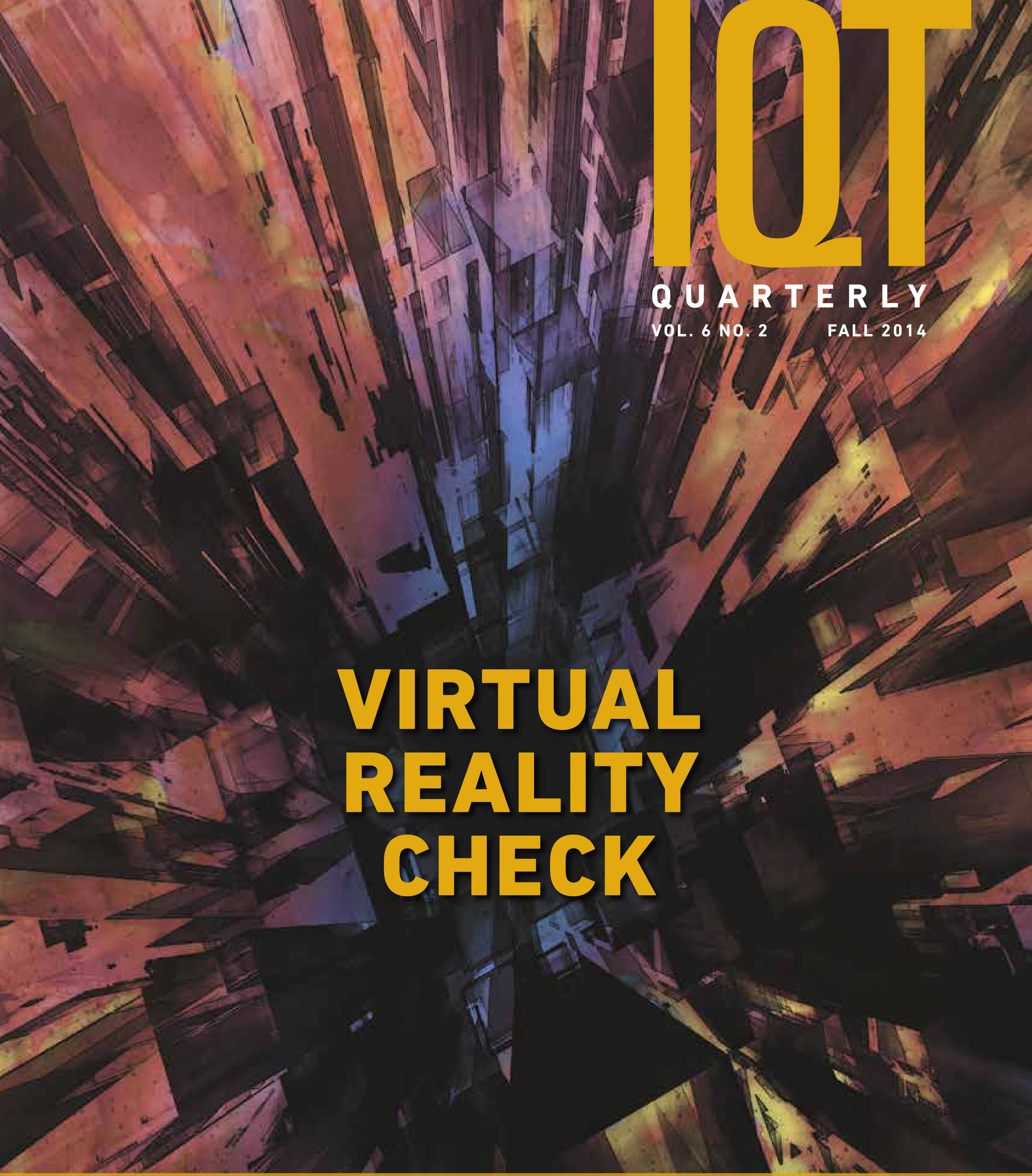

IQT QUARTERLY

VOL. 6 NO. 2 FALL 2014

VIRTUAL REALITY CHECK

IQT IN-Q-TEL

IQT Quarterly is a publication of In-Q-Tel, Inc., the strategic investment firm that serves as a bridge between the U.S. Intelligence Community and venture-backed startup firms on the leading edge of technological innovation. *IQT Quarterly* advances the situational awareness component of the IQT mission, serving as a platform to debut, discuss, and debate issues of innovation in the areas of overlap between commercial potential and U.S. Intelligence Community needs. For comments or questions regarding IQT or this document, please visit www.iqt.org, write to iqtquarterly@iqt.org, or call 703-248-3000. The views expressed are those of the authors in their personal capacities and do not necessarily reflect the opinion of IQT, their employers, or the Government.

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QUARTERLY

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ON OUR RADAR

VIRTUAL REALITY: LESS VIRTUAL, MORE REAL

By Kevin P. O'Connell

Virtual reality (VR) is the simulation of an environment in a way that creates an immersive, "you are there" experience. VR applications span the range from industrial-scale training technologies (e.g., flight simulators used in military and civil aviation) to entertainment (e.g., the sophisticated simulations of fantasy worlds in amusement parks). As those who have experienced these simulations know, there are both computational and physical aspects to creating the simulated, immersive experience. Attempts over the years to create "Smell-O-Vision" notwithstanding, the more senses that these simulations engage, the more immersive or realistic the environment feels.

Historically, the highest quality VR experiences have been expensive to create, so the use of VR has been motivated by the even greater expense of not using simulators. One enterprise example of a VR use case is flight simulation. Airlines employ large, full-scale mockups of cockpits that are suspended on gimbals, and the entire structure yaws, rolls, and pitches in response to the trainee's controller inputs. While "flying" the simulator, the trainee sees and hears sights and sounds she might encounter during real flight operations. Flight simulators are very complex and expensive to build and maintain, but less expensive than real airliners, and certainly less costly in lives and resources if trainees make fatal errors. Defense contractors have developed simulators for combat aircraft, armored vehicles, and infantry training as well, and like civilian flight simulators, they are expensive to build and maintain, which in turn limits their use.

The key components enabling VR immersion are plummeting in cost. The current trajectory will allow consumers to enjoy high-quality, commercially available simulations in fully integrated systems at a reasonable price within one or two years. While most of the current buzz about VR is devoted to displays, the immersive nature of VR means that the experience is not driven by a single technology, but by an ecosystem:

- **Displays.** Displays are rightly at the forefront of the VR buzz because humans gather most of their information visually. Indeed, no other part of the VR ecosystem was going to break out commercially until the problem of high-definition displays with ultra-responsive head motion tracking was solved. Oculus VR has introduced Rift, a VR display whose sufficient quality and affordability demonstrate that consumer VR is now within reach.
- **Sound.** Oculus VR, Sony, Avegant, and other companies are working to provide sound resolution in three dimensions so that virtual objects or persons sound as though they are in the intended location.
- **Movement and body tracking.** An immersive sense of presence requires that users be able to see their own hands, and that their virtual hands move when their real hands move. VR technologists are solving this problem through a combination of accelerometers and gyroscopes (in hand-held controllers) and optical methods that track larger-scale motion of the head, body, and limbs.

While most of the current buzz about VR is devoted to displays, the immersive nature of VR means that the experience is not driven by a single technology, but by an ecosystem.

- **Haptic feedback.** Users will encounter objects in the virtual world and manipulate them. A sense of immersion requires that objects held, touched, or struck feel that way. Weapons must kick when fired, and a stick must recoil when it strikes an object. Force feedback game controllers have been in the market for some time, but now that the VR ecosystem is burgeoning, developers are tuning haptic feedback more finely to enhance the feeling of realism.
- **Environment/applications.** While hardware is required to create the VR experience, content will ultimately be king. Compelling "killer apps" will be no less commercially important for VR than high-quality games are for console sales. After all, how many Xbox units would Microsoft have sold without the Halo franchise? While gaming is an obvious early application, VR will enable new capabilities in workplace collaboration, training and education, communications, and data visualization.
- **Cameras, game engines, 3D rendering, and physics.** Once compelling concepts for VR apps are identified, virtual worlds must be created (or replicated from the real world). A fusion of 3D imaging/rendering technology, gaming engines, and physics engines will be required to construct the virtual world, give it visual realism, and add properties like gravity, mass, and inertia to objects.

Market Forces

Why is the VR ecosystem exploding *now*? Several recent technology trends (many of which have been the themes of past issues of *IQT Quarterly*) are converging to drive this timing:

- **Low-cost, high-quality components.** Just as developers of other wearable technologies have done, VR developers are leveraging the massive economies of scale driven by the mobile device industry. There are currently about 1.6 billion smartphones and tablets in the world, whose price points are all less than $1,000 (and most are far cheaper). Their components, therefore, are far less expensive still, and of remarkable quality. The first Oculus Rift prototype used displays and motion sensors sourced from mobile technology, and similar motion sensors and vibration motors are the key components in controllers that provide haptic feedback.
- **Open source hardware.** Just as the broader wearable technology community is leveraging open source hardware to inexpensively and quickly prototype novel devices, VR entrepreneurs are taking advantage of open source hardware, especially Arduino processors, to provide inexpensive compute platforms to run VR applications.
- **Additive manufacturing and maker spaces.** The cost of access to sophisticated manufacturing technology is plummeting with the spread of maker spaces, business incubators that for a fee provide workspace and access to computer-aided design, milling, and additive manufacturing ("3D printing") capabilities. Outside of maker spaces, the cost of 3D printing and CNC milling equipment is itself in the range of a few thousand to less than a thousand dollars. Together, these trends mean that inventors can turn the design/build/test/revise cycle faster and less expensively than ever.
- **Crowdfunding.** Just as entrepreneurs have unprecedented access to manufacturing technology at low cost, crowdfunding allows them to simultaneously raise funds, conduct market research, and develop a following of early adopters. For example, the founders of Oculus VR raised more than $2 million (having set a goal of $500,000) in a matter

of weeks in mid-2012 on the website Kickstarter, whose structure includes a public comments board through which the company gained valuable insight into their early adopters' desires in a first product. The company communicated its progress there until launching a corporate website and blog.

What does the near-term future hold for VR? Most of the VR buzz of the last 18-24 months has been generated by small companies backed by crowdfunding and venture capital. However, as their technical success has accelerated, large companies have begun to take notice. Sony showed up at the January 2014 Consumer Electronics Show with a head-mounted display that was a clear response to the Oculus Rift. Shortly thereafter, Facebook paid $2 billion for Oculus VR, without the company having yet launched its commercial version of Rift and without a commercially available VR "killer app" to view through Rift.

A growing number of small companies are beginning to develop content specifically for consumption by Rift users. However, a fully integrated VR platform that incorporates 3D sound resolution, full-body motion tracking, display, and controllers with haptic feedback will likely be required to reach the consumers beyond techies and gamers who will first adopt VR. A broader audience, convinced of the value of VR beyond gaming, will be required to drive the investment returns that justify deals like the Oculus VR acquisition.

How will IQT's customers realize the benefits of VR? Virtualization of mission spaces and locations, more realistic training, and immersive training outside of traditional environments are all possible to achieve within the next two years. The equipment required to create such fully immersive experiences, including the compute platform, will soon fit in a suitcase, enabling users to provide immersive training, mission preparation, and mission simulation almost anywhere. The ability to quickly capture 3D renderings of places of interest and recreate them for immersive visualization is likewise only around the corner, and streaming applications that will allow users to be "present" while half a world away are not far behind. More speculative are the possibilities for data visualization. What advantages — for applications like network analysis and cyber threat detection — can be realized by being "immersed" in data one can manipulate, in ways foreseen in the films *Minority Report* and *The Matrix*? The answers to these questions are less clear, but it is apparent in the near term that a genuine revolution in VR is taking place that will enable wide access to new mission use and training capabilities in the very near future.

How will VR affect our lives more broadly? We are currently living in the age of the mobile device. Smartphones and tablets are the distillation of a host of technologies that put a world of data at any user's fingertips. The VR revolution, along with the concurrent explosion in the broader area of wearable computing, and the fusion of data and life called "augmented reality" (as exemplified by Google Glass), will eventually drive the definition of the next great computing platform. VR will be among the applications that redefine our experience of presence, just as smartphones redefined our personal relationships with connectivity and data. Q

Dr. Kevin P. O'Connell *is Vice President with In-Q-Tel's Field Deployable Technologies Practice. He has been with IQT since 2007. His 29-year career began in applications of molecular microbiology to problems in agriculture, and progressed to R&D projects in biological defense. O'Connell was a scientist and principal investigator with a Department of Defense laboratory for 10 years, where he focused on pathogen detection and genetic characterization. He is the author of more than 50 peer-reviewed journal articles, book chapters, and other publications, edited a book on biological defense, and holds eight patents. O'Connell holds a B.S. degree in Life Sciences from MIT and an M.S. and Ph.D. in Bacteriology from the University of Wisconsin-Madison.*

A Look Inside: Virtual Reality Check

This issue of the *IQT Quarterly* examines recent advances in virtual reality technologies. While VR hype is nothing new, the current landscape suggests that it is finally coming to fruition and ready for widespread adoption. Low-cost components, open source collaboration, and crowdfunding are converging to create high-quality VR that's accessible for the masses. An early, evolving awareness of commercial innovation is critical to identifying the new intelligence opportunities that VR will enable.

