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Virtual realities

Reaching into other worlds

Virtual realities

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Computer-generated realities are becoming ubiquitous, no headset required, says Alok Jha

As other musicians were settling down on their sofas during lockdown, Travis Scott was seizing the virtual moment. On April 23rd the American hip-hop star staged a concert that was attended live online by more than 12m people within the three-dimensional world of "Fortnite", a video game better known for its cartoonish violence. As the show began, the stage exploded and Mr Scott appeared as a giant, stomping across a surreal game landscape (pictured). He subsequently turned into a neon cyborg, and then a deep-sea diver, as the world filled with water and spectators swam around his giant figure. It was, in every sense, a truly immersive experience. Mr Scott's performance took place in a world, of sorts—not merely on a screen.

Meanwhile, as other betrothed couples lamented the cancellation of their nuptials, Sharmin Asha and Nazmul Ahmed moved their wedding from a hip Brooklyn venue into the colourful world of "Animal Crossing: New Horizons", a video game set on a tropical island in which people normally spend their time gardening or fishing. The couple, and a handful of friends, took part in a torchlit beachside ceremony. Mr Ahmed wore an in-game recreation of the suit he had bought for the wedding. Since then many other weddings, birthday parties and baby showers have been celebrated within the game.

Alternative venues for graduation ceremonies, many of which were cancelled this year amid the pandemic, have been the virtual worlds of "Roblox" and "Minecraft", two popular games that are, in effect, digital construction sets. Students at the University of California, Berkeley, recreated their campus within the game to stage the event, which included speeches from the chancellor and vice-chancellor of the university, and ended with graduates tossing their virtual hats into the air.

People unversed in hip-hop or video games have been spending more time congregating in more minimal online environments, through endless work meetings on Zoom or family chats on FaceTime—ways of linking up people virtually that were unthinkable 25 years ago. These many not seem anything like virtual realities—but they are online spaces for interaction and the foundations around which more ambitious structures can be built. "Together" mode, an addition to Teams, Microsoft's video-calling and collaboration system, displays all the participants in a call together in a virtual space, rather than the usual grid of boxes, changing the social dynamic by showing participants as members of a cohesive group. With virtual backgrounds, break-out rooms, collaboration tools and software that transforms how people look, video-calling platforms are becoming places to get things done.

Though all these technologies existed well before the pandemic, their widespread adoption has been "accelerated in a way that only a crisis could achieve," says Matthew Ball, a Silicon Valley media analyst (and occasional contributor to *The Economist*). "You don't go back from that."

This is a remarkable shift. For decades, proponents of virtual reality (VR) have been experimenting with strange-looking, expensive headsets that fill the wearer's field of view with computer-generated imagery. Access to virtual worlds via a headset has long been depicted in books, such as "Ready Player One" by Ernest Cline and "Snow Crash" by Neal Stephenson, as well as in films. Mark Zuckerberg, Facebook's boss, who spent more than $2bn to acquire Oculus, a VR startup, in 2014, has said that, as the technology gets cheaper and more capable, this will be "the next platform" for computing after the smartphone.

But the headset turns out to be optional. Computer-generated realities are already everywhere, not just in obvious places like video games or property websites that offer virtual tours to prospective buyers. They appear behind the scenes in television and film production, simulating detailed worlds for business and training purposes, and teaching autonomous cars how to drive. In sport the line between real and virtual worlds is blurring as graphics are super-imposed on television coverage of sporting events on the one hand, and professional athletes and drivers compete in virtual contests on the other. Virtual worlds have become part of people's lives, whether they realise it or not.

Enter the Metaverse

This is not to say that headsets do not help. Put on one of the best and the immersive experience is extraordinary. Top-of-the-range headsets completely replace the wearer's field of vision with a computer-generated world, using tiny screens in front of each eye. Sensors in the goggles detect head movements, and the imagery is adjusted accordingly, providing the illusion of being immersed in another world. More advanced systems can monitor the position of the headset, not just its orientation, within a small area. Such "room-scale VR" maintains the illusion even as the wearer moves or crouches down.

Tech firms large and small have also been working on "augmented reality" (AR) headsets that superimpose computer-generated imagery onto the real world—a more difficult trick than fully immersive VR, because it requires fancy optics in the headset to mix the real and the virtual. AR systems must also take into account the positions and shapes of objects in the real world, so that the resulting combination is convincing, and virtual objects sitting on surfaces, or floating in the air, stay put and do not jump around as the wearer moves. When virtual objects are able to interact with real environments, the result is sometimes known as mixed reality (XR).

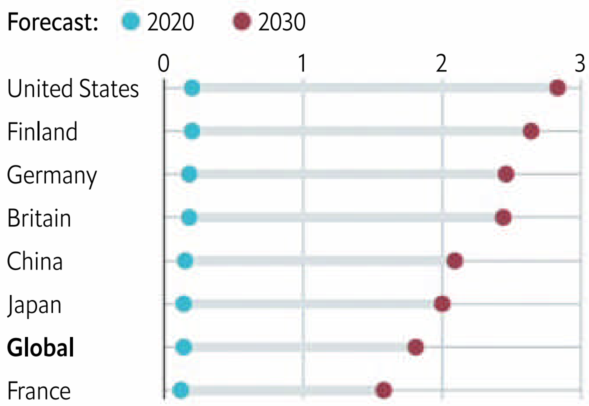
Despite several false dawns, there are now signs that, for some industries, these technologies could at last be reaching the right price and capability to be useful. A report in 2019 by PWC, a consultancy, predicts that VR and AR have the potential to add $1.5trn to the world economy by 2030, by spurring productivity gains in areas including health care, engineering, product development, logistics, retail and entertainment.

Because the display of information is no longer confined by the size of a physical screen on a desktop or a mobile device, but can fill the entire field of vision, the use of VR and AR "creates a new and even more intuitive way to interact with a computer," notes Goldman Sachs, a bank, which expects the market for such technology to be worth $95bn by 2025. And these predictions were made before the pandemic-induced surge of interest in doing things in virtual environments.

