Immersing Humans in Virtual Environments: Where's the Holodeck?

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ABSTRACT

The Office of Naval Research's Virtual Technologies and Environments (VIRTE) program is developing leading edge technologies for immersing humans in Virtual Environments (VE). This paper will examine some of the challenges in using VE for training specific tasks in the military such as marksmanship and shoot/no shoot decision-making. In particular, we will examine the Marine Corps Indoor Simulated Marksmanship Trainer Enhanced (ISMT), and how the Corps uses it. We will discuss both the technical and human dynamics in the system. We will also examine the current state of VE technologies and the challenges in using them for military training.

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INTRODUCTION

As the military focuses on reducing the overall cost of training while increasing the efficiency with which this training is provided, without sacrificing quality, Virtual Environment (VE) systems will become an increasingly attractive alternative. While simulation-based training has been a critical component of any training regimen (U.S. Congress, 1994; Valverde, 1973), VE technology offers a quantum leap in how such training can be delivered. Its small footprint and flexibility make it the ideal solution for many training requirements. Yet, as with any system developed to provide training through simulation, the primary constraint to this technology lies both in our understanding of what elements within a given real world scenario–the *to-be-trained-scenario-* must be modeled in order to enhance performance, as well as in our ability to faithfully incorporate these models into existing systems.

What makes this effort all the more challenging is that the expectation for what VE can do far exceeds its capabilities. Popular culture's depiction of VE as the penultimate, mirror image depiction of true reality has contributed heavily to this (Heim, 1997). Virtual technologies are commonplace throughout the media, from science fiction novels to popular television programs, to even playing starring roles in blockbuster films. Consequently, the bar for success has been raised to unattainable levels. End users have come to expect a completely immersive environment, providing a sensory experience indistinguishable from that afforded by the real world. While it is unlikely that anything as compelling as Star Trek's 'Holodeck' will be possible in the near future, VE technologies are contributing to military training today in many important ways.

One of the first obstacles that must be overcome in understanding the many ways in which VEs can contribute to training is to realize that there are many possible definitions of what, exactly, comprise a Virtual Environment. Milgram et al (1994) proposed a continuum of these experiences, ranging from completely real to completely virtual. Just as there is a range of virtual technologies, there is also a range of training applications that can be supported by them. This suggests that there is no 'one size fits all' approach for mapping one onto the other; rather, the overwhelming body of training literature indicates that there is a critical intersection between training requirement and technology solution. The ideal solution is to combine a number of diverse technologies within a single system, in a manner defined by the training goals and objectives. This leads to the idea that there is a large virtual design space, governed by a tension between training needs and technology maturity; each point within this space has the potential to be a dimension of the ultimate holodeck.

DIMENSIONS OF VE DESIGN

It is the determination of those aspects of the real world environment that VE technologies must emulate and providing this in a sensorally meaningful context that spurs so much of the current research in this field. There are two dimensions along which virtual environments are typically decomposed. The first refers to the user's perspective, which can be either egocentric or exocentric, also referred to as allocentric, in nature (Klatzky, 1998). Typical examples of exocentric environments are those that focus on vehicle based platforms, such as flight simulators, while examples of egocentric environments are the familiar first person shooter games. The second dimension refers to the multi-modal sensory stimulatory nature of the environment, which is determined to a great extent by the level or real world fidelity necessary to provide adequate training. Typically, when considering design characteristics, one dimension is nested within the other.

Exocentric Environments

The development of vehicle-based simulations requires a certain level of Usability/ Human Computer Interaction assessment (Muller, Cohn, & Nicholson, 2003). The primary focus of these efforts is, typically, determining the level of fidelity – or ecological validity- that the simulated interfaces must share with their real world analogues. Thus, for example, when developing cockpit interfaces, a primary concern is determining which instruments need to be reproduced so that the way in which the user interacts with them is preserved, and which ones could be reproduced using a more minimalist approach, for example, by allowing their activation through other means, such as a mouse click or keystroke entries. Solutions to these interface challenges are typically derived through design specifications developed from a Task Analysis, which can then be implemented in the overall system and evaluated in terms of performance measures. For example, if the main goal is to familiarize student pilots with the visual cues associated with landing on an aircraft carrier, it is likely that the primary flight controls must have a high degree of correspondence with their real world counterparts, while other instruments (transponder, communications system) could have less correspondence using visual representations, which could be activated through mouse clicks and keystroke entry.

