A Future for Entertainment-Defense Research Collaboration

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The Department of Defense and the entertainment industry are combining their expertise in a drive to exploit advances in technology toward the mutual benefit of each group.

In 1997, the National Research Council (NRC) issued a report that specified a joint research agenda for defense and entertainment modeling and simulation.[1] This report showed the excellent opportunities for synergy between the entertainment and defense industries. For years, they have been solving similar problems for very different application areas. While those two communities' opposing cultures have been difficult to reconcile, recent efforts have proven promising.

The looming question is whether the military sector can follow the leaping technological pace in the entertainment sector. That pace indicates tremendous growth in the entertainment industry, which will be coupled with continued technological innovation. This article shows how those advances will be equally vital for future defense applications, thereby demonstrating the importance of continued and increased defense-entertainment collaboration.

NRC report summary

In the NRC report, we see that games and Networked Interactive Entertainment (NIE) have become the main technology drivers for networked virtual environments. In recent years they've surpassed even defense research efforts. In addition, the NIE industry's standards have become the de facto standards for the military developers. The demographics for the gaming community and the military are similar—predominately males in their late teens to early twenties, with the percentage of females rising. Therefore, today's recruits are likely to have gaming experience and will compare any system they encounter on duty to what they use in their off-duty hours. To ensure effectiveness, the military's virtual training experiences must compare favorably to the entertainment industry's game experiences.

Viewed from the outside, several differences between the military and the NIE field exist. The military's goal is to defend the country in battle, while the entertainment industry's goal is split somewhere between making money and making good art. This means that the defense field is more concerned with the simulation's effect on users (that is, will it improve task performance). On the other hand, the NIE field wants to be the first to market with the most enjoyable experience—one that will grab users and make them want to return for more. This dichotomy creates inherent cultural differences between the two groups. An NIE company rarely has time for the luxury of pure research, and tends to focus on the development speed and flash of its final product. The contracted Department of Defense (DoD) developer can ignore competition issues and focus on delivering a quality product.

Upon closer inspection, however, several similarities exist in the goals and challenges each group faces. Each group's final product is ultimately judged on its immersiveness, ease of use, and realism. The military and entertainment industries can cooperate in several areas to mutual benefit.

The Navy recently began training prospective student aviators using a commercial off-the-shelf flight simulator and found that it improves their performance in flight school. The Internet was a military system, later adopted by the general public, which the NIE sector uses extensively. Networked gaming across the Internet has exploded, and most computer games sold today have the capacity for networked play. Game developers incorporate the latest in military innovations into their games—today, the only way the average Army infantryman can use the next-generation Land Warrior gear is to play NovaLogic's latest DeltaForce video game.

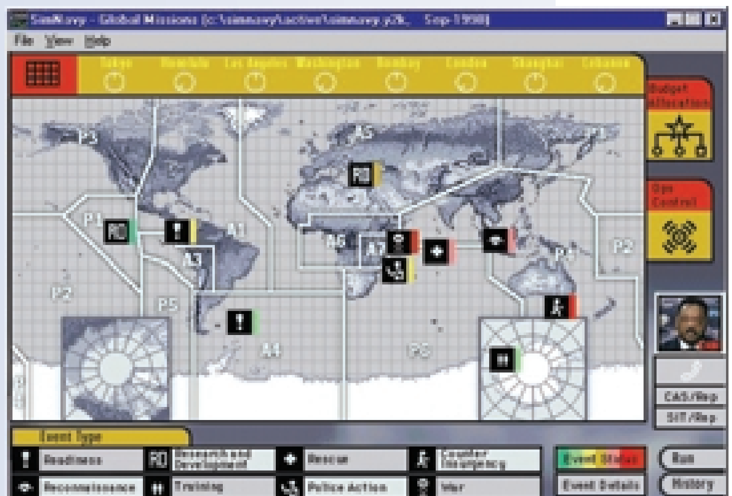
These crossover uses have occurred even though the overall goals of these two groups are quite dissimilar. Because of this dissimilarity, the NRC's report predicted that collaboration between the two groups would be most effective in the early research stages, rather than at the final development stages. However, this view has proven to be too limited, precisely because the goals of the two groups are so disparate. Since neither group

Moves Research Projects

The NPS Moves Research Center (http://npsnet.org/~moves) features an academic program in modeling, virtual environments, and simulation. Moves and the NPSNET Research Group primarily aim to achieve the entertainment-defense collaboration goals[6] of the NRC report. A number of ongoing research projects supports those goals.