Progress in developing virtual realities is being driven by hardware from the smartphone industry and software from the video-games industry. Modern smartphones, with their vivid colour screens and motion sensors, contain everything needed for VR: indeed, a phone slotted into a cardboard viewer with a couple of lenses can serve as a rudimentary VR headset. Dedicated systems use more advanced motion sensors, but can otherwise use many of the same components. Smartphones can also deliver a hand-held form of AR, overlaying graphics and virtual items on images from the phone's camera.

Augmented economies

Increase in GDP attributed to augmented-reality and virtual-reality technologies*, %



*Expected increase above the baseline of technology-driven GDP growth as a result of AR/VR technology

Source: PwC "Seeing is believing" report, 2019

The most famous example of this is "Pokémon Go", a game that involves catching virtual monsters hidden around the real world. Other smartphone AR apps can identify passing aircraft by attaching labels to them, or provide walking directions by superimposing floating arrows on a street view. And AR "filters" that change the way people look, from adding make-up to more radical transformations, are popular on social-media platforms such as Snapchat and Instagram.

On the software front, VR has benefited from a change in the way video games are built. Games no longer involve pixelated monsters moving on two-dimensional grids, but are sophisticated simulations of the real world, or at least some version of it. Millions of lines of code turn the player's button-presses into cinematic imagery on screen. The software that does this—known as a "game engine"—manages the rules and logic of the virtual world. It keeps characters from walking through walls or falling through floors, makes water flow in a natural way and ensures that interactions between objects occur realistically and according to the laws of physics. The game engine also renders the graphics, taking into account lighting, shadows, and the textures and reflectivity of different objects in the scene. And for multiplayer games, it handles interactions with other players around the world.

In the early days of the video-games industry, programmers would generally create a new engine every time they built a new game. That link was decisively broken in 1996 when id Software, based in Texas, released a first-person-shooter game called "Quake". Set in a gothic, 3D world, it challenged players to navigate a maze-like environment while fighting monsters. Crucially, players could use the underlying Quake Engine to build new levels, weapons and challenges within the game to play with friends. The engine was also licensed to other developers, who used it to build entirely new games.

Using an existing game engine to handle the job of simulating a virtual world allowed game developers, large and small, to focus instead on the creative elements of game design, such as narrative, characters, assets and overall look. This is, of course, a familiar division of labour in other creative industries. Studios do not design their own cameras, lights or editing software when making their movies. They buy equipment and focus their energies instead on the creative side of their work: telling entertaining stories.

Once games and their engines had been separated, others beyond the gaming world realised that they, too, could use engines to build interactive 3D experiences. It was a perfect fit for those who wanted to build experiences in virtual or augmented reality. Game engines were "absolutely indispensable" to the growth of virtual worlds in other fields, says Bob Stone of the University of Birmingham in England. "The gaming community really changed the tide of fortune for the virtual-reality community."

Two game engines in particular emerged as the dominant platforms: Unity, made by Unity Technologies, based in San Francisco, and Unreal Engine, made by Epic Games, based in Cary, North Carolina. Unity says its engine powers 60% of the world's VR and AR experiences. Unreal Engine underpins games including "Gears of

Game-engine power

War", "Mass Effect" and "BioShock". Epic also uses it to make games of its own, most famously "Fortnite", now one of the most popular and profitable games in the world, as well as the venue for elaborate online events like that staged in conjunction with Mr Scott.

Epic's boss, Tim Sweeney, forecast in 2015 that there would be convergence between different creative fields as they all adopted similar tools. The ability to create photorealistic 3D objects in virtual worlds is not just attractive to game designers, but also to industrial designers, architects and film-makers, not to mention hip-hop stars. Game engines, Mr Sweeney predicted, would be the common language powering the graphics and simulations across all those previously separate professional and consumer worlds.

That is now happening, as the tools of virtual-world-building spread into many areas. This Technology Quarterly will explore where computer-generated realities are already starting to make an impact—work, entertainment and health are all seeing changes—and where the technology is heading.

Building a complex, immersive, virtual social space, like the "Metaverse" depicted in "Snow Crash" is the goal for many serious minds in technology today. Mr Sweeney sees the Metaverse, or something like it, as the next iteration of the web, where people can go to work, play games, shop or just pass the time.

Similarly, Mr Ball reckons game engines will become a base layer for digital 3D worlds, a standard upon which new industries will be built. Rather than predict specific future results of this standardisation, he cites the introduction of railways as a way to think about the many opportunities that lie ahead. "What happens when you layer the country with railroad infrastructure?" he asks. "What happens when you massively drop the friction to experimentation and creation?" When it comes to virtual worlds, that is now a very real question. ■

Simulation

Reality bytes

Virtual environments, objects and imagery are being adopted in a wide range of fields

In an early scene from Disney's new television series, "The Mandalorian", a door opens to reveal a barren, icy landscape. The camera swoops outside to follow the titular character, a solitary gunslinger in silver armour, making his way across the vast expanse of ice. It is an impressive, expensive-looking shot, of the kind you might expect for a show set in the "Star Wars" universe.

The "Star Wars" franchise has been pushing the limits of film-making technology for more than 40 years. Its creator, George Lucas, set up a now-iconic special-effects company, Industrial Light and Magic (ILM), specifically to serve the fantastical effects needs of his space opera. ILM went on to create special effects for dozens of films, including some of the earliest computer-generated 3D characters in "The Abyss", "Terminator 2" and "Jurassic Park", pioneering a new industry in the process. Now ILM is at the forefront of using computer-generated reality to bring cinematic special effects to the small screen—and it is using game engines to do it.

