UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA

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Case No.: 4:20-CV-05640-YGR

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EPIC GAMES INC.,

Plaintiff,

v.

APPLE INC.,

Defendant.

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File Name: APL-EG_07868680

TIM SWEENEY: Thank you very much. I'm going to talk about the long-term future of technology and give -- share some thoughts on this. This started with a YouTube video that's been circulating where somebody hands a magazine to a little girl and she picks it up and she drags her fingers around it, and it doesn't respond, and she gets very, very frustrated with it, and she concludes that it's a broken iPad.

As somebody who was born before the personal computer era even began, it really impresses on me how far we've come, how much the technology has changed and how much that's enabled better experiences with gaming and computing and the entire consumer experience.

And so I wanted to talk about that, but at the same time we're on the verge of a new generation of hardware. Everybody is talking about will there be another console generation or are consoles good enough today? And perhaps -- perhaps we've already seen our industry's brightest days.

But I don't think so at all. And to try to move away from just giving a sheer opinion on this I wanted to draw from some experience in some very diverse fields to share my thoughts on this important question for us all.

Now, one important thing to realize in all of this is gamers are actually just biological organisms, right? We tend not to think of people that way but we are. We are -- our experience of video games is driven by our ears and our eyes, but most importantly our eyes and our optical cortex.

Now our eyes consist of a huge number of photoreceptors, they're transmitted through our optical nerve to our brain. And there are physical limits to these devices. (to screen) Thanks, Windows.

So there are physical limits to our capability to perceive detail and scenes. And so it's reasonable to say that eventually computer will be good enough. But we really have to ask how much -- how good is good enough and how close are we to that right now?

And this has actually been really thoroughly studied in the theoretical research. We found ultimately that the human eye and optical cortex is about the equivalent of a 30-megapixel camera.

Now I like to go hiking through the woods and take 20-megapixel pictures with my camera of nature photographs. So the human eye is actually fairly close to that. And we -- scientists have also discovered that you don't really respond or perceive improvements in frame rate beyond 70 frames a second.

And so from these pieces of data we can look at resolutions that are actually to the point of -- hitting the limits of human perception, and we're very close to that today with today's iPad and with high definition televisions. And in another generation or two we'll actually be there for devices you're viewing fairly up close. Or from a fairly -- from a distance.

But if you want an immersive display that fills your entire field of view with imagery, you really need a much higher resolution display. And it looks like the limit is about 8,000 by 4,000 pixels, or about 16 times higher resolution than our current high definition televisions. And so we have a ways to go there, but the limit is really within sight.

Now, knowing these limitations we can

really plug them into the graphics pipeline and look at what impact they have on computing power and games. Now there's an important theorem. Gosh, who knows what the theorem is, anybody? Okay.

I'm used to talking to very technical audiences. But the idea is that if you have a screen of a given resolution there's no point to having more than a certain data in your computer's memory from which you generate the scene.

Beyond that limit known as the Nyquist limit, any additional detail that you're putting into rendering your scene is just largely wasted. And so there is a finite limit of data -- to the amount of data we need to render to create a perfect scene that can't be beaten from a human's point of view.

And that limit turns out to be only about 50 times more triangle rendering power than we have in today's GPUs. So from that point of view you can conclude that we have at least two more generations to go. But that's not the whole story at all. That's just looking at pixels.

But computer graphics is the art of

approximating all of the aspects that contribute to the visual scene, from the objects you see to the lighting and the way the light traverses through the environment, to the movement of objects that are animating within the scene.

And as with all sorts of approximation, we start with a simple approximation and as we get more computing power we add more to it. The approximation is also a mathematical concept as we all learned through calculus. Everybody's a big fan of calculus, right?

At any rate, we start out with a very simple approximation to some function we're looking to generate, whether it's a computer image or a mathematical function or a number, and we add successive approximations until our approximation becomes good enough for our purposes and doesn't need any more clarity.

And graphics has gone through the same process of approximation over the past 20 years. And it started out -- this is my first game, ZZT, written back in 1991. It wasn't an approximation to reality whatsoever. It was just an iconic representation of some objects that move around a scene in a puzzle game.