Egocentric Environments

The switch in emphasis from vehicle based systems to non-vehicle based ones introduces a level of complexity to the relationship between training and technology. Unlike the vehicle simulation, where an artificial interface that mapped onto a well-defined real world correlate must be developed; in this case, the challenge is actually defining what elements of the real world itself must be supported during normal interactions in order to make behaving in the virtual world smooth (Templeman, Denbrook, & Sibert, 1999). These specifications cannot simply be determined by 'sampling' the real world. Instead, the general context within which the behaviors that are being trained may occur must be identified, and the stimuli propagated by them –as well as the stimuli that are necessary for certain behaviors- must be recreated in the VE. Thus, unlike the vehicle-based experience, the reliance for system specifications for egocentric systems depends more on an understanding of the perceptual and cognitive components of a human behaving in the real world.

Multi Modal Sensory Requirements

It is well established that the closer the training environment is to the real world environment within which the training will be called upon, the better the odds are for successful training transfer (Osgood, 1949; Boldovici, Bessemer & Bolton, 2002). Moreover, it is also becoming clear that the more sensory modalities that are supported during a given training experience, the better the training will be (Lachs & Pisoni, 2004; Paivio, 1991). This extends to training provided in virtual systems (Greenwald, 2002). When designing a virtual training system to satisfy this requirement, the challenge is to ensure that the sensorial experiences that are provided via VE training solutions match those that are anticipated to be present in the real world environment. In order to develop virtual systems that meet this requirement, it is crucial to not only understand which sensory components must be supported for a given task, but how these multi-sensory components should be integrated into the overall system, to deliver the ideal training experience. Currently, most VE systems fail to fully integrate the complete range of sensory cues generally associated with complex, real world tasks (Cohn, 2003; Durlach & Mavor, 1995; Carr & England, 1995), relying for the most part on high quality visual representations, coupled with lower quality audio cues and the relative absence of other stimuli. As long as this state of affairs remains *de rigueur,* it is only to be expected that training will suffer (Birch & Bitterman, 1949).

It is interesting to note that the most advanced use of multi-modal applications of VE technology today is not being used by military training, but by military recruiting. The Army Recruiting Command recently unveiled a "virtual reality experience that places the viewer "inside" an Army Black Hawk helicopter performing an exciting mission. Participants rescue a downed pilot in this Black Hawk situation, and feel the helicopter vibrate beneath them while smelling the oil and machinery of an authentic helicopter" (VirTra, 2004). For each of theses senses to be adequately rendered in VE, the primary technology challenge hinges on developing the correct tools to provide adequate sensory stimulation.

Visual

There are two general approaches for generating visual content, Computer Generated Imagery (CGI) and Video. During the 1980's, video became used in a small set of training applications, primarily those involving decision training. With the rapid pace with which computer graphics technology has been advancing, it is now possible to integrate high-end CGI for an affordable price. For example, today the movie industry can render CGIs that are indistinguishable from film-based images. Of course, they must use farms of thousands of PCs running for weeks to accomplish this. There have also been significant improvements in real-time applications driven by the gaming community, which continues to take advantage of improved graphics hardware to improve the realism of the virtual worlds. In addition, characters in the games continue to look and act more realistic, thanks to improved physics and artificial intelligence.

In addition to improvements in generating the Virtual Environment, technologies to display them continue to improve but at a slower pace. Front screen projectors and CAVEs continue to increase performance at reduced price points. Head Mounted Displays (HMDs), however, have not progressed as rapidly as many predicted. They still lack the needed field of view and are too expensive for widespread use.

Spatialized sound

While many current simulations function by primarily supporting the visual channel, for many domains, auditory cues play a pivotal role in providing trainees with the ability to locate other objects and themselves in their surrounding environment. In order cues to be salient when integrated into a VR system, they must preserve both the spatial and temporal qualities of the 'real' cues (Brokhorst, 1995). Since the information extracted by the human auditory system is dependent on the structure of the individual's receiving organ, models supporting the transmission of these stimuli are typically developed based on individual Head Related Transfer Functions (HRTFs) (Kistler, & Wightman, 1992). Implementing individual HRTFs is a laborious exercise requiring specialized equipment. In order to support the level of independent operation necessitated by current training needs, efforts must focus on developing technologies that support both quick, personalized calibration of audio cues, as well as demonstrating the *level of performance enhancement* attributable to the inclusion of this modality.

