implementation of the next generation collaboration tools and possibly lead to the next generation Human System Interface (HSI) paradigm, breaking the limitations of the traditional Graphical User Interfaces (GUI).

1.2 Mixed Reality is not just Augmented Reality

The term Augmented Reality has been inappropriately interchanged with Mixed Reality in many demonstrations and in the literature; however, AR does not span the MR continuum. Moreover, most AR systems (software and hardware) are capable of delivering just one particular dimension of AR (see Figure 2) that does not actually melt the boundaries of the real and virtual, as is required by true MR and creative collaboration. The term Mixed Reality is many times applied as a catch-all phrase for mixing any portions of two realities, such as embedding projection displays in physical environments or augmenting CAVE environments (Cruz-Neira, Sandin, DeFanti, Kenyon & Hart, 1992) with props and scenery. Projection-based systems do not actually allow for the virtuality and reality to mix, but rather to be interspersed (such as oil and vinegar). A system cannot be truly considered capable of MR without being able to dynamically service and mix the entire range. The solutions within this paper are applied to work within a suite of hardware and software tools within the dynamic range of MR that can apply to all the dimensions of AR, as well as extend to AV.

The need to balance the degrees of physical versus virtual reality based on the requirements of the application and not the limitations imposed by some arbitrary selection of technologies places a great demand on the underlying software system. Most software systems for MR are tied to one mode of AR and a limited range of hardware; they do not support the full spectrum of Mixed Reality. To address this in our environment, we have created our own authoring / delivery system, the Mixed Reality Software Suite (MRSS), to support a wide variety of MR technologies and the needs of applications that span the entire MR spectrum. In particular, this suite supports the capabilities of the Mixed Simulation Demo Dome (MSDD), our primary means of delivering AV for creative collaboration.

Dimensions of Augmented Reality

1D AR	2D AR	2.5 D AR	3D AR	3D AR	3D MR	3D AV
						
Mobile Worker	HiEnergyMagic	US Army JFETS	Siemens	BARS	MR.MOUT	MS Isle
						
Eye Piece	Phone/PDA	Embedded Projection	Vehicle Display	HUD	MR HMD	MR HMD
Data Overlay	Video Overlay	2D Projections	3D Registered Graphics	3D Spatially Registered Graphic	Richly Layered Multi-Modal	Immersion Venue

Figure 2: Visual continuum of AR dimensions aspects of 1D, 2D, 2.5D, 3D AR, 3D MR

1.3 Next Generation Mixed Reality Richly Layering All the Senses

Many implementations of MR are strictly visual and just two layered, with either virtual in front of real or real in front of virtual. While these approaches greatly simplify the science and technologies required, they fail to achieve MR's ultimate goal of a seamless integration of the senses and realities. The next generation of MR requires us to provide many layers, with the virtual occluding the real and the real occluding the virtual, depending on their depth from the viewer. Moreover, our work also address issues of virtual-real interaction as with the case of inter-object shadowing and lighting, with virtual objects casting shadows and, where appropriate, casting light on real and vice versa. See (Hughes, Kontinen & Pattanaik, 2004) for details on how this can be accomplished.

While most MR experiences involve and are even dominated by the visual domain, our view is focused on enhancing experience with a more balanced multi-sensory simulation. In fact, the experiences we create typically place the auditory at an equal footing with the visual domain. Our goal is to put other senses, smell, taste and touch at that same level. We have not reached that stage, but we have effectively addressed another sense, that of wonder and imagination. In fact, we consider imagination (the user's contribution to the experience) to be the most important sense of all, primarily for its contributions to creative collaboration. See Figure 3 for a visual presentation of this concept and (Stapleton & Hughes, 2003) for further details.