It wasn't until the first 3D games that we began to actually approximate reality through computer rendering. And Doom is a great example of that. It's the first-order approximation. In Doom, the scene is rendered by approximating a single bounce of light from each point in the world straight to your eye without any intermediate affects.

And that was very efficient but as we got more computing power we were able to reach the second-order approximation. And I mean this in the strictest -- approximation in the strictest sense. We're modeling two bounces of light.

Light starts at a light source, it bounces off a point in the world, and it reaches the viewer's eye. And in between it might encounter shadows and color propagates throughout the environment. And this is a scene from Unreal I that shows the -- an early second-order approximation of computer graphics.

And this same approximation has been carried over. In fact, 99 percent of the graphics you see in even today's games for Xbox 360 and PlayStation 3 are just using the second-order approximation. And we're just starting to get enough computing power now to reach a third-order approximation.

And this is a scene from the Samaritan demo that we put together for the Games Developer Conference last year. It's running on the fastest in video cards that money can buy. And here we're approximating three bounces of light.

Light goes from a light source to a point on the world, it lights that point up, and then we reflect all of the surfaces in the world off of all of the other surfaces in the world and the light eventually reaches the eye.

So what you see here in this scene are all of the bright areas and all of the walls, they received a lot of light bouncing off of the ground in a glossy reflection and reaching your eye. And as you move around you see an amount of detail that's fairly surprising and shocking relative to today's games.

It clearly shows that there's at least room for another generation here. But I think we have a lot more than that to go. Now if we boil this down to raw computing power, Doom's rendering approximation required about 10 million floating point operations per second of computing power.

Unreal in 1998 required a billion, and then our latest demo required about two and a half trillion floating point operations per second. So we've already scaled performance across many orders of magnitude. I think we have farther to go still. Because many aspects of realistic scenes we see today require many bounces of light to simulate accurately.

For example, the soft shading you see on skin is the combination of many different effects. There is the oiliness to their skin which reflects light and other aspects of the environment off of our skin and to the viewer.

There's also light transmitting through the surfaces and through the three-dimensional space within your skin picking up and transmitting color as it goes to produce the real subtle highlights that you expect in the human face.

And we're so far short of being able to achieve this in real time with a complete and movie-level of accuracy. We seem to be stuck here. Well, figure out if we can advance the slide. There we go.

Anyway, the point I'm working up to here is that there are some known knowns, and any scientific problem which we completely understand we can eventually approximate perfectly given sufficient computing power.

And we absolutely understand lighting and shadows and color and skin 100 percent, and we can expect over the next several decades that we'll achieve, you know, very close to reality in computer graphics in these areas.

But we're still a very long way from accomplishing that and I think we're still about a factor of 2,000 short of being able to simulate these known aspects of light transmission throughout environments and represent completely accurate scenes.

But it gets worse than that because there are unknown problems, there are problems which we don't even know how to solve given infinite computing power. These come in the form of simulating accurate human thought or movement or speech, or any other aspect of human intelligence.

We don't have the algorithms, and even

if you gave us an infinitely fast computer today, we still wouldn't be able to conduct -- or animate characters more realistically than you see today in games like Gears of War and Call of Duty.

So we're relying on not more computing power in the areas but simple advances in the state of the art and invention. And in the meantime we'll resort to tricks and other hacks to get those aspects of gaming good enough.

But -- so knowing that we want a whole lot more computing power, the next question is can we actually have it. And this is an interesting question right now because we've seen about 40 years' worth of Moore's Law ever since Gordon Moore at Intel articulated the principle in 1968.

We've seen computing power double roughly every two years as transistor sizes have been shrunk smaller and smaller. But we're starting to run into trouble because our transistors are approaching the size of atoms.

And while you might be able to make a one atom transistor, you certainly can't split an atom in half and create smaller transistors. So we're really running into a crossroads here in approaching the physical limits.

But nobody's ever seen more than about three generations ahead in terms of microprocessor manufacturing technologies. And so there are actually a lot of possibilities for the future to go beyond our current limits.

One of the big possibilities is to go vertical. That's to stack multiple layers of chips on top of each other vertically until you achieve the amount -- a much higher amount of computing power. And if that can be done than there's another factor of 10,000 to be had perhaps, in Moore's Law.

