Mixed Reality in Education, Entertainment, and Training

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A multidisciplinary research team transforms mixed reality technology into diverse applications used for military training, situational awareness, and community learning.

Transferring research from the laboratory to mainstream applications requires the convergence of people, knowledge, and conventions from divergent disciplines. Solutions involve more than combining functional requirements and creative novelty. To transform technical capabilities of emerging mixed reality (MR) technology into the mainstream involves the integration and evolution of unproven systems. For example, real-world applications require complex scenarios (a content issue) involving an efficient iterative pipeline (a production issue) and driving the design of a story engine (a technical issue) that provides an adaptive experience with an after-action review process (a business issue). This article describes how a multidisciplinary research team transformed core MR technology and methods into diverse urban terrain applications. These applications are used for military training and situational awareness, as well as for community learning to significantly increase the entertainment, educational, and satisfaction levels of existing experiences in public venues.

Background

An MR experience is one where the user is placed in an interactive setting that is either real with virtual asset augmentation (augmented reality), or virtual with real-world augmentation (augmented virtuality).[1] Figure 1 depicts these discrete points in the MR continuum. In previous projects, the Media Convergence Laboratory at the University of Central Florida has developed novel tools, displays, and interfaces to produce instances using each of these aspects of MR technology. The Mixed Reality Software Suite includes a special-effects engine that employs traditional scenography and show control technology from theme parks to integrate the physical realities of haptic and olfactory devices.[2] The graphics and audio engines capture, render, and mix visual and audio content for both augmented reality and augmented virtuality.[3] The Mixed Simulation Demo Dome introduces compelling augmented virtuality interface display devices to provide real group interaction within a virtual setting, seamlessly mixed with real and virtual objects.[4] Traditional VR production techniques and tools help create the virtual assets. Users can then blend these assets with the real environment using real-time, realistic rendering algorithms.[5]

The key for creating an effective MR experience goes beyond Milgram's technology centric continuum.[1] The underlying story must draw on the user's imagination to complete the mixed fantasy continuum between the physical venue, the virtual medium, and the audience's interactive imagination.[6] This latter requirement is needed to leave a lasting impression of the experience with users. This requirement is important in the fields of entertainment, training, and education and is economically vital for any mainstream application or product.[7] The ultimate criterion for judging an application's success is not a functional requirement, but the human impact measured by affective evaluation. Our research quest forced us out of the laboratory and into demanding experiential venues to evaluate this ultimate challenge. In particular, we were motivated to go beyond a one-time staged demonstration of MR, into settings where multiple uses occur without the intervention or oversight of our team members.

Filling in the gaps of MR

To illustrate our approach and accomplishments, we focus on two extreme experiences that are equally demanding, each presenting drastically different priorities and criteria for success. These tests validate both the functional demands and the effective range of our tools and techniques.

The MR for Military Operations in Urban Terrain (MR MOUT) is installed at the US Army's Research Development and Engineering Command (RDECom), where researchers evaluate the latest training technologies for transitioning into acquisition readiness. This application focuses on an extreme and complex layered representation of combat reality, using all the simulation domains (live, virtual, and constructive). It applies the advanced video see-through MR HMD from Canon[8] and tracking technology from Intersense, integrated within a re-created city courtyard.

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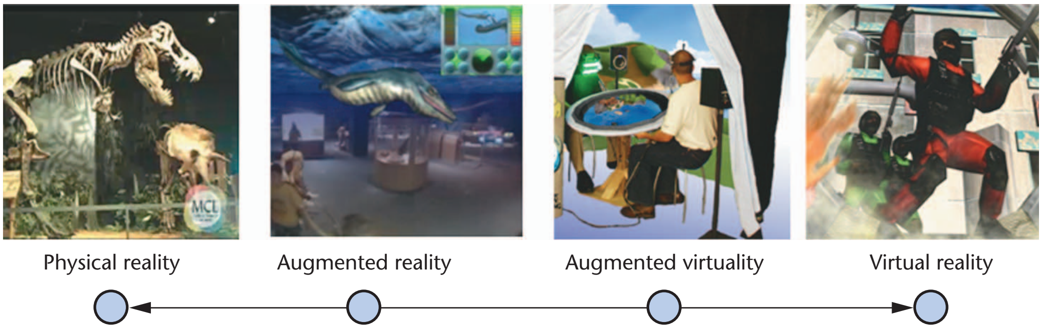