1.4 Augmented Virtuality and Unidirectional Retro-reflective Surround

The focus of this paper is on augmented virtuality. Thus, we need to embed our users and their physical artefacts within and around a virtual setting. Inserting humans and other physical objects in a virtual space can be accomplished by a variety of techniques, one of the most obvious of which is to surround the real with a projection display, such as a CAVE (Cruz-Neira, 1992). Unfortunately, this approach restrains the virtuality to be behind the projection surface separating the virtuality from the reality and severely limits other modalities such as precisely placed audio or multi-user views. Applying video see-thru MR HMD technology (Uchiyama, Takemoto, Satoh, Yamamoto & Tamura, 2002) with a traditional "chroma-key" matte, commonly used in weather reporting, has several disadvantages due to the physical light casting shadows on the "blue/green screen" disrupting a clean matte and requiring significant separation between the person and key to prevent degradation. In this context, the lighting of physical objects and even of the chroma-key surface are in constant competition.

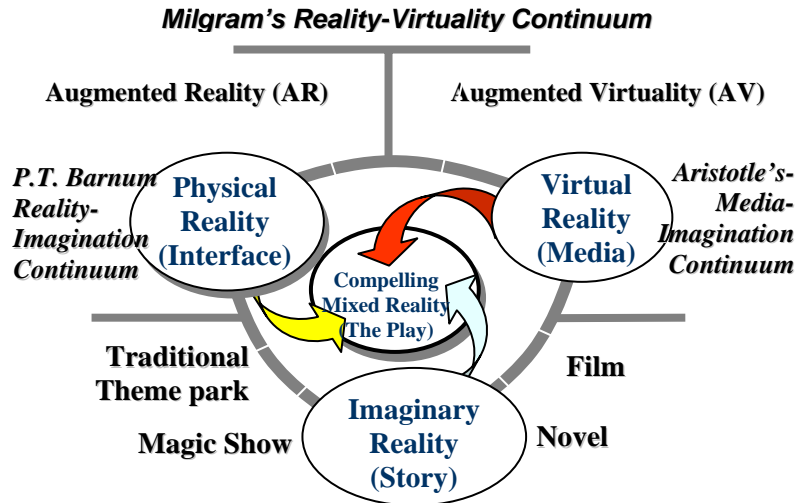


Figure 3: Milgram diagram extended to include imagination

As an alternative, we use a combination of a soft unidirectional retro-reflective fabric and camera-mounted illuminated film or cold cathode light with ceiling mounted lighting to avoid the previous limitations. Since a unidirectional retro-reflective screen reflects light only to its source, the light emitted from the HMD is reflected back with negligible chromatic distortion or degradation from the surrounding environment. As a result, consistent lighting keys are achieved, dramatically reducing computational complexity and at the same time allowing for a dynamic venue with environmental lighting. Avoiding the use of hard projection surfaces allows for proper audio projection and acoustic absorption to provide more versatile Mixed Reality audio landscapes.

2 Mixed Simulation Demo Dome

The consequence of our use of a unidirectional retro-reflective curtain is a novel MR environment that has capabilities beyond a CAVE but deploys as easy as a beach dressing cabana and greatly reduces square footage, set-up time, costs and the infrastructure of projection displays. We call this the Mixed Simulation Demo Dome (MS DD). Not limited to a dome, it scales to whatever size is required and forms to the space. In our typical set-up, the dome contains a surround of curtains, a round table with two chairs and two HMDs. Users sit on each side of the table, which is itself covered with retro-reflective material. Real artefacts may exist on the table and in the room. Virtual objects can be placed on the table and on the walls. The real objects on the table can interact with virtual objects on the table through mutual occlusion and shadow casting. The virtual objects on the table can partially occlude humans when these people are viewed so that the virtual objects lie in between the viewer and the other person. The retro-reflective cabana itself displays (through the HMD) a virtual context in which the users interact. Audio speakers, fans and lighting are placed in convenient areas above, around and outside the some (Figure 4).

2.1 MS Isle: A Prototype Experience

Here we describe a first experiment that we carried out using the Demo Dome. The experience is that of a simple free-will journey around a virtual island with under the water and over the land paths that surround the island. This is a collaborative experience, involving two users (Figure 4).