Tracy McSheery of PhaseSpace opens the issue with an overview of potential VR and AR (augmented reality) applications, such as training first responders and modeling medical procedures. He explains that this future of VR is possible because VR presents information in ways the brain can process more naturally.

Next, an interview with Karl Krantz, founder of Silicon Valley Virtual Reality (SVVR), reveals some of the key takeaways and innovative technologies demonstrated at the first SVVR Conference. This event connected a group of developers, entrepreneurs, hackers, and artists with a shared passion for VR technologies. Krantz also provides insight into the aligning factors that have allowed VR to become widely available, and shares his vision for widespread VR adoption in the coming years.

James Iliff and Nathan Burba of Survios discuss the recent democratization of VR. Their efforts to create fully immersive VR gaming at a consumer price point has spanned software and hardware challenges while using sight, space, and sound to create a convincing sensation of space.

William Provancher of Tactical Haptics provides an overview of touch feedback in VR and its role in creating a compelling, realistic experience. While head-mounted displays and 3D audio help create immersion, multisensory feedback will be required to create a true sense of presence when users physically interact within virtual environments. Provancher's research at the University of Utah has surfaced a new tactile feedback technology that mimics real-world haptics and physically confirms users' interactions.

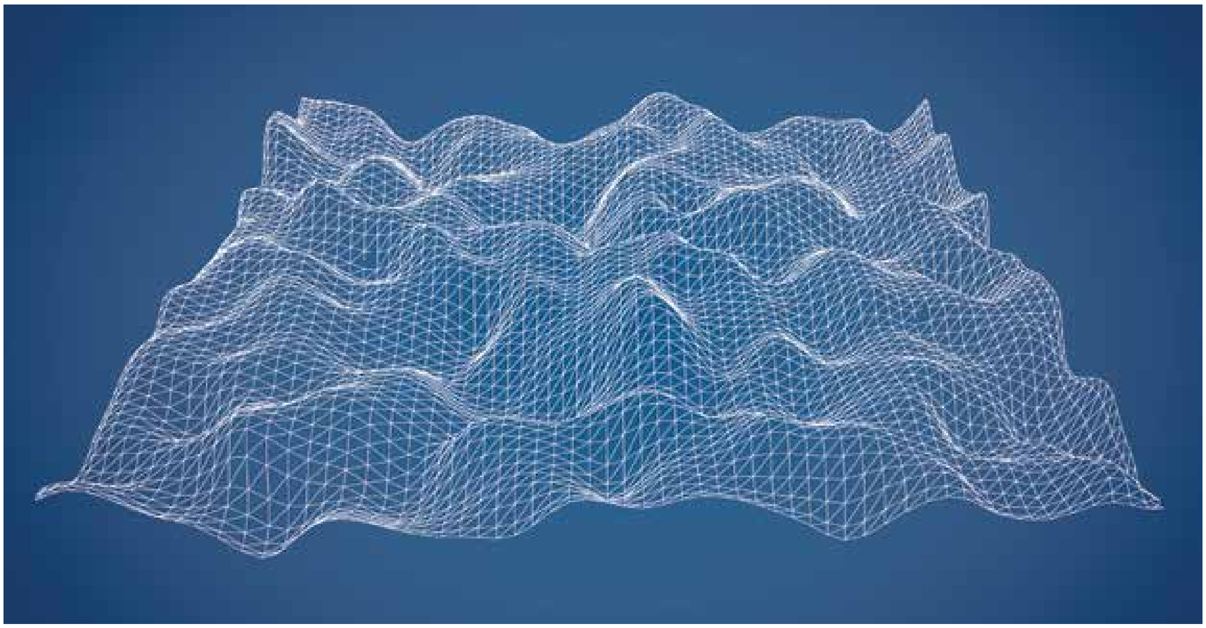
Next, Gavin West and Jan Goetgeluk of Virtuix present the concept of a Virtual Intelligence Environment (VIE) for the IC, a detailed and accurate 3D digital database that allows immersion through a VR system. Four integrated components — sensory, locomotion, training, and content — create a platform that would enable training for specific scenarios in an environment that has been constructed using exact details.

Drew Oetting of Formation 8 provides an investor's perspective on the emerging VR industry. His view of the space is shaped by his firm's experience as an early investor in Oculus VR.

Beyond the scope of this issue, there is much discussion around the recent proliferation and democratization of virtual reality. What was recently an expensive, distant technology is now ripe for innovation. A timely understanding of the progress in this arena will be vital to realizing VR's potential for national security applications.

Really Virtual: A Survey of VR and AR Application Spaces

By Tracy McSheery



Virtual and augmented reality devices are becoming mainstream, with low-resolution tethered devices available for less than $500 and wireless devices with higher resolution available in the next two years. The recent advances have billions of dollars being invested in hundreds of startups to cash in on the excitement.

On the other hand, there are currently less than 200,000 devices deployed worldwide, and most of them are tethered to a computer with a high-end graphics card. This means the investments in VR software are made anticipating markets of users that don't exist yet. VR is experiencing a chicken and egg problem that will require a dozen smaller markets to create a critical mass. When companies prove they are saving money, increasing productivity, and improving training for first responders and educators, this shortage of potential customers will gradually decrease and the market will grow organically. But at this point, everyone is looking for killer applications that are as virtual as the technology. What makes this different after decades of research and virtual promises are new capabilities driven by mobile phone technology. For example, system on a chip (SoC) quad-core processors with subprocessors performing graphics, 3D sound, image processing, and other complex tasks that only 10 years ago required a large computer, now run on a chip under five watts. Bulky CRT displays are now replaced by small and flat LCD, OLED, and MEMS displays or projectors with megapixel resolutions and refresh rates that eliminate the flicker that often contributes to user fatigue. With displays costing less than $10 per diagonal inch, hardware performance is not limited by the wearable computer as much as the available software and development tools.

VR Application Spaces

VR applications — ranging from technician repairs to virtual training for first responders and law enforcement — take advantage of the newest game engine technology to provide realism and create scenarios that will allow better preparation for emergencies. Working with law enforcement, we've seen how incident responses can vary for entry depending on the physical layout, number of agents, and dozens of other variables. A training

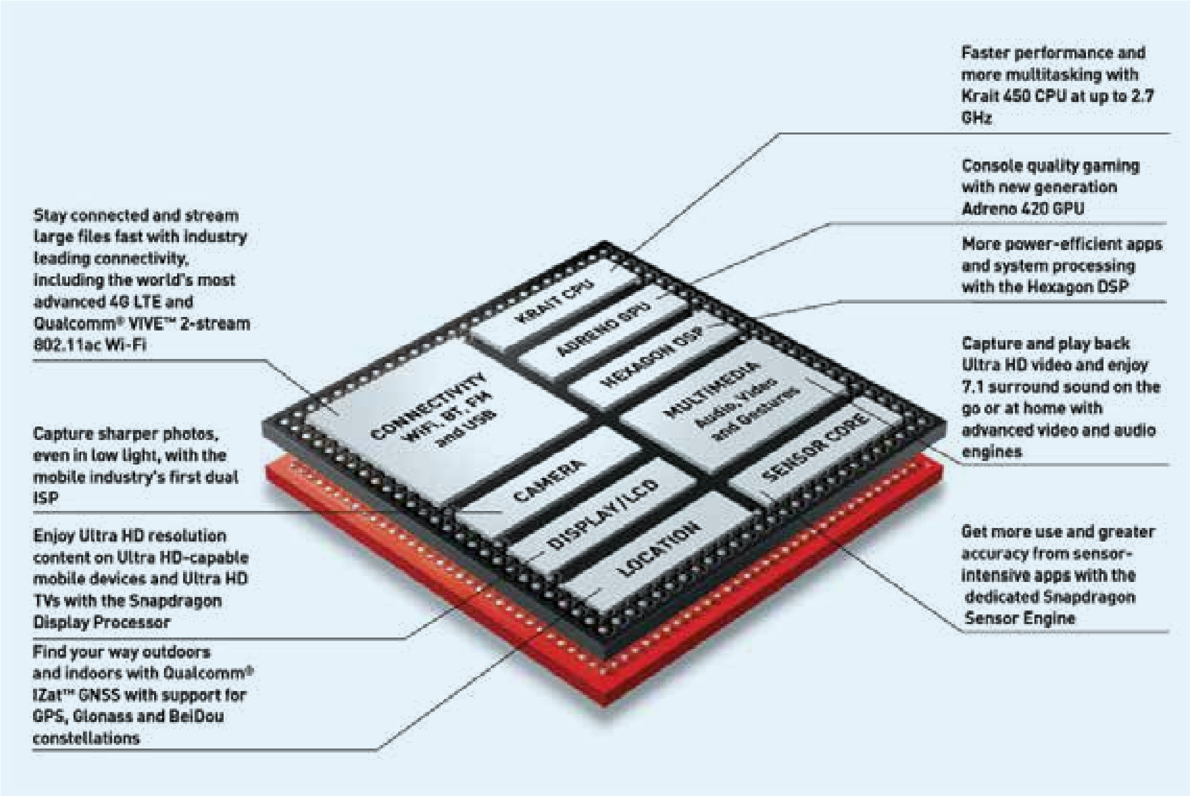


Figure 1 | The Qualcomm Snapdragon 805 has capabilities that exceed desktop performance just a few years ago.

system that allows interaction with physical objects (albeit padded for protection) makes it easy to create training exercises that would otherwise be dangerous and allows evaluation of tactics and procedures.

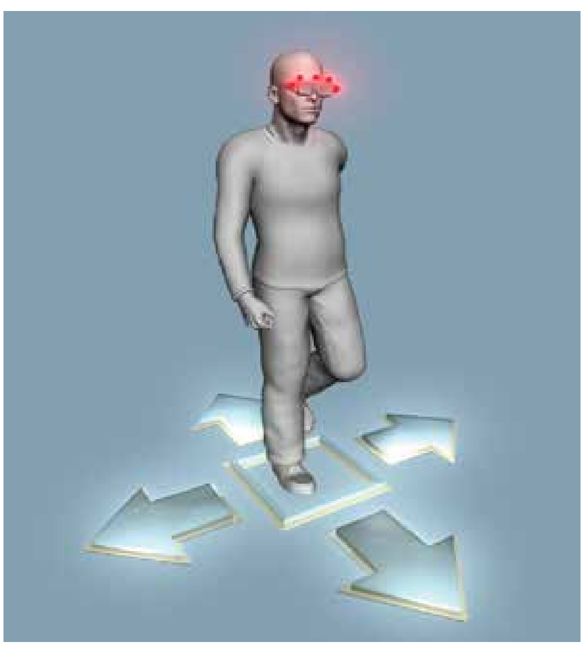


Figure 2 | Users can walk around inside the virtual training, reacting to otherwise dangerous scenarios.

Creating all the scenarios a firefighter is likely to encounter in single, multi-story, or high-rise buildings and reviewing responses now takes an empty room and a few props. Wireless technology keeps VR devices from becoming encumbering and producing negative training where you have to account for the VR system as part of the learning experience.

For police, low-cost devices and easy-to-use tools will make it easier for community colleges and universities to collaboratively create training scenarios and reinforce positive actions, mitigating the effects of decreased budgets and appeasing public demand for better training.

For medicine, maintenance, and repairs, virtual reality allows training that increases memory retention by creating a more realistic environment with a sense of immersion. Parts can be seen in context and then removed and rotated to understand how they fit together, and diagnosis and training can be presented in ways impossible with physical objects. Peripheral vision stimulation and auditory cues that correspond to the training make the sense of being inside the training more realistic and memorable. While reading and processing information is a relatively new task for our brains, spatial processing and exploration are second nature. Imagine a doctor playing a video game that assigns antagonists to different parts of the body and asks the doctor to determine which tools are needed to combat each disease. The association of treatments with parts of the body, the juxtaposition of data and information, and repetition in a competitive environment where 100 percent is the minimum score make the concept of rote memorization pale in comparison. Repetition that would be boring becomes competitive, and therefore more memorable, with the added benefit of monitoring progress and resolving issues using the latest software tools.