- *Army Game Project.* We're engaged in a multi-year project to explore repurposing commercial video game systems for military use. Within that project, we plan to build both an educational Web-based product and a real-time multiplayer training system similar to games like Rainbow Six. We've found that game-engine technology can provide an excellent software platform for high-fidelity virtual environments (see Figure A). Additionally, game systems offer stable, easily configurable tools useful for teaching advanced graphics and networking topics.
- *NPSNET-V.* The next generation of NPSNET systems is a networked component framework that offers dynamic extensibility for all major system features. We recently described this system in the Projects in VR column in the September/October 2000 issue of this magazine. Up-to-date information is available on the Web at http://npsnet.org/NPSNET-V.
- *SimNavy.* The goal of the SimNavy prototype was to simulate the operation of the US Navy, including resource allocation, the psychology of decision making, the zero-sum economy, multilateral decisions and constraints, and the conflict between political process and military requirements. SimNavy intends to provide an interactive experience through which naval officers might learn how to make decisions at the various levels of the Navy's hierarchy. We've completed a Windows prototype of SimNavy, as shown in Figure B, and we're currently seeking funding for full development.
- *SimClinic.* This cooperative project with the Army's Training and Doctrine Command Analysis Center (TRAC) Monterey office will offer game-like simulations for training DoD personnel to run day-to-day operations of healthcare clinics.
- Relate: Relate is a new distributed agent architecture that defines simulations through relationships among software entities. Its environment for the construction of multi-agent systems has been used for education and rapid prototyping for simulation. We look forward to integrating Relate with NPSNET-V to offer full-featured architecture for development of deployable simulations.

A NPS' Herrmann Hall building viewed with the Quake 3 Arena engine.



B A command screen in the SimNavy prototype.

views the other as a competitor for its market, much more detailed discussions and partnerships are possible. In addition military designers can gain access to commercial products otherwise unavailable because the companies don't view the military as a threat to their market share. This can create a symbiotic relationship. The military can get a state-of-the-art system without spending years in development, while the licensing NIE company often sees military use of its product as a way to get its merchandise and technology exposed to a new group of people and thereby increase its market share.

The crossover also has had another effect. It has resulted in creating groups throughout the country designed to leverage this relationship and produce merchandise for both the DoD and entertainment industries. Such groups include the University of Central Florida, the Institute for Creative Technologies at the University of Southern California and the Modeling, Virtual Environments and Simulation (Moves) Academic Group at the Naval Postgraduate School (see the sidebar).

Finally, the NRC report cited five research areas of interest to both the entertainment industry and mili-

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tary; technologies for immersion, networked simulation, standards for interoperability, computer-generated characters, and tools for creating simulated environments. These five areas remain critical to the current efforts of both groups.

Technological assumptions

Predicting the future is extremely difficult. Even the most optimistic predictions in 1994 underestimated the Internet's impact. The acknowledged dean of science fiction, Robert Heinlein, offered some advice to those predicting the future,

> A "common sense" prediction is sure to err on the side of timidity. The more extravagant a prediction sounds, the more likely it is to come true … some (wild predictions) will be wrong, but cautious predictions are sure to be wrong.[2]

Heinlein's comments are backed up by what we've seen in the computer industry since the birth of the PC when clock speeds were under 5 Mhz and it was inconceivable that anyone would need more than 640 Kbytes of memory. Now, multiple manufacturers have exceeded 1-Ghz clock rates and are expected to exceed 300-Ghz by 2015.

Game machines are claiming 66 million textured polygons per second this year,[3] and it is predicted that 300 million to 5 billion textured polygons per second will be possible in two to five years.[4] Ed Catmull defined visual reality as 80 million polygons per picture.[5] Eighty million polygons per picture at 60 frames per second (fps) is 4.8 billion polygons per second. This means that machines can visually display computer images indistinguishable from reality.

Combine this with the proliferation of high-speed networks to the home. Broadband access will be available to more than 100 million US homes by the year 2003 and deployed in some 28 million homes.[6] Digital subscriber line speeds of 1.5 megabytes per second downstream and 384 kilobytes per second back let us interact with 500 players in a game and have a video stream at the same time. Cable modems promise greater speeds and allow interactions with an even larger number of simultaneous participants.