When the users start the MR experience, each wearing an HMD, they see a 3d map embedded in the table. Each user has a unique POV. The map is of an island with an underwater coral reef surrounding it. A scaled avatar, representing both users, is on the island map. The users have a God's-eye view of their position and movement, and must cooperate to move their character around the island and through the coral reef from opposite points of view. Tilting the 3-DOF tabletop left or right changes the avatar's orientation; titling it forward or backward causes the avatar to move around the world, basically in the direction of its current orientation. An underlying ant-based behavior model for the avatar prevents it from going up sharp slopes or through objects, such as coral reefs.

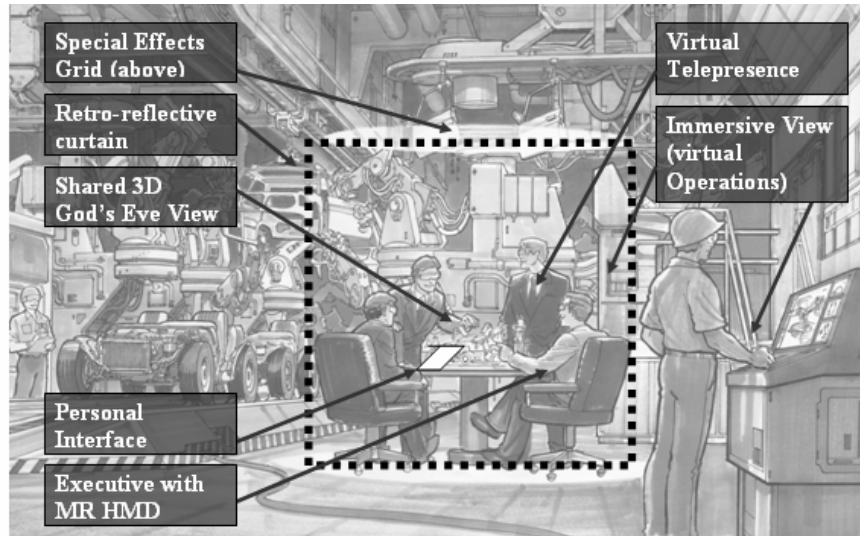


Figure 4: The MR Demo Dome

In providing both a “God’s eye” point-of-view on the table and an immersive first person perspective around the users, the level of interactive play dramatically increases, yet remains intuitive due to the tangible haptic feedback. The desired effect is achieved by creating a dual chroma mask on the retro-reflective material that is produced by opposing green and blue lights on each of the user’s HMDs. This first person scene is a shared one, although the users are typically looking in different directions. Since each user sees the other as part of the MR experience, a collaborator’s pointing and gazing are obvious. To encourage such collaboration, we added many enticing virtual objects: trees, seagulls, a shark, coral fish, butterflies, a sting ray and a giant tortoise

The use of multi-modal displays adds to the experience and the ability to test the user performance with different combinations of senses. This ability to simulate and utilize different senses for different cognitive memory and functions can lead to potential enhanced cognitive performance. An overhead special effects grid provides interactive lighting to match the virtual world lighting. Fans provide a subtle haptic sense on the skin to provide the feeling of motion and help avoid sim-sickness when visually moving. Base shakers and vibration speakers provide a sense of mechanical movement or collision. Heat lamps and air blowers provide temperature change. The addition of head mounted olfactory for localized disbursement of scents near the nose allows for quick change in aromascape (musty in the caves, lavender in the forest, sea foam in the water). Unfortunately, the current availability of manufactured scents limits the number of possible variations.