The challenge again is to create the tools, although the game engine technology is already up to the task. This ability to visualize in 3D, see different layers exposed, highlighted, and connected, and then see the effects of drugs on different organs as the blood perfuses through the body is a science fiction dream that will quickly become a reality.

Surgical robots are currently an expensive curiosity that still carry a legacy of performing surgery with scalpels and sutures instead of lasers and laparoscopy. With an MRI or CAT scan of the patient, a doctor can practice a procedure prior to operation and explore variations to arrive at the easiest solution with the best results. Traditional tools do not allow planning; doctors are literally opening up patients to look inside due to the limited resources available. But in the virtual world, MRI, CAT scan, and X-ray data can be superimposed with ultrasound and thermal imaging to provide a more detailed model of the patient. The information can be processed in layers, or combined to provide information of changes over time, and progress in treatments. Complex procedures can be created by combinations of traditional techniques and studied with multiple inputs, rather than opening a patient with the clock running before they have to be sewn back together.

Augmenting Reality

Augmented reality displays, the near cousin to virtual reality, differ by allowing the user to see through the display screen or by using a camera to superimpose virtual and real views. These allow collaboration between remote users — for example, giving a doctor the ability to remotely guide an emergency medical technician through triage, or a component expert to guide a technician in the repair or maintenance of critical equipment. The cost and complexity of these devices are and should be lost to the user; that is, the applications should make the function transparent so that the goal is the equipment working at top performance, not learning how to use a new tool.

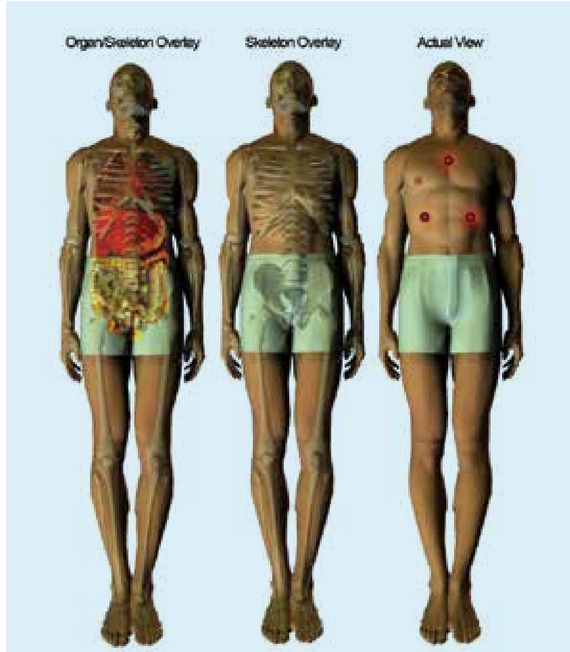


Figure 3 | Augmented reality displays allow doctors to see imagery superimposed on the patient, or technicians to see schematics on top of equipment.

This focus on usability is part of the maturation process: moving from research tools and the first clunky devices to mainstream consumer products that are expected to perform better at a lower cost with intuitive software.

The goal of virtual and augmented reality is to make interaction with computers and information easier and more intuitive. This requires a back and forth process between hardware and software development. In some applications, the solution is not possible with existing devices, and so novel solutions will present themselves as the new hardware is deployed. However, this bootstrapping requires the existing markets to provide the financial base to support ongoing development.

Presenting and Processing VR Data

This future of VR is made feasible because VR combats information overload: it allows information to be presented in ways that the brain processes more naturally.

Since the brain's processing is heavily visual with a spatial component, presenting data as objects in a 3D space with representations that reflect their attributes allows huge amounts of data to be presented without becoming lost. While programmers and databases are fine with pointers and linked lists, most people find it easier to look at a scene and find objects that don't belong, rather than read through a list of attributes. The challenge is to create software and visualization tools that allow quick interpretation of data in 3D formats that preserve the information.

Virtual reality allows visualization of large amounts of data while retaining geospatial relationships and fine tuning responses based on hand-eye coordination and motor skills. In a disaster relief scenario, site commanders can view all available issues and assets with a giant's-eye view of the scenario collected from ground, air, and satellite information translated into a single, large-scale 3D map they can walk around and scale up or down. Moving around within the map, they can assign assets to specific buildings or individuals with gesture and voice commands instead of a non-intuitive software interface.

The ability to process huge amounts of data, coordinate thousands of people, and provide individualized responses requires a resolution that would be lost on a 2- or 4-megapixel display, but is easily portable to any location via a head-mounted display with gesture and voice controls.

Finding that mix of information is even more complicated if you are processing multispectral information from a low-altitude UAV, or hybrid sources such as a combination of synthetic aperture radar with a feature size of one meter and visual data with a feature size of a few centimeters. The combination of features can eliminate camouflage and detect movement of objects or changes in terrain, but it is the presentation of data into 3D spatial information that makes it easy to process differences and then find focus areas.

Adding 3D audio to indicate attributes and provide awareness of alerts gives additional information without creating data overload. The ability of a person to recognize visual patterns and changes is challenged by flipping through hundreds of images, whereas using software to create megapixel mosaics and then analyzing the changes from previous or expected data can be rapidly processed.

Figure 4 | VR projection allows 360-degree battlespace awareness with a compact footprint and intuitive interface.

Identifying VR Markets

The key is that low-cost devices, combined with sophisticated but affordable development tools, allow all of these applications to be created, and then the market will vote on which one is the killer application. With more than a billion potential customers in the educational, gaming, scientific, and industrial spaces, there is room for any and all of the above, but it will require billions of dollars in development spread across hundreds of companies to fully explore the opportunities.

While each community feels its needs are most important, customer requirements will be met with an array of devices whose costs, performance, and features suit the software applications. Like computers, people purchase equipment for the software and tools that they need, not the other way around. The market drivers remain to be seen, but a plethora of 3D VR games will hit shelves within the next year, and it is important not to base the entire VR roadmap on the success or failure of a few early pioneers. Q

Tracy McSheery *is CEO of PhaseSpace, where he has designed, prototyped, and delivered position tracking systems for computer animation, telepresence, sports medicine, and virtual training. He has been a consultant on numerous engineering issues, particularly where technology plays a central role. McSheery also does consulting work for several Bay Area companies on areas ranging from biomedical devices to education software. He was previously a Lieutenant in the U.S. Navy, where he managed more than four hundred people and several million dollars in equipment and budgets. McSheery holds a B.S. in Mechanical Engineering from UC Berkeley and a Masters in Applied Physics from UC Davis.*

THE VR COMMUNITY COMES TO LIFE

A Q&A with Karl Krantz

In a recent interview with IQT, Karl Krantz of Silicon Valley Virtual Reality (SVVR) discussed some of the key takeaways and innovative technologies demonstrated at the first consumer-focused VR conference. He also offered insight into the converging factors that have allowed VR to become mainstream, and his thoughts on how commercial applications and adoption will develop in the coming years.

What is Silicon Valley Virtual Reality? How did it start?

Silicon Valley Virtual Reality (SVVR) is a group of entrepreneurs, developers, hackers, and content creators who share a passion for creating and exploring virtual reality technologies.

Over the past few years, as it started to become apparent that technology was finally catching up with the dream of VR, communities of VR hackers and enthusiasts began to form online. We created SVVR to provide a home for that community to meet in the real world to discuss ideas, collaborate on projects, and share experiences. In May 2013, we launched SVVR as a monthly meetup, and after a full year we grew into the first consumer-focused VR conference and technology expo.

We've had tremendous momentum and energy from the very beginning. There are not many technology areas that incite the level of excitement and passion in people as VR. There is a definite sense that we are witnessing the birth of something important. A number of Silicon Valley technology veterans have compared SVVR to the Homebrew Computer Club at the beginning of the personal computer industry. Because of our location and our strong community, we are the perfect place for VR startups from around the world to connect with investors, decision makers, potential partners, and other resources.

What were some of the highlights of the first annual conference in May 2014?

We are proud of what a melting pot the first SVVR Conference was. People from so many industries came together around a shared goal and passion. Hollywood directors networked with top game developers, hardcore optical engineers, interaction designers, architects, visual effects artists, researchers, medical professionals, 3D modelers, and content creators. VR seems to attract the brightest and most forward-thinking individuals from any industry it touches.

One highlight was watching Palmer Luckey, creator of the Oculus Rift, try the Sony Morpheus headset prototype for the first time. Instead of acting like adversaries and competitors, Palmer appeared to be genuinely pleased that the Sony product provided a good experience, and the Sony representatives seemed happy to hear his feedback. The industry is so small right now that most people know each other, and everyone is working toward the same goal of making high-quality VR. If we succeed in doing that, the potential market is big enough for everyone.

Another highlight that showed the collaborative spirit of this community was the virtual SVVR expo, which happened a few days after the event. One of the exhibitors developed software to run a VR chatroom where people can meet and hang out as avatars online. Another exhibitor demonstrated a technology to scan real people and turn them into avatars, and yet another exhibitor's technology created 3D scans of physical spaces. They all came together to create a virtual conference using scans of the actual expo hall, with avatars that were scans of the actual attendees. They had it all working in just a few days and hosted an online discussion in VR for people who missed the physical event.

What technologies at SVVR caught your eye as the next game-changers?

One of my favorite projects is the virtual world startup High Fidelity. They are mapping facial expressions and body language onto avatars in real time, and putting those avatars into a shared virtual world. While the avatars are not realistic yet, they do capture the spirit and personality of the person driving them. High Fidelity's Philip Rosedale delivered his keynote address in person, but with his avatar mirroring him in real time on the big screen behind him. I found myself making eye contact with his virtual avatar instead of his real body. When you start to combine body language, eye contact, and facial expressions, it really does bring these avatars to life.

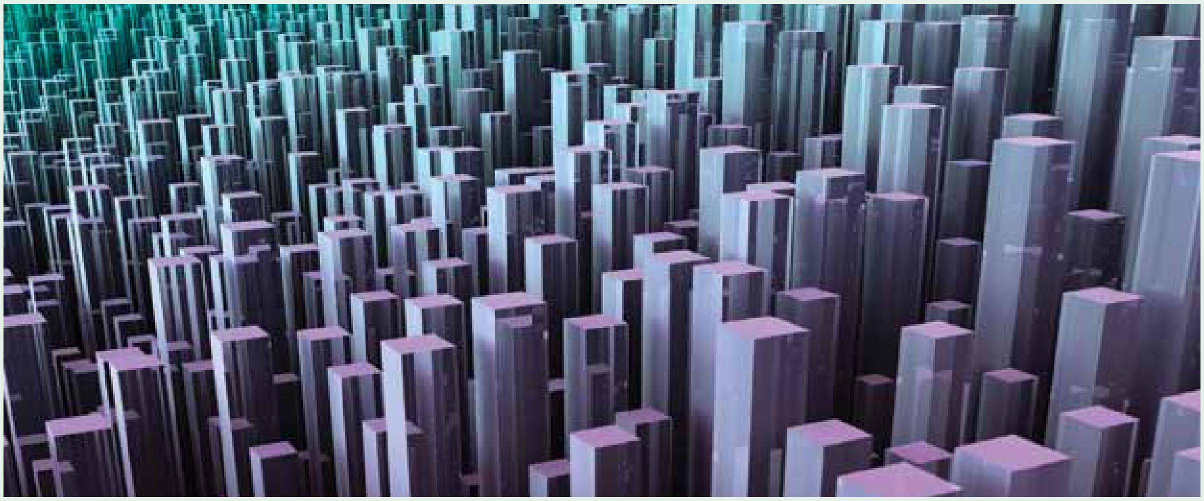
Input and locomotion are two of the big unsolved problems in VR, and we are starting to see some solutions that could work. One of our exhibitors demonstrated a true omnidirectional treadmill called the Infinadeck. It was an incredible feat of engineering, built by a single hobbyist in his garage. While this prototype was clearly too big and too expensive for anyone to put in their home, it reinforced to me that many of these difficult problems can be solved by a single clever and determined individual.

Why now? What has happened in the last few years to make VR widely available, and why will the new VR ecosystem be more successful than previous efforts?

The biggest difference from previous attempts at making VR a reality is that the technology is now affordable enough for the masses. The gaming market and the explosion of mobile devices have allowed displays, sensors, and GPUs to become cheap enough and good enough for VR at roughly the same time. Instead of a few hundred engineers solving problems, we now have tens of thousands of hackers and hobbyists trying just about everything they can think of. More eyes on the problems means a wider variety of creative solutions.