Locomotion

While it may, at first, seem inappropriate to categorize locomotion as a 'sense', at the most fundamental level, it is likely that the more accurately a given VE affords the capability to stimulate individual components of the human sensory system in accordance with how they are stimulated in the real world context, the more likely the system will be to provide effective training (Gross, Stanney & Cohn, in press). Under normal conditions, when one locomotes through a real environment the nervous system has a rich sensorial pool from which to draw, including information from sensoriceptors, mechanoceptors, and so forth, simply from the act of physically locomoting. In a virtual environment, there is a wide range of locomotion interfaces, from simple joystick solutions to more elegant (and costly) ones, such as those that allow users to physically walk in place while their virtual representation is propelled (Templeman, et al, 1999). Thus, while incorporating a range of sensory stimuli within a VE may be useful, if the trainees can not access and sample this information as they would in the real environment, it may be of no use.

Smell

While the concept has been around for a long time, there are still no widely available and practical methods for distributing smells. In the 1960 film, *Scent of Mystery*, a technique known variously as Smell-O-Vision and Odorama made its debut. Basically a device was placed under each seat in the theater and would emanate a smell timed to the scene in the film. It was a commercial failure. According to the All Movie Guide, it "was perhaps the only genuine stinker ever produced by the motion picture industry" (Erickson, 2004). An air canon developed at the Advanced Telecommunications Research Institute in Kyoto, Japan, tracks people's eyes with video camera and "shoots" a smell to the nose. They claim the sprays are so fine that two people 50 cm apart two meters from the spray canon can each have a unique smell. (Knight, 2004) There has been little research in the military community into the use of smell in Virtual Environment systems**.**

Haptics

While some forms of VE systems, such as those supporting mission rehearsal systems for vehicles can be easily supported by existing technology, others, like Close Quarters Battle (CQB) training for dismounted infantry, which involves a significant level of physical interactions with virtually rendered objects

(Templeman, Denbrook, & Sibert, 1999), are currently limited by the degree to which these non-visual stimuli can be represented. Specifically, the ability to fully exploit VR systems for training individuals or teams moving through an immersive VR is limited by the ability to render haptic stimuli.

Haptic information is a form of sensory stimulation that is acquired through collisions with objects (Durlach & Mavor, 1995). Most VR training simulations essentially ignore the haptic domain, relying instead on the visual domain and to a lesser extent, the auditory one, to provide trainees with the range of information typically encountered in the real world. This approach has been favored in part due to limitations of current technology. Haptic interfaces must render any number of a wide range of sensations (e.g. force, vibration, texture etc) while minimizing restrictions on movement. Currently, haptic interfaces are extremely bulky, have significant latencies, and fail to capture the range of frequencies/amplitudes typically encountered in real world settings.

Yet, given the degree to which the haptic sense is stimulated in the real world, it is clear that haptic cues should play a critical role in supporting fully immersive VR systems; during a single training exercise, trainees may repeatedly contact walls, furniture and other objects as well as each other. At the same time, haptic information can also provide an alternative mode for providing information, in the VE, that may be lacking due to deficits in other technologies. For example, while humans typically have available to them a horizontal field of view greater than 180 degrees, even the highest grade visual system supporting Virtual Environments has a field of view of significantly lesser size. In the vertical domain, the discrepancy between the naturally afforded field of view and that provided by HMDs is even more pronounced. Thus, haptic information is even more essential for making the user aware of where, when, and what kind of contact is made with virtual objects outside of this limited field-of-view. In the real world, these collisions provide trainees with critical information that ultimately supports their mental model of the environment; in the virtual one, which lacks these cues, the mental model is consequently much poorer.