The shot of the Mandalorian walking across the ice was one of many created on a film set in Manhattan Beach, California, using its "StageCraft" technology (pictured overleaf). This is a facility (or a "volume", as ILM calls it) in which a giant curved video wall is positioned behind the actors. The wall is 6 metres (20 feet) high by 55 metres wide, and composed of more than a thousand individual LED screens. The photorealistic imagery that appears on the screen is generated from a 3D virtual world (Unreal Engine was used during the development process). As the camera moves, the view on the screen changes accordingly. The result is that the video wall, from the camera's perspective, behaves exactly like a window looking onto a 3D environment. This approach also helpfully lights the actors realistically, with the scenery reflecting off the Mandalorian's silver armour, for example. That would not have been possible using conventional green-screen techniques, says ILM's general manager, Janet Lewin, who co-produced the show.

"The Mandalorian" is filmed in a partially virtual world. Though tested beforehand, producers had their doubts about the set-up. "The Mandalorian was the first time that we had used real-time graphics at this scale to completely wrap around a set and photograph it directly and put it right in the show," says Rob Bredow, chief creative officer at ILM. "And to be honest, we weren't sure that it was going to work when we started. [But] it really exceeded all of our expectations."

The techniques pioneered by "The Mandalorian" are now spreading across the industry, because they allow for cinema-quality special effects within the tighter budgetary and time constraints of television production. For the third season of HBO's "Westworld", producers digitally recreated the City of Arts and Sciences complex in Valencia, which stood in for the headquarters of one of the main companies in the series, using the Unreal Engine. On set in Los Angeles, the digital images were rendered on an LED wall, 15 metres by six, showing the view from the floor-to-ceiling office windows of one of the lead characters. Look at a window and move your head from side to side, and you will notice the scene framed by the window changes slightly. Similarly, the images shown on the LED wall changed as the camera moved, perfectly mimicking a window onto a 3D world.

ILM recently announced plans to build a second StageCraft volume at Manhattan Beach and a third at Pinewood Studios in Britain. A fourth—in Sydney, Australia—will mark StageCraft's arrival into major feature films for Marvel's upcoming "Thor: Love and Thunder". Mr Bredow says there are more volumes in the pipeline. "Our technology has just advanced so much from what everyone is familiar with from the first season of 'The Mandalorian'," he says.

Watching a sci-fi series is one situation where you may not be surprised to learn that the images you see have been conjured from a virtual world. But the same thing is happening in more mundane situations. Open a catalogue from IKEA, a giant furniture retailer, and you will see images of kitchens, living rooms and other interiors. They look perfectly realistic, if spotlessly clean. The vast majority of these photographs are in fact computer-generated from detailed 3D models, saving the company time and money.

Photographing kitchens is particularly challenging because they look so different from one country to the next. Ensuring that each country's catalogue reflected local tastes meant bringing appliances from all over the world to a studio in Europe to create multiple sets, and then sending everything back at the end. Assembling virtual kitchens using 3D digital models of furniture and other items is far easier. Software lets designers mimic the way lights reflect and scatter across surfaces, making the computer-generated scenes indistinguishable from the real thing. Different versions of products, in different colours, can be easily swapped in and out. Images shot in a virtual world are also easier to fix if a piece of furniture gets redesigned or withdrawn from sale—its digital version can simply be replaced or removed in the image, which is preferable to the expense and hassle of reassembling a roomful of furniture for a fresh photo shoot.

3D product rendering has been adopted by other industries as a convenient way to produce flawless photorealistic images and videos for advertisements, websites or in-store displays, for everything from cars to industrial machinery to smartphones. Taking pictures in the virtual world, rather than the real one, makes it possible to zoom in on tiny details, fly through a product, or show it in exploded form that then reassembles itself.

Having 3D models of its entire product range to hand also meant that it took IKEA just seven weeks to build IKEA Place, an augmented reality (AR) app that lets customers drop virtual furniture into spaces in their homes and see whether they fit and how they look on the screen of a smartphone. It was one of the first apps to appear after Apple added support for AR to iOS, the software that powers the iPhone, in 2017. The app's success prompted the company to add AR features (powered by the Unity engine) directly into the latest version of its main shopping app.

The techniques and engines used to create realistic game worlds can do more than just produce images, however. As video games have become more sophisticated, so their underlying world simulations have become more capable and realistic. "Right now, the world is increasingly understanding that these game engines aren't toys," says Matthew Ball, a media analyst. "They're actually hyper-capable."

Help from your twin

Architects can use the technology to simulate, rather than simply render images of, the buildings they are working on. The operators of Hong Kong International Airport, for example, have produced a "digital twin" of one of its terminals—a virtual replica of a physical asset—using Unity. On their computers, they can wander through a photorealistic 3D model that integrates real-time data from sensors all over the terminal, including information on passenger and baggage flows, staff movements and equipment status. The model displays the state of the terminal at any given time and can provide alerts for areas that need attention or maintenance.

Such models can also be used to look into the future, by using the data collected about the real-world operation of the airport as the basis of simulations. It is then possible to evaluate how a new construction project might affect the operation of the airport, or model people-flow in the event of a terrorist attack or the simultaneous arrival of several large aircraft. Engineering and rendering

This is the way

software is not designed to do that. What that actually requires is simulation technology, which is precisely the type of situation that games have been focusing on.

> "The next big thing will start out looking like a toy"

Virtual environments are also increasingly used for simulation-based training. The US Army uses immersive environments, including VR helmets, for training in areas such as infantry combat and the operation of weapons systems. Its spending on VR and AR simulation has increased from $1.6bn in 2015 to an expected $3bn in 2020, according to Bloomberg Government. Globally, the military training and simulation market is worth over $9bn, says Frost & Sullivan, a market-research firm, and will be worth nearly $20bn by 2027, it predicts. The same technology also has peaceful uses. Network Rail, a British railway operator, uses simulations built using Unreal Engine to plan maintenance and track-renewal operations. VR Perspectives, a company based in Ohio, uses simulations of office environments for diversity and inclusion training, enabling trainees to experience the same events from the perspectives of different people.

Sometimes it is machines, not people, that are trained in virtual environments, as in the case of autonomous vehicles. For self-driving cars to become a reality, their software needs to understand busy urban environments. They need to recognise street signs, traffic lights and road markings. They need to be able to deal with dozens or hundreds of moving objects (including people, cars, lorries, bikes, animals) at complex junctions. They need to be ready for emergencies such as a rogue driver barrelling down the wrong side of the road or a child suddenly jumping into the road. All that needs training—billions of miles of it.

