Justin Rattner; Intel Chief Technology Officer

Justin Rattner: Well, good morning. And thanks for sticking around. I know it's tough. Three days of IDF kind of wears you out. So I always appreciate the audience on Thursday morning when we get around to talking about research and technology.

Given that it's Intel's 40th anniversary year, I guess it would be reasonable to expect that I'd be doing some kind of retrospective on Intel technology over the years. But we thought we'd have a little more fun. Rather than look back, we're going to look forward 40 years and try to imagine what things might be like 40 years from now.

It's in that future where many people think that machine intelligence will surpass human intelligence. Can you imagine that? Doesn't that sound almost too fantastic to believe? Well, let's hear from inventor and futurist Ray Kurzweil and get his view on that idea.

[Video plays]

Justin Rattner: Singularity, the point at which machine intelligence will surpass human intelligence, it might be only a few decades away, because technology is advancing not a linear rate, but at an exponential rate. And we're familiar with exponentials. Progress in the next 100 years won't be like progress in the last 100 years. It'll be more like progress in the next 20,000 years because of that exponential advancement in technology. We're literally watching technology move at an ever-increasing pace. How's it going to happen? What will the key technologies look like? That's what we're going to explore in this morning's keynote.

So let's start with a familiar topic which is computation. It seems like a good place to start, because that sort of forms the foundation of everything we do. And at the heart of computation, of course, is integrated circuit technology. It's been that way for many decades, more than 40 years, in fact.

How is it advancing? Well, of course, it's advancing at an exponential rate as described by Moore's law. We all know that. That's one of Kurzweil's exponential growth curves. It's one of the growth curves that he cites in the book. He talks about other technologies and how they're moving forward at that exponential rate.

So it's reasonable to ask this morning, when will silicon run out of gas? Can it fuel this exponential growth for 40 years to come? Well, we got very close to a limit of silicon technology at 45 nanometers. But we were able to innovate our way out of what seemed like an unsolvable problem, and that was with the development of the high-k/metal gate. And it was able to keep Moore's law right on schedule. Nobody missed any deadlines. The next processor, next chipset came out right on time, 45 nanometers.

And at 32 nanometers we appear to be in good shape. Paul Otellini was on this stage last fall, showed that big wafer full of 32-nanometer memory chips. So it looked to be in good shape. But beyond 32 nanometers, and possibly beyond CMOS, what's it going to take to keep going? To tell us, I've invited Dr. Mike Garner who's a senior technologist and manager of our emerging materials group to give us some answers. Come on out, Mike. There you are.

Dr. Mike Garner: Hi, Justin.

Justin Rattner: Thanks for being here this morning.

[Applause]

Dr. Mike Garner: Good to be with you, Justin.

Justin Rattner: That's great. Well, we've got some challenges ahead of us, you know? And it looks like 32 nanometers is on track, but, you know, you go beyond that and I don't know, it gets a little bit iffy. So let's start and talk about some of the developments that are taking place right now to sort of push beyond 32 nanometers. What's the next step in your mind?

Dr. Mike Garner: Well, the next step is basically to continue working on new materials to improve transistor performance, but also look at more novel structures such as the tri-gate transistor and other things. So there are several options on the books for future technologies.

Justin Rattner: Okay, now, tri-gate sort of moves the transistor from the bulk up onto the surface. What's that going to do for us?

Dr. Mike Garner: That gives you higher speed, lower power consumption. There's lower leakage. And it clearly gives you higher density and potentially a reduced variability in devices.

Justin Rattner: So we get a better transistor when we do that?

Dr. Mike Garner: That is correct.

Justin Rattner: All right. So, okay, moving up to the surface, when you move up to the surface, I assume you're not limited to silicon? You can use other kinds of materials?

Dr. Mike Garner: Well, there are other materials such as compound semiconductors, quantum well structures. There are a lot of options when you get --

Justin Rattner: Three/five kind of materials?

Dr. Mike Garner: Three/five-type materials, gallium, indium, arsenide, other types of materials like that.

Justin Rattner: Okay, and what are their advantages?

Dr. Mike Garner: They basically allow electrons to move much faster. And by going to lower voltages, you can also potentially have higher energy efficiency, but with an improved speed.

Justin Rattner: Okay. But now those are, I mean, they're still CMOS devices in some sense, right?

Dr. Mike Garner: This is correct.

Justin Rattner: So what happens when we get to the point where we just can't scale those devices, those CMOS devices any more?

Dr. Mike Garner: Well, we're going to keep pushing as far as we can. I don't know what that point is.

Justin Rattner: I know, you guys never want to let go. That's the problem.