HUMAN PERFORMANCE DESIGN PROCESS

Given the wide variety of technologies to address the dimensions of perspective/degree of control and sensory modalities within VE today, designers are challenged with many choices. Our research team, operating under ONR's Virtual Technologies and

Environments (VIRTE) program has adapted the Human Performance System Model (HPSM) in Figure 1 as a guiding design process for VE development. The HPSM is the cornerstone of the CNO's Revolution in Navy Training http://www.excel.navy.mil/human.htm. The guiding principle is to make the challenging design choices based on a traceable impact on human performance on the operational task. Using this dynamic four-quadrant model, researchers define the required outcome of human performance and training systems and continually measure and adapt the VIRTE products to optimize the results.
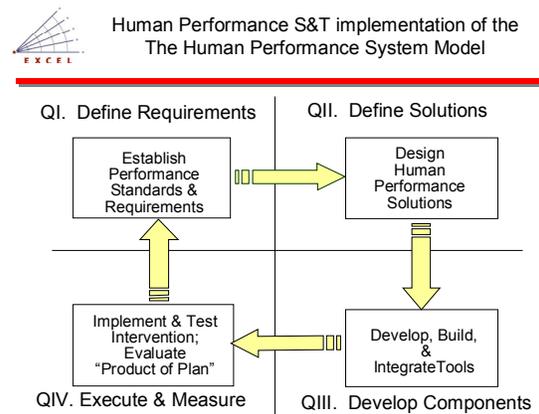

Figure 1. The Human Performance System Model (HPSM)

Starting the process from the upper left quadrant (QI), researchers work closely with fleet transition customers using Knowledge Acquisition and Engineering (KA&E) processes and documenting the Systems Requirements Specifications (SRS) to establish performance standards and requirements. In this phase the domain requirements for perspective and degree of control are defined as exocentric or egocentric VEs.

Following the process to second quadrant (QII), an assessment of the wide range of currently available, commercial off the shelf (COTS) and R&D prototype science and technology available to represent the multi-modality sensory inputs in the VE is conducted. Then design solutions are recommended and presented to the end-user community through a High Level Design (HLD) document and review.

In the third phase of the process, represented in quadrant III (QIII), a cycle of iterative prototype builds and frequent Intermediate Feasibility Experiments (IFEs) are conducted to demonstrate newly integrated components and allow continuous testing and user feedback.

The impact to human performance is determined in the fourth phase, represented in quadrant IV (QIV). Usability assessment of each build is an integral part of the test plan. Human in the loop testing can measure the Human Performance and Training Effectiveness, which are continually compared to the target standards and requirements.

ISMT EXAMPLE

In order to better understand how these issues come together in developing and enhancing a VE system, a practical example from a currently fielded system will prove useful. In this example, an egocentric VE system will be discussed and an assessment will be made of its training potential based on the range of sensory modalities that it supports. Based on this assessment, modifications will be suggested, which should also extend the range of training applications for which this system may be used.

The USMC has been using a Virtual Environment for Marksmanship training for over a decade. The Indoor Simulated Marksmanship Trainer (ISMT) is used to train recruits in basic marksmanship before they use an actual weapon on a live fire range. It is also used to sustain marksmanship skills. The latest version is known at the Indoor Simulated Marksmanship Trainer Enhanced (ISMT-E). In this paper we will use the abbreviation ISMT to refer to all versions. The ISMT uses actual weapons that have been demilitarized and adapted for simulator use. They are fitted with a laser, so that the system can determine where the weapon is being aimed and they are fitted with sensors to give the instructor information about the human interaction with the weapon such as trigger squeeze and butt plate pressure. In addition, the weapons have a recoil system that uses Carbon Dioxide or compressed air to give the weapon realistic recoil. The Virtual Environment is presented to the trainees on a large projections screen. We will examine Virtual Environments and the ISMT system in terms of how they address all of the senses. We will also discuss some of the research that the ONR VIRTE team is conducting using the HPSM design process to address the shortcomings and guide future ISMT development.

Unlike a new program that would start with the front-end-analysis (QI), in this case the analysis was performed during the initial procurement of ISMT. Consequently, the recent process was started in the test and evaluate phase (QIV). VIRTE researchers are working with the MC training community to evaluate the current ISMT system.