1 **Milgram's continuum with examples from Media Convergence Laboratory projects.**

MR Sea Creatures, on the other hand, deals with the engagement of a child's insatiable curiosity within a museum. The goal is to make the static contents of the museum come to life, leading to a continually evolving adventure in science. We developed this experience as an experiment to broaden the content and appeal of an existing dinosaur exhibit at the Orlando Science Center. Unlike desktop-based, optical see-through enhancements,[9] our approach deals with large spaces (entire venues). For operational and economic necessity, we replaced the advanced HMD and tracking in this system with an MR portal (a fixed Elumens Vision Station equipped with a camera with a fish-eye lens and special multisensory effects) to capture and engage the entire space. Unlike typical digital technology used in science centers, this effect does not separate the dynamic media from the immersive venue.

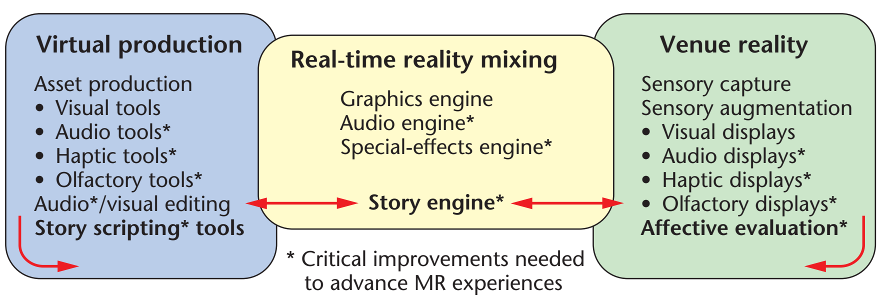
Most MR experiences are about the visual domain, with the principal differentiation being between display types.[1,8] The primary scientific and technical issues generally center on tracking, registration, and rendering. Our emphasis is to supply the missing parts to produce a full spectrum of multisensory, nonlinear, immersive MR experiences. Our goal is to give as much attention to the audio as to the visual, with special effects currently addressing the olfactory and tactile senses. Such effects include water vapor to simulate steam and smoke; servomechanisms to cause objects to act as if they have been hit, for instance by being bumped by a virtual character; and haptic vests, vibrating devices, and shakers to provide tactile stimulation for the users.

Figure 2 depicts a roadmap for MR, showing the key areas of development that we identified as critical to providing a seamless MR experience. The areas we recognized and have sought to address include a creative pipeline, MR audio capture and production tools, and a delivery suite that can aid in the transfer of this emerging technology to practical commercial use. We measure how well we achieve our goals by the affective evaluations conducted on each project. MR Sea Creatures' preliminary evaluations are complete and encouraging. RDECom and the Army Research Institute are presently conducting equivalent evaluations of MR MOUT.

