

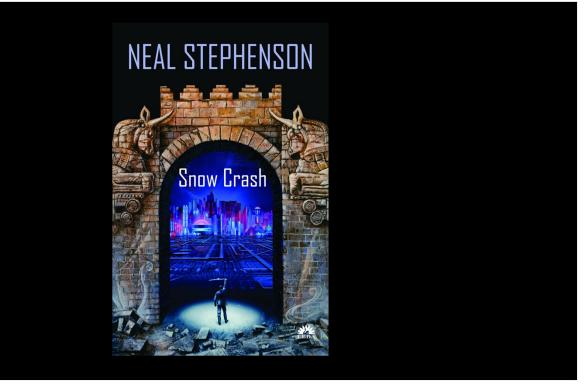
Hi! I'm Michael Abrash, and I'm part of the team working on virtual reality at Valve.

I have a nice talk prepared for you today, with a lot of meat and a look at an exciting future – and I'll get to it in a minute, but first I thought I'd sum up the whole thing in 59 words. I'm sure someone out there will be counting, so I'm just going to read this to make sure I get it right:

Compelling consumer-priced VR hardware is coming, probably within two years It's for real this time – we've built prototypes, and it's pretty incredible Our technology should work for consumer products VR will be best and will evolve most rapidly on the PC Steam will support it well And we think it's possible that it could transform the entire entertainment industry

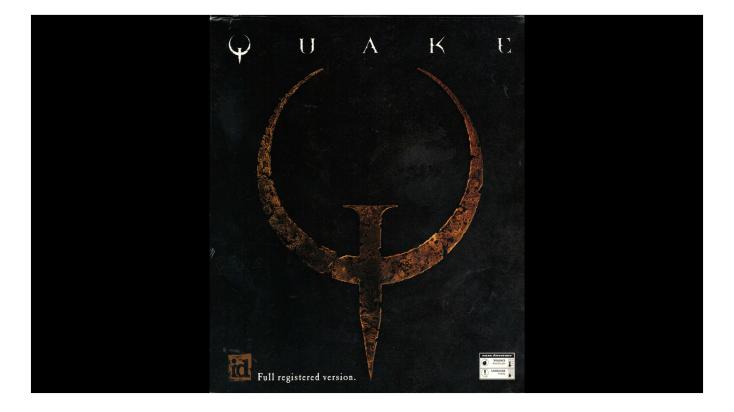
If you come away today with nothing but those 59 words, your time will have been well spent.

Still, there's a lot more to be said on the subject, so let's look at the future of VR in more detail.



My personal path to working on virtual reality has been a long and winding one, and without the good fortune to encounter a couple of visionaries 20 years ago, I might never have taken the first step on that path. Back then, I understood networking – after all, I worked at Microsoft, and used the network constantly – and I had seen demos of 3D rendering on workstations and had written a simple 3D package myself, so I knew about realtime 3D too. And I had read and watched a ton of science fiction, so I was familiar with the concept of virtual worlds. Fascinating as the idea was, though, and even given my knowledge of 3D and networking, virtual worlds still felt more like fiction than like something to think about seriously.

Then I read Neal Stephenson's *Snow Crash*, and it all started to come together. When I thought about what it would take to build the Metaverse, I estimated that I had at least an idea of how to implement maybe 80% of it with existing technology. I was too optimistic – I'm still waiting for my first VR swordfight – but still, *Snow Crash* made me realize that networked 3D virtual worlds were ripe to happen.



Later, I got together with John Carmack, and he talked for two hours straight about how he was going to make it possible to create virtual 3D worlds running on persistent servers, with the ability to link servers together and for anyone to build their own worlds, and how those virtual worlds would accrete to form cyberspace, and suddenly I saw the shape of things to come, and wanted very much to be a part of it. I jumped in to work with John, *Quake* happened, and today, tens of millions of people immerse themselves in networked 3D on a regular basis.

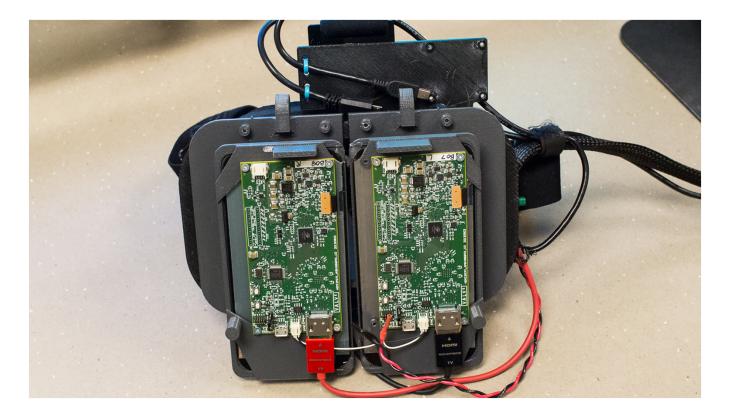
And I wouldn't have been a part of it without Neal and John pointing the way to the future.