If you figure out the number of transistors in a chip, it's about 10,000 transistors by 10,000 transistors. That's a really impressive number, but the stack is only one level high now and if you made that as high vertically as it is horizontal, then there's another huge increase in computing power.

There's also the promise of quantum computing coming up over the next few years. In the last few years there have been a lot of practical advances in this area, people constructing computer chips up to like, five bits in size. You know, versus the gigabits we have today in classical computing.

But we're really starting to now develop the fundamental building blocks we need to build far more powerful computers. And the big, interesting thing there is that while traditional computing chip has a series of transistors, and each transistor performs one operation at a time, a quantum computer can operate on many pieces of data in parallel and thus produce a much, much higher level of computation.

And ultimately if we look at this, since the 1980s the physicist Stephen Hawking did some very interesting work that started with black coal physics that developed into a sort of quantum theory of information which established there's actually a physical limit to the amount of computation -- or computational power that can be packed into a given space.

And that's known as the Bekenstein bound. And it's a really interesting thing to look at that bound because it's about a factor of a trillion trillion higher than our current computers are in processing power. And so if we're able to get to these limits, then we could potentially have Moore's Law continuing to double computing power every couple of years for another 200 years almost.

And that starts to sound science fiction-y at some point, but if we look at practical advances in physics and how they've translated to later engineering advances that affect the real world, there's a fairly long time lag from the discovery of electricity and its existence to the employment of practical consumer electronics devices.

And then in 1905 Einstein discovered the equivalence between matter and energy and came up with the idea that matter -- a small amount of matter could be converted into a vast amount of energy, in 1905. And then 40 years later that was turned into a physical reality with the invention of atomic weapons.

So these areas of leading-edge physics can be a bit scary but also promising for the future of computing. Because you might expect that over the course of our lifetimes we really start to push up to such high levels of computational power that we can come very close to simulating reality.

But these technical aspects are very predictable, just from the laws of physics and science. The social implications are much, much cloudier because there's no Moore's Law applied to invention or to the social adoption of new technologies.

Rather the progress that we see in the industry comes in fits and starts. You know, the internet was initially developed in 1968 before I was born. But it was about 25 years later that it actually became a consumer force that started to affect people's lives.

The technology and substrate that was there for Facebook could have been developed 10 years earlier, but for some reason it didn't come along. And these -- the reasons behind these fits and starts in the industry are really social rather than technical.

Facebook is something that my generation really has trouble with. I mean am I supposed to take up drinking so I can post embarrassing pictures of myself for my friends to see? I don't get it.

But what Facebook needed was a new generation of kids who'd grown up seeing computers as a social device, not as a tool for work or science or development, but as a social medium. And who are comfortable doing that sort of thing online.

And -- so many of the limitations we face are really just limits of the imagination here. You know, the progress -- the lack of progress that occurred between the invention of the Blackberry, this breakthrough device which put email in everybody's pocket, to the invention of the iPhone was marked with a real lack of progress for many years.

That was just because somebody who was really brilliant had to come along and realize that you could combine touch screen technology with a very fast, mobile CPU, with a high-resolution display and internet connectivity, and create a device like the iPhone.

It's limited by invention. And the technologies that have been put before us, you know, with this always on 3G-based internet connectivity that goes with you mobilely, and all the other technologies we have among us, these ultra-fast CPUs that are in our pockets, are driven by completely different forces than Moore's Law.

And so we can't predict the future here but all we can do are identify trends that might shape the future of computing and gaming. And so I'm not going to try to make a detailed proposal here, but I'm just going to point to some of the things that really inspire me and make me think that we're headed to an entirely new level of consumer experience. And that this will continue to happen over the next couple of decades.

First of all is the pervasive connectivity in GPS and orientation sensors. You know, my iPhone always knows exactly where it is. I can now go on a hiking trip and never have any possible risk of getting lost because it always knows exactly where I am, can place me on a map.

This is fundamentally important. You know, if you look at what Facebook does with social networking, enabling people to make social connections, there's a whole new dimension of that that could be connected physically based on physical proximity, connecting people to business and other nearby aspects.