Physically training autonomous cars on the streets is expensive and time-consuming—and dangerous, if things go wrong. Computer simulations and racing games have long been used to train autonomous cars' vision systems, by testing them with highly realistic computer-generated streetscapes. But more advanced simulators can replicate the complexity of city driving, with its rules, intersections and pedestrians. One such system is CARLA, built by researchers at the Computer Vision Centre in Barcelona, Spain, with support from Intel, a chipmaker, and the research arm of Toyota, a Japanese car giant. To create test scenarios for their autonomous-vehicle algorithms, carmakers can customise several aspects of CARLA's world, from vehicle and pedestrian density to weather conditions, time of day and illumination. It is now the leading open-source simulator for autonomous driving.

Oxbotica, an autonomous-vehicle startup created by engineers from Oxford University, built a virtual environment in Unity in which to test its algorithms. Software agents in the simulation perform tasks such as driving from one place to another, stepping out onto zebra crossings and obeying (or disobeying) traffic lights. Oxbotica's autonomous vehicle is then placed in this virtual world and tricked into believing it is real. "Our gaming simulation helps us to train the software to understand what it can do in difficult scenarios that are almost impossible to create in real life," says Todd Gibbs, the company's head of simulation development. Almost all development in the self-driving algorithm is now put through the simulator first before being unleashed on a real road.

Realistic simulated worlds have a promising future. In 2018 Unity announced a partnership with DeepMind, an AI-research firm owned by Google. Danny Lange, Unity's vice-president of AI and machine learning, said at the time that the game engine would become "a primary research platform for creating complex virtual environments that will enable the development of algorithms capable of learning to solve complex tasks". Unity's platform can create simulated environments that are rich in sensory complexity and contain multiple intelligent agents that can all interact with each other. These virtual worlds can set up the cognitive challenges that AI researchers need to improve their algorithms for everything from computer vision and natural-language processing to industrial robots.

Simulated worlds could help architects design more user-friendly and liveable buildings. By populating proposed designs with intelligent virtual occupants, designers can identify potential problems before having to break ground, for example, by watching how well the virtual inhabitants are able to navigate around the floors of the buildings. In future, these kinds of simulations could also help fundamental researchers. Chemists might use virtual environments to carry out billions of experiments using virtual chemicals as a way of winnowing down interesting leads for potential drugs or other industrial uses.

Anyone raising an eyebrow that such serious uses for simulated worlds could come from not-so-serious gaming roots should perhaps bring to mind the words of Chris Dixon of Andreessen Horowitz, a venture-capital firm, who wrote a decade ago that "the next big thing will start out looking like a toy". Mr Ball points to a few more examples. "Look at the Wright Flyer. It was dinky. It could barely stay in the air, and it could only hold one person. It looks like a toy, in that regard. The early mobile phones, or even a BlackBerry, to some extent. Snapchat felt like a toy." ■

Hardware

The promise and the reality

Headset technology is cheaper and better than ever, but has yet to go mainstream

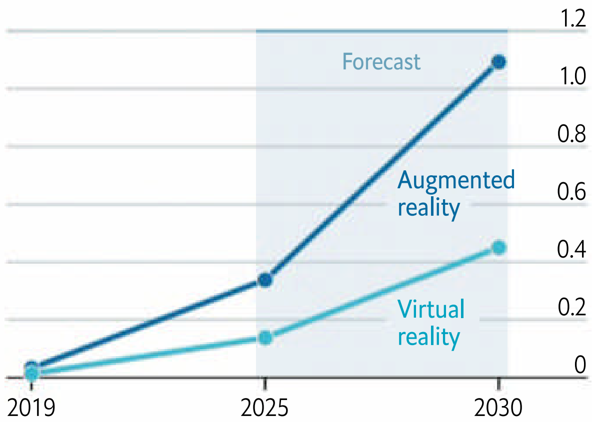
THE CUBES fly towards your correspondent slowly at first, then quickly gather pace as the music speeds up. On his head he wears a chunky set of goggles. In each hand, he holds an imaginary laser sword that can chop the cubes in half before they reach his body. Each cube is marked with an arrow (designating the direction in which it must be sliced) and a colour (for which hand has to do the slicing—blue for right, red for left). The more vigorously the cubes are sliced in time with the music, the more points are scored. Horizontal and vertical barriers, mixed in with the cubes, must be avoided at all costs. A few minutes of swinging the imaginary swords around is tiring but oddly diverting. The simulation breaks down only when your correspondent gets too energetic with his jabs and crashes into a nearby (non-virtual) bookshelf.

Welcome to "Beat Saber", one of the most popular games available on the Oculus Quest, a virtual-reality headset. Though it is possible to experience and explore virtual worlds without having to put on a headset, doing so provides a new level of immersion, as screens in front of each eye, and sensors that map the movement of the wearer's head, create the illusion of being inside a 3D environment. It is magical—but the awkwardness and cost of VR headsets is the main reason why there has always been a gulf between the promise of VR and the reality.

Every few years a new headset comes along that is hailed as the device that will finally bring VR into widespread use. The Oculus Quest headsets, the first of which was launched in 2019 at $399, are the latest. Compared with previous headsets it is cheap and light and can detect the position of the wearer's head, not just its orientation. It is an impressive piece of kit, but has not broken through with consumers. Facebook, which paid more than $2bn for Oculus in 2014, has just announced a cheaper and more powerful version.

The VR headset, also known as a head-mounted display (HMD), traces its origins to a device called the Sword of Damocles. Developed in 1968 by Ivan Sutherland and Bob Sproull, two computer scientists who were working at the time at Harvard University, it consisted of a pair of cathode-ray tubes, one for each eye, that were updated with images at 30 times per second. Users could move within a six-foot square and had a 40-degree field of view while wearing the headset, which was so heavy that it had to be suspended from the ceiling, like the mythical sword. Mechanical and ultrasonic sensors detected the position and orientation of the user's head in space. The cathode-ray tubes could display simple wireframe graphics, and could also superimpose them on real-time video of the wearer's surroundings.