The near future of virtual reality



- VR is likely to be here sooner than you think
- We've learned this from our R&D
- We've built a hardware prototype that creates presence

I'm not a visionary, but I hope to do much the same for you today with a part of the Metaverse that hasn't yet happened, virtual reality. I'm sure you're all familiar with the Oculus Rift DK1, and I'd guess that most of you think it's just an interesting curiosity at this point. That's a reasonable take right now, but we think you should pay close attention, because VR is likely to have a big impact much sooner than you think – and Valve's working hard to make that happen.



Two years ago, we identified virtual reality as a promising way to enable compelling new experiences. Our research and development since then has led to prototype head-mounted displays – like this one – and a set of demos that together create a powerful sense of what's known as presence.

The near future of virtual reality



- Presence is VR magic
- We think people are going to want presence badly

I'll talk much more about presence later, but, briefly, it's the sense of being someplace else while in virtual reality; many people feel as if they've been teleported. Presence is an incredibly powerful sensation, and it's unique to VR; there's no way to create it in any other medium. Most people find it to be kind of magical, and we think that once people have experienced presence, they'll want it badly.

The near future of virtual reality



- The same hardware reduces motion sickness
- This hardware makes it possible to create incredible VR experiences that won't make people sick
- We believe that a consumer version is feasible within two years

The same hardware that enables presence is also highly effective at reducing motion sickness. Our demos show that given the right hardware it's entirely possible to create astonishing VR experiences – experiences that could only happen in VR – that don't make people sick. And we strongly believe that it's feasible to use the same technology to ship a consumer version within two years.

Who might ship this?

- Oculus is the obvious candidate
- The DK1 is a good first step, but not good enough
- Crystal Cove is a big step in the right direction
 - Resolution, latency, persistence, translation
 - Low persistence driven by Valve prototyping
 - Valve and Oculus collaborated on tracking
- We're continuing to work with Oculus to drive PC VR forward

The obvious question is: who might actually ship this class of VR hardware within two years? Oculus is clearly the leading candidate. They've made VR a hot topic again, and they've already shipped more than 50,000 Rift DK1s. The DK1 is not good enough to enable strong presence for most people, but Oculus' new version of the Rift, Crystal Cove, offers higher resolution, lower latency, low persistence, and translation, all of which are key elements of presence, as we'll see later, so it's a big step in the right direction.

Valve's goal is to enable great VR for the PC, so we've shared what we've learned through our R&D with Oculus. We've showed them our prototypes and demos, we've explained how our hardware works, and we've provided them with feedback on their hardware designs. By showing them a prototype with low persistence, we convinced Oculus of its importance, and the lack of blur in Crystal Cove is a direct result of that. We collaborated with Oculus on tracking as well. We're continuing to work with them to improve tracking, displays, lenses, and calibration, and we're excited about where they're headed. If Oculus executes well, and so far they seem to be, I think they could well deliver strong presence on the PC within the next two years; we hope that happens, because it would be a huge boost for PC VR.

Implications of presence

- VR could evolve into a major platform
- Presence could tip the balance of the entire industry toward computer entertainment
- Presence requires a head-mounted display connected to lots of local compute power
- The PC is going to be the best place for VR

Once hardware that supports presence ships, we think it has the potential to cause a sea change in the entertainment industry. Not only could VR rapidly evolve into a major platform, but it could actually tip the balance of the entire industry from traditional media toward computer entertainment. You see, for latency and bandwidth reasons, presence can only happen with a head-mounted display connected to a device capable of heavy-duty 3D rendering, so there's no way that TV, movies, streaming, or anything that lacks lots of local compute power is up to the task. A corollary is that the PC – Linux, Windows, and OSX – is going to be the best place for VR, because that's where the most FLOPs are.

The bottom line is that we think VR has tremendous potential as a gaming platform and has an excellent shot at taking off soon, so we're working to enable great VR for the Steam community. First, we're building VR support into Steam, as you'll learn from Joe Ludwig's talk. Second, we're driving VR hardware forward on the PC by continuing to do R&D and by collaborating with Oculus. Finally, we're prototyping software to figure out how to produce great VR experiences, and we'll share what we find with you as we learn it.