Before discussing which aspects of ISMT required improvement, it is useful to explore some of the applications for which the system was originally designed. Figure 2 shows the four general training areas.
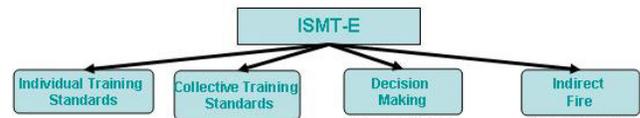
Figure 2. Training applications for ISMT

The ISMT requirements include rifle and pistol qualification courses, field range firing, offensive and defensive combat situations, judgmental shooting situations, and forward observer/forward air control procedures. The Individual Training Standards (ITS) deals with how to properly use a weapon. They include loading and unloading, actions upon a weapon malfunction, target identification, aiming, and firing techniques. In theory, a person trained on an ISMT should perform as well as someone trained with an actual weapon and live rounds. Collective Training Standards (CTS) are more difficult to train with the ISMT, primarily due to technical limitations of the current system. Although command and control of fires can be trained, many units do not use the system in this mode. Decision making training uses the video mode and is useful for training rapid decision making under stress. Finally, Indirect Fire is a critical function that ISMT can train. This involves close coordination between Naval Gun Fire, Mortar, Artillery, and Forward Observers.

In addition to the originally defined requirements, the VIRTE team is working with the training community in refining the requirements and specifications documents (QI) to incorporate new requirements and expanding their concept of operations. As with many systems, ISMT is being used today for applications not initially intended. Some of the new requirements include using low cost COTS devices, with a modular architecture to enable multiple configurations for different training audiences, as well as operational considerations such as ease of set-up, configuration and operation. Additionally, common requests such as being deployable and reconfigurable are included in the requirements.

MULTI-MODAL DESIGN

The core of the VIRTE research initiatives is focused on defining design solutions for the next generation of ISMT (QII). As you can imagine, there have been significant advancements in all of the multi-modal interface technologies since the initial ISMT program acquisition began in 1988. The research entails analyzing the component technologies such as visual, sound, locomotion, and haptics to determine how well current components address the updated requirements. Where there are numerous solutions, the team relies on research findings to suggest which will be more effective. The recommended component technologies are integrated into a prototype design all the while trying to capitalize on the modular open architectures of today's distributed simulations. The following discusses the multi-modal sensory components of ISMT.

Visual

ISMT has two major visual modes. The first is a video of actors portraying various scenarios with multiple branches depending on instructor/trainee action. Thus the scenario can unfold several different ways depending on the actions taken. This is typically called shoot/don't shoot. The criticism of this mode is that the scenarios are very quickly learned and it is too expensive to obtain new scenarios.

The second mode is Computer Generated (CG). This mode is used for both marksmanship training and for presenting more complicated scenarios. The critique of this mode is that the underlying Computer Generated Forces (CGF) do not demonstrate realistic behavior. In addition, the scenarios are difficult to author and change.

ISMT originally used large Cathode Ray Tube (CRT) projectors to display the environment, but newer versions use portable LCD projectors. Commercial trends in projection technology have allowed ISMTs brighter and sharper images with reduced maintenance and cost.

VIRTE research has concentrated on the CG mode of ISMT. By using the latest high-end consumer graphics cards and the Gambryo commercial game engine, the VIRTE research prototype demonstrates PC game quality graphics and native High Level Architecture (HLA) support. By leveraging the significant DoD investment in the JSAF, VIRTE is able to demonstrate a sophisticated Opposing Forces (OPFOR). In addition to improved CGF, the VIRTE prototype can take advantage of numerous government-owned terrain databases.

We began research into the trade-offs of using HMDs for this training domain. HMDs provide better immersion into the VE than front screen projection, but there are significant issues. First of all, the HMD may physically effect the interaction with the weapon. Second, cables must be managed and kept out of the way of the trainee. Finally, HMDs are expensive. One of the fundamental questions that we are trying to answer is how good is good enough for the training tasks.

Sound

ISMT uses stereo sound, but the quality and repertoire of available sounds is limited.

The VIRTE program has made a significant investment in the development of a government-owned 3D sound system. In addition to developing a system to play 3D sound, with the help of the Navy and Marine Corps, we recorded a large library of sounds appropriate to training. Hollywood has even borrowed some VIRTE sounds for use in movies. An example of this is the futuristic vehicles in *Minority Report,* which are based on the VIRTE LCAC sound recordings.

Our research prototype allows us to study the contribution of 3D audio and realistic sound to the training task.