The crowdfunding phenomenon has also been playing an important role. So many companies got burned on VR in the past that it's unlikely they would take another risk on consumer VR without the growing movement of consumers putting their money on crowdfunded projects and demanding them. It's not just the Oculus Rift that was crowdfunded — it's everything from input devices and controllers (e.g., the Sixense STEM controller or PrioVR motion capture suits) to locomotion devices (e.g., Virtuix Omni omnidirectional treadmill) and VR-based 3D modeling applications (e.g., MakeVR). Almost every product in the VR space is being tested first on crowdfunding sites like Kickstarter. This allows entrepreneurs to efficiently test ideas for market interest without investing too heavily.

Another trend that shouldn't be underestimated is the active, collaborative nature of maker and hacker culture,



where ideas are exchanged and developed. You can still go onto forums and read the threads where Palmer Luckey developed the first Oculus Rift prototype. You can watch it evolve, step by step, from a modest personal project into something he planned to sell to a few hundred people as a kit, to what eventually became a company that Facebook purchased for $2 billion.

Apart from gaming, where does VR have the most potential for disruption?

Watching a movie in VR is surprisingly compelling, and there is no more cost-effective way to have a full-sized movie theater in your home. Existing 3D movies are particularly fun in VR, since many of the problems that plague typical 3D displays don't apply when you're wearing a VR head-mounted display (HMD). Watching "Avatar" in 3D in VR was actually a more comfortable 3D experience for me than watching it with 3D glasses in a theater. As resolutions improve, VR will quickly become the best way to experience movies. This will certainly disrupt the large display and home theater industries.

The more interesting entertainment application will be the VR equivalent of a movie. Cinematic VR is a brand new art form and the rules are still being defined. The big question there is whether this will be complimentary to the existing movie industry, or will it replace it?

Social VR is going to be another killer app, both for work and play. Virtual spaces will become infinitely more compelling when there are people in them.

Education is ripe for innovation from VR. Virtual classrooms could offer a number of benefits over existing online classes, and even some advantages over physical classrooms.

I also love VR as a technology for creative expression and architecture; many architects have embraced VR. It's interesting that VR and 3D printing are coming of age at the same time, and they will certainly be complementary technologies. One of the big problems in the 3D printing space is that right now, only those who are trained in complex 3D modeling software can create new content. VR offers a potential solution by allowing people to work with 3D models in the same intuitive way they might work with clay or blocks.

What do you see in VR adoption over the next five to ten years? How fast will VR gain consumer traction? Enterprise/commercial traction?

I think it will only be a few years before we see millions of VR users on the consumer side, starting with games and entertainment, and slowly working their way into more "serious" applications.

The gaming industry will definitely be the first big win for VR. Once I experienced a VR racing simulator, it became impossible to go back to a normal screen; it just didn't hold my attention anymore. I think this will happen across most of the gaming industry. I would not be surprised to see the majority of PC and console games move to VR within the next three to five years. In entertainment, there are also big opportunities in cinematic VR, adult content, and virtual tourism.

I think we'll see only limited enterprise use of VR for a decade or so. Many executives fear any new technology, and will be particularly resistant to one as radical as VR. That said, there will be areas where it provides a competitive advantage, such as applications where large dashboards of visual information are key. Trading desks and network operations centers are great candidates for VR.

What are the challenges for widespread VR adoption (both consumer and enterprise)?

VR sickness is a real issue that needs to be addressed. It gets better as the technology improves and as developers learn how to work around it, and most users become acclimated to it over time. The triggers can vary from one individual to the next, and everyone has a different tolerance level. It won't stop VR from reaching mass adoption, but it could slow things down until we learn how to deal with it.

Many people are concerned that VR is an isolating technology, but I think this is less of a problem than it seems. In my experience, the first thing people want to do when they have a great VR experience is share that experience with their friends. I believe this will result in stronger and more intimate personal relationships while removing geographical and physical barriers.

Older generations may never accept avatar-based communications as anything other than a game. It will probably take a full generation before VR is widely accepted in the business world. But when it finally does, it will change the way we meet and work forever.

I think it will only be a few years before we see millions of VR users on the consumer side, starting with games and entertainment, and slowly working their way into more "serious" applications.

Imagine a world where we no longer have to commute to physical offices each day, or wait in rush hour traffic, or fly around the world for meetings. The environmental impact alone will be tremendous.

What are some of the challenges facing user interface and interaction designers in VR?

Virtual reality is a brand new medium, and we are still learning the rules. So far, there are more questions than answers. The best UI in VR becomes part of the world. If you need a time readout, put a clock on the wall or a watch on your avatar's wrist instead of a floating display that obscures the user's vision.

Locomotion is a huge problem right now. While you can use a standard video game controller to move around in a virtual environment, it doesn't feel very good. Some people can tolerate it, but most will experience some level of nausea. Experiences where your virtual body is mirroring your physical body seem to work best.

User input is another big challenge. The standard mouse and keyboard do not work well in VR. When you're immersed in a virtual environment, even finding the keyboard can be a challenge. I haven't seen any great solutions for text input yet. Perhaps voice recognition will finally have its time to shine.

What do you predict in the battle between phone VR adaptations (e.g., Durovis Dive, Google Cardboard) vs. dedicated devices (e.g., Oculus)?

Because it's so cheap and easy to do, many people's first experience with VR will be on a mobile device using a VR adapter like the Durovis Dive or Google Cardboard. While rendering complex worlds at very high frame rates on a mobile device is probably still a few years away, there are other areas where mobile VR will shine. Watching a movie in VR is very doable on today's mobile phones. You can recreate the feeling of being in your own private IMAX theater, complete with 3D audio. It's also possible to render complex 3D scenes in the Cloud and stream the output to a mobile device. Under ideal network conditions, this can be done with a low enough latency to provide a decent VR experience. I could see a very large market of this type of casual VR user.

The most immersive and impressive VR will be done with PC-based devices like the Oculus Rift for years to come. A purpose-built device will always have the advantage and be able to deliver a better experience. Ultimately, I think the majority of VR HMDs will be self-contained devices running Android, but separate from our phones and computers. GameFace Labs is one of the first companies taking this approach, and I think we'll see a lot more in the coming months and years.

Karl Krantz *is the Founder and Chief Curator of Silicon Valley Virtual Reality, and a UX-focused product designer with a life-long passion for virtual reality and virtual worlds. Prior to SVVR, Krantz led Teliris Telepresence Research Labs, an R&D group in a leading telepresence company, where he designed high-end, low-latency enterprise video and collaboration tools for Fortune 500 companies. In addition to his efforts to promote and democratize virtual reality through SVVR, Krantz has several VR software projects, including VR LaunchPad, a VR desktop environment and application launcher for the Oculus Rift.*

DEMOCRATIZING ACCESS TO VIRTUAL REALITY: FULLY INTEGRATING THE CONSUMER VR EXPERIENCE

By James Iliff and Nathan Burba

Figure 1 | A virtual gaming interface developed by Survios.

It has long been recognized that virtual reality (VR) has tremendous potential in gaming, but the profound experiences possible in VR offer many other practical applications. Psychologists are using VR as a form of therapy, which can provide a fascinating perspective about how we trick people's brains into believing a virtual environment.

Patients can be treated for phobias and post-traumatic stress disorder through a process called systematic desensitization, where they experience the object of fear or trauma in a safe way until they no longer have an instantaneous negative emotional reaction to it. Addiction therapy also utilizes VR, for instance, by placing an alcoholic in a virtual bar, with beer on the table, even simulating the smell of beer in the room and the sounds of a loud crowded bar, and then measuring heart rate acceleration and other physical effects.

The impact of these applications depends a great deal on the quality of realism and sensation of presence in the VR simulation. By quality, however, we don't necessarily mean photorealism. In the era of console gaming, immersion was all about photorealistic graphics. Top-notch graphics are always desirable, but some abstract VR experiences that are nowhere near photorealistic are incredibly immersive in terms of sense of presence. To create this "mind-blowing" sensation in VR requires excellence in three areas: displaying the world to the user via the headset, capturing the motion of the user's body, and the fusion of individual participation to create shared experience.

Building Democratized VR

Our work at Survios (formerly called Project Holodeck) is the latest expression of our passion for virtual reality technology. The origins of the project go back to March 2012 conversations with our colleague Palmer Luckey (founder of Oculus VR) at the IEEE VR conference in Orange County, CA. We realized that there was an unmet need for inexpensive virtual reality, and that components were cheap enough to actually create fully immersive VR gaming at a consumer-level price point.

Previously, we had been working at the University of Southern California (USC) with professional motion capture (mocap) systems that used multiple cameras, mocap suits that placed trackers all over the body, and expensive head-mounted displays (HMDs) that used heavy lenses or micro-displays. This kind of equipment created an incredible experience: a user was tracked in real time and could move around and interact in a massive VR space. The HMD had a wide field of view, and users had a very strong sense of presence in the environment. It was near 100 percent immersion.

However, this kind of setup is incredibly expensive. A mocap stage costs $200,000; factor in thousands more for military-grade HMDs, and you still end up with a system that consumers would never fit into a house. And because these systems were primarily used by research communities, the content was primarily research related. There was nothing inherently entertaining about it whatsoever.

Our goal was to create a platform that offered about 90 percent of the immersion of these large, expensive, research-grade systems, but for less than one percent of the cost. To accompany a system we could make and sell at a consumer-level price point, we also wanted to start creating virtual reality games that everyone could enjoy and engage with. We initially called the concept "Project Holodeck" after the fictional Holodeck featured in the TV series *Star Trek: The Next Generation;* the Holodeck is the ultimate "holy grail" virtual reality experience. In mid-2012, our project was accepted into the Advanced Games program at USC, and over a period of nine months, we developed our first functional prototype using early versions of the Oculus Rift, Sixense motion controls, and body tracking using Sony's PlayStation Move. We also developed several games for this platform to show that true VR in a physical space wasn't just technologically feasible, but also insanely fun. Our ultimate mission is to provide everyone with the tools they need to create these kinds of VR experiences in the simplest and most convenient way possible.

Lessons Learned

The biggest lesson we've learned through this project is to take full advantage of three spatial dimensions, otherwise the game will feel no more interesting than a port of a traditional first-person game. This may seem like an obvious point, but it has profound implications across all facets of game design, such as props, interactive items, artificial intelligence, audio, and lighting. For the first time ever, players aren't just looking at a screen — they are living within a space. It's intimate. This is the key difference that VR brings to the table, so the best VR games and experiences will take full advantage of the sensation of space that players are feeling.

Using sight. The head-mounted display is the gateway to VR, so a wide field of view, high-resolution screen, and lightweight components are what make users take the first psychological leap. With a good VR headset, the brain can achieve a strong suspension of disbelief. The Oculus Rift has surpassed this threshold, which is why VR is having such a watershed moment right now: virtual reality is psychologically believable for the first time in history.

Figure 2 | A virtual gaming environment developed by Survios.

Using space. If VR game designers are not taking full advantage of virtual space, then they are missing out on an opportunity to subconsciously affect the player in a tremendous way. Subtlety is all the rage with virtual reality gaming — because for the first time we can actually achieve it. For instance, we place the most interesting and detailed models near eye-level, so players will get up close and examine the hell out of them. The closer an object is to a player's face, the greater the sensation of depth and parallax. We make weapons as detailed and interesting as possible, and assuming players are using motion controls, we have them manually reload their guns with new clips. Slow-moving projectiles in games provide objects that players can dodge, or obstacles can be placed that force players to watch their step. If a game includes a piece of paper on a table, we place game-relevant content on the paper, and enable the player to pick it up and read it. Of course, we have monsters sneak up behind players and breathe down their necks. We make players jump out of planes, climb ladders, press elevator buttons, or pull a cord to start a chainsaw. By focusing on the things that involve — and invade — a player's space, we take the fullest advantage of virtual reality.

Using sound. Audio turns out to be more important than we expected. Sound is important in conventional gaming and other entertainment media, and getting it right is crucial in good VR. Having robust soundscapes throughout the game can make all the difference. As an

The more things that subtlety change as a player moves within a virtual environment, the more the player feels present there.

example, in one of our game demos called *Zombies on the Holodeck,* we added numerous rain sound effects in a fairly small environment. The rain sounds change depending on if the user is outside on the street, under an overpass, metal overhang, or wooden roof, standing in a doorway, deep inside a room, or next to a window. Blending these different rain variants throughout the environment helps simulate the feeling of being fully present in it. The more things that subtlety change as a player moves within a virtual environment, the more the player feels present there.