We have no current plans to ship VR hardware ourselves, but that could change in the future. Right now, we're just figuring out what's fun about VR, and as we learn more we'll do whatever's needed to enable VR on the PC and Steam.

Decide for yourself



- Try it for yourself and decide what you think the future looks like
- mabrash@valvesoftware.com

It should be pretty obvious by this point why we think you should keep an eye on VR, but of course you should develop your own opinions about its potential. The best way to do that is to try our demos. Unfortunately, the demos currently take half an hour and require a dedicated room, and there are only two such rooms at Dev Days, so we haven't been able to give most of you demos here. What I can offer is this: any Steam partner who's in Seattle in the next few months and wants to try the demos can send me email at mabrash@valvesoftware.com, and we'll schedule a day and time. Once you've tried the demos, I think you'll agree that the near-term future of VR is brighter than almost anyone imagines.

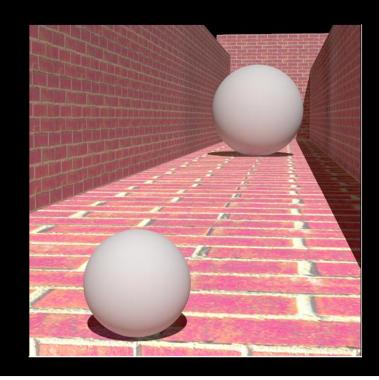
The key to that bright future is presence, so it's important that you understand what it is, why it matters, and what it takes to enable it. Before we can discuss presence itself, though, we need to lay some groundwork.



WHAT DOES IT TAKE TO MAKE VR COMPELLING?

At Valve, we've spent a lot of time investigating the factors that affect how people experience virtual reality. Most critically, we've learned that the key to making the experience unique and compelling is convincing perceptual systems that operate at a low level - well below conscious awareness - that they're perceiving reality.

Since by definition you're not directly aware of the relevant systems, it's hard to understand what they are and why they matter. To illustrate, I'll briefly describe an example that doesn't involve VR but that does clearly demonstrate low-level processing.



Murray, S.O., Boyaci, H., and Kersten, D. (2006). The representation of perceived angular size in human primary visual cortex. Nature Neuroscience. 9, 429-434. doi:10.1038/nn1641

Fang, F., Boyaci, H., Kersten, D., and Murray, S.O. (2008). Attention-dependent representation of a size illusion in human V1. Current Biology, 18 (21), 1707-1712. doi:10.1016/j.cub.2008.09.025

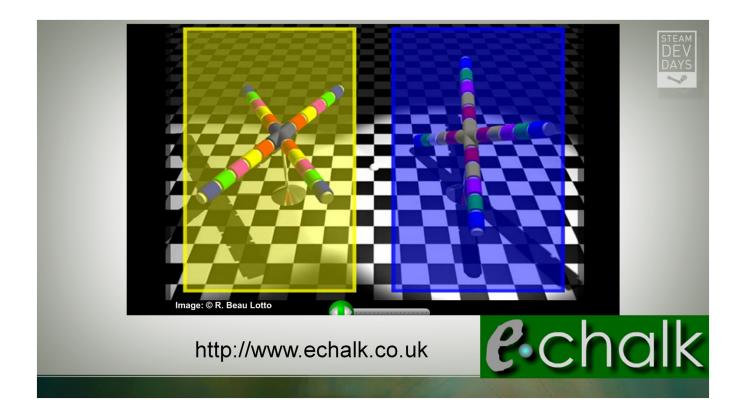
http://www.bilkent.edu.tr/~hboyaci/Vision/SizeAppletLarge.html

The example involves the scene you see on this slide, which contains a number of cues that suggest a considerable distance to the farther sphere, including lighting, perspective, texture convergence, and the relationship between the spheres and their shadows. The user's task is to adjust the size of the nearer sphere, using the arrow keys, until the 2D circles formed on the screen by the two spheres look to be the same size.