Locomotion

Moving around in the Virtual Environment still represents a fundamental challenge. Today, you can have a room-sized VE with a person wearing a HMD. There are significant limitations to this approach, however. To use a high quality HMD requires video cables and these must be managed. If lower quality HMDs are used, a wireless solution is possible. An additional challenge is that you soon run out of "room". There has been some promising work at UNC (Razzaque et al, 2002) that changes the visual presentation to "trick" the user into heading away from walls, but much more work needs to be done.

Another class of movement techniques keeps the person in place and moves the Virtual Environment. ISMT uses an instructor-controlled joystick for moving the trainees through the VE. For the near term, we will continue to see variations of the computer joystick to provide movement in the Virtual Environment. While its limitations are well known, it is ubiquitous and cheap. In our prototype, we are experimenting with

mounting joystick-like controls directly on the weapon so that the individual can move through the virtual environment without instructor intervention.

There are a number of other techniques that have been tried such as foot pedals, unicycles, and treadmills, but locomotion is still an area that needs additional research. We are experimenting with NRL's Gaiter system (Templeman et al, 1999), which harnesses the individual and translates walking in place motions to walking motions in the VE.

Smell

As suggested in Figure 1, the determination of which sensory modalities must be supported is informed by the training goals and objectives. Given the current goals and objectives defined by the USMC, ISMT doesn't have any olfactory component, and the VIRTE program is not pursuing research in this area.

Haptics

ISMT has an interesting use of haptics, because the weapons are all "real". In addition to the correct weight and balance, ISMT weapons produce a significant fraction of the actual recoil of the weapon when fired. One of the drawbacks, though, is that the recoil mechanism requires cables and hoses. This is not a large issue with the rifles, but it is an issue with pistols because the tether interferes with removing them rapidly from a holster, which is a critical training task. Some intriguing challenges remain in this area of VE. How do you throw a physical grenade mockup in the VE without hurting someone in the real world? Another challenging task is aligning the site picture in the VE with the cheek weld in the physical world.

PROTOTYPE DEVELOPMENT

While a sub-team of VIRTE researchers, referred to as the Training Requirements and Operational Evaluation Virtual Product Team (VPT) continue to experimentally explore the multi-modal sensory considerations of the ISMT design, the Systems Integration VPT is focused on building iterative prototype demonstrations (QIII). VIRTE is building a suite of design solutions based on a common synthetic virtual environment, which can be reconfigured with a variety of interfaces to explore the utility of hardware solutions for various training requirements, i.e. projection display vs. HMD, joystick vs. Gaiter.

The prototypes are installed at NRLs WHSIL (Warfighter Human Systems Integration Laboratory).

Empirical studies are being conducted to analyze the effectiveness of each candidate interface technology in the sensory modality areas as well as integrated training effectiveness studies are being conducted to evaluate the most likely configurations (QIV). One possible configuration, which blends a range of VEs as discussed in Milgram et al (1994) is illustrated in Figure 3. Using this configuration, a range of hypotheses regarding the development of specific VE systems to support particular training requirements, can be tested.
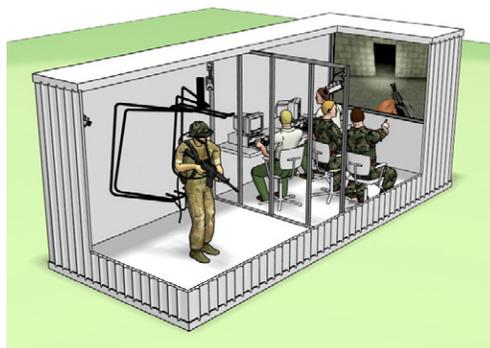

Figure 3. Conceptual drawing of a range of VE systems, varying in terms of sensory modalities supported. *Foreground:* Fully immersive system, complete with realistic weapons effects; *Midground:* Desktop based system using keyboard and mouse interfaces; *Background:* Rear screen projection system, similar to the ISMT system discussed in the paper.

CONCLUSION

Many aspects of Virtual Environments are mature enough to provide real training value today. So, when are we going to be training on holodecks? In 2002, William Shatner (aka Captain Kirk) *wrote Star Trek-I'm Working on That -A Trek from Science Fiction to Science Fact* in which he discussed when Star Trek technologies might become real. As for the holodeck, at the Office of Naval Research, *we're* working on that.

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