Dr. Mike Garner: That's correct. We think that CMOS will still be a workhorse for many years beyond in the future. But there are options.

Justin Rattner: All right, tell us about it.

Dr. Mike Garner: And we're looking for some options for novel state variables such as electron spin, magnetic memory, molecular devices.

Justin Rattner: Okay, so moving away from electronic charge now to other quantum effects?

Dr. Mike Garner: We think that actually that CMOS will probably be the platform, and then we'll have other functions on top of that, the other things such as these other state variables. And it may enable some new computing functions, more than maybe two states at some point.

Justin Rattner: So moving beyond binary logic, is that what you're talking about?

Dr. Mike Garner: That's correct, possibly moving beyond binary logic. There are other things such as quantum computing, and things like that could have multiple states.

Justin Rattner: Okay. So there's a lot of talk these days about carbon nanotubes and graphing. Tell us a little bit about those kinds of materials.

Dr. Mike Garner: Okay. Those materials do have extremely high velocity for electrons. They can support very high speeds, and so they could enable lower power operation, higher computing speed. Also, they have spin functions, so you could actually have a combination of electronic transport and spin properties at the same time.

Justin Rattner: I see.

Dr. Mike Garner: Those are some of the types of things we're looking for.

Justin Rattner: Okay. It sounds like there are a lot of options here.

Dr. Mike Garner: There truly are a lot of options.

Justin Rattner: How do you sort through all these options?

Dr. Mike Garner: Well, we are working with the Nanoelectronic Research Initiative which is a consortium of the National Science Foundation, several federal labs, Intel, and others working at four different centers that are sponsored by state governments and federal to identify innovative concepts and devices.

Justin Rattner: This is really an industry/academic collaboration of some scale.

Dr. Mike Garner: That's correct. It's a very large organization; four major centers all working and coming up with innovative ideas to develop spintronics. At UCLA they're working on spin-based devices.

Justin Rattner: Now, aren't there European activities along that line, as well that we're a part of, too?

Dr. Mike Garner: Yes, There are clearly. We're participating in Europe with IMEC and [LETEE] in a couple of things as wells as a center in Ireland called [CRAN]. Crown -- actually if you pronounce it's correctly, it's crown.

Justin Rattner: All right.

Dr. Mike Garner: We are, but there's not one singular research effort in Europe.

Justin Rattner: Well, for a materials person this sounds like a very exciting time. We basically were building that one transistor for many, many decades and now it looks like there are a lot of options on the table.

Dr. Mike Garner: Justin, this is really an exciting time for materials. If you're looking for the beyond CMOS, we're like back in the 1940s trying to invent the new transistor and developing new materials to support these new concepts.

Justin Rattner: Well, when you get one of these things come on back and we'll have you up on the stage and you can tell us all about it.

Dr. Mike Garner: We'll bring the University in to show you.

Justin Rattner: All right, thank you. Thanks, Mike! Mike Garner, everyone.

[Applause]

Justin Rattner: Well, of course building faster, smaller, more efficient transistors is fundamental to moving towards the singularity, but just having fast transistors isn't sufficient. We have to have high-speed signaling. We need to move information very quickly both across the chips and between the chips.

But wires use electrons and pushing those electrons ever faster means more heat, more power, more energy, and in fact at some point we literally can't get enough electrons to move across those wires to actually detect the signal at the far end.

So what's the alternative? I was delighted to hear, but the way, Steve Wozniak mention photons. He's one fiber in, one fiber out. It sounds like a good idea to me. So, in fact, we're actively exploring the use of photons in our silicon photonics project. The nice thing about photons is the fact that they don't interfere with one another.

They move almost losslessly across various kinds of optical media, and that means a lot less energy is wasted and, of course, the bandwidth of photons is phenomenal. Once you form that photonic link you can push it to trillions of bits per second.

So, to catch us up on what's happening in the area of photonics, particularly silicon photonics which is our focus at Intel, let's welcome Brian Koch from the University of California at Santa Barbara. Come on out, Brian.

[Applause]

Justin Rattner: Welcome to IDF.

Brian Koch: Hi. Thanks for inviting me.

Justin Rattner: It's great to have you here. Tell us a little bit about yourself. I think the audience would be interested.

Brian Koch: I just received my Ph.D. from UC Santa Barbara from Professor John Bowers and also Dan Blumenthal there.

Justin Rattner: And what have you been doing this summer?

Brian Koch: This summer I've been working on a continuation of a project that they started about two years ago which is hybrid silicon laser, and so the way they made these lasers is to bond a piece of indium phosphide on top of silicon wave-guides.