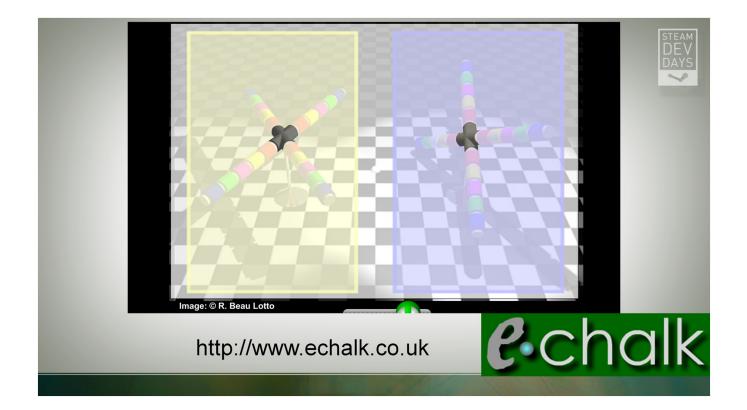
What unfailingly happens is that the user makes the front circle larger than the back circle. (You can try it for yourself at the URL shown.) In fact, take a moment now and look up the alley. Which circle seems bigger? To me, the back circle is clearly the bigger one. In fact, though, the front circle is nearly 20% larger.

This may not work for you, since seeing the illusion at a distance is not ideal, but if you had a similar result, that's not surprising. Research using functional MRI imaging shows that even in the earliest layer of the visual cortex, long before conscious awareness comes into play, the sphere that appears farther away projects to a larger area in the brain even if it occupies the same area on the retina. The visual system has already judged the sizes before the data reaches conscious awareness.

There are many similar processors in your visual system, all contributing to your perceptions of the world in ways you're not directly conscious of. Here's another one:



Take a look at the center piece of each 'X'. One's gray, and the other's dark yellow, right? Now let's mask out the background, without changing the colors of the center pieces, and see what happens.



It turns out that due to the need for consistent vision across a wide range of illumination conditions, there's a huge contextual element involved in low-level color processing. Consciously, you're not even aware of this, just as you're not aware of the processing that alters the perceived size of the circles in the previous example, but collectively, signals like these from low-level processing form your sense of the world. If virtual reality provides inputs that stimulate the low-level processors properly, you'll feel like you're actually someplace; if it doesn't, you'll feel disconnected from the scene in some indefinable way.

So far this hasn't been directly relevant to VR, so let me give another example that's closer to home. This is a bit of a spoiler for one of our demos, so if you don't want to hear it, cover your ears. I'll wait a moment while you decide.



We have a demo where you're standing on a ledge, looking down at a substantial drop. Here's the scene; the stone texture is a diving board-like ledge far above the floor of a box room that's textured with outdated web pages. Yes, I know it doesn't look like much of anything here, but that just illustrates how different VR can be from staring at a screen. Looking at this on a screen (even when it's not warped) doesn't do anything for me, but whenever I stand on that ledge in VR, my knees lock up, just like they did when I was on top of the Empire State building. Even though I know for certain that I'm in a demo room, wearing a head-mounted display, looking at imagery of the inside of a badly textured box, my body reacts as if I'm at the edge of a cliff. What's more, that effect doesn't fade with time or repetition. The inputs are convincing enough that my body knows, at a level below consciousness, that it's not in the demo room; it's someplace else, standing next to a drop.

Presence



- The sense that you are really someplace else
- More than just immersion
- Can only understand by experiencing it

This feeling of being someplace real when you're in VR is well known to researchers, and is referred to as "presence," and it's presence that most distinguishes VR from 3D on a screen. Presence is distinct from immersion, which merely means that you feel surrounded by the image of the virtual world; presence means that you feel like you're *in* the virtual world.

Trying to describe presence is bound to come up short – you can only really understand it by experiencing it – but I'll give it a shot. Presence is when, even though you know you're in a demo room and there's nothing really there, you can't help reaching out to try to touch a cube; when you automatically duck your head to avoid a pipe dangling from the ceiling; when you feel uneasy because there's a huge block hanging over you; when you're unwilling to step off a ledge. It's taking off the head-mounted display and being disoriented to find the real world there. It's more than just looking at someplace interesting; it's flipping the switch that makes you believe, deep in your lizard brain, that you *are* someplace interesting. Presence is one of the most powerful experiences you can have outside reality, precisely because it operates by engaging you along many of the same channels as reality. For many people, presence is simply magic.

Presence



- Varies from person to person
- Has gotten stronger as technology has improved

Different people experience varying degrees of presence in response to our demos; clearly there are significant variations within the population. Responses have strengthened overall as we've improved the experience, so we expect presence to become steadily more powerful as VR technology evolves.

Presence



- It's why we're so excited about VR
- Powerful at a visceral level
- Unique to VR
- Likely to be the key to VR's success

Presence is hard to quantify, but our demos have shown that it is a very real and compelling phenomenon, one that hooks far deeper into the perceptual system than anything that's come before, and it's why we're so excited about the future of VR. It's our belief that great VR will be built on presence, because it engages you at a deeper, more visceral level than any other form of entertainment, and can only be experienced in VR. Consequently, we think that building hardware that's capable of delivering a strong sense of presence is the key to VR's success.