So I think technologies like Google search haven't even begun to touch on that. And then there's the thought of integrating, you know, your 3D positioning in the real world into games, you know, through augmented reality. And that's incredibly tantalizing.

There have been some early experiments there but I think that's a whole area that's prone to a major revolution over the next decade or so as people just discover the right ideas for games and the right mix that makes an entertaining experience.

Right, really see the possibility of Zynga-scale startups coming along, figuring out the key mechanics of that space and exploiting it successfully. With Kinect, we've also seen the idea of pervasive sensors becoming aware of your body and its motion and being able to replicate that in a computer environment.

And Kinect is really -- this is an idea that's been around for a long time, but the Kinect is the first consumer product that's actually carried that through to its full completion with a combination of some amazing Microsoft research work on camera technology and

3D image recognition, combined with the fun consumer experiences developed by game creators.

We're starting to see some -- a lot of new possibilities. But just think what's going to happen over the next decade or two as these sensors become mounted to every device. You know, what if your iPhone could see your entire body and could recognize gestures? And what other control mechanisms could we have that way as we get more and more precise input from these sorts of devices?

I also find Apple's work with Siri really impressive. You know, it's a voice recognition app but it's the first one that really works. You know voice recognition, everybody's been talking about it since the 1980s as being just on the verge of practicality.

And then you try to use your Windows PC and tell it open file and it shuts down because apparently they sound alike. But -- (to screen) don't do that. But Siri does it well enough that I'll actually be out driving, I'll say Siri, tell me how to get to McDonald's or something like that, and it recognizes it perfectly every time and it pops up with the correct result.

It really -- there's some magic to it that they've perfected that technology to a level where it's now easy to see that voice technology, voice command and control being applied to every consumer product across a wide range of devices and becoming a real permanent part of our computing experience that lets us do a lot in a hands-free manner that frees up our hands to do more important things.

Whether it's controlling a game or driving through while you're asking for street directions, there are some real interesting possibilities there. Also there's been a lot of work with cloud computing.

The really amazing thing with something like Google search or Siri is that you enter a command, it's sent to a server, and then for a short period of time, a few milliseconds, an absolutely colossal amount of computing power is applied to your problem, and it results in a simple result sent back to you.

Now I can just imagine the power grid in China dimming when you ask Siri for directions to McDonald's with the computing power it's applying to recognizing your voice out there.

And we're also seeing the move to cloud gaming with OnLive and Gaikai, and so a lot of people are thinking about what does this really mean to us.

But as game developers, this is a super interesting technology because it means that we could now build games that exploit huge amounts of computing power in the server farm and don't require a whole lot of client power.

But ultimately the value of these services isn't going to be that they bring new features to us, but it's that they're transparent, that if OnLive and Gaikai are to be successful, it will be because their gaming experience is as good as playing on your Xbox or your computer and as seamless and as perfect.

So from a game developer's point of view, I don't see these having a big effect. We'll build the same game, we'll create the same meshes and you know, have the same design considerations and the consumer will play it in the same way, and the only question is whether it runs on a machine that's sitting in your living room or up on a server somewhere.

And so I think we can largely look at

that as a factor that's not going to change our industry fundamentally, but will make it more convenient to consumers.

Now the other interesting thing that's been happening for the last few years, and Epic's now in this game despite being a latecomer -- virtual goods and microtransactions. The ability to sell people things that don't actually exist.

It's a kind of a neat idea. But if you think about it, we have a world full of countries like China and India, they're becoming increasingly wealthy. But we can only mine so much iron ore out of the ground and only pump so much oil out for mankind.

And so in the future, physical goods are going to be increasingly expensive and scarce. And rather than being a catastrophe, I just think this means a larger and larger portion of our economy will transform from making stuff to creating virtual experiences and selling them online.

I would say that in another 10 or 20 years you might find that the virtual economy is a sizeable fraction of the real economy. Like the worldwide real estate market is something like 25 trillion. Well, the virtual economy in 20 years might be 25 trillion as well, which is probably a few hundred dollars of today's dollars.

But I really think this is going to fundamentally change. And if you look at young people and especially in markets like Korea and China, there are people who don't -- who are not enormously wealthy but they're extremely eager consumers of virtual goods and games.