3 Applications of the Shared Imagination for Creative Collaboration.

3.1 Beyond Reality

The challenge with creating tools for creative collaboration is that the only tools typically needed are speech, arm waving and facial expressions. In fact, many extremely novel tools have been invented and quickly abandoned in lieu of simpler tools with more ambiguous interactions such as drawing in the sand, writing on a chalk or marker board, and manipulating a rigid 3D model. However, there are circumstances where creative solutions require a constant interchange between diverse disciplines. These often require more support, and include applications such as military command and control, urban planning and pre-visualization for filmmaking. More sophisticated visualization tools are needed to directly relate on-going decisions with elaborate and complex systems to increase team performance. The key is to not lose the traditional, more immediate and intuitive methods of exchange with verbal, gesture or tangible interactions and to layer in responsive and adaptable virtualized concepts.

Due to costly consequences in funding and human life, executive decisions have increasingly relied on thoroughly “rehearsing the future” in all its facets, layers and unpredictability to understand potential impacts beyond any one discipline. This process is most evident in the collaborative nature of storytelling and has been practiced for millenniums with the rapid development of “what if” scenarios. This is the basis of refining the MSDD into an

intuitive collaboration tool to be applied to disciplines making decisions with complex, expensive or dire consequences.

3.2 Evolution of Product Matching the Evolution of the Tools

Collaboration demands tools that meet the dynamic nature of the output. In collaborating on a written document (from technical manuals to the Declaration of Independence) the creative exchange can be conducted with the same limitations as the final product; in this case, linear threads of words, grammar and punctuation. With creative output, such as a theatrical performance, a physical 3D model is utilized to represent its environmental context and audience perspective. When dealing with more time-based graphic products such as film, television and especially animation, storyboards (a series of shot-by-shot images and captions providing the content, transition and story flow) and animatics (the adaptation of storyboards, live action and a rough soundtrack) into an edited linear stream become a mock up of the final show. However, as the content product becomes more immersive, real-time, interactive and non-linear, such as with video games, training simulations and experiential learning, the collaborative tools need to follow suite. The challenge is to weave dynamic virtualization into highly tangible physical creative interaction.

3.3 Informing the First iteration of the MSDD

Once our team had gotten the interaction of the MR HMDs and the retro-reflective material working, the task was to transfer the current creative collaboration process to this immersive virtual context. Since our laboratory has a fully operating creative production studio we decided to use them as our test group. We observed their traditional creative processes and noticed what key aspects needed to be accommodated.

The most critical and obvious component of creative collaboration was the *face-to-face interactions*. Ironically, many tools of collaboration place the collaborative plane on the wall with most everyone facing in the same direction. However, the most heated collaboration occurred across the tabletop. Our first decision regarding the MSDD was to make a table surface the primary working surface. Covering the top with retro-reflective material allowed us to occlude objects on the virtual tabletop with the hands of the participants and with their interactive tangible objects, such as model pieces, paper and pencils.

With most projection based, group immersion systems like the CAVE, everyone shares the same *Point of view (POV)*, controlled by a tracker on a select user. However, our observation is that creative participants examine alternative and often opposite points of view to help reveal aspects that are invisible to the group. A unique ability of the retro-reflective chroma-key technique is that you can assign different colors per HMD camera (and consequently per user) to provide a unique point of view. This also provides the option to tailor the virtual information per participant, perhaps catering to the user's expertise or level of security clearance. This allows for more multi-level and cross disciplinary discussions and validation.

Each creative process entailed multiple simultaneous creative interactions. Active participants were either engaged in *personal or group creation*. The personal process entailed being able to tinker with a tangent idea in parallel with the group discussion. This involved personal data and tools of the trade that fed off the larger discussion. Once an individual concept was formed, it could be introduced and accepted (or not).

The *tangible and tactile* components became critical with more artistically inclined creative participants. With the common practice of Charrettes with designers and architects, the use of brain candy or sensual distractions were widely utilized to spark the playful imagination. In a low-tech experiment, we equipped our conference table with a shallow sand box in the center to observe its use within creative exchanges. It was used minimally as a demonstration tool (drawing in the sand). The primary function was for sensual feedback. One visitor expressed that it "relaxed the brain to more freely contribute. It was like stroking a cat to soothe my creative anxiety."