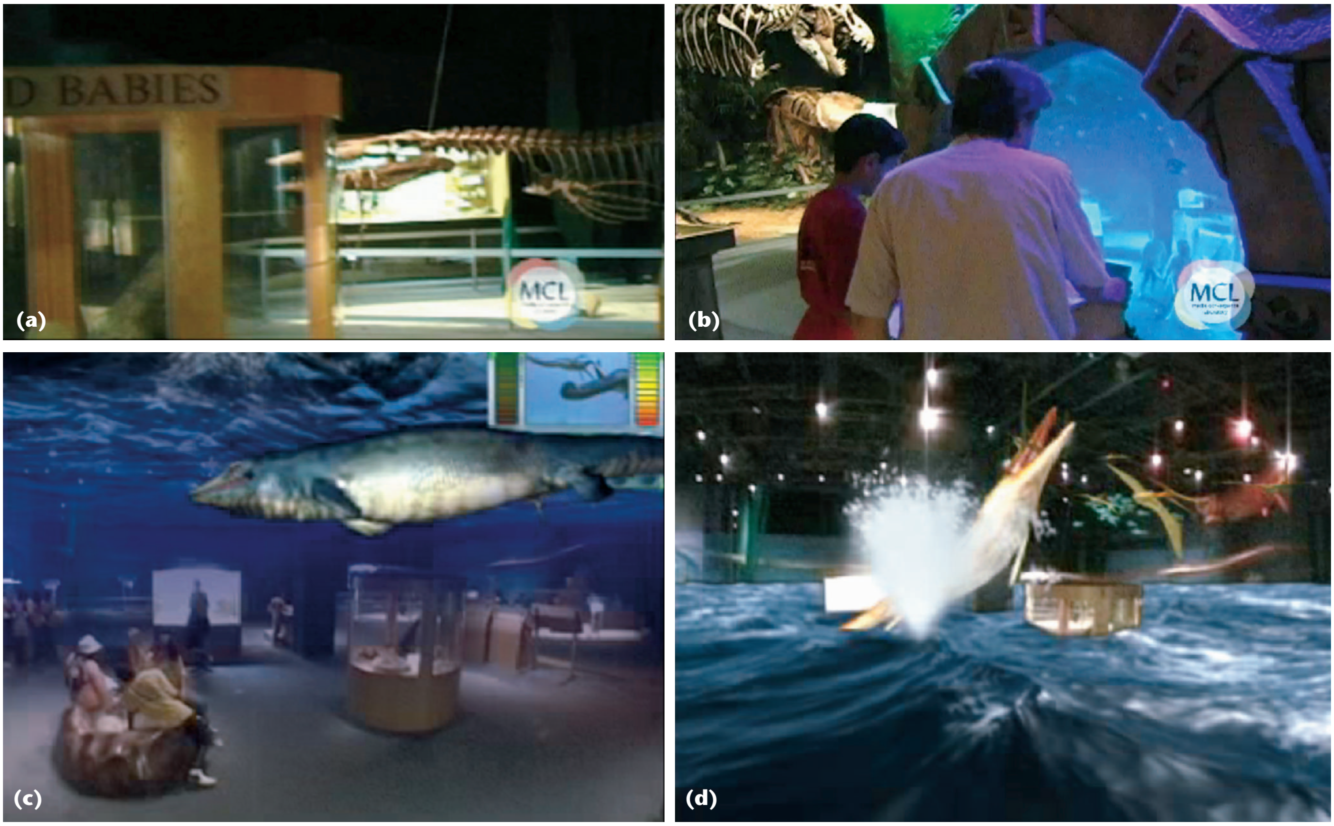
MR Sea Creatures: Flights of fancy

The Sea Creatures experience begins with the reality of the Orlando Science Center's DinoDigs exhibition hall (see Figure 3a, next page), which presents fossils of marine reptiles and fish in an elegant, uncluttered environment. As visitors approach a spherical screen and projector beyond a scenic MR portal at one end of the exhibit's venue, a virtual guide walks onto the screen and welcomes visitors to an underwater journey. When the guide finishes telling the back story, the museum venue, as seen in the dome exhibit, appears to be flooding with water and visitors experience the virtual Cretaceous environment as fossils come alive (see Figure 3b). Guests navigate a rover vehicle through the ocean environment to explore and collect specimens of the vegetation, reptiles, and fish. The augmented reality experience includes an embedded VR window, showing the rover's virtual point of view of the sea life that augments the DinoDigs exhibit (see Figure 3c).