So, what does it take to create a sense of presence? Hard-won experience from a lot of R&D and prototyping has taught us that all of the following aspects have to be good enough before a strong sense of presence emerges:



All of the following are needed

- A wide field of view
- Adequate resolution
- Low pixel persistence
- A high enough refresh rate
- Global display
- Optics
- Optical calibration
- Rock-solid tracking
- Low latency

I'll talk about each of these in more detail in a minute, but first I'd like to note that these elements also reduce motion sickness. While the causes of motion sickness are not well understood, there are good reasons to anticipate that many of the same factors that affect presence should affect motion sickness as well. For example, flawed tracking causes a mismatch between what your eyes see and what your vestibular system reports, and those sorts of conflicts are thought to be key to motion sickness.

Let's take a few minutes to look at each of the elements and see why they matter.

A wide field of view

- Immersion
- Peripheral cues
- At least 80 degrees
- More is better

A wide field of view is obviously required so that you feel immersed, but also provides peripheral visual cues that are critical for motion, balance, and situational awareness. Presence starts to work somewhere around an 80 degree field of view, and improves significantly at least out to 110 degrees, which is the widest we've tested.

Adequate resolution

- Problematic for VR due to wide field of view
- One-seventh the pixel density per degree of a wide-screen TV
- 1080p works
- More is better

Resolution is a particular issue with VR because the wide field of view spreads out and magnifies the pixels; the per-degree pixel density of a 1K x 1K, 110-degree VR display is roughly one-seventh that of a big-screen TV, and about one-tenth that of the eye itself. In fact, it's actually lower pixel density than the original Quake running at 320x200

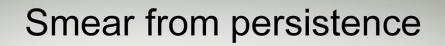


which as you can see is pretty low density. We've found that 1080p seems to be enough for presence. We expect that 1440p, or better yet 2160p would be huge steps up, but won't know until we can get appropriately sized panels at those resolutions.

Low pixel persistence

- Necessary to avoid blurring with eye motion
- No more than 3 ms

Persistence is the length of time each pixel remains lit. It's not that important for TVs, monitors, or mobile, but it's uniquely important for VR, due to the much faster motion of the eyes relative to the head-mounted display. This is especially true due to a low-level visual system called VOR, which allows the eyes to remain steady during rapid head motion. The longer pixels persist, the farther the pixel images smear across the retina when the eye is moving, and the blurrier the scene becomes.







Here's an example of the sort of smear that results from persistence. The image on the left is with the head held still, and the image on the right is a simulation of what happens with a leisurely 120 degrees per second head turn rate. On a 60 Hz full-persistence display, that results in two degrees of smearing across the retina per frame, which as you can see reduces detail considerably.

We've found that persistence of 3 ms or less is required for presence with a 1K x 1K, 110-degree head-mounted display. Shorter persistences will be required at higher pixel densities.

A high enough refresh rate

- Necessary to avoid flicker with low persistence
- 95 Hz seems to be sufficient
- Somewhat less than 95 Hz may be adequate

Given a wide field of view, once persistence is lowered, refresh rate has to increase; at 60 Hz, low persistence images flicker badly. In order to address this, we built the fastest low-persistence head-mounted display we could; it runs at 95 Hz, and that successfully eliminates visible flicker. A somewhat lower refresh rate may be adequate, but we haven't done the experiments yet.

It's worth noting that VR quality suffers noticeably when rendering doesn't keep up with frame rate, and that it's going to be a challenge to maintain 95 Hz stereo rendering, especially as resolutions climb.



Global display



- Illuminates all pixels simultaneously
- Avoids motion-induced compression, stretching, and skewing
- Rolling display may work, but will have failure cases without low-latency eye tracking

Our prototype uses global display, where all pixels are illuminated simultaneously. This avoids the compression, stretching, and tilting problems that can occur with the more standard rolling display, where pixels are illuminated in a scanned sequence over the course of a frame. It may be that the artifacts of rolling display can be largely corrected by adjusting the frame buffer during each frame to account for eye motion, but that's not yet proven; also, while head motion can often be used as a proxy for eye motion, without eye tracking there will always be failure cases, and low-latency head-mounted eye tracking is not a solved problem. So right now global display is the only approach known to work.