Game engines of growth
Global GDP, increase, $trn
By type of technology



Source: PwC "Seeing is believing" report, 2019

HMDs have been steadily decreasing in weight and improving in capability since the 1970s, and have been available commercially since the 1980s. "There are people that have worked in the VR industry now for almost 40 years," says Anthony Steed of University College London. But the technology has still not moved far beyond academic labs and bespoke uses in training, engineering and design. When Dr Steed entered the field in the 1990s a breakthrough seemed imminent, at least as far as the media were concerned: "It was on front pages of national newspapers". When the breakthrough did not come, Dr Steed says, the public concluded that the technology was terrible. "And to some extent it was," he admits, but "it was just way ahead of its time."

Goggles box

Industrial early-adopters kept plugging along. Jaguar Land Rover used VR in the early 2000s to test and iterate the designs of its upcoming vehicles. Rather than using HMDs, though, its system required users to enter an immersive virtual environment in a small room whose walls and ceilings had high-definition, stereo displays. The technology, based on an idea known as the Cave Automatic Virtual Environment (CAVE), allows several people to share the same virtual experience. The displays rapidly show a pair of images, one for the right eye and another for the left. By wearing glasses that are synchronised with the displays, so that each eye sees only the image meant for it, users in the CAVE see three-dimensional objects apparently floating in the centre of the room.

This form of VR was very expensive to set up, and needed a dozen or more computers to drive the images on the walls. But it helped designers and engineers share ideas for the interior spaces of their vehicles, observe ergonomics (how easy was it for the driver to reach for controls, for example, or interact with other passengers?), and judge the lines of sight out of the vehicle. In any engineering task where people need to share complicated 3D ideas with others, says Dr Steed, it can help to have a VR visualisation. But the cost was prohibitive except in rare situations.

Bob Stone, a 33-year veteran of academic and industry VR at the University of Birmingham in England, has also been through multiple cycles of hype around the technology. "I hope and pray after all these years, we're on the cusp of something that's really going to make a difference," he says. In 1992 he built a virtual model of a Rolls-Royce jet engine that users could explore using a VR headset. "To do that jet engine, we had to have a piece of software that cost £75,000 ($132,000 at the time) and required at least £5,000 a year on maintenance, and we were running it on a million-pound Silicon Graphics supercomputer," he recalls.

In the past decade, smartphones and video games have made the hardware and software needed for VR much more cheaply and widely available. A crucial moment a few years ago was when consumer devices became capable of generating real-time graphics quickly enough to create a realistic sense of immersion, says Dr Steed. In the 1990s a VR headset in Britain cost around £6,500 (roughly $10,700 at the time) the system to track the wearer's position cost another £5,000, and VR gloves could cost up to £13,000. The latest generation of VR headsets have been able to take advantage of powerful processors, vivid colour screens, cameras and sensors borrowed from the smartphone industry, while game engines have made virtual environments and their contents much easier to construct.

Today consumer headsets range in price from $400 to $1,200, and the VR systems Dr Stone builds, for use in research and education, are driven by laptops that cost less than $1,200. In some cases his students have built VR systems in a few months, with no prior experience of the technology. "They've been producing all kinds of fantastic demonstrations, industrial demonstrations, health care, you name it," he says. "And that really is testament to the way in which these toolkits have matured."

A sense of immersion depends on more than just fancy graphics. Another crucial factor is latency—the time delay between a user's head movement and the images shown on the headset's screens being updated accordingly. In the 1990s the latency was often as high as 150 milliseconds. Today, even consumer headsets have latency of less than 20 milliseconds, thanks to faster chips and improved sensors. That makes movements more natural and less likely to cause motion sickness (thought to be caused by a discrepancy between what the user sees and expects to see).

Even as consumer-grade VR headsets such as the Oculus Quest, HTC Vive and Sony PlayStation VR are improving in quality and falling in cost, a problem remains: a lack of content for them. The big video-games studios have been reluctant to invest in VR titles because, they argue, there are not enough headset owners to justify it. Consumers, in turn, are reticent to buy technology that has no associated games. Things may be starting to shift. A spokesperson for Oculus says that more than 20 of the titles in its store have now generated more than $1m. "Beat Saber" has surpassed 2m sales across various VR devices and now has a new version, "Fitbeat", to take advantage of the growing interest in fitness. Another big hope in the gaming world is the recent release of "Half-Life: Alyx" by Valve, a new entry in a popular franchise, that has been made specifically for VR headsets.

"We are in a really nice place now, a place where VR is developing nicely, with ecosystems forming, with successful VR headsets emerging," says George Jijiashvili, an analyst at Omdia, a research outfit. But, he adds, "it will take time for this to become a mass market opportunity". He predicts there could be around 55m users with the latest VR headsets by the end of 2024, up from around 13m at the end of 2019. That is a big jump, but is still just a niche market.

The eyes have it

As consumer headsets have improved, the fancier models used in industry show where the technology is going next. Varjo, a Finnish company, makes high-end headsets that claim to have "human-eye resolution". Most VR headsets use the same kinds of screens found in smartphones, with a typical resolution of 500 pixels per inch (pixels are the coloured picture elements that make up the image). When such screens are placed close to the eye, individual pixels can be easily discerned. Varjo's headsets have an extra set of high-resolution screens, with a resolution of 3,000 pixels per inch, to cover the centre of each eye's field of view, where most detail is perceived. Specialist optics combine the images from both sets of screens. The result is that images look much sharper.

Varjo's founder, Niko Eiden, says this makes it possible to examine fine details in the virtual environment, such as text labels, dials and buttons in a car interior or a flight simulator (Boeing uses the VR-2 when training astronauts to operate its Starliner spacecraft). The headset also has a gaze tracker, so instructors can monitor whether or not the wearer has been looking in the right places during training. But it does not come cheap: it costs €5,995 and is intended for business and academic use, not gaming.