As the experience winds down, the water recedes within the dome, and the unaugmented science center hall begins to emerge again. At the point where the water is about head high, a group of pterodactyls flies overhead, only to have the straggler snagged by a tylosaur leaping out of the water (Figure 3d). Holding the pterodactyl in its mouth, the tylosaur settles back down to the ocean floor. A walk through the exhibit space (the real exhibit) reveals that the tylosaur fossil is there with a pterodactyl fossil in its mouth. This connection of the MR experience back to the pure real experience is intended to imply unbounded pathways to explore the museum content through MR experiences layered within a social and immersive physical surrounding. This physical and interpersonal interaction is



2 **Mixed reality development roadmap.**



3 **Cretaceous life at Orlando Science Center: (a) physical reality, (b) MR dome, (c) augmented reality, and (d) tylosaur lunch.**

intended to permanently bind the experience to the visitor's mind.

Because the purpose of a free-learning education experience is to inspire curiosity, create a positive attitude toward the topic, and engage the visitor in a memorable experience that inspires discussion long after the encounter, we conducted an affective evaluation to test whether this installation met these criteria. We were particularly interested in whether the experience led to deeper learning, better entertainment, more return visits, and an increased interest in exploring the subject matter. We developed a questionnaire that was given to visitors during the three weeks we had MR Sea Creatures installed. Table 1 shows those results. What is critical to recognize from this data is that, for 98 percent of visitors, the MR experience encouraged them to spend more time in the hall. More than 80 percent of the visitors queried noted that this exhibit encouraged repeat visits. Furthermore, approximately the same number of guests noted that they would visit similar exhibits. Importantly, visitors also felt that the experience improved their understanding of the Cretaceous period. In summary, these preliminary data strongly support our contention that MR substantially augments the overall experience and encourages repeat visits.

These results were made possible by an iterative production process that allowed subject matter expertise, play testing, and artistic conventions to be employed to overcome technical deficiencies. The MR portal's limited visual representation was expanded with 3D surround sound that incorporated novel capture, rendering, and display technology. This increased the interactive group's (visitors') immersion in a shared space and provided a heightened sense of presence beyond the projected video display, deemphasizing the fidelity limitations of the visual projection system. We

Table 1. User reactions to the MR Sea Creatures experience.

Statements	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
Encouraged longer time	34	64	2	0	0
Encouraged repeat visits	25	59	16	0	0
Learned more about Cretaceous period	20	63	16	2	0
Visit similar exhibits	22	66	8	2	2
Entertaining experience	35	53	10	2	0

created a subtle ambient environment employing underwater audio, acquired using unique surround capture tools. We then rendered these effects on hybrid audio surround displays that grabbed the group's attention without the isolating effects of earphones. The creative mixing and design system allowed for subtle effects that complemented the visual exhibit and drew the visitors' attention without increasing the dissonance that would have been caused by a higher volume. The audio provided the emotional and immersive qualities normally attributed to subtle artistic techniques used in motion pictures and theme parks.

MR MOUT: Extreme reality

The MR MOUT testbed is a training simulation using a video see-through HMD and a re-creation of urban facades that represent a 360-degree mini MOUT site. We extended the realism to a four-city block situational awareness experience using computer-generated environments; characters; props; a realistic gun or other tracked interface device; and real lights, crates, and walls. Standing inside the mini MOUT creates the sense of ultimate combat reality (and nightmare) of a soldier dismounted from a vehicle who is open to attack on all sides and from high up.

Using a combination of bluescreen technology and occlusion models, we developed a script that directs our software system to layer and blend the real and virtual elements into a rich MOUT site. The trainee can move around the courtyard and hide behind objects with real and virtual players popping out from portals to engage in close-combat battle. The most effective and powerful result of this MR training is that the virtual characters can occupy the same complex terrain as the trainee. The trainees can literally play hide-and-seek with a virtual soldier, thereby leveraging the compelling nature of passive haptics.