Early Challenges

One of our biggest challenges was the first one we encountered: how do we track a player's entire body in the simplest way possible? We are still exploring many different technologies related to positional tracking, and our choices are influenced by the kind of experience we are trying to provide. Magnetic tracking devices don't depend on line-of-sight, but are subject to interference from electromagnetic (EM) sources. Optical tracking isn't affected by EM, but the user can be occluded from the camera. Incredibly, infrared (IR) tracking doesn't need markers on the player's body, but the accuracy is much worse than an optical system using markers, and occlusion is still a big problem. Radio frequency-based methods are being explored, but spectrum access then becomes a potential issue. Inertial tracking is another option, but has issues with drift. All of these methods are still in play, however, and we think that a dominant solution will emerge in the next several years.

In our own development work, we concentrated early on adapting off-the-shelf methods and technology. We started out using four Microsoft Kinects placed around a VR playspace, but it didn't work well; it was too jittery. While the Kinect is a great gestural interface, it does not provide the precise and consistent positional tracking data we need for proper avatar embodiment, and it does not provide rotational tracking. So instead of using an IR system like the Kinect, we opted for a magnetic/optical tracking combination of the Razer Hydra and PlayStation Move controllers. The Sixense magnetic tracking technology in the Hydra ended up providing the most robust data for hand movements, and the Move was perfect for placing on the head and tracking a person's absolute position/orientation in space. The initial prototypes worked well but looked silly; however, we have made tremendous progress on form factor since the early days.

Outside of hardware, there was a lot of new ground to cover on game design and interface. 3D user interface is a major focus area for us. Creating VR interfaces that are natural and intuitive was a huge challenge. In 2D interfaces, there are menu buttons to click on, and while it's easy to render those in 3D, they're boring. Our players can move around, reach out, and grab things like weapons, furniture, and tools in a VR space, which is decidedly not boring.

There are also lots of actions in traditional games that are automated in ways gamers take for granted but, if ported directly into full-motion VR environments, would seem strange and unreal. For example, in first-person shooters, reloading a weapon (if you have ammo) and opening a door (if you approach it) are both actions that avatars perform automatically. Pressing buttons and picking up objects are often done with an invisible set of hands, and we know from lots of player interactions that being able to see one's own hands contributes enormously to one's sense of presence in a VR gamespace. Traditional games and their avatars behave this way because traditional input devices (e.g., mouse, joystick, keyboard) are limited in what they can do. The controllers and body tracking VR device inputs, however, have no such limitations. We can now physically press buttons and physically throw grenades and physically punch a bad guy in the face. This is a whole new way to interact with games, and it also happens to be more realistic, natural, and intuitive.

What is the Future of VR?

While we're still far away from a true Star Trek Holodeck experience, it is something that the VR community aspires to achieve. A perfect simulated reality that is indistinguishable from real life will ultimately take one of two forms: it will either manipulate real light and real matter, like the Star Trek Holodeck, or it will remove the "middleman" of wearable VR inputs and instead directly manipulate our perceptions through a machine-brain interface, like that envisioned in *The Matrix*. Between those perfect simulations and the current state of the art, we envision the emergence of hybrids, such as the manipulation of real light (holograms) combined with haptic gloves, or the direct manipulation of the brain's sense of touch combined with VR/AR contact lenses, or many other such combinations involving other senses. Given where VR is now compared to just 10 years ago, and the historical pace of technological change since the Industrial Revolution, it's astounding to consider how VR might continue to evolve. We think these "perfect systems" may emerge within the next two centuries, and that the current state of the art provides a strong foundation to build upon.

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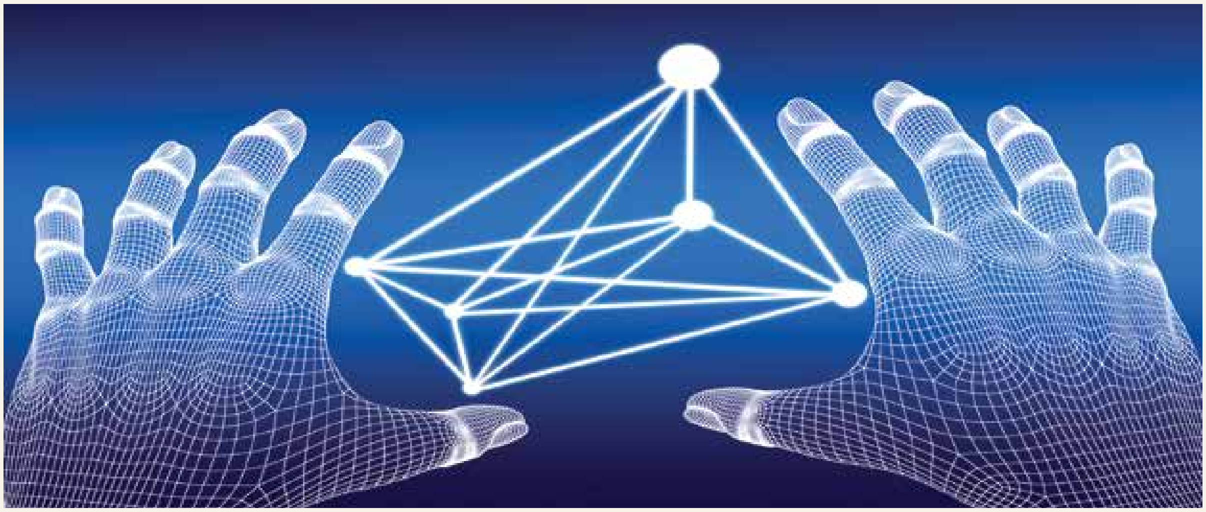
Nathan Burba *is Co-founder and CEO of Survios, and a VR researcher, game designer, and entrepreneur. He is also an accomplished mechanical engineer, web designer, software engineer, and film editor. Burba has presented at numerous conferences including the IEEE Virtual Reality Conference and the Sweden Games Conference. He is the author of the best-selling Cocos2d for iPhone Game Development Cookbook from Packt Publishing.*



Creating Greater VR Immersion by Emulating Force Feedback with Ungrounded Tactile Feedback

By William R. Provancher

Multisensory Feedback in Virtual Reality

The availability of optical displays from mobile phones and motion tracking from video games and handheld electronics have made it possible to produce head-mounted displays (HMDs) for virtual reality (VR) that are inexpensive, yet of sufficient quality to be viable as consumer products. While these new consumer HMDs may not rival the quality of traditional VR systems, which can cost more than $10,000, they nonetheless provide compelling products that are more than sufficient for consumers to experience VR firsthand for less than $500. This is an impressive accomplishment since not only must the HMD provide sufficient resolution, it must also integrate head tracking so that the displayed scene is updated in a manner that shifts as the user moves his or her head and does so with sufficient accuracy to avoid motion sickness. Additional display features, such as "low display persistence" can also help reduce motion blur in HMDs.[1]

While a human's experience of the world tends to be vision dominant, having a great HMD isn't the alpha and omega of VR. An effective HMD can give a greater sense of immersion than watching a computer monitor, but VR is a unique medium in which providing feedback to all of the senses can actually create a sense of presence. So while having a great HMD is necessary, it isn't sufficient by itself unless one remains a spectator. Most people agree that VR is meant for interaction.

Interaction in VR can come in as many forms as in real life. For example, when walking in a hallway, you expect to hear echoes change as you progress or someone approaches. And you expect to be able to interact physically in the world, especially for simple activities such as turning a doorknob to open a door. However, research to enable this type of physical interaction has lagged behind that of HMDs and 3D audio (taste and smell are also important senses, but vision, audio, and haptic interaction are essential to interactive VR).

Touch Feedback in Virtual Reality

Haptic (touch feedback) interfaces have been commercially available for more than 15 years and vary in form from desktop force feedback devices (e.g., SensAble Phantom or Force Dimension Omega) or hand exoskeletons for portraying grasp forces (e.g., CyberGrasp) to larger devices that are used for welding simulators (e.g., Moog Haptic Master). These devices are sufficient when the virtual task is at a fixed location such as dental or surgery simulation, but these systems can be quite expensive and generally do not allow the user to move over a large workspace, as one might want in a generalized consumer VR system.

A more affordable alternative to force feedback is vibration feedback, which most of us are familiar with in mobile phones and game controllers. In these applications, vibrations are traditionally generated by rotating an eccentric mass, which has the limitation that the frequency and magnitude of the generated vibrations are coupled. A next generation of "HD haptic" vibration actuators overcame this limitation through the use of a piezoelectric or electroactive polymer actuator to provide a greater range of vibration feedback. While this form of feedback is great for portraying the vibration experienced through contact or from textures, it lacks the ability to convey the sense of interaction forces, which is essential for manipulation. Researchers have also developed inertial feedback systems that use spinning or sliding masses to provide haptic feedback, but these systems tend to have large power and space requirements and typically cannot portray sustained interaction forces.

Conveying interaction forces is essential for almost any form of manipulation in VR (or teleoperation). This is true whether providing training through a surgery simulator or picking a lock in a puzzle game. However, no current haptic interface appears to be capable of providing the fidelity available through traditional force feedback devices combined with a large workspace that allows VR users to move their hands naturally.

This issue is also observed with motion interfaces for gaming such as the Microsoft Kinect or Leap Motion hand gesture sensor. Tracking the user's hand motions and representing them in VR (e.g., the hand motions used to interact with computer menus in the movie *Minority Report*) is insufficient. Without physical confirmation of an action, these motion interfaces leave the user with a clumsy, tentative interaction, since they often need to make gross gestures and linger until an entry or action is registered on the computer. Physical feedback provides confirmation that is familiar and intuitive to users.

However, it is a challenge to provide suitable feedback for a range of VR interactions at a price that is appropriate for consumer VR — to be combined with the many HMDs that will become available in the coming year.

Reactive Grip Feedback

Tactical Haptics has developed a new form of haptic feedback called Reactive Grip™ that fits this middle ground between force and vibration feedback. That is, it can mimic force feedback, but with a large workspace, at a lower cost, and without connectivity to a desktop through a robotic arm.

Reactive Grip feedback works by mimicking the friction forces experienced by users as if they were actually holding the object. These friction forces are applied through the motion of actuated sliding plate contactors (also called tactors) that move on the surface of the device's handle (see Figure 1). When grasped, the sliding contactor plates induce in-hand shear forces and skin stretch that mimic the friction and shear forces experienced when holding the handle of a device, tool, or other equipment. Through the coordinated motion of these distributed, sliding contactor plates, this device is capable of providing force and torque cues to a user.

When the sliding tactor plates are actuated in unison in the same direction, the controller communicates a force cue in the corresponding direction along the length of the handle to the user (Figure 2b). When the

Figure 1 | Tactile feedback device with sliding contactor plates placed around the handle. The contactor plates are independently actuated and slide vertically.

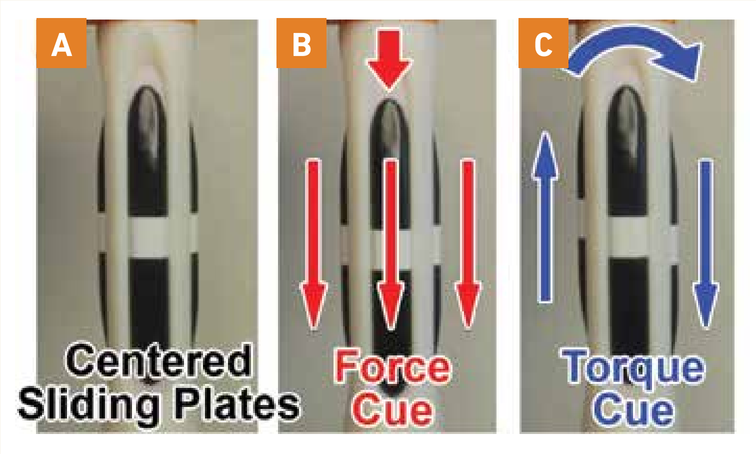


Figure 2 | Sliding contactor plates in their (A) centered, (B) down, and (C) differential positions. A downward force is portrayed in (B), and (C) portrays a torque.

sliding plate tactors are moved in opposite directions, the controller portrays a torque to a user (Figure 2c). The speed and magnitude of the tactor motions can be altered to create varying force/torque cues, which can also be superimposed to layer simulated feedback with different tactile effects.

The device has been refined over time to utilize three sliding plate tactors, instead of four sliding plate tactors used previously.[2] With three sliding plate tactors, the device has a smaller handle diameter, making it easier to grip. Force cues are still portrayed by moving sliding contactor bars together along the length of the handle, while torque cues are communicated by moving combinations of contactor plates in opposite directions.