The use of *constructive distractions* tends to be helpful in engaging highly creative people. All their senses and brain hemispheres want to be activated. In pitching ideas or providing instructional presentations, gaining the full attention of the audience is critical. However, with creative collaboration, full attention is valued vastly less than full participation. With more creatively minded participants, their full participation needs to be regulated to allow for

alternative views. Keeping them active with constructive distractions such as toys, or drawing in the sand allows for creative ebb and flow. If you are able to keep the actively curious engaged within the collaborative space, they will more likely fully participate and avoid checking messages on their blackberry. This is similar to training elephants for parades. Trainers use the task of holding a stick curled up in their trunk as a way to keep the trunk from straying to steal fruit from carts and hats off of heads. The use of individual interactive devices, dynamic models and unique views as personal, constructive distractions does not become a disruptive distraction for the group.

The individual views will need to eventually resolve themselves within a *shared display* for the group experience. With a simultaneous *God's Eye View* between users linked to an *Immersive View* surrounding the viewers, the sense of situational awareness provides for the dialogue to attend to “devil in the details” without getting lost in them. The retro-reflective surround and multimodal immersive displays allow for more complex presence within the three dimensional space, by layering dynamic composites of video capture and computer generated content.

The group display and creative process also needs the application of *shared interfaces*. As James Surowieki contends in (Surowieki, 2004), large groups of people are smarter than an elite few – no matter how brilliant at solving problems, fostering innovation, coming to wise decisions, even predicting the future. On a smaller scale, how can shared interfaces and displays assist in the collective intelligence of the group in real-time? We have experimented with a table top on a trailer hitch, bungee cords and a sensor. With handles below the table, groups are able to twist, tilt and turn the table top as a group steering wheel using intuitive tangible feedback as a way for group mediated navigation. Assigning functions to each manipulation and experimenting with response time, a group can zoom into and scroll complex terrain, manipulate vehicles, etc.

Naturally, the more important the meeting, the more likely key players will be unavailable or traveling. Video see-thru allows for the *telepresence* of remote attendees. Places around the table can be replaced by video captured from these remote participants. The video capture of the participant can be placed within the 3D immersive collaborative space where the camera is capturing each individual's personal view. The challenge is to provide the *scalability and interoperability* of being able to even plug in a participant with a cellular video phone.

The group's fluctuation in size and placement will require the need for *scalability and portability*. The retro-reflective curtains allows for easy transformation of the space's shape and size. Without the need for highly precise projection mirrors and screens, or heavy projectors, easy mobility and adaptation to spaces is possible. Ambient light and folds in the material do not affect the quality of image key. However, scale in terms of space may be an issue, and is an of continuing research in our lab.

3.4 Project Evolution: from planning to production to monitoring

Creative collaboration in most applications tends to be confined to the early planning stages of the project; just after the development of an individual participant's creativity and just prior to the delegation to the various disciplines and trades. The use of a creative collaboration tool is usually short-lived due to its inability to adapt to the evolution of a project or interface with the standards of each discipline and trade. The *flexibility and adaptability* of the MSDD is intended to provide a persistent tool throughout the evolution of a project.

A target application for the system is in developing a theme park ride. The highly-integrated ride system is usually tightly configured with diverse and conflicting design constraints including creative direction, safety considerations, operational capacity, engineering integrity and profitability. With little tolerances in all these areas, even the smallest decision at any point in one aspect of development can have devastating consequences on all other aspects.

The creative collaboration process within the MSDD needs to address three changing requirements that arise throughout project development. First, it must consider the unique tools of the participating groups and of the overall project. Second, it must take into consideration the social requirements in context and interactions of the development group. Third, it must represent the preferences of individual contributors. Each of these aspects change over the evolution of the project from *Planning and Design* to *Implementation* to *Monitoring*

The *functional requirements* of the MSDD system depend upon the functional requirement of each discipline's tools such as, a structural engineering or dynamic flow program virtualized with an architectural CAD program; or dynamic crowd flow models and decisions with operational staffing to determine compounded consequences for

capacity and throughput. While the individual systems are functional on a strictly virtual desktop interface, their data must be integrated for the AV display; this is a requirement for the MRSS we discuss in section 4.