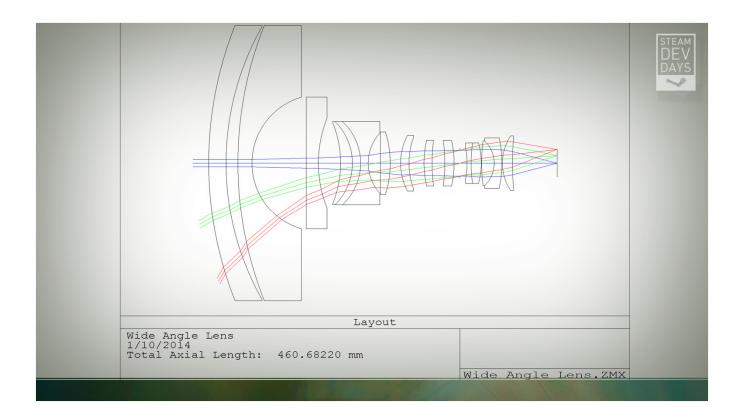
Optics



- Only one or at most two lenses per eye
- Not enough to allow simultaneous control of
 - Focal length
 - Viewing distance
 - Size
 - Distortion
 - Various forms of aberration

It seems like the selection of the lens or lenses and the design of the optical path should be simple. We have to use a cellphone panel with magnifying lenses, because there's currently no reasonable way to get a wide enough field of view with a microdisplay or waveguide. Furthermore, due to the demands of field of view, weight, and industrial design, there can only be one or maybe two lenses per eye. How hard could it be to optimize such a simple system?

The problem is that there's no way that just one or two lenses can produce ideal VR viewing; there are many different types of aberration and distortion, so something like this:



would be required to get everything exactly right. For reference, the two big lenses on the left are more than a foot in diameter, and the whole assembly would weigh more than five pounds – not particularly practical for a head-mounted display.

With a limitation of just one or two lenses, fixing one problem often means making another one worse, especially with the requirement for a wide field of view. This is further complicated by the many possible focal lengths, sizes, and viewing distances.

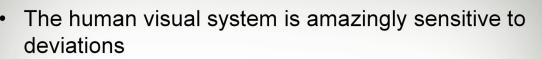
Optics



- Search for best tradeoffs in a huge space
- Evaluation has to be done by a human

So lens design becomes a process of searching for the best set of tradeoffs in a huge space, made even more complicated because there's no mechanical way to evaluate the resulting visual quality. The only test that matters is actually using the lens in VR, which is time-consuming, subjective, and varies from person to person. We've developed lenses that work well enough to allow presence, but there's lots of room for improvement.

Optical calibration



 Many problems are impossible to identify until calibration is nailed

Optical calibration seems like a minor point, but has proven to be critical and hugely challenging, because the human visual system is astonishingly sensitive to slight errors, especially when motion and straight lines are involved. A scene that looks perfect when viewed statically can ripple horribly when you swivel your head from side to side. This destroys presence, and can induce motion sickness almost instantaneously.

It's also impossible to figure out what else needs improving until optical calibration is dead-on. As one example, until we got calibration right, we didn't really notice small tracking glitches, because the image wasn't any more stable than the tracking. Once calibration was good enough, the glitches jumped out at us. The bottom line is that a highly accurate process for characterizing the lenses and correcting the rendered image is absolutely essential.



Tracking



- Must support translation (position in x, y, and z) as well as orientation
- Position with at least millimeter accuracy
- Orientation with at least quarter-degree accuracy
- Volume at least 1.5 meters on a side

At this point, we have the ingredients we need to produce the visual quality required for presence. However, that alone is not sufficient. The image has to be presented in such a way that the perceptual system accepts it, and that requires rock-solid head tracking that reports translation - position in x, y, and z - as well as orientation. We've found that we can get presence with tracking accuracy of a millimeter in position and a quarter-degree in orientation, maintained over a volume no smaller than a meter and a half on a side.

Achieving this is much harder than it sounds; there is no currently-available consumer system that comes close. Here's what we're using for our demos:



It works, but you can see that it isn't exactly consumer-friendly. We have a couple of promising tracking systems in development that don't involve wallpapering your house, and while they may or may not pan out, they're close enough to make us confident that a consumer-grade tracking system is feasible in the near future.

Low latency



- 20 ms motion-to-last-photon works
- 25 ms may be good enough

The virtual image needs to be in the right place at the right time, which means that latency has to be very low, as measured from the time head motion occurs to the time the last photon is emitted as a result of that motion. We've found that latency of 20 ms, combined with good prediction, works well, and it's possible that latency up to 25 ms may be adequate. Past that, the virtual world no longer seems nailed in place, and the human perceptual system is no longer convinced that it's looking at reality.