Looking at these advances and keeping Heinlein's advice in mind, we made several assumptions about advances in technology to determine which areas would benefit most from collaboration between the DoD and the entertainment industry. While none of these assumptions is trival, the likelihood of their solution conveniently allows the omission of any detailed discussion from this article.

Those assumptions are:

1. Network bandwidth will be essentially unlimited. We'll be able to pass whatever information is necessary to as many participants as required.
2. Bandwidth will exist via wireless means. This is foreshadowed by wireless modems for laptop computers, wireless personal digital assistants, and satellite high-speed Internet service.
3. Latency reduction research is key to fielding usable NIE systems. Singhal and Zyda[7] indicated that latency must be less than 100 ms for high interactivity. Since the time for light to travel between players can be greater than 100 ms, we need advances in predictive modeling for a fair low-latency experience.
4. Polygonal throughput will continue to increase rapidly, so that computer-generated images will continue to improve in fidelity.
5. Electronic miniaturization will continue, affecting not only the size of computers, but also the sensors feeding the computers.
6. Sensors and computers will know their location and recognize objects more efficiently.

Obviously, reaching these goals will take the combined effort of industry, academia, and pure research labs. But regardless of their source, both the DoD and NIE industry will co-opt these technologies to increase the immersion and effectiveness of future simulations.

Predicted innovations

Here we'll identify the technological innovations that will drive NIE's future.

Computer-generated characters

The public wants characters in virtual environments that interact intelligently. To achieve that intelligence, the virtual environment needs both networked human players and autonomous computer-controlled characters. Artificial intelligence of this sort is an extremely active area of research, both for entertainment and for defense simulation.

Television is the most pervasive form of human entertainment and will likely be the first medium to benefit from advances in artificial intelligence. Probably the earliest vision of interactive TV was captured in the 1966 motion picture *Fahrenheit 451,* starring Oskar Werner and Julie Christie. Interactive TV in that film showed Julie Christie participating in a TV story with two on-screen characters. When it was time for Julie to respond, the characters looked in her direction and a red light blinked on her wallscreen, appealing for a response. Julie's character theoretically could change story direction, chat meaningfully with the on-screen characters, and be a part of something bigger than herself. (The film unfortunately, continued the story as planned regardless of Julie's response). In our future, we really do want the story to change. The requirement for autonomous characters and an interactive storyline engine is critical.

That same capability opens new entertainment possibilities for video games. The already blurred separation between TV and video games will continue to wane. Viewers and players will interact with both people and autonomous characters and will rarely know the difference in narrow domains such as fantasy role-playing settings (a sort of modern day Turing test). Smart opponents increase variability, and therefore replayability. Game players will soon have the coveted opportunity to talk with Lara Croft, the memorable heroine from the Tomb Raider game series, and will learn about both her preferred tactics and her favorite cereal.

The military applications of realistic computer-generated autonomy are clear. More intelligent characters would yield increased fidelity in simulation systems. Emergent artificial intelligence behaviors might expose improved tactical procedures, or at least provide a training system that forces subjects to react to situations that fall outside the expected doctrine. True-expert navigation agents could choose patrol routes that minimize exposure while maximizing coverage, taking into account the ever-changing battlefield.

Augmented reality

Augmented reality systems display graphics in the user's field of vision without occluding the real world from view. In the past, it has been used most noticeably in heads-up displays (HUDs) in military aircraft to display vital information on the aircraft canopy. HUD systems let the pilot fly the aircraft with less frequent shifts of gaze to the instrument panel. To date, the NIE and military sectors have infrequently used augmented reality even though it offers an outstanding avenue for exploiting the advances in technology.