The Reactive Grip controller is integrated with a Razer Hydra 6DoF (six degrees of freedom) motion tracker, which is used to measure the hand/device position and orientation and provide this information within virtual environments. However, Reactive Grip feedback will work in combination with any type of motion tracking.

The current device system development kit (SDK) supports development in both Unity and C++, and examples of several demo scenarios have been developed as shown in Figure 3. Developers can utilize their own physics models or any physics engine (including Unity's internal PhysX physics engine) to calculate the virtual forces and torques applied to virtual objects. These calculated forces and torques are then portrayed to a user through the motion of the sliding contactor plates. Virtual forces are portrayed by moving the sliding plates in the same direction, and virtual torques are portrayed by moving the sliding plates in opposite directions (Figure 2). These sliding contactor motions are superimposed for portraying combined loading cases that would be common during virtual interactions.

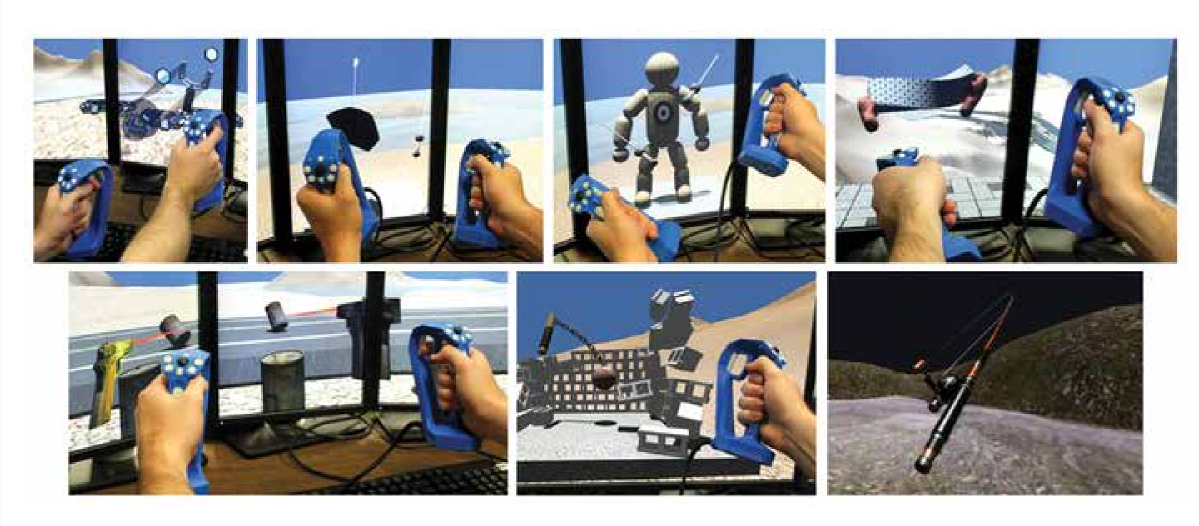


Figure 3 | Examples of the physical interaction possible with dual-handed Reactive Grip haptic motion controllers.

Reactive Grip feedback works by mimicking the friction forces experienced by users as if they were actually holding the object.

Forces and torques can also be measured with a load cell and portrayed with the Reactive Grip controllers for teleoperation applications. Support for additional development environments such as CHAI 3D, WorldViz's Vizard, Unreal Engine, and others are anticipated in the future.

As shown in Figure 3, the two tactile devices allow for independent motion of the user's hands. Because of this, it is possible to demonstrate a wide variety of interactions. Several demonstrations have been created to highlight different types of interaction with this device, including a slingshot, sword and shield, shooting gallery, medieval flail, stretching of a deformable object, dune buggy driving, and fishing, among others. These scenarios highlight the system's ability to simulate coupled interaction forces between the user's hands and portray virtual inertia (continuous and impulsive), compliance, and friction.[3]

Conclusion

The availability of low-cost head-mounted displays will bring virtual reality into the mainstream and make VR affordable to consumers. While low-cost HMDs and 3D audio will create an immersive VR experience, the lack of a solution to provide compelling touch feedback will break the sense of presence when users try to interact physically with the virtual world. One possible solution is Reactive Grip touch feedback, which will allow users to move their hands naturally while providing compelling touch feedback. Q

Dr. William R. Provancher *is a tenured Associate Professor in the Department of Mechanical Engineering at the University of Utah, where he teaches courses in mechanical design, mechatronics, and haptics. His active areas of research include haptics and tactile feedback. Provancher has also recently formed a company, Tactical Haptics, to commercialize his lab's research related to tactile feedback. He previously worked for Lockheed Martin Missiles and Space. Provancher earned B.S. in Mechanical Engineering and an M.S. in Materials Science from the University of Michigan, and a Ph.D. from Stanford University's Department of Mechanical Engineering in the areas of haptics, tactile sensing, and feedback.*

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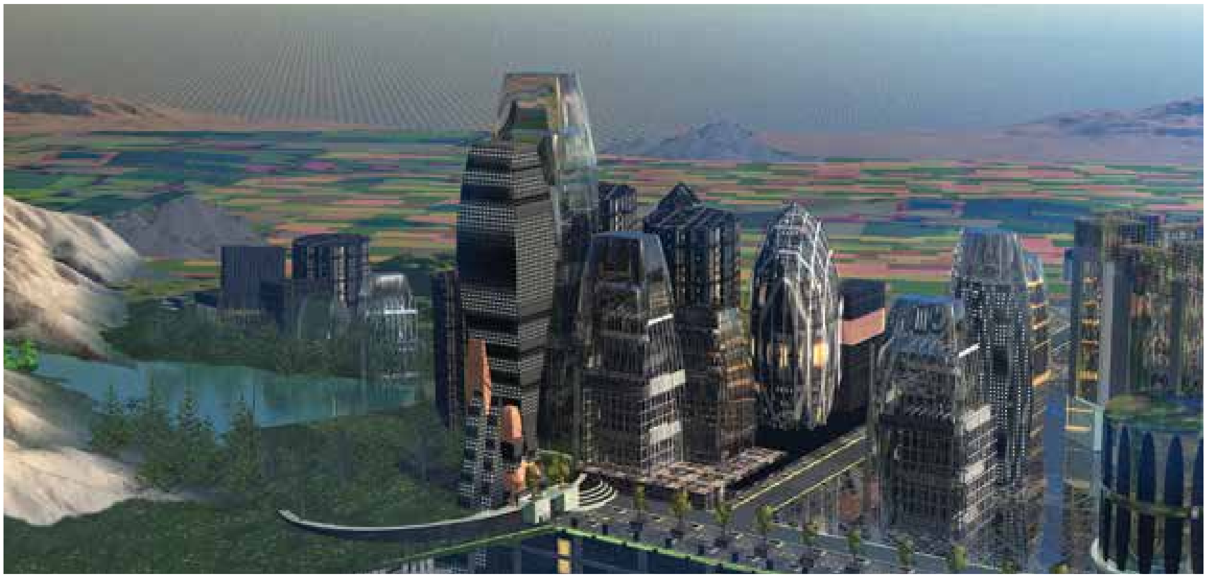
REFERENCES AND FURTHER INFORMATION

[1] For further information on design requirements for HMDs, see Michael Abrash's presentation on the future of VR from Valve's Steam Dev Days (Jan. 2014): http://media.steampowered.com/apps/abrashblog/Abrash%20Dev%20Days%202014.pdf.

[2] A. L. Guinan, M. N. Montandon, A. J. Doxon, and W. R. Provancher. Discrimination thresholds for communicating rotational inertia and torque using differential skin stretch feedback in virtual environments. Proc. of the 2014 Haptics Symposium, Houston, Texas, USA, Feb. 23-26, 2014.

[3] A video showing interactions that are possible with Reactive Grip can be found at http://youtu.be/uD3hhlYr1f4.



Creating a Virtual Intelligence Environment

By Gavin West and Jan Goetgeluk

The intelligence world is a complex environment that seeks to meld signals intelligence, human intelligence, geospatial intelligence, and other pieces of information into a coherent and predictive view of the opposition. The fusion of intelligence into a single accurate picture is challenging, specifically because we are often unable to physically occupy the world of our adversaries. Whether in the tribal region of Pakistan, the streets of Mogadishu, or the Crimean Peninsula, American intelligence analysts and military commanders often never see the ground that the opposition calls home. The Intelligence Community can help overcome this limitation with the creation of a Virtual Intelligence Environment (VIE): a detailed and accurate 3D digital database in which we can immerse ourselves via a virtual reality system. Virtual reality (VR) can enable us to view the streets from the opposition's vantage point, explore villages and compounds, and experience the world through his eyes.

Recent Evolution of VR Technology

VR has undergone a revolution in the past 18 months. While VR products have existed for several decades, the technology never achieved mass market acceptance due to technical limitations. Until recently, head-mounted displays (HMDs) were expensive and low-quality, and tracking technologies were complex and unaffordable. That has finally changed. HMDs, such as the Oculus Rift, now offer a wide field of view and an immersive experience that creates the sense of being in a different world. Omnidirectional treadmills, such as the Virtuix Omni, enable the user to move freely and naturally in virtual worlds. The recent advances in VR offer significant advantages to the U.S. Intelligence Community, special operations forces, and conventional military units. To understand the benefits of a Virtual Intelligence Environment, one must first understand the components that comprise a VR system.

The first element of a full VR system is the Immersive Sensory Platform, a current example of which is the Oculus Rift head-mounted display. The HMD provides the visual component by projecting a 360-degree 3D image to the display worn by the user. The second component is the Mobility or Locomotion Platform that is best represented by the Virtuix Omni. The Omni allows the user to walk, run, jump, crouch, and interact with the

Besides the recent advances in VR technology that fully immerse a user in a virtual world, advances in virtual rendering toolkits enable us to quickly and accurately create virtual 3D environments by using maps, satellite images, and other geographical information.

virtual environment that the user sees through the HMD. The third component is an Immersive Training Platform, which may be used for training, manipulation of objects within the virtual environment, or various other interactions. To date, much of the user interaction has focused on weapons training for military personnel and is proving to be an affordable and effective supplement to traditional training methods such as live fire. The final component of the VR system is a 3D software engine (Content Platform), which creates the virtual world for the end user. Prominent engines in which VR worlds are currently being created include Unity and Unreal.

When integrated, these components create a virtual reality immersion platform that allows the user to see, move through, and interact in a virtual environment that can be shared between any number of users.

The Virtual Intelligence Environment

Besides the recent advances in VR technology that fully immerse a user in a virtual world, advances in virtual rendering toolkits enable us to quickly and accurately create virtual 3D environments by using maps, satellite images, and other geographical information. Commercially available software, such as CitySurf, provide a good example of a 3D geographic information system (GIS). More powerful systems can elevate detail to a level that transforms the 3D world from accurate to truly immersive. Readily available data ranging from Google Street View to online blueprints can add detail and accuracy. Programs such as QuickARC can take a 2D blueprint of a building and turn it into a 3D model for importation into the virtual environment. Using these technologies, a Virtual Intelligence Environment database can be created, digitizing areas of routine interest to the U.S. such as overseas military bases, forward operating bases, U.S. embassies and consulates, and any other locations that may be likely targets of adversaries. Additionally, major landing zones, evacuation points, main supply routes, as well as other key terrain, religious, or cultural features can be recreated in the virtual world.

Let us examine two instances in which the development of a Virtual Intelligence Environment could have aided U.S. national interests. One of the most common examples of U.S. power projection is our ability to quickly evacuate our embassies and American citizens as conditions rapidly deteriorate in various foreign countries. Nigeria, and its largest city Lagos, have been the site of an NEO (Non-Combatant Evacuation Operation) on several occasions in the past two decades. Figure 2 depicts some of the areas of Lagos that could

Figure 1 | When used together, the four main components of a VR system create an environment in which users can move, interact, and communicate just as if they were acting in the real world.

Figure 2 | An example of initial designated virtual collection points in Lagos, Nigeria. Major features of importance to a NEO (Non-Combatant Evacuation Operation) could be digitized and updated routinely so that, as a crisis nears, the U.S. has a virtual world ready in which to plan and test various contingencies.

become standing Designated Virtual Collection Points (DVCPs) of which virtual renditions are created and routinely updated and shared. This virtual world could be expanded as rapidly as time and resources permit, providing the Intelligence and military communities an unparalleled source for planning and training for NEOs.