The *social requirements* need to consider the context and cultures of the contributors and decision makers. For the entertainment industry, having the flexibility for dialogue to happen anywhere or anytime is essential. In the case of theme park rides, the design and implementation involves international coordination with ride vendors in Europe, show vendors in California, sponsors in New York, designers all around the world and theme parks residing in Orlando or Asia. With the addition of being a very social industry relying on diverse consensus, the system must have the ability to easily connect and capture each individual's direct feedback.

With the diversity of players in the entertainment field, *Personal Requirements* weigh heavily on the success of a system. The first issue is to allow for the input of very diverse disciplines which are usually answerable to different executive authorities. From design, finance, engineering, operations, maintenance, marketing and merchandising, what results in the same experience is a result of conflicting and diverse personalities and disciplines. The ability to accommodate the diversity from the artistic to the technical, from the techno-phobic to the technophile in the same meeting is mandatory. This is where scalability and interoperability are critical. In addition, each discipline has a healthy distrust of each other and requires a personal touch.

The *Planning Stage* requires a low-cost, big impact solution for the feasibility and financing of a project. Developers and feasibility studies evaluate industry standards with specific site considerations and market temperament to validate financing of a project that can reach hundreds of millions of dollars. While the Disney Parks have discontinued the use of ride tickets in lieu of gate admission, estimates are still based on the value of each experience (the A-Ticket is the least expensive mild experience and the E-Ticket is the most expensive thrilling experience) to evaluate the investment of time, material, money and staff to an individual attraction; the more thrilling an attraction, the more money that can be pumped into the cost estimate. The MSDD can be applied not only to an interactive table for both God's Eye and immersive view displaying assumed contributing factors, but it could also accommodate a ride simulator so that investors can validate the visceral as well as the visual and audio experience in order to match expectations with feasibility.

The *Design and Implementation Stage* must provide real-time cross discipline review to drastically reduce approval time and oversight. This allows for a more robust design by identifying issues earlier in the process and supporting more detailed solution designs. On-line sharing of data and telepresence of contributors are essential in both the effective and affective requirements. With integrated systems, more accurate financial models can better foresee critical complications and plan for unforeseen opportunities. This allows for mediation of fun systems with safe systems, and helps avoid financial disaster by validating the creative solutions from conflicting disciplines. As implementation develops, the conflicts become more apparent and more abundant. The ability to rapidly and effectively visualize small decisions on the big picture allows for rapid decisions that have less compromising effects of the net result.

The *Monitoring Stage* of a project utilizes virtualization tools the least, yet with the right configuration could have great long term value. Monitoring of a theme park involves capturing data from complex systems with highly demanding audiences in real-time. The MSDD is designed to accommodate diverse data capture and to superimpose these data on the dynamic models used for design in order to help in the design of novel monitoring devices for safety, crowd control, staffing assignments, materials management, merchandise stocking and technical maintenance priorities. Through networked access, the captured data can be shared on different scalable devices for up-to-date display on desktops, PDAs or video phones.