Some labs are already testing the technology required to implement augmented reality systems. Researchers at Massachusetts Institute of Technology have developed an augmented display prototype indistinguishable from eyeglasses. With a wearable computer to drive the display, it provides an augmented reality experience with no more encumbrance than a pair of glasses.[8]

Augmented reality can be used for entertainment in a number of ways. In Rome, the trinket shops sell books with pictures of the great ruins as they exist today. Clear plastic pages contain drawings of the parts of buildings that were lost over the years. When readers lay the drawings over the pictures they can see buildings such as the forum as they exist now and when they were built. This technique proves more effective than a simple drawing of the original structures. An augmented reality system can significantly improve that experience. Tourists might rent a computer and pair of glasses from the ticket office before they stroll the forum. It would not only be possible to see the entire complex at the height of Imperial grandeur in full 3D, but avatars could demonstrate the daily life of the ancient Romans. Tourists could watch Brutus stab Caesar and Mark Anthony rile the crowd. Researchers at Columbia University have developed prototypes that explore similar work.[9]

Similarly, augmented reality could bring Shakespeare's "All the world's a stage" statement to life. You can imagine the next generation of murder-mystery theater, where a murder occurs and the audience interactively tries to solve it. A group of "detectives," in trench coats and deerstalkers, could traverse the city trying to determine the murderer's identity. Detectives might interact with both other players and computer-controlled avatars. Variations of this could be based on a variety of other themes such as the popular assassin game played on college campuses, in which all the participants are hit men assigned to take out one another; James Bond, where the participants fight Spectre and engage agent provocateurs; and the open plains, where participants in John Wayne's virtual posse hunt cattle rustlers.

Augmented reality has many military applications beyond cockpit HUD systems. Foot soldiers can be equipped with wearable computers and see-through displays, essentially extending the HUD from the pilot to the infantryman. Prototypes of such systems are currently in development. The Army's Land Warrior system, for example, uses a monocle display that obstructs one eye. Clearly, available hardware technology doesn't yet meet the strict requirements of an Army soldier.

Another military use of an augmented reality method is deployment of expert systems. A mechanic wearing a computer can get real-time instructions through headphones attached to the display system and see visual clues to help him complete his task. Researchers at Columbia University have performed similar work.[10]

Ongoing work at the NPS presents a third military use, personalized briefings, in which each participant has augmented reality gear. This permits combining a large, shared theater view with personalized augmented reality displays. This system provides individual customization for each participant with the convenience of a shared environment that can be physically referenced. For example, a group might share a wall-sized relief-map display, but the assets shown in the augmented reality headset might be customized by security clearance or area of responsibility.

Whole-body tracking

Researchers have long been searching for ways to implement noninvasive whole-body tracking, but until recently, the best efforts have been fairly large and clunky suits containing many large and heavy sensors. These suits were constrained to a very limited radius, either

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because they were tethered by wires or were restricted by distance from a sensor. The military used this technology to some extent by tracking a user's gun and arm position to determine the path of shots fired. The inherent limitations greatly reduced the feeling of immersion and freedom of movement. In addition, since the user's normal body movements couldn't be used in the simulation, the user had to spend time learning an artificial interface. However, recent advances in this field lead us to believe that great promise this technology has because computers will be able to track the position of all of a user's limbs either through wireless sensors the individual wears[11] or via camera systems.[12] This will greatly increase the feeling of immersion and the intuitiveness of the interface. In addition, whole-body tracking can be extended to include telemetry for bodily functions such as respiration, heart rate, blood pressure, and so on. This opens a whole new range of potential uses.

The NIE industry can take advantage of whole-body tracking in several ways. Interactive games would be much more fun and immersive if the participants used actual body movements to direct their avatar's actions in the virtual world. All sorts of games; from soccer to baseball to martial arts; would be enhanced if the participants used the same motions to play them virtually as they use in reality. In addition, the games would be much more intuitive. They would no longer need to remember to press the enter key to swing the bat and the space bar to run to first base.

Another growing entertainment format that might benefit from whole-body tracking is the cyber communities that have sprung up since the Internet boom. Ever-larger numbers of people spend social time interacting in cyberspace with people they may or may not have ever physically met. Whole-body tracking can add entire new dimensions of communication—the coarseness of text is augmented by the subtlety of body language. Interaction between people in existing communal spaces is anti-intuitive. For example, a user must learn mouse and keyboard combinations to wave or shake someone's hand. Whole-body tracking can ameliorate the learning process that currently prevents casual participation in 3D chat spaces.

The military plans to use whole-body tracking to improve the quality of immersion in training virtual environments. Dismounted infantrymen will be able to use the actual body movements used in the field, rather than having to learn nonintuitive ones that will not benefit them in combat. This results in more effective training, since it's not necessary to train someone how to train and more time is spent actually preparing for the real mission. In addition, users' movements can be tracked and examined after the exercise for proper techniques, giving them more personalized feedback than otherwise available.