Justin Rattner: So the graphic here shows that on the left-hand side, right?

Brian Koch: That's a cross section. So, when they inject current into the indium phosphide they actually get light out of the indium phosphide that couples into the silicon wave guide and travels across the top of the wafer.

Justin Rattner: Okay, and we actually had that on stage. Professor Bowers was here and we demonstrated the hybrid silicon laser, the first one. Now, tell us a little bit about the second generation.

Brian Koch: The new laser is basically the same idea except now we have these mirrors that are integrated on the chip. Before, the device required the edge of the silicon to form the mirrors so we couldn't actually integrate it.

Justin Rattner: I see. So that means what?

Brian Koch: Well, so now we can put things like an external modulator which encodes data onto the CW laser signal.

Justin Rattner: I see. Okay, well that sounds like a fundamental advance.

Brian Koch: Yeah.

Justin Rattner: Do you have one we can take a look at this morning?

Brian Koch: Yeah, I do. There's one running over here. This is basically my entire lab on the floor here.

Justin Rattner: I have to say, maybe it's just the research and technology keynote -- we don't have moving screens and all that stuff; we have hardware.

Brian Koch: Right. You can see on the right image up on the screen; that's the laser.

Justin Rattner: It's kind of hiding back here under the microscope.

Brian Koch: It's very small. It's about 1 millimeter long and I'll just show that this is real. I can turn this off here. On the left side of the screen is actually the data that's coming out of the laser and that's at 3.2 gigabytes per second.

Justin Rattner: Wow! Now this is different. You're directly modulating the laser.

Brian Koch: Right, and we're doing it at 3.2 gigabytes per second, which is fairly fast, but we want to go a lot faster than that.

Justin Rattner: That's why it's so important to be able to couple the laser to the modulator.

Brian Koch: So, the modulator we demonstrated recently running at [40] gigabytes per second.

Justin Rattner: Can you give us some of the specs? How much power are you putting out? What wavelength?

Brian Koch: This is sending out about 8 milliwatts of power which is enough to easily go hundreds of kilometers on a fiber.

Justin Rattner: Yeah, I don't think we're going to need that just to go chip-to-chip.

Brian Koch: Right.

Justin Rattner: So we can build smaller ones and less powerful ones. Eight milliwatts is really phenomenal. I think at 5 milliwatts you have to get a license from the government to run this laser. I don't know where your license is but I won't push that any further. [Laughs.] All right. So that's quite a powerful laser. So second-generation hybrid silicon laser. What's next?

Brian Koch: One thing I didn't mention about these lasers that is very important is that the gradings allow us to select a single wavelength for this laser and we can choose this wavelength.

Justin Rattner: So you can tune the laser and that means?

Brian Koch: We can make different wavelengths for different lasers on the chip, have an array of them, each with the 40-gigabit-per-second modulator, then we can combine them to form -- if we had 25 of these then we would have a 1-terabyte-per-second link.

Justin Rattner: Wow; very impressive. That's sort of the transmit side; are we solving the receive side as well?

Brian Koch: On the receive side we can so basically the exact opposite, and they've demonstrated 40-gigabit-per-second [photon] sectors as well.

Justin Rattner: Wow. So we're waiting. We want that photonics transceiver. We'll have you back up here when that's ready, all right?

Brian Koch: I would love it.

Justin Rattner: Thanks, Brian.

Brian Koch: Thanks so much.

Justin Rattner: Brian Koch, everyone.

[Applause]

Justin Rattner: We can't run fiber everywhere. We love our mobile devices and nobody wants to be dragging the fiber optic cable everywhere with them, so what's really obvious is we have to look beyond photonic communication to wireless communication. And to talk to us about the challenge of having everything connected -- not just our phones or our MIDs but literally everything, almost all the devices we can imagine in our universe -- we're going to have to make very clever use of the spectrum.

And here to share his vision of that massively connected world is Dr. Jan Rabaey from the University of California at Berkley and the Donald O. Pederson Distinguished Professor. Good morning! Thanks for being here.

[Applause]

Dr. Jan Rabaey: Thank you.

Justin Rattner: You're looking very spiffy this morning, I have to say.

Dr. Jan Rabaey: Thanks.

Justin Rattner: I've read your stuff; it's just fascinating. You've got this whole concept behind massive communications. Can you share that with the audience?

Dr. Jan Rabaey: Sure. I think we're actually at the point that we see some major changes in the way that we look at computing. The concept of actually fully distributed ubiquitous computing is really happening and one of the main forces behind that is really the wireless connectivity.