4 Mixed Reality Software Suite

Support for the MSDD comes from the MR Software Suite, MRSS, a collection of components that operate collaboratively to develop and deliver an MR experience. This suite involves multiple interactive and interacting system elements. The central component is the MR Story Engine (aka MR Script Engine, abbreviated SE from here on). The SE is the container for agents (actors), one for every user, virtual object and real object that interacts with other agents, plus other agents that might be useful for the story line. The agents manage the semantics of the story in that their states and behaviors determine what a user sees, hears and, in certain experiences, some of what he or she feels through touch. The other elements include, but are not limited to, graphics, audio, show-control devices,

interaction devices, physics engines and user interfaces. The SE provides a linking, synchronizing/control, and agent support mechanism for utilizing these elements in an interactive environment. Environments that are candidates for using MRSS include those delivering interactive story-telling experiences, collaborative design environments, technology demonstrations, games, and educational or training programs. The experiences can be situated anywhere along the MR continuum; the actual degree of real/virtual mix can vary as the experience evolves and can be different for different users or different perspectives for the same user. Experiences do not necessarily have to be visually dominant – in fact, pure aural experiences can and have been developed/delivered with MRSS. The basic structure allows multiple elements to connect and be utilized for the realization of any number of such environments, whether shared or stand-alone.

Besides linking and synchronizing diverse sensory components, MRSS operates as the nerve center for all artificial intelligence, scripted, and user-interactive behavior. It is the focal point for a user's interactions, and allows environments and experiences to be developed using artificial intelligence plug-ins, physics engine plug-ins or simple scripting; one chooses that which is appropriate to achieve a particular goal.

The SE is composed of various parts: a main engine, a default physics engine, a real-time dynamic reference resolution system, an Advanced Scripting Language interface (a C/Java-like way to implement complex behaviors), and client networking support. The elemental construct that the engine is based on is interacting agents. Each agent contains intrinsic elements, such as physics characteristics, that allow for a common interface with the system. Agents may or may not have representation on external client elements that connect during runtime (for example, an agent may exist as a sound on one client element, but have no graphical representation or vice versa). When they do, a peer system is used, where an agent on the SE typically communicates with its peer agents on other engines, e.g., on the graphics engine.

Within agents, behaviors can be invoked by communiqués from other agents, triggers (scheduled call backs) and reflexes (invoked when certain preconditions are met). Each agent has state, represented by a set of state variables, along with behaviors. The engine operates on an iterative basis. That is, operations on state variables, transmission of signals, etc, are carried out once all agents have operated. Therefore, there are two stages to the operation of the engine during normal running conditions: *update* and *operate*. The *update* stage forces state variables to update their values to whatever changed values were stored in the midst of the last operation cycle; it also copies signals that were queued up during the most recent operating cycle to an operating queue that is used during the next iteration (note that this ensures that signals received during one iteration must wait for the next iteration before they can be acted upon). Finally, the update stage makes internal system elements such as the system clock current. The *operate* stage causes agents to evaluate any signals received, to evaluate any triggers that have fired, and to operate reflexes. At the end of this stage, the agent's physics attributes are updated by a physics engine, the default one of which considers such things as linear and angular velocity/acceleration when updating the agent's physical characteristics.

Figure 5 depicts the various interactions among the MRSS components. Using its labels as reference points, the MRSS receives and integrates B) sensor data (tracking, registration, orientation, etc.) with C) plug-ins (user interfaces, AI modules, physics engines, networked simulators, etc.) and D) executes a non-linear, interactive script. It then produces A) a multi-modal simulation situated within real world conditions based on the interoperable and scalable rendering and display technology available. The experience is F) captured (multi-modal capture, physiological monitoring, sensory enhancement, etc.) as a whole for human performance evaluation, aggregate empirical data and playback capability. The scenario is then E) adapted based on the conditions and actions of the participants whether human, robotic or virtual.

5 Conclusions

The Demo Dome concept has proven viable for collaboration in entertainment, but the experiment also points towards its broader applications. These include science virtualization; allowing scientists to fully interact with each other on “what if” simulation models. The ability to melt the boundaries between multi-sensory virtual and real worlds allows us to re-examine core design methodologies by modelling human experience and replicating, manipulating and capturing human behaviour and interaction. Multidisciplinary team performance and collaboration is also enhanced. Imagine urban planning with architects, civil planners, politicians, trades and stakeholders collaboratively testing redevelopment designs, with multiple views and overlays representing dynamic and complex environmental information about the proposed site.