4 **Views of MR MOUT: (a) physical reality and (b) augmented reality.**

Figure 4a shows the mini MOUT without virtual assets. Figure 4b shows an MR version of this testbed, along with environmental models (sky, clouds, and buildings in the distance). This is the view the trainee sees through the HMD. The models that match physical assets are not displayed, but are used for occlusion (they clip the rendered images of characters inside the buildings, allowing us to see only those parts that are visible through portals). The environmental models are displayed, thereby completing the visual landscape. Show action control completes the effects to create realistic combat scenarios where the real world around the trainee feels physically responsive. This is done using computers to control lights, doors, window shutters, blinds, and other types of on/off or modulated actions. The system can monitor the trainee by an interface device, such as a special gun with tracking, and then change the real environment based on the user's behavior. For example, the lights on buildings can be shot out, resulting in audio feedback (the gunshot and shattered glass sounds) and visual changes (the real lights go out).

With all the compelling visual and haptic effects, this training can provide a competitive edge due to a heightened acoustical situational awareness.[10] You can't see or feel through walls, around corners, or behind your head. However, your ears can perceive activity where you cannot see it. In urban combat, where a response to a threat is measured in seconds, realistic audio representation is vital to creating a combat simulation and to training soldiers in basic tactics. Standard 3D audio with earphones shuts out critical real-world sounds, such as a companion's voice or a radio call. The typical surround audio is still 2D with audio assets designed for a desktop video game that tend to flatten the acoustical capture. Our system temporally and spatially synchronizes audio, leading to an immersive experience. This is especially important in military training, where sensory overload prepares the soldier for the real battlefield.

Iterative MR production pipeline

While creating MR Timeportal for Siggraph 2003—an experience extending Canon Mixed Reality Laboratory's groundbreaking work on AquaGauntlet entertainment[8]—our team devised an iterative MR production pipeline for developing scenario content, incorporating interdisciplinary collaboration at each iteration of development. Taking our cue from the pipeline used in the film industry and the experimental development of off Broadway, our approach allows the artistic and the programming teams to move forward in interdependent, parallel steps, going from the concept to the delivery of an MR scenario.

Consensus: Eyes on the prize

The process starts with graphic preproduction that includes the written story and a rapidly produced animatic. The video animatic is a simple visual rendering of the story from a single point of view following the participant's emotional journey. Its purpose is to communicate the vision of the creative team and confirm the key stakeholders' expectations. This then allows the subject matter expert, art director, audio producer, and lead programmer to effectively exchange ideas and determine each team's focus, seeking to avoid compromise and achieve a compelling creative solution. This supports an early determination as to whether a perceived problem has a technical, scientific, artistic, or programmatic solution.

Asset production: Into the third dimension

Once the animatic is presented and the behaviors are agreed upon, the artists can begin creating in parallel high-quality virtual assets (CG models, textures, animations, images, and videos). Concurrently, the programmers implement a first-cut virtual 3D experience using the preliminary models developed for the animatic. Similarly, the audio producer creates and/or captures appropriate ambient, 3D, and point-source sounds. Typically these tasks take about the same amount of time. This represents the 3D prototype stage where alternative scripts, effects, and viewpoints are tested to validate the big picture scope.

Scenario design: Into real time

The next step is to validate the cause-and-effect interaction with more complex, compounded action scripts playing out behavioral and environmental assumptions. Before enhancing the virtual world with the new artistic creations, a purely virtual version of the scenario needs affective evaluation. This is where we view and hear the scene from multiple angles and positions. Using this bird's-eye view provides us with the equivalent of a virtual camera that can move around the environment in real time to see every aspect and interaction point in the scenario. This allows the teams to see problems and prioritize solutions now, rather than after creating the full MR experience. The content and story are evaluated and decisions are made that improve the scenario's playability. The art, audio, and programming teams then continue to work on their respective areas addressing the issues that were raised at this stage.