Presence is emergent

- All of these factors have to be good enough
- No one factor is enough by itself

I want to emphasize that presence is not a property of any one of the elements I've discussed; it's a property that emerges when *all* of the elements are good enough. If the optics aren't calibrated perfectly, then the scene will warp as you turn your head no matter how good everything else is. Likewise, no amount of fidelity will convince your visual system that a virtual scene is real if latency is too high. Presence can't be induced if even one of the key elements is subpar.

Okay, due to time limitations, this has been a very fast overview of the elements of presence. If you'd like to know more, there's lots more detail on my Valve blog.



SO WHEN IS PRESENCE COMING?

So – how does hardware that could plausibly appear in a consumer product in the next couple of years measure up with respect to the key elements of presence? As it turns out, things look surprisingly good. It's my opinion, based on Valve's R&D, prototypes, and projections, that a consumer head-mounted display could be built to the following spec in 2015:



Feasible 2015 consumer HMD

- 20 ms motion-to-last-photon latency
- 3 ms pixel persistence
- 95 Hz refresh
- 110-degree FOV
- 1K x 1K resolution per eye
- High-quality, well-calibrated optics
- Tracking
 - millimeter-accurate resolution translation
 - quarter-degree-accurate rotation
 - volume of roughly 2 meters cubed

This head-mounted display would support a powerful sense of presence and would have an excellent shot at widespread adoption. VR can certainly get much better yet down the road, but that'll require time and major hardware R&D. In contrast, we believe everything on this slide is doable with relatively minor tweaks of existing technology; no breakthroughs or miracles are needed, just solid engineering.

Presence in 2015



- We've built prototypes to this spec
- We believe the technology is transferable to consumer-priced head-mounted displays
- We'll share what we've found with PC companies that want to develop VR hardware

This specification is based on direct experience. Our prototype head-mounted displays have all the characteristics I've specified, and enable a strong sense of presence. They're also built from modified commodity parts that point the way to cost-effective manufacturing at scale.

That doesn't mean it'll be trivial to build and ship consumer VR hardware. We've created an R&D prototype, not a product. We think that the technology we've used will be transferrable to consumer head-mounted displays, but lots of additional work will be required to turn that into a shipping product. I'm confident that that work will happen soon, now that we've demonstrated what's possible, and if that happens, it should be feasible to have these head-mounted displays on the market within a couple of years.



There's a lot left to be done

- Improve every key element
 - Up to 100X resolution would help
 - Optics are far from optimal
 - Head tracking isn't fully solved
 - Eye tracking is far from solved
- Solve per-user lens positioning (IPD, eye relief)
- Get rid of the tether
- Get a display manufacturer to make VR-optimized panels

Beyond manufacturing issues, there's still a lot to be solved and improved. For one thing, presence would benefit from every one of the key elements getting better than what's in our prototypes. We could literally use up to 100 times as many pixels, and a wider field of view, lower latency, and all the rest would also improve the experience; the optics in particular are far from optimal. Also, getting peruser lens positioning right is a challenge. As I mentioned, we think we're close on head tracking, but we don't have a shippable solution yet, and then there's eye tracking, which could greatly enhance presence but is nowhere near solved. Going to a wireless connection and eliminating the tether would be a big plus. And while we believe that it's possible to modify existing display panels to support low persistence, global display, and low latency, that remains to be proven, and will require the close cooperation of a display manufacturer.

There's a lot left to be done



- 3D audio
- Haptics
- Body tracking
- Input
 - Especially the interaction between input and game design in VR

Then there's all the stuff that needs to be figured out in non-visual VR areas. 3D audio, haptics, body tracking, and input are going to be huge positives for presence, and they're bigger and harder problems than head-mounted displays. In particular, VR input and its interaction with game design is at the core of the experience, and almost completely unexplored. We're researching those areas, but it's going to take many years and the combined efforts of the whole game industry to fully explore them.

VR software



- Movement
- Gameplay
- Multiplayer
 - Could be the best online social experience yet
- Content

And then there's software.

Once the hardware's built, it won't really matter until software provides great, unique VR experiences, and those have yet to be created. In addition to the question of how games will interact with input, rules about how players can move around a virtual space without getting motion sick or losing presence have yet to be figured out. We've found that traditional FPS movement is far from optimal and tends to cause motion sickness, so VR may be best with slow movement and a lot of up-close interaction, in which case we'll have to learn how to create fun games around that. In the end, a whole new VR gameplay vocabulary will need to be developed, just as was the case with FPSes.