An NEO is largely a preventative or defensive operation, but a VIE can be equally valuable for offensive operations. Often, a potential target will be monitored for extended periods of time before the political, intelligence, or military conditions are right for an operation. A classic example of this scenario is the raid on the bin Laden compound, which was monitored for months before a decision was made to launch a team of U.S. Navy SEALs. Leading up to the raid, the SEALs constructed a replica of the compound in which they rehearsed multiple scenarios. Virtual reality allows teams to digitize the compound and rehearse in that environment not just a few times, but repeatedly against various scenarios and from anywhere in the world. A Red Cell can play the role of enemy fighters in the virtual rendition. An omnidirectional treadmill like the Virtuix Omni, coupled with an immersive HMD and an interactive weapon replica, allows teams to move through environments naturally and freely as they would in the real world, providing an unparalleled level of mission training and rehearsal that is accessible by users in any geographical location, in any jurisdiction, and at any echelon.

The U.S. Intelligence Community can both contribute to and benefit from the creation of a VIE database. Agencies can work together to develop this virtual world, providing details of building construction, design, and contents in order to create an accurate rendition. Likewise, service components that have standing contingency plans for various areas of the world can submit what Named Areas of Interest they would like to convert into a VIE. Other agencies can play supporting roles by passing on intelligence that aids in the construction of an accurate virtual world.

Conclusion

The creation of a Virtual Intelligence Environment database is the next logical step in the evolution of

Figure 3 | The Virtuix Omni is an omnidirectional treadmill that allows the user to walk, run, jump, and interact within a 360-degree virtual environment.

the collection, analysis, and dissemination of intelligence. The VIE database can provide a central location to house and evaluate all geospatial intelligence, and allows the intelligence and military community to train through scenarios based on HUMINT, SIGINT, and other sources. Courses of action can be tested and vetted. Most importantly, assessment and training can be done in real time, regardless of the geographic separation of the participants. Imagine a scenario where intelligence experts on a particular country's tactics manage an enemy force against U.S. military forces preparing for joint exercises. They are immersed in a VIE that has been constructed to exact details. Intelligence analysts could practice conducting analysis based on reports they receive that are generated from the real-time actions of the virtual team. In turn, that analysis is fed to the military to complete the collection cycle. In this manner, the VIE closes a loop that has all too often proved elusive in the real world. It elevates the art and science of intelligence work to a new level, supports our nation's strategic goals, and hones our operating forces' tactical execution.

Gavin West *is a graduate of the United States Naval Academy and served as an officer in the United States Marine Corps in both Afghanistan and Iraq. He held various intelligence and infantry positions for both conventional Marine forces and various national intelligence agencies and special operations units. After leaving the USMC in late 2007, West has held various strategic positions in medical devices and technology. He currently advises Virtuix on military-related business development opportunities for the Omni, the world's first fully immersive virtual reality locomotion interface. West holds a B.S. in Political Science from the U.S. Naval Academy and an M.S. in Strategic Organizational Development from Johns Hopkins.*

Jan Goetgeluk *is the founder and CEO of Virtuix and the creator of the Virtuix Omni, which he started developing in early 2012. Prior to starting Virtuix, he was an Investment Banking Associate with J.P. Morgan. Goetgeluk holds B.S. and M.S degrees in Mechanical Engineering from the University of Ghent in Belgium, and an M.B.A. from Rice University.*

VIRTUAL REALITY: THE VENTURE CAPITAL VIEW

A Q&A with Drew Oetting

IQT recently interviewed Drew Oetting of venture capital firm Formation 8. He discussed his view of the current VR landscape, and how his experience as an early investor in Oculus VR helped shape his perspective.

How did you first come to invest in the VR space?

Formation 8's involvement in VR really starts with our investment in Oculus. Shortly after Formation 8 was created, we were introduced to Brendan Iribe (Oculus CEO) and Palmer Lucky (Oculus founder). We were impressed with the original development kit, but more importantly we saw that the developer communities were clearly excited. VR has been discussed for years, both by hobbyists and leading hardware companies, but the reality is the required technologies (namely compression and screen resolution) weren't ready. Smartphone innovation really changed this. From our close relationships with Samsung and LG — who have the most advanced screen technologies — we understood what was theoretically possible.

How did you pick Oculus VR as your first investment in the space, and what did you consider when deciding to invest?

We met Brendan and Palmer in early 2013 shortly after the historic Kickstarter campaign (which raised nearly $2.5 million). We were small investors in the large $16 million "party round" led by Spark Capital and Matrix Partners. The most important factors to our initial participation were:

1) A world-class team which included both technical genius and experience building large-scale businesses in related industries, who decided to team up and work together as opposed to competing;

2) The company had already solved significant technical problems in building the initial

experience — from both hardware and software perspectives;

3) Our understanding of screen technologies and comfort that Oculus' mass-scale product could deliver a better experience by orders of magnitude if proper partnerships were secured (and the knowledge we could help deliver these partnerships).

Then in December 2013, we co-led the $75 million growth round with the addition of Andreessen Horowitz and the existing investors from the previous round. By early 2014, Oculus was perhaps the hottest company in Silicon Valley. The HD Dev Kit won best console at CES 2013, besting Xbox One and PlayStation 4. The developer community had exploded and content proliferated (from both amateurs and major corporates). As investors, we also had the opportunity to test the newest Oculus; the (still) unreleased Crystal Cove device which had effectively eliminated all discernible latency, a fundamental VR problem previously unsolvable. But perhaps the single strongest signal was John Carmack joining the company as CTO. As the founder of Doom, John is a legend in both gaming and computing circles and considered the father of massively multiplayer online (MMO) gaming (and the technology required for it). Suffice to say every VC was circling the company, and we were no exception. The opportunity to invest was really the result of extensive work done by Brian Koo (Founder and Managing Partner at Formation 8), which helped secure key display partnerships in South Korea.

What was your experience with Oculus VR before the exit? What lessons did you learn that you are bringing to your current view of the VR space?

Oculus is a unique company, starting with the people. Palmer is a prodigy; he wasn't even 21 when he built the first Oculus. But he also surrounded himself with people who previously blazed similar trails (e.g., Brendan and John). The company also added highly strategic investors who were able to offer valuable shortcuts. These decisions enabled Palmer to take Oculus from a Kickstarter project to a company positioned to disrupt multiple segments of the economy. I think my experience with Oculus instilled in me a respect for how hard and rare such a company is, especially in a nascent space like VR. In general, this respect probably makes me skeptical on many aspects of the broader VR space. I'm especially skeptical about alternative VR device companies. I generally doubt a startup competitor will be able to solve the latency problem unless working closely with a screen OEM. Further, most startups underestimate the difficulty of building super-complex hardware at scale. Finally, it's hard to overestimate the importance of a winning brand. The Oculus executives are branding geniuses; I would imagine they'll leverage the platform and resources of Facebook very effectively.

But the experience also helped highlight certain areas of opportunity. Most of these are loosely related to content enablement. It's been clear from very early on that Oculus is being built as a platform: elegant, innovative hardware powered by an open operating system which allows (or necessitates) third parties to distribute experiences. I believe Oculus' approach is roughly analogous to Apple's iPhone/iOS strategy, and therefore I see similar opportunities for third parties. Valuable third parties will provide fundamental experiences (e.g., WhatsApp, Uber, Netflix) or will solve hard problems which enable fundamental experiences (e.g., Stripe, Twilio). Early on, while the third-party ecosystem is limited, it may not be clear which bucket a company's business model falls into. My approach has been to first focus on the best companies tackling these fundamental experiences with the faith that they will be best positioned once the ecosystem is mature.

One fundamental VR experience we identified early on, which seems obvious now, is social. It's my opinion that nearly every type of VR content will have social as a core element. Along these lines, Formation 8's only other VR investment thus far is into a company called AltspaceVR. The company is very young, but has developed the best VR social experience. From simply watching a common 3D movie with others in an interactive environment to collaborating with a 3D design from Autodesk, AltspaceVR's technology enables multiple users to share experiences while maintaining perspective and relativity. There are undoubtedly many other fundamental experiences which third-party companies will solve, and I continue to actively seek these out.

Is VR still a rich field for investment opportunities or is it becoming overheated?

I get variants of this question frequently and it actually surprises me every time, because all the evidence I have suggests we are at the very beginnings of VR as an investable space. If anything, it's not developed enough for widespread institutional investing. Compared to other much talked about spaces (e.g., payments, big data, genomics) VR has far fewer companies raising money. So is it overheated? No — I really see zero justification for that. Valuations for VR companies aren't out of the ordinary, in fact they may well be below average. When I spoke alongside Palmer at the Silicon Valley Virtual Reality Conference this year, he gave a great quip on this topic, which I'll paraphrase: perhaps there is an Oculus bubble, but certainly not a VR bubble. While this was a joke and I think Facebook got a great deal on their purchase of Oculus, his observation that for many people Oculus serves as a proxy for the greater VR market rings true. It's important to realize that Oculus represents the very beginning of the VR space — not the mainstream arrival.

In what areas is the best work being done? Hardware? Content? Mobile?

I'm most bullish on software that empowers the content ecosystem. I also think very interesting work is being done by content creators who are pioneering new media concepts beyond gaming which are only possible with VR.

I'm less focused on mobile VR for a couple reasons. First, the highest-quality VR experience will require tethering for years due to a variety of technical limitations ranging from wireless connectivity to rendering graphics. Secondly, logical mobile use cases are less clear. The advantage of a mobile device is that it offers an instantaneous, frictionless bridge between the digital and physical worlds. We now can go about daily life supplemented with the vast amount of information and access to services offered by cloud computing. VR, however, is by nature fully immersive; it replaces reality. While VR may indeed become indistinguishable from AR, I believe the near term opportunity is limited, and likely to be dominated by existing mobile phone giants.

What areas of VR are underserved by startup launches or by lack of investment?

I'm sure there are many fundamental experiences which haven't been built yet. One area I think will be important is the structuring and storing of data created by VR interactions.

I also think enterprise solutions are probably underserved, but I'm not sure if the appropriate investment should come from startups or from larger enterprises as internal initiatives. I am uncertain that startups should be building enterprise VR solutions because 1) most enterprises currently have no hardware/infrastructure and 2) it's unclear to which workflows VR is most applicable.

What applications besides gaming will likely gain consumer traction?

I think one of the most popular will be one of the most simple: 3D video/television. Oculus can deliver a fairly incredible experience already, and most major studios are developing content for Oculus. Why go to an IMAX theatre when you can have a totally immersive experience in your home?

Does VR eventually become augmented reality? Are they distinct in your mind from an investment standpoint?

Long term, yes, I believe AR and VR will probably become a single concept. Pagers, phones, computers, GPS, and (dare I say) televisions were all independent hardware products which have collapsed into the smartphone. I think the smartphone allegory is important, however, because the convergence of AR and VR is really a discussion of what's the next form factor for computing.

This convergence could take decades, and the result probably won't be all that similar to our current notions of VR or AR. All this being said, I'm more bullish on VR in the short- to medium-term. The use cases of VR are far more defined and the impact within these use cases is far more transformative. Compare Google Glass versus Oculus. Oculus is set to have a huge impact on gaming and entertainment, with early demonstrations of

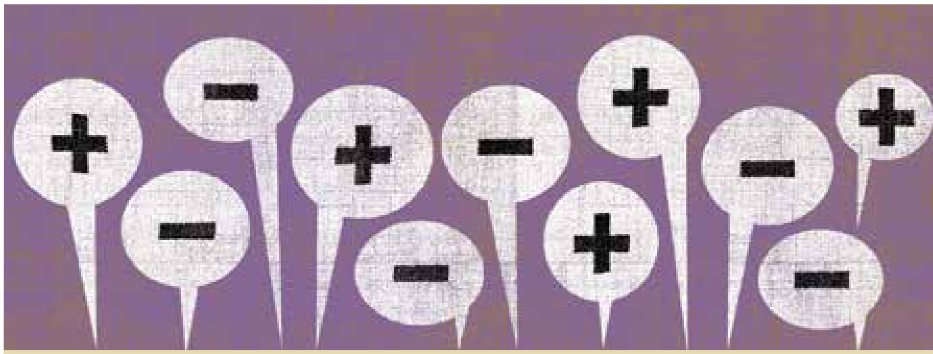
We now can go about daily life supplemented with the vast amount of information and access to services offered by cloud computing. VR, however, is by nature fully immersive; it replaces reality.

value in enterprise communications and design. Google Glass has generated some buzz, but there's not yet a consumer application that has potential en masse.

What do you think is the next "wow" VR moment on the scale of Oculus Rift?