Wireless connectivity is one of those things that is, if you look at Ray Kurzweil's description, one of those exponentials. Exponentials are happening and they're really happening quite rapidly. A couple of us have this prediction that about 10 years from now there will be about 1,000 radials per person on earth.

Justin Rattner: A thousand per person?

Dr. Jan Rabaey: That's right, about 1 trillion --

[cross-talk]

Dr. Jan Rabaey: Well, no. They're going to be so small they're going to be hidden in the environment. Every object will have some connectivity to it and this is all due to the fact that we have been progressing in information technology as well as semiconductor technology.

Just to give you an example here, I'll show you a little note. This is a little wireless note. It has a radio in it. It has a processor in it. It has sensors in it. It has power in it. It can be cell-powered; it uses about 6 microwatts in power total. So these types of technology advances make it possible for us to really see this future of your --

[Cross-talk].

Justin Rattner: So Jan, I knew you were going to bring some of your radios, so I brought some of my radios. This is a radio and I think this is what you were talking about, part of your vision. This is what we call a WISP. This was developed by the Intel Seattle Research Lab. And this radio doesn't require a battery. It gets its power from the environment. It scavenges power and when it gets enough charge it wakes up and [finds] a signal.

Dr. Jan Rabaey: This one is solar powered.

Justin Rattner: The dueling radios here.

[Laughter]

Justin Rattner: My radio is smaller than your radio!

[Laughter]

Dr. Jan Rabaey: Anyhow, obviously this dream of having [unintelligible] radios has some challenges to it. Technology has made it possible but at the same time we see some problems. Every one of you who works in wireless technology knows it's kind of unreliable. It goes in, you drop calls all the time, all those kinds of things. And one of the main reasons behind that is, number one, the spectrum is limited. If you put more and more devices down you basically run out of spectrum.

Number two. energy is limited. You only have so much energy available and number three is that we have so many different standards around. Everything is incompatible, so how are we going to make this thing work?

It's clear to me that business as usual is not going to work. We really have to rethink the way we're going to deploy those metrics. Actually, about a couple of months ago there was a very interesting article in [REEE] Proceedings by Peter Cochrane where he said if he would redesign his wireless metrics from scratch today, would he do it in the same way as he have done it before? The answer is a resounding no; you will do it very differently.

A lot of the decisions we have made are because of historical reasons, what we could do at that point in time, and so it's time for us to think about how would we rebuild a wireless networks in such a way that we can provide always-on connectivity in an absolutely reliable way? These are the questions that we basically have to answer.

Justin Rattner: It sounds like a big challenge.

Dr. Jan Rabaey: And there are some interesting ideas around. Here's an example of some of the technology we're playing around with today. Today, spectrum is a static commodity. It's basically assigned by FCC and you either pay a couple billion dollars for a 50-megahertz or something like that, or if you're lucky you get it for free.

So the disadvantage of that is that a lot of the spectrum is not utilized very well. It's empty; nothing's happening. So, it's available there for the taking.

Justin Rattner: But the radios don't know it's there.

Dr. Jan Rabaey: That's exactly right. That's why we need to revolutionize how we design radios, change the way our radios operate. So we have introduced this concept that I call Connective Brokerage. Make it into an economic term and basically create spectrum dynamically on the fly based on need, availability and a set of rules/policies that are out there.

So that's kind of the idea that we're pushing -- Connectivity Brokerage. And in order to make that happen we need to basically have two technology breakthroughs. Number one we call cognitive radio -- we'll explain in a second -- and the second one is collaboration. Those are the key concepts from a technology perspective. We believe that it's going to make connectivity brokerage and a lot more efficient usage of wireless spectrum a lot easier.

So let's talk a little bit about cognitive radio. As I mentioned today, you go to the FCC, you get a chunk of spectrum and you are stuck with that. If you're basically overflowing and saturation happens and you drop calls and all those kinds of things, you're stuck. If I could make an intelligent radio that sniffs around, senses the environment, and figures out what bands are available and what frequencies and channels are available, I could dynamically move my frequency and move to other bands. Or I can change my power or do some other things and move around in such a way that we have a much better utilization of our spectrum availability.

Now, this requires some changes, obviously. This requires us to redesign our radio. It actually becomes a sensor because it has a sensor on it and then it basically does some processing, some optimization, and actually then it adapts.

Justin Rattner: So it senses the spectrum?

Dr. Jan Rabaey: That is correct. It has sensors and adaptation to it, so it then becomes a flexible entity, what we call a software-definable radio. Again, it is enabled by some technology advances of today. So, that's step number one, more effective usage of spectrum.