And then there are the augmented-reality or mixed-reality headsets, which overlay virtual imagery onto the real world, a trick pioneered by the Sword of Damocles. One way to do this is to place cameras on the front of a VR headset, and then augment their real-time video with extra graphics. But nobody wants to wear a VR headset in public, and true believers in AR imagine a lightweight headset, like a pair of glasses, that overlays information and graphics on the wearer's field of vision, so that virtual objects are realistically blended into the real world.

One company pursuing this vision is Magic Leap, a secretive startup based in Florida whose backers include Google, AT&T and NTT DoCoMo. In 2018, after years of speculation and rumour, it finally released a headset, resembling a pumped-up set of sunglasses, which cost $2,295. But its capabilities fell short of the grand claims that had been made about it, and only a few thousand units were sold, according to *The Information*, a tech-industry news site. A less ambitious but more successful approach to AR is that taken by Microsoft's HoloLens 2, a $3,500 device that resembles a chunky set of skiing goggles, and is considered the most capable AR headset on the market. Researchers use it in fields from military simulation and medical training to education and gaming. But its high cost and limited field of view suggest that AR headsets with broad appeal to consumers are still a distant prospect. ■

Ready, headset, go

Health care

Getting better

How surgery and mental-health treatment can benefit

A SOLDIER WATCHES a car approaching a check-point on a hot, dusty road. As the vehicle slows to a stop in front of him, he asks the driver to get out and show his identification. Seconds later, the rattle of gunfire pierces the air, followed by a bang and an intense, searing flash. Knocked to the ground and scrambling to safety, the soldier turns to see a flaming wreck where the car had been just moments before.

The scene pauses. A voice in the soldier's ear says: "Let's rewind the simulation to the seconds just before the explosion—describe exactly what happened." The voice is a therapist, speaking to a veteran who is placed in a virtual environment. The simulation they are watching has been modelled on the veteran's own experiences in a war zone, events that have led him to develop post-traumatic stress disorder (PTSD).

This is the Bravemind system, developed in 2005 by Albert "Skip" Rizzo and Arno Hartholt, experts in medical virtual reality at the University of Southern California, to treat soldiers returning home from the wars in Iraq and Afghanistan. Immersed in a virtual environment that mimics their traumatic experiences, veterans narrate the scene to a therapist, who can control how the events in the simulation unfold. The sounds, time of day and number of people or vehicles on the scene can all be customised. Over several sessions, the veteran is exposed to increasingly intense scenarios that get closer to reliving the memory of the original trauma. The aim of the therapy is to steadily dampen the veteran's negative reactions to the memory. Bravemind is now used in around 60 treatment centres around the world.

Bravemind builds on a well-established psychological technique known as exposure therapy, in which people are brought to face their fears in a controlled way. VR adds a way of creating detailed, carefully tuned scenarios that can elicit different levels of fear. It works because, even when people know they are watching computer graphics, their brains nonetheless react to virtual environments as if they were real.

Someone who is afraid of heights will find that their heartbeat quickens and palms get clammy even if the precipitous drop they can see is clearly a computer graphic in a VR headset. This is because the brain's limbic system, which controls the fight-or-flight response, activates within milliseconds in response to potential threats, long before the logical part of the brain—which knows the VR experience is not physically real—can intervene.

May contain graphic content

Scientists have used VR systems to create and control complex, multi-sensory, 3D worlds for volunteers in their labs since the 1990s. Rather as an aircraft simulator can train and test pilots in a wide variety of settings, virtual worlds allow psychologists and neuroscientists to watch people's cognitive and emotional responses in situations that are difficult to set up or control in the real world. But the technology has usually been too clunky and expensive for widespread clinical use.

That has started to change, thanks to the falling costs of computing and the increasing capability of the new generation of VR systems. At the same time, the scientific evidence base for the clinical uses of VR has grown. The technology has been successfully applied to tackling schizophrenia, depression and phobias (including the fear of flight, arachnophobia, social anxiety and claus-

When screen time is good for your health

trophobia), and reducing pain in cancer patients undergoing chemotherapy. It can help train spatial-navigation skills in children and adults with motor impairments and assist in rehabilitation after a stroke or traumatic brain injury. The kit can also be used to monitor people and identify medical problems: VR has been used to diagnose attention-deficit hyperactivity disorder (ADHD) and Parkinson's and Alzheimer's diseases.

Though each condition is unique, researchers have found common ground rules for designing virtual experiences that work: therapists need to be in control of the scene, deciding what a patient sees and hears in order to modify the strength of the fearful stimulus; the therapy works best when the patient is embodied within an avatar, rather than floating, so that they feel present within the scene; and the patient needs agency, so that they can leave the scene if it gets too overwhelming for them. All this adds up to giving the patient the illusion of control and makes the VR experience feel psychologically "real".

In some cases the therapeutic regime is so robust that, instead of a real-life therapist guiding a patient through an anxiety-inducing simulation, an animated avatar can do the job instead. A clinical trial showed that such an automated system, designed by Daniel Freeman, a psychiatrist at the University of Oxford, helped people reduce their fear of heights. In the simulation, a virtual counsellor guided patients up a virtual ten-storey office complex, where the upper floors overlooked a central atrium. At each floor, the counsellor set the patient tasks designed to test and help them manage their fear responses, such as walking to the edge of a balcony while the safety barrier was lowered or riding on a moving platform over the space above the atrium.

Dr Freeman found that six sessions of virtual, automated therapy over two weeks significantly reduced people's fear of heights, compared with people who had no therapy. A similar automated virtual therapy for arachnophobia, developed by Philip Lindner at Stockholm University, helped patients eventually touch spiders. The reduction in fear was still apparent when the participants were followed up a year later.

For doctors, virtual environments also provide a risk-free way to practise important procedures. Surgeons operate in high-pressure environments with a lot of cognitive demands. "You've got to learn very rapidly, and you've got to make decisions under time pressure, with millimetre precision," says Faisal Mushtaq, a cognitive neuroscientist at the University of Leeds in England.