The biggest benefit of this technology for training is that an entire unit could be outfitted in this gear, along with augmented reality gear, and have a mock battle with a force located thousands of miles away. Currently, the military spends huge sums of money to bring the various units together for exercises. This technology would allow a unit to move through the countryside, exactly as they would in a real-world operation, interacting with another unit virtually on their flank but physically located across the country. These two units could either be fighting computer-generated characters or a third adversary unit, not physically collocated with either of the other two. This approach works better than current training because it uses live ammunition, since the enemy is only simulated down range.

Military uses for whole-body tracking go far beyond training. The military is investigating smart vests, which record biological information about the wearer and transmit it. By combining this with body position information, it's possible to determine the status of the wearer and dispatch medical attention if necessary.

Dynamic environment extensibility

Dynamic extensibility gives persistent environments the capability to update both application code and content during system execution.[13] Currently, the academic community is the primary driver for extensibility framework research.

This limited interest results from the current paucity of truly persistent environments. Most military simulation exercises last a few hours at most, and online action-game scenarios take only minutes. Such environments haven't presented a genuine need for runtime bug fixes or content expansion. Extant "persistent" game environments, such as Ultima Online, regularly deactivate servers and clients for software updates.

This will change. We predict a serious paradigm shift in NIE systems with a near-term deployment of hundreds of twenty-four hour, seven-days-a-week environments. Similar to the World Wide Web, content must be dynamic to keep visitors returning. Subscription pricing models, combined with the in-game advertising championed by companies such as Adaboy (http://www.adaboy.com) offer clear financial incentive for dynamic NIE environments. Shutting down an NIE world for updates, and thereby disconnecting all paying customers, will be as economically destructive as the failure of an e-commerce site's back-end database.

Multi-user object-oriented (MOO) text adventure systems instill client loyalty through persistence and extensibility. MOO players can change the world around them and even create new places and objects. Players who invest their creative energies into an environment clearly are more likely to have continued interest in that environment. Providing similar extensibility in a 3D persistent cyberspace will require significant advancements in software construction and computer security, but this is key to the success of future NIE systems.

The military can clearly benefit from persistent, dynamically extensible, virtual environments. Generally, current simulation technology is constructed to explore a single problem, and can only be modified between simulation runs. Long-term simulations are only useful as long as their problem space is static. Dynamically extensible simulations can reflect the simulation customer's changing needs and incorporate the simulated problem's changing state. For example, large-scale conflict simulations might be altered to determine the effect of recent technological developments in strategic weaponry. A tactical simulator used in transit to a military operation might be changed to reflect updated estimates of enemy force strength.

We believe feature enhancements such as these will prove useful in both simulations and training environments. However, it is just as important for systems that support extensibility to be constructed of compatible components. Sharing a component architecture across multiple simulation environments will help solve one of the military's greatest technological issues; software incompatibility among hundreds of simulation systems with overlapping functionality.

Haptic devices

Computers have moved slowly in increasing the number of senses they affect. For a while the only output was text. Then people started outputting computer graphics to the screen. Computer immersion remained strictly visual, but people realized that the experience was definitely lacking without sound. Sound started slowly, but quickly evolved to the point now where every computer is a mini sound system, and people can't believe that they ever enjoyed computer games without sound. We expect that the next sense to receive attention will be touch and that the same type of explosion will happen to haptics. Neither entertainment nor the military have done much in this field. Force-feedback joysticks exist in both entertainment and military applications and add another degree of immersion, but are fairly rudimentary. The military has experimented with telesurgery, which requires haptic feedback, but it still remains in the early stages. However, once haptics are commonplace, no one will understand how anyone could have felt immersed without them.

Haptic applications for the entertainment industry are incredibly widespread—try to imagine any sort of immersive game that haptics wouldn't improve. Imagine feeling the sting of connecting with a fastball thrown by a major league pitcher in a sports simulation or feeling a pistol in your hand in a first person-shooter game. Now imagine feeling the recoil of the pistol as you fire at the bad guys and feel their bullets hit your chest as the haptic vest you're wearing lets you know you've been hit. Hopefully, we'll never reach Ivan Sutherland's "goal" of a person dying from a virtual bullet; however, the feeling of immersion would be much greater with haptic feedback. Additionally, it would make the game more intuitive since it would dispense with the clumsy visual methods of indicating damage location seen in current video games.