I can say honestly I don't know (otherwise I would be trying to invest in it). Oculus was one of the most unique companies in recent memory — VR or otherwise. Individually, the company's key players possessed rare talent and experiences. Together they compromised control and ego in order to achieve something truly remarkable. They did this realizing that they stand at the technological tipping point when a previously "impossible" product became possible. And then they were bought just 18 months after founding by the world leader of new media for billions of dollars. In short, I'm not sure we'll see another splash this large in VR for a while.

__Drew Oetting__ is a Partner at Formation 8, where he focuses on investments in virtual reality, consumer marketplaces, and vertical enterprise software. He serves as an advisor to Living On One, an impact production studio which creates documentaries that inspire action around global issues, and Thorn, a non-profit that leverages technology to end child exploitation. Prior to Formation 8, Oetting worked at Cascade Investment, Moelis & Company, and Asia Pacific Investment Partners. Oetting received a B.A. in Economics and Mathematics cum laude from Claremont McKenna College in Claremont, California.



TECH CORNER

To supplement the ***IQT Quarterly***'s focus on technology trends, *Tech Corner* provides a practitioner's point of view of a current challenge in the field and insight into an effective response.

THE PROMISE OF VIRTUAL REALITY REALIZED

A technology overview from IQT portfolio company zSpace

Fans of the blockbuster movie *Iron Man* observed Tony Stark developing his armored suit via three-dimensional holography. Tony seamlessly tweaked components of his suit in open air, sized and tested his holographic prototype for proper fitting and functionality, then finally produced his suit of armor. There was a time when this concept could only have been seen in movies, and it was dismissed as science fiction — until now. Virtual reality (VR) and stereoscopic 3D imaging technologies are realizing the promise of interactive imaging, and transforming human interactions with modern computing environments into an incredibly lifelike and interactive experience.

The advantages and potential of virtual reality have been appreciated for years; yet only recently have technical advances enabled the beginnings of a trend that will lead to mass market adoption.

VR experiences have the potential to move our physical world into a sensory-rich virtual environment that anyone can naturally and intuitively navigate, significantly advancing the way we solve problems, learn, teach, and communicate. VR users can manipulate any object with the same fluidity that they would in the real world, where if one needs to grasp an object behind another object, the actions seem obvious and natural.

The Deep Value of Virtual Reality

The fundamental value of VR is tied to the design and performance of the human visual perceptive system; our spatial cognition abilities are enabled by amazingly complex neurobiological infrastructure. It's obvious that our physical ability to interact with the spatial environment is closely tied to our visual system — we spend a significant percentage of our active hours using our hands under guidance of the visual system. The most natural way we interact with our environment, which we do all day long, is to reach in and directly interact.

Short of VR, our interactions with computers are nothing close to what could be considered natural. Given millions of years of evolution to perfect our perception of our volumetric world (consider the fact that essentially all complex life has exactly two eyes), why do we stare at 2D displays and indirectly wiggle a mouse? Much of what we see on 2D screens is perfectly suitable for 2D; however, much has been adapted, projected, reduced in information content, or otherwise artificially represented in a way that can be interpreted on a 2D display.

We've come to accept the limitations of today's computer interaction models. We expect flat representations. We'd never think to reach a hand into a computer screen to grab, move, point, or rotate. That's fine, but it does not take full advantage of our abilities to interact with information.

A VR system, if delivered with sufficient fidelity, allows users to take advantage of their spatial cognitive abilities in a way that is strikingly familiar, comfortable, and powerful. Such an environment is also virtual. In the virtual world, only our imagination limits the kinds of things that can happen. The application of computing technology, exponentially increasing in capabilities, can be applied in a VR system to take advantage of our abilities in a way that few people have experienced.

What Does It Take for VR to be Immersive?

In order for a user to become immersed in the VR experience, the environment has to meet certain minimum criteria. Beyond that, it must be comfortable to use for long periods of time. Some of the early experiments in VR required bulky devices, and even the latest Oculus Rift developer unit will put some serious strain on users' necks.

Visual comfort requires a quickly updating display without flicker, minimal ghosting, and good contrast between lights and darks. Similar to a conventional display, the better the quality, the more impressive the image. A rule of thumb is that a system will be comfortable at 60 frames per second (FPS), which in a stereoscopic environment means that you must deliver 60 FPS to each eye. A system between 40 and 60 FPS is still usable with minimal discomfort, but below 30 FPS the user will notice and start to compensate for the interface, which breaks the immersive experience.

Other aspects of comfort and reality are somewhat obvious, but often ignored. For one, users should be able to hold and move their heads in a natural fashion. Humans are not robots, so any system that requires a vigilant posture, or one that breaks down if you turn your head is neither comfortable nor immersive. Similarly, the ability to naturally interact, (i.e., have your hand move in and out of a scene and the system respond intuitively) is important. The slower the manual interface, the less comfortable and immersive it is. The less accurate it is, the less "reality" in your VR.

Finally, a good immersive system should encourage users to interact with it. If users reach out to pick up an item in the scene, they shouldn't have to wait for the mouse to catch up, nor should they be surprised by how the system responds. Much of this requires incorporating the concept of natural UI into virtual reality in ways that were not traditionally done, learning lessons from the mobile world. The other aspect is ensuring the system is responsive to a user's position, motion, and interaction so as to be seamless. User perceived latency is the antithesis of immersion.

The Promise Realized: VR for Everyone

Virtual reality opens doors that would otherwise be impractical or impossible:

- Explore complex or difficult concepts in a very natural, comfortable environment
- Visit locations that are otherwise inaccessible
- Examine endless biological objects or systems, as if they were floating in space
- View and interact with systems whose scales range from the atomic to astronomical

Figure 1 | The zSpace system for education applications.

- Invent and prototype endlessly, without the associated materials costs
- Experiment, practice, and train with impractical or dangerous materials or scenarios
- Collaborate in ways that up to now have been limited to science fiction

zSpace has created a VR system that is centered around a desktop monitor. The primary system design objective is to deliver an immersive, comfortable experience. The user sits at a desk wearing lightweight, passive, polarized glasses. The display delivers full-resolution HD images to each eye, and allows accurate responsive interaction with a stylus as the primary input device. The system tracks the position and orientation of head and stylus in real time. The graphics system renders images accordingly. The result is a convincing, responsive, and immersive experience that evokes a reaction of amazement and wonder.

zSpace provides a highly realistic visualization experience that enables users to directly interact with virtual simulations as if they were real physical objects. Using a stereoscopic display, trackable eyewear, a direct interaction stylus, and an innovative software platform, objects in zSpace appear "solid" in open space, with full color and high resolution, and can be directly manipulated — giving users a natural way to navigate, grab, slice, carve, zoom, and explore 3D models as never before possible in traditional 2D environments.

The key functionality of this new form of 3D visualization centers on the authenticity and comfort of the user experience. New users to a 3D virtual-holographic environment instantly grasp its most subtle concepts and act without thinking. By making the experience natural and seamless, the users are allowed to apply their creativity to the project at hand, rather than trying to interpret conventional 2D or 3D projections in their minds.

VR and Education

For the reasons discussed previously, the range of potential value of VR extends to a wide range of markets such as simulation and training, education, product design, healthcare, e-commerce, entertainment, and gaming. Common throughout the set of applications in those markets is the element of discovery, which zSpace has leveraged in its first major target market of education. The obvious link between discovery and learning makes the classroom an ideal setting to take advantage of an immersive platform. Applications that help convey the concepts of Newtonian mechanics, biology, anatomy, electricity, and electromagnetism have been met with praise and excitement from students, parents, and administrators. Teachers report two key factors that influence their students' ability to learn with zSpace:

1) Students are more prepared for classroom teaching after being introduced to concepts in zSpace, as the exploration and immersion lead them to ask questions about the topic; and
2) The hands-on experience creates opportunities beyond what was possible with current tools, resulting in student excitement and engagement.

The interactive environment allows students to explore and discover in a way that textbooks do not. Students report many benefits after their classroom experiences with zSpace. They can:

1) Learn faster by interacting with 3D objects because they don't have to imagine how things look or are arranged, but they can see for themselves;
2) Learn more effectively by being interested and able to use their intuition; and
3) Do things that are difficult or impossible in real life. For example, dissecting a beating heart, or instantly setting up (or cleaning up) a complex Rube Goldberg machine.

This is how a teacher described a recent zSpace lesson on the heart and cardiovascular system:

> Seeing the heart and its functionality in 3D offered students a more realistic view than seeing pictures in a textbook or watching a video online. They learned not just the parts of the heart, but understood the purpose of heart valves by viewing the heart from all sides, inside and out. In a 3D reality, students are able to virtually dissect the heart and carefully examine each part. One student reflected, "We got to see inside the human heart. You could feel the heart beating and put a camera through the heart. It was awesome!"

Other Markets

Education is one of many exciting application areas for a desktop VR experience. In the area of simulation and training, users can better understand safety, maintenance, and product training in an engaging, interactive way. Designers can simulate and model more accurately. Engineers can create incredibly realistic virtual prototypes. Desktop VR can be used to accelerate design processes and increase productivity through immersive visualization in manufacturing — including the aerospace and defense, transportation and mobility, and industrial equipment markets.

In research, such an environment offers opportunities for exploration and discovery in multiple arenas. For example, in drug development, researchers can manipulate representations of complex compounds more naturally in a stereo 3D environment than in 2D. Similarly, analysts can view and interpret volumetric data more intuitively. Top universities are also using zSpace to develop innovative ways to visualize and interact with data, conduct research, and change the way they teach. The key is that a great amount of information is best represented volumetrically; yet, prior to the availability of effective VR systems, data visualization and interactivity have been artificially limited to 2D projections and indirect interactions.

Medical information is a great example of data that is intrinsically volumetric in nature. Consider CT and MRI data, which are captured and stored in planes. Analysis of this data in planes is to abstract the volumetric nature of the data source. An alternative is to visualize the data in a volume, which is not only a more faithful representation of the nature of the data, but also allows clinicians, researchers, and patients to take advantage of their natural spatial processing abilities.

zSpace has established itself as an industry leader in desktop VR. The zSpace platform brings fidelity and life to applications, giving developers and their customers new and unforeseen opportunities for success. With support for Unity3D, Ogre, and Unreal in addition to OpenGL, DirectX, C, C++, and Java, developers are equipped to quickly port or build their own immersive applications. zSpace has turned Tony Stark's interface into a reality. The future of immersive technology truly lies in the hands of developers and killer applications. Q

***zSpace** is an IQT portfolio company that integrates human perception into a realistic, interactive experience with a multisensory platform for viewing, manipulating, and communicating complex ideas. To learn more, visit www.zspace.com.*

FROM THE PORTFOLIO

The *IQT Quarterly* examines trends and advances in technology. IQT has made a number of investments in innovative technologies, and several companies in the IQT portfolio are garnering attention for their unique solutions.

Elemental Technologies

Elemental Technologies provides massively parallel video processing solutions for content programmers and distributors looking to deliver multi-screen video. The company was recently recognized for enabling viewers in Brazil to watch the final three matches of the 2014 World Cup in ultra-high definition, at four times the resolution of current HD TV. Elemental is based in Portland, Oregon, and has been an IQT portfolio company since October 2008. **www.elementaltechnologies.com**

Expect Labs

Expect Labs is the creator of MindMeld, a cloud-based service capable of powering intelligent assistants for any app, device, or website. Companies use the platform to create voice-driven assistants that understand what users say and automatically find the information they need before they type a search query. Expect Labs was recently featured in *Fast Company,* who touted MindMeld's potential to power "voice-operated everything" by adding Siri-like capabilities to applications such as connected cars and video-on-demand. The company is based in San Francisco, California and has been a part of the IQT portfolio since December 2013. **www.expectlabs.com**

Mersive

Mersive is a provider of display management and collaboration software. The company was recently featured in several publications for its new Solstice 2.0 software, which features display-side interaction, multi-touch support, and an intuitive user interface. Solstice has been implemented in several large-scale higher education deployments, where it allows hands-on, collaborative visual learning experiences and helps universities break away from hardware-specialized environments. Mersive joined the IQT portfolio in February 2012 and is located in Denver, Colorado. **www.mersive.com**

QD Vision

QD Vision is a quantum dot product company that delivers lighting and display solutions. The company recently partnered with TPV, the world's largest PC monitor manufacturer, to provide its Color IQ quantum dot technology for the broader desktop monitor marketplace. Color IQ improves the color quality of TVs, monitors, and other displays by delivering 100 percent NTSC color accuracy, tenability, and high-volume manufacturability at a low price point. QD Vision became an IQT portfolio company in March 2008 and is located in Lexington, Massachusetts. **www.qdvision.com**

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