Practising with computer simulations can help. In the NeuroVR system, developed by a group of Canadian hospitals and universities, surgeons can use MRI scans from their patients to rehearse removing brain tumours before going in with the knife for real. The surgeon gets a 3D view of the tumour on screens and practises cuts and movements by manipulating instruments attached to a robotic arm that responds with haptic feedback. This allows users to sense whether they are cutting through hard or soft material, or through a tumour versus healthy tissue. An advantage of such a system is that, once a doctor is trained, the technology can be used to perform remote surgery. Both virtual training and remote procedures for patients are useful at a time when covid-19 has forced health-care systems around the world to keep doctors and non-emergency patients apart.

In operation

When surgeons try to reconstruct a limb, a key problem is identifying important blood vessels that need to be protected during the surgery. In the past a surgeon would try to identify those vessels using an ultrasound probe, but the process is lengthy and imprecise. So James Kinross, a consultant surgeon at Imperial College London, has been experimenting with Microsoft's HoloLens, an augmented-reality headset, which can overlay computer-generated text and images onto the real world.

Dr Kinross has used a CT scan of a patient's limb to highlight the most important blood vessels. He reconstructed that scan as a 3D model in Unity, a games engine. The HoloLens then overlaid that simulation onto the patient's real limb in the operating theatre during treatment. "What it meant was that the surgeon could immediately visualize, and very precisely map, the anatomy of these blood vessels, and very quickly identify them and protect them," says Dr Kinross, who has also used this technique during cancer surgery to help surgeons identify and protect healthy tissue. The adoption of the technology has proceeded very smoothly, he adds, because it is easy to learn and provides "an immediate and very obvious advantage to the clinician".

He thinks the technology could be pushed much further and wants to try some real-time collaboration with his colleagues during a surgical procedure. "So if you're running an operation that's challenging, or you want to have a discussion with a peer, it's very easy to do and they can have a first-person view of what you're looking at," he says.

Medical uses for computer simulations are promising, but how useful they are will take time to evaluate. That will require robust clinical trials and discussions of frameworks for data protection on technologies that could, if their potential is achieved, become a new type of medical device.

"We don't want to poison the well," says Dr Mushtaq. "We don't want to put out systems that are ineffective, that are going to cost our health-care system, and that are going to negatively impact on

Who's using?

Spending on augmented and virtual reality by sector, %

Based on 2020 market share

Source: International Data Corporation

the growth of this sector." His research focuses on closing some of those knowledge gaps by examining how the lessons users learn from practising on virtual simulators translate into skills in the real world. Surprisingly, the fidelity of the images to real surgery is not so important. "Something can look very, very, flashy…it's got all the blood spewing everywhere and so on," he says. "But it doesn't necessarily translate to better learning."

Defining the validity of a simulator can take several forms. The most basic is "face validity", which reflects how well a simulation looks like the task in the real world. "Construct validity" is a way of comparing performance differences on the simulation between experts and novices. Finally, "predictive validity" is most useful, because it measures how well a person's performance on a simulator predicts their ability to do the same task in the real world.

Just like real life

This can also be used to flag when learners are struggling, and provide early intervention and support. Dr Mushtaq and his colleagues have demonstrated both construct and predictive validity for the Nissin (formerly Moog) Simodont dental-surgery simulator, used by the University of Leeds to train its students. In research published in 2019, they found that scores on the simulator predicted someone's performance in a clinic two years later.

Video-game engines have made face validity easier to achieve for simulators. The next step is to measure construct and predictive validity more robustly. Unfortunately, precious little of this kind of validation work is undertaken by academics or companies selling simulators. To help grease the wheels and encourage researchers to build a body of knowledge, Dr Mushtaq and his colleagues recently created a set of tools and protocols that streamline human-behaviour research and make use of the Unity game engine as a platform. This Unity Experiment Framework takes care of the tedious programming steps—downloading files that track all of a user's movements, for example, or anonymising participants—needed to turn the game engine into an environment optimised for studying people.

Mark Mon-Williams, a cognitive psychologist at the University of Leeds who has worked with VR for more than two decades, reckons simulated worlds have huge potential for improving education and physical and mental health. "But if you're going to make the most of that powerful set of tools," he says, "then use the scientific process to ensure that it's done properly." ■

Brain scan | *Lord of the Metaverse*

A novelist's vision of the virtual world has inspired an industry

IN THE LATE 1980S, a young author named Neal Stephenson was working on a project to create a graphic novel. He typed in some code on his Apple Macintosh II and a pair of spherical mirrors appeared on the screen, hanging in space. To make the images look more realistic, the code he used calculated how light bounced off the objects in the frame, so each mirror featured on it a convincing reflection of the other.

"At the time it was unbelievable that you could use code to generate that kind of an image," he recalls. He remembers having two conflicting thoughts: 3D computer graphics presented a tremendous opportunity to create a whole new medium, but they were too expensive and too difficult to make.

"And so I got to thinking about what could make it cheap," he says. Television had started out as an expensive curiosity and then became cheap and accessible by becoming a mass-broadcast medium. Mr Stephenson began to imagine what might be necessary to bring about a similar transition for 3D computer graphics. "I was trying to imagine what a popular medium would look like, centred on the use of the 3D graphics technology. And the Metaverse was my best guess as to what something like that might look like."

Introduced to the world in 1992 in his novel, "Snow Crash", the Metaverse was a persistent virtual world—accessible to

individuals via special goggles—in which people could meet, claim territory, build things, make money and more.

The impact of Mr Stephenson's idea on the real, non-fictional world has been profound. Ask anyone working to create interactive 3D virtual environments what has inspired them, and "Snow Crash" will be somewhere on that list.

That explains why Mr Stephenson is also a sought-after futurist in Silicon Valley. Over the years he has been tapped by firms including Blue Origin, Jeff Bezos's space-launch company, and most recently as "chief futurist" for Magic Leap, a start-up making augmented-reality glasses.