Game design: Play ball

The next step is the interactive scenario. This is a version of the scenario implementation, which is interactive and nonlinear, but is still completely virtual. This is the final time to make minor changes and tweaks to the interaction, story, and technology.

Technical rehearsal: Melting the boundaries

The last step is integration. If all of the previous stages have been followed, there should be no major surprises. This is the step in which the entire team needs to be involved, from the programmers to the artists to the audio producers. All the pieces (audio, graphics, special effects, and story) of the MR scenario come together now without the confusion of rendering, tracking, story, or game issues. The key at this stage is to recognize and make the subtle tweaks that turn an interesting experience into a compelling one. This occurs in the refinement of the detail where the real meets the virtual. If the system is well designed, these changes are made through GUI interfaces, for example, to adjust chroma keys, or reposition virtual assets to interact more dramatically or precisely with real elements.

Production and delivery tools

Our modeling team uses standard tool sets, particularly Autodesk 3ds Max with its comprehensive set of plug-ins. The programming team uses Eclipse (http://www.eclipse.org) and Microsoft Visual Studio .NET as its development environments. Audio production and story development use homegrown tools.

Our focus on creating original audio production tools was driven by the limited capabilities of existing tools. These limitations exist partially because venues such as games and VR systems, with their constrained movement, can focus on delivering audio to select sweet spots. With MR, while we can assume some constraints on a person's motion, these constraints do not lead to any single sweet spot. Moreover, since MR is integrated into the real world, an MR audio system must perform within the constraints on speaker placement imposed by the physical environment. This is especially true when we wish to install a single experience in diverse settings such as museums.

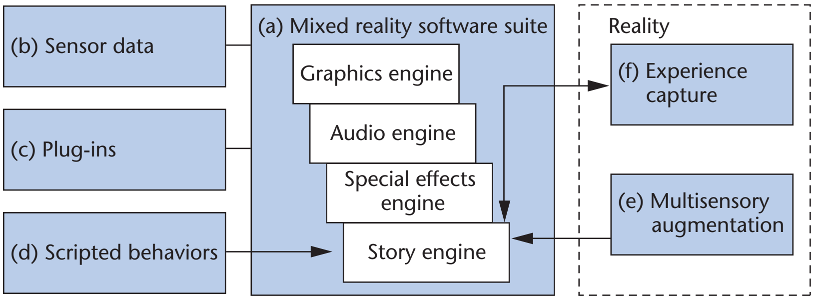
The audio landscape

Our experience with mainstream audiences is that the standard for a compelling story is cinematic expression. In films, audio is the equal of visuals. In contrast, audio production in virtual environments is rarely given the attention it deserves. This is unfortunate as sound can travel through walls and around corners providing information that is well out of the line of sight. Additionally, audio plays a crucial role in environmental awareness, immersion, and presence, and is essential in most forms of communication. Adequate methods of capturing, synthesizing, mixing and mastering, designing and integrating, and delivering soundscapes are crucial to creating immersive and compelling experiences.

We are currently using a Holophone (http://www.holophone.com) to capture accurate 3D soundscapes to produce a sense of subtle environmental presence. The Holophone H2 is an eight-channel microphone that captures audio in 360 degrees and on the vertical plane. This capture device can record a fairly accurate spatial impression and has the advantage of portability and ease of use. It is especially useful in capturing general ambience for military simulations, for example, MR MOUT, where an accurate sound field is required.

For entertainment or artistic applications, more experimental techniques can be used. One such technique is that of spatial scaling whereby individual microphones can be placed over extended distances. The effect created by this technique is unlike anything that human ears are accustomed to hearing. Where a car passing by might take only a few seconds, this capture technique stretches the spatial image out over a longer time span, avoiding changes in pitch or additional audio artifacts. Likewise, the reverse can be done with miniature microphones embedded in places such as ant mounds. These experimental techniques might create perceptual changes that can alter the emotional experience of a simulation. The novel use of captured sound from foley sessions (audio effects capture for cinema) can provide a more real-than-real experience when the captured audio is played out of context for heightened emotional effect. The classic example is how a lion's roar was used in an Indiana Jones movie to intensify the turning of a steering wheel in a climactic action.