Cybersex is one application that the entertainment industry will certainly exploit. While there's no need for a detailed analysis in this venue, it's easy to judge from the proliferation of Internet sex sites and erotic games that the public would be more than willing to pay for haptic development for VR interfaces.

The military would obviously be able to find several uses for haptic feedback. First-person shooter games would obviously apply to military training and would also provide benefits in training for fine repair work. By feeling the torque required to turn a bolt, mechanics would receive more valuable training in replacing a component. This virtual training would significantly reduce the amount of on-the-job training required to make mechanics proficient at their trade.

Another use of haptics for the military would be long-distance communication, especially between families separated during a standard six-month naval deployment. A new father would be able to hold his baby's hand, even though he's on a peacekeeping mission in another part of the world, or a mother in the Arabian Gulf would be able to hug her kids goodnight.

Conclusion

Defense-entertainment collaboration is intuitive given their symbiotic needs. Continued collaboration will help each party better exploit the opportunities presented by upcoming technolical advancements in augmented reality, whole-body tracking, dynamic extensibility, computer-generated characters, and haptics. ■

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References

1. M. Zyda and J. Sheehan, eds., *Modeling and Simulation: Linking Entertainment & Defense*, National Academy Press, Washington, DC Sept. 1997, http://books.nap.edu/catalog/5830.html.
2. R.A. Heinlein, "Where To?," *Expanded Universe*, Ace Science Fiction Books, New York, 1980, pp. 318.
3. H. Yoshiko, "Microprocessor Forum: Sony to Use Playstation2 Technology for Workstation Line," *EE Times*, 8 Oct. 1999, http://www.eetimes.com/story/OEG19991006S0040.
4. M. Smith, "X-Box vs. PlayStation 2," MSN Gaming Zone, 30 Mar. 2000, http://www.zone.com/zzzz/gamesdomainxboxvsplay.asp.
5. N.I. Durlach and A.S. Mavor, eds., Virtual Reality: Scientific and Technological Challenges, Committee on Virtual Reality Research and Development, National Research Council, National Academy of Sciences Press, Washington, DC, 1995, pp. 252.
6. M. Zyda, "The Naval Postgraduate School MOVES Program—Entertainment Research Directions," *Proc. Sum-*

mer Computer Simulation Conference, Vancouver, BC, Canada, July, 2000, pp. 1-6.

7. S. Singhal and M. Zyda, *Networked Virtual Environments: Design and Implementation*, ACM Press Books, Siggraph Series, New York, 23 July 1999, http://www.amazon.com/exec/obidos/ASIN/0201325578/michaelzyda.
8. A. Pentland, "Perceptual Intelligence," *Comm. ACM*, vol. 43, no. 3, Mar. 2000, pp. 35-44.
9. T. Höllerer, S. Feiner, and J. Pavlik, "Situated Documentaries: Embedding Multimedia Presentations in the Real World," *Proc 3rd Int. Symp. on Wearable Computers*, *ISWC '99,* San Francisco, CA, Oct., 1999, pp. 79-86.
10. S. Feiner, B. MacIntyre, and D. Seligmann, "Knowledge-based Augmented Reality," *Comm ACM*, vol. 36, no. 7, July 1993, pp. 52-62.
11. E. Bachmann, "Inertial and Magnetic Tracking of Limb Segment Orientation for Inserting Humans into Synthetic Enviroments," PhD Thesis, Department of Computer Science, Naval Postgraduate School, Dec. 2000.
12. A. Bobick, et al., "The Kid's Room, " *Comm ACM*, vol. 43, no. 3, Mar. 2000, pp. 60-61.
13. M. Capps, K. Watsen, and M. Zyda, "Cyberspace and Mock Apple Pie: A Vision of the Future of Graphics and Virtual Environments," *IEEE Computer Graphics & Applications*, Nov./Dec. 1999 pp. 8-11.

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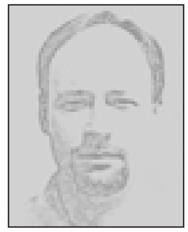

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