And I think more and more of the world is going to look like that. You know, we're going to get by with smaller and more efficient cars and smaller houses, but we're going to be living more and more of our lives online and have incredibly realistic experiences there in that virtual economy.

I also look at augmented reality experiences like Word Lens. This is a little app for the iPhone. You pull out your iPhone, you point it at things and it's kind of a window into a world where all the text is translated into a new language.

So you point this at a stop sign and it translates the stop -- the word stop to Spanish in 3D, in a scene that looks just like the real world behind it. That's one of those few apps that stood out to me as really magical, and really is a hint of the things that are to come to our industry.

There are many other things heading in this direction. You know, Samsung recently showed the Samsung Window, this really funny device which is a -- it's a window, a transparent window, and when the device is turned off it looks just like any ordinary window.

When you turn it on, it pops up a 3D display that's overlaid on top of the window that has an alpha channel. So you have the ability to display color images but also to backlight it with an LCD so that you have portions of the background masked out from behind you.

And so if you had one of these in your houses you might, you know, go up to it and you might, you know, arrange your recipes or control your microwave oven or do anything like that on a surface that's a mix of a view into the world and virtual objects overlaid on top of it.

But this could also become a lot more pervasive. Sony recently has announced a virtual reality headset product. Now this is an idea that we all kind of look down on because it was a cool idea in the 1980s but it sucked then and we assume that it's going to suck forever into the future.

But that's only the case until somebody does it really well. Now here's a product -- a company that's announced a product and shown it in public demos. It's basically like your Oakley sunglasses except they have a -- basically a very high resolution LCD display on the inside that projects onto your eyes.

And so as you're walking around with these they overlay arbitrary images on the environment in a real augmented reality display device that's, you know, basically a convenient consumer form factor.

This is going to be really exciting to see what game developers do like that -- do with that, because augmented reality, if it's you walking around doing this sort of thing it's not very fun, right? But if it's just there and it's always pervasively in front of you, that's an entirely new level of experience and it becomes very interesting.

And at the same time we have a lot of platforms coming together. There are the tablet platforms, there are the smartphone platforms, and computers, you know, PC and Macintosh, and then there are consoles, Xbox 360, PlayStation 3, Wii, and some new handheld dedicated gaming devices, and God knows what else.

This is too many platforms. And we're seeing now, iPad sales have surpassed the sales of desktop PCs. That's a real revelation to me. This is a product that wasn't invented until a few years ago, and it's basically supplanting the personal computer industry as we know it.

Over time these platforms will be winnowed down into a much smaller set of computing platforms. You know, there might be one or two or maybe three winners worldwide across everything -- computers, game platforms, smartphones.

So we should expect a lot of consolidation here, and winners and losers according to who picks the right directions and executes successfully on them.

To wrap up, there are a lot of huge technical changes, and I think just of the technologies and bits of computer hardware that we know how to manufacture now, I think we've just barely scratched the surface of their consumer implications.

What we can do with an iPhone or an iPad today is limited by our experience with computers and our histories, but when a whole new generation of kids is raised with these devices pervasively around us, it's going to lead to an entirely new world.

And I think -- think about that girl who was handed the magazine and thought it was a broken iPad. What's life going to be like in 20 years when she goes off to college? You know, will she just have a Facebook account like today's college kids or will she be pervasively connected to all of her friends in a way that we can't even imagine today?

You know, having augmented reality connections to them wherever she goes in life, to being able to see and stay connected and see what friends are doing. I find the possibilities here fascinating, both scary and interesting.

But the big point is I see a bright future for the future of computing and its implications on games. I really see the ability for us as game developers to exploit another thousandfold increase in computing power in future generations of platforms.

Some of them will be consoles, some of them will be PCs, some of them will be tablets. The form factors we can't predict, but the opportunity is there and I think our industry's brightest days are yet to come. And it excites me very much. Thank you very much for listening.

(Applause)

C E R T I F I C A T I O N

I, Sonya Ledanski Hyde, certify that the foregoing transcript is a true and accurate record of the proceedings.

Date: March 26, 2021

Sonya Ledanski Hyde