Transducers are a particularly useful tool for capturing the direct vibrations of an object. This is convenient when either the desired source does not transmit a sufficient signal for standard microphone capture or when the sound designer is interested in capturing only the direct vibration of a source and not the sound it creates in air. Dramatic effects can be created when transducer capture is delivered through a subwoofer or bass shaker beneath a user in an interactive experience. This provides the artistic variable of scale to audio for unique effects. Details of our mixing are published elsewhere.[10]



5 Flow of major Mixed Reality Software Suite components.

Delivery system: MR Software Suite

The visual compositing and blending of real and virtual objects requires an analysis and understanding of the real objects so that proper relative placement, interocclusion, illumination, and intershadowing can occur. We assume here that this is possible in real time and so our efforts focus on the delivery of the experience.[5,11,12] The key areas that we address are the

- layering of the real and the simulated,
- interaction of dynamic agents, and
- integration of multiple synchronized senses in real time.

The MR Software Suite (MRSS) acts as the development and delivery system for the MR experience.[2] It integrates a collection of concurrent cooperating components. The central component is the MR story engine, a container for agents (actors), one for every user; virtual and real objects that interact with other agents; plus abstract agents that might be useful for the story line. The agents manage the story semantics in that their states and behaviors determine what a user sees, hears, and feels. Environments that are candidates for using the MRSS include those delivering interactive storytelling experiences, collaborative design environments, technology demonstrations, games, and educational or training programs. In other words, the MRSS is not strictly tied to MR, although that's the focus here.

The MRSS system consists of four subsystems called engines (see Figure 5a). Three rendering engines deliver the multimodal simulation (visual, audio, and special effects) while a fourth engine drives the integration and creates an interactive, nonlinear scenario. These engines are interoperable with other commercial components. The central networking protocols receive and integrate sensor data such as tracking, registration, and orientation (see Figure 5b) with input from other sources, for example, artificial intelligence and specialized physics engines (see Figure 5c), and execute a nonlinear, interactive script (see Figure 5d). This then produces a multimodal simulation situated within real-world conditions based on the rendering and display technology available (see Figure 5e). The experience is captured (by means of multimodal capture, physiological monitoring, and so on) for human performance evaluation, aggregate empirical data, and playback (see Figure 5f). The scenario is then adapted based on the conditions and actions of the participants whether human, robotic, or virtual (see Figure 5e).

The key technologies used in this MR system are Open Scene Graph and Cal3D for graphics, Port Audio for sound, and a DMX (http://www.usitt.org/standards/DMX512.html) chain for talking to special effects devices. Our network protocol is built on top of TCP/IP. Authoring of stories is done in XML, which can include C or Java-style advanced scripting. The MR system can run stand-alone (one user) or in combination with multiple MR systems (each managing one or more users). Thus, the system can be configured for collaboration. In this context, users see each other as real people in a common setting, while interacting with each other, real props, virtual characters, and virtual props.

Next-generation MR

Every new medium has required decades to overcome its limitations before being transformed from a laboratory invention into mainstream innovation. This is achieved through the maturation of creative conventions and experimentation with real-world applications. To achieve this desired maturation with MR, we must recognize that it is an expressive medium and not just a rendering tool. MR's success will come about not only by advancing technological capabilities, but also by exploiting creative possibilities. We will need to make creative leaps in how we define the breadth and depth of the next generation of MR in terms of art, science, and business before we will transform the laboratory application of MR from novelty to true real-world innovation. This is something we have sought to achieve in every case study reported here. ■

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