Multiplayer VR is also going to be very different – and more compelling – than on a screen. Sharing a virtual space that feels real with other people has the potential to be the most powerful online social experience yet, but raises many questions. Remember when deathmatch and mods and team games on persistent servers evolved? This is going to be like that, but much more so.

Then there's content. For example, no one knows yet which art styles work in VR. Detailed scenes that look great on a screen can look like cheesy stage sets in VR – and simple scenes can seem startlingly real. Normal maps don't look good, and textures sometimes do and sometimes don't. So we're going to have to come up with a whole new visual vocabulary for VR too.

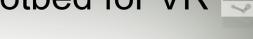
This is where you come in

- Could be one of the biggest platform shifts ever
- Platform shifts create opportunities
- Great VR requires custom experiences
- Someone is going to write the DOOM of VR

This is where you come in. Platform shifts enable software to create breakthrough experiences – think Myst, Quake, Wii Sports, Angry Birds. VR has the potential to be one of the biggest platform shifts ever, and you can be on the leading edge of that. That's all the more true because we've learned that great VR requires dedicated experiences designed specifically for virtual reality; immersion can make ports to VR interesting, but great VR really requires custom software. Much as was the case with the first 3D games, pretty much everything about the VR gaming experience remains to be invented. I'm sure you saw some of the adoring press on the 20th anniversary of *Doom*; the first game that nails the VR experience is likewise going to be fondly remembered for a long, long time.



The PC will be the hotbed for VR



- PC Linux, Windows, OSX will be the VR epicenter
 - Rapid evolution
 - Already happening with the Rift
 - Many developers and IHVs, with complete freedom to innovate
 - Most powerful platform, and getting more so
 - Valve will continue to help drive VR on the PC & Steam forward

When that first great VR game does show up, it's likely to be on the PC, for several reasons. First, VR hardware is going to evolve rapidly on the PC, as you can already see with the Rift, while the consoles, if they even support VR, will remain static for years. Second, there are going to be far more hardware and software developers figuring out how to do awesome VR on the PC than on the consoles, and they'll be much freer to experiment. Third, VR needs as much processing power as it can get – remember, we're talking about stereo rendering at 95 Hz – and high end PCs are already much more powerful than consoles, with the gap due to increase for years to come. And because of power and heat constraints, PCs will always be far more powerful than mobile. Finally, having figured out how to bring presence to consumer VR, and having added VR support to Steam, Valve is going to continue to help drive VR on the PC and Steam forward, so that all of us can deliver new, compelling experiences. All of which means that the PC and Steam are going to be at the heart of VR for the foreseeable future.

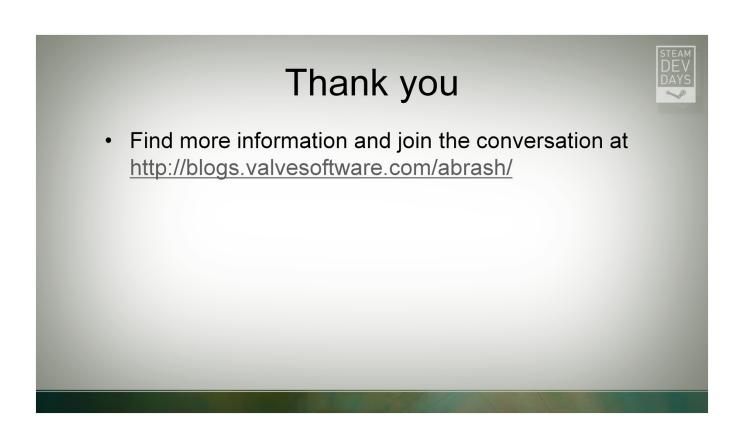
Takeaway



- A great VR system at a consumer price in 2015 is primed to happen
- It will happen, in 2015 or soon after

Today's key takeaway is simple, but it has powerful implications: a great VR system at a consumer price in 2015 is more than just possible – it's sitting there waiting to happen. And it will happen, if not in 2015, then soon after.

Virtual reality on the PC over the next few years may be as exciting as anything that's ever happened in games. We're sharing what we've learned with you, and we'll continue to do so. There's a huge amount to be learned and figured out about VR, and we certainly can't figure it all out by ourselves; I hope that as you dive into VR, you'll make it a two-way exchange, so together we can make VR one of the great entertainment revolutions.



There's a lot more to talk about, and I look forward to continuing the conversation with you at the Q&A and on my blog.

Thank you.