Today it is Mr Stephenson's vision—a social, persistent, virtual-reality 3D space accessible to anyone and which will one day be a successor to today's internet—that many tech companies are seeking to build. One of the biggest supporters of Mr Stephenson's idea of a Metaverse is Tim Sweeney, boss of Epic Games and creator of Unreal, the game engine that powers "Fortnite" and many other popular games. Mr Sweeney's stated ambition is to turn such games into some version of the persistent virtual world described in "Snow Crash".

"One thing I got wrong…was assuming a television model for the development of this medium," says Mr Stephenson. "What grew instead was games." Still, he reckons that what makes science fiction useful to people in the real tech world is plasticity—leaving some room for interpretation, so that people who try to implement it can incorporate their own ideas and point of view.

"I think that where Tim and the Epic folks are going with it, is based on an understanding that you do have to start with a game engine if you're going to build a Metaverse," says Mr Stephenson. "Because just having a game engine that works, and that is sustainable as a business, is kind of the table stakes. If you can't do that, you can't build a multi-user realistic 3D platform."

The future

What is real, anyway?

The Metaverse is coming

WITNESS ANY videoconference call, and it is striking how awkward it still is—everyone is in boxes, looking off in random directions. Microsoft tried to fix this recently with "Together" mode for its Teams application. Created by Jaron Lanier, a virtual-reality pioneer, it does away with boxes and puts everyone in a shared virtual space such as an auditorium. All participants see the whole group at once, as if they were all being reflected in a huge virtual mirror. Mr Lanier says this allows social and spatial awareness functions in the brain to work more naturally, and makes it harder to notice irregularities in eye contact.

For Mr Lanier, "Together" mode is a small contribution to a philosophy he holds dear—that, as technology develops, it should keep people in mind. Instead of asking "is videoconferencing good or bad?" or "is VR good or bad?", he says, the real question is "how can we make this more human-centred?" He sees virtual realities as a path to that goal, by making computing more human-friendly.

Take posture, for example. Sitting at a keyboard, locked in position for hours and focusing on a fixed screen is a recipe for a range of physical complaints, from sore necks to tingling hands. "Humans have not evolved to sit for long periods of time at a desk, staring at a screen whilst hammering away on a keyboard," says Mark Mon-Williams of the University of Leeds. Humans evolved to walk around and use their hands to explore the world that is in front of them. Virtual and augmented realities afford the option of using more natural movements when interacting with computer-generated environments—grasping and pointing at text or objects, for example, and physically moving them around a workspace.

> "How would you tele-concert if you were God?"

Alex Kipman, a computer engineer at Microsoft and inventor of the company's Kinect and HoloLens devices, poses a similar question: why are humans required to conform to the needs of computers, rather than the other way around? "Why don't we flip it?" he asks. "Why don't we ask technology to understand our world? How do we get digital technology to come out into our analogue space, as opposed to trying to get us into the digital space?" His inventions are specifically aimed at tackling those challenges. The Kinect sensor's microphones and infrared cameras let people use speech and gestures to control games and other functions on Microsoft Xbox devices. The HoloLens extends that by mapping and understanding the user's environment, too. Both devices bring technology out of screens and into the real world.

These sorts of ideas will bring increased ease and richness to interactions between humans and computers. The same technologies could also be used to push people beyond their own, or even any, human experiences. Scientists know that, as long as an avatar in a virtual world is programmed to respond in real time to a user's actions, those users will often co-opt the avatars as almost-real extensions of their own bodies. People can easily inhabit avatars of a different gender or ethnicity, for example. They can even easily learn to control drastically different bodies, soaring over landscapes as virtual eagles or munching grass as virtual cows.

This is more than just a curiosity. Mr Lanier wants to know what would happen if inhabiting different bodies in virtual reality gave people access to new forms of human intelligence and understanding—the kind that "peeks out once in a while with a great athlete or with somebody playing jazz piano". And if that could be made more accessible, he believes, then it might get interesting. "Can you turn yourself into a mathematical equation...in order to gain the kind of rapid body intelligence that's possible?"

That is the future of extending human experience. Travis Scott's concert in "Fortnite" hinted at some of the creative opportunities already available. His was not the first concert in that virtual world. In 2019 Marshmello, a DJ and producer, performed a set in the game watched by more than 10m fans, but that was just a musician playing a concert on a virtual stage in a game world. By contrast, Mr Scott's event played with the idea of how a concert might look if it did not have to take place in the real world. The audience could therefore fly around beaches, in outer space and underwater. "You can think of this as, how would you tele-concert if you were God?" says Matthew Ball, a tech guru. "If you controlled physics."

Virtual mosh pit

That the event took place during a pandemic, when this was the only type of concert people could participate in, is important. Such events might in the past have been dismissed as "video-game experiences". But as interactions through Zoom and other services come to be seen as "legitimate" meetings, parties and performances, so events such as Mr Scott's should also be seen as legitimate concerts, says Mr Ball. "We can't go to physical concerts," he says. "So, either we have to say it's a concert or we have to accept that there are no more concerts."

There are still many technical hurdles to making the digital and physical worlds work together. As fast and capable as computer graphics have become, for example, VR focuses only on just two of the senses through which people experience reality: sight and sound. In the physical world, it would be difficult to imagine life without the other senses and, in particular, touch—grasping and manipulating objects is a fundamental part of the way people experience and gather information about their surroundings.

If history is a guide, computing platforms and internet connectivity will become faster and more widespread, latency will go down, input and output devices will improve and game engines (and their successors) will be able to create customised virtual worlds on the fly. At some point in the future, anyone who wants to may be able to switch in and out of fully immersive virtual worlds, flitting in and out of whatever the real version of Neal Stephenson's Metaverse turns out to look like.

What seems certain is that sophisticated 3D digital worlds will appear on ever more of the screens of successive generations of devices that people already use every day. As activities, particularly interactions between people, in virtual realities can generate practical and aesthetic outcomes that have moral consequences and personal meanings, the idea that the "real" world is limited to that which is physically present nearby will seem increasingly bizarre. What, after all, is real, anyway? ■

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