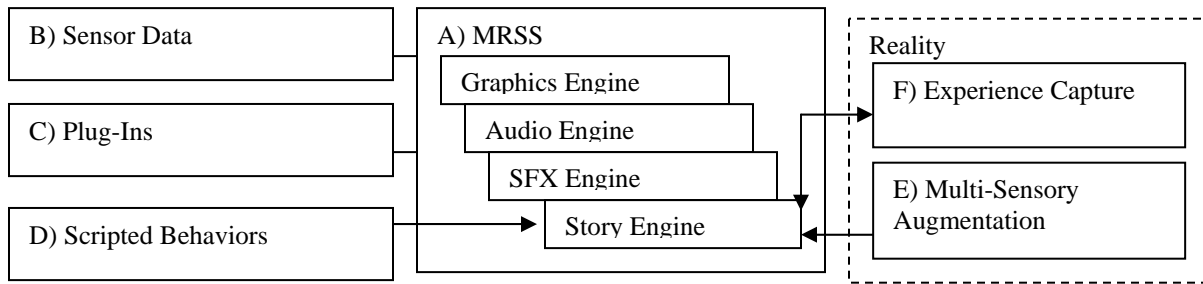


Figure 5: Mixed Reality Software Suite Diagram

6 Acknowledgements

The research reported here is in participation with the Research in Augmented and Virtual Environments (RAVES) supported by the Naval Research Laboratory (NRL) VR LAB. The MR MOUT effort is supported by the U.S. Army's Science and Technology Objective (STO) Embedded Training for Dismounted Soldier (ETDS) at the Research, Development and Engineering Command (RDECOM). Major contributions were made to this effort by our chief software guru Matthew O'Connor, design production supervisor Scott Malo, artists Shane Taber and Theo Quarles, software developers Nick Beato and Scott Vogelpohl, audio producer Darin Hughes and education specialist Eileen Smith.

7 References

- Cruz-Neira, C., Sandin, D.J., DeFanti, T.A., Kenyon, R., & Hart, J.C. (1992). The CAVE, Audio Visual Experience Automatic Virtual Environment. *Communications of the ACM*, 35(6), 64-72.
- Hughes, C. E., Konttinen, J., & Pattanaik, S. N. (2004). The Future of Mixed Reality: Issues in Illumination and Shadows. *Proceedings of I/ITSEC 2004*, Orlando.
- Hughes, C. E., Smith, E., Stapleton, C. B., & Hughes, D. E. (2004). Augmenting Museum Experiences with Mixed Reality. *Proceedings of Knowledge Sharing and Collaborative Engineering 2004*, St. Thomas, US Virgin Islands, ACTA Press, Calgary, Canada
- Milgram, P., & Kishino, A. F. (1994). Taxonomy of mixed reality visual displays, *IEICE Trans. on Information and Systems*, E77-D(12), 1321-1329.
- O'Connor, M., & Hughes, C. E. (2005). Authoring and Delivering Mixed Reality Experiences. *Proceedings of 2005 International Conference on Human-Computer Interface Advances for Modeling and Simulation (SIMCHI'05)*, New Orleans, 33-39.
- Stapleton, C. B., & Hughes, C. E. (2003). Interactive Imagination: Tapping the Emotions through Interactive Story for Compelling Simulations. *IEEE Computer Graphics and Applications*, 24(5), 11-15.
- Stapleton, C. B., Hughes, C. E., Moshell, J. M., Micikevicius, P., & Altman, M. (2002). Applying Mixed Reality to Entertainment. *IEEE Computer*, 35(12), 122-124.
- Surowieki, J. (2004). *The Wisdom of Crowds*, New York:Doubleday.
- Uchiyama, S., Takemoto, K., Satoh, K., Yamamoto, H., & Tamura, H. (2002). MR Platform, A basic body on which mixed reality applications are built. *ISMAR '02*, Darmstadt, Germany, 246-256.