The second one is what I call collaborative radio. The idea of collaborative radio is that -- if I can get this to move forward. In this room, everybody has a cell phone with them, right? Every one of you has one. Now, suppose that the tower goes out right now. all of you lose connectivity even though all of you have a radio sitting there. Isn't that sad?

What happens today is that wireless radios don't work together. Actually, they fight each other. If you like the IA7 band and things like that, they're basically Bluetooth and Wi-Fi -- they all fight each other.

Now, if I could make radios work together you could become a lot more effective. Rather than from me basically hopping right away to the [star router,] which is just a couple of miles away, I could hop to your sensor to your radio and you can hop to the next one and so on, so forth.

If you do so, you can actually prove that the system gets more efficient, you get more capacity, and you save energy. So, what's to lose?

Justin Rattner: Yeah, it sounds like a perfect world.

Dr. Jan Rabaey: Absolutely, so there's some work to be done to make it happen and you have to rethink some of the ideas, but this is something which is a very powerful --

Justin Rattner: Is the government supporting these novel uses of spectrum?

Dr. Jan Rabaey: Well, those things are not going to happen immediately. Obviously things are not going to change overnight. But it's happening slowly but surely. The FCC is actually looking very actively at some experiments in this space and collaborative radio and so on and so forth. So this is something that's progress. It's going to take time.

And also I see the big companies. You talk about the Nokias of the world, the QUALCOMMs of the world; they're all looking very actively at this set of ideas.

Justin Rattner: Fantastic. Well it's an incredible vision.

Dr. Jan Rabaey: Pleasure.

Justin Rattner: I hope we see it in the not-to-distant future. Thanks for being here, Jan.

[Applause]

Justin Rattner: Okay, we're pretty familiar with wireless communication, using the electromagnetic spectrum to move information from point to point. But there's another opportunity to use wireless technology, and that's to use it to transmit energy, to deliver power from one point to another. What if we could transmit power as easily as we transmit information?

Well, it turns out that there's been some recent progress in this area, and we thought we'd show you an example of wireless power transmission. So here's our own Nikola Tesla, [Alanson Sample]. Come on out, Alanson.

[Applause]

Alanson Sample: Hi, Justin.

Justin Rattner: Well you don't look like the famous inventor, but I think you'll do. So tell us a little bit about yourself.

Alanson Sample: So I'm an intern at Intel Research Seattle, and I'm a grad student at the University of Washington in the Electrical Engineering Department.

Justin Rattner: This is becoming the all-intern keynote. [Laughs] Well it's great to have you here. What have you been doing this summer?

Alanson Sample: So let me show you my project. We call it WREL, Wireless Resident Energy Link. And the motivation here is to transfer large amounts of energy through the air, so --

Justin Rattner: It looks like something out of a Frankenstein movie.

Alanson Sample: Right. So, on this side we have a transmitter. It's a thin design here. We have its [drive] loop and its resident coil. On the receive side here we have a resident coil as the receiver. It's smaller, a little bit more like a laptop form factor and this light bulb.

Justin Rattner: Okay. So we're going to transmit power from that antenna to this antenna.

Alanson Sample: Right. So what we're going to do is we're going to use the magnetic field. So we're going to charge up these coils and transfer magnetic energy across. And this is not like inductive coupling where the efficiency drops off with distance. This is nice because there's a constant efficiency for a period of distance and then it drops off. So that's the exciting new part here the [unintelligible].

Justin Rattner: And what's the hardware you've got kind of sitting over there?

Alanson Sample: So we have a signal generator and an amplifier.

Justin Rattner: So it's just a big power amplifier.

Alanson Sample: Yep.

Justin Rattner: How much power are we going to dump into this?

Alanson Sample: All right, so let's see here. We're going to turn this guy on so we're going to let this light bulb warm up for a second here and turn it up.

Now we're transferring about 60 watts through the air. It's about 75 percent efficiency over about 2 feet.

Justin Rattner: Sixty watts at 75 percent efficiency?

Alanson Sample: Right. So that's more efficient than a lot of [unintelligible]. So to show this as wireless then we can bring this out here and put it back and the light bulb warms up.

Justin Rattner: Nothing up your sleeve?

Alanson Sample: Nothing up my sleeve. We can move it around in the space here.

Justin Rattner: Fantastic. This is a nice demonstration, but what's a practical application of this?

Alanson Sample: Right. So what you need to do is figure out form factors that are usage models that are nice. For instance, laptop designs, so this could fit in the frame of laptops so you can have a smart work environment or wireless USB devices, these sorts of things.

Justin Rattner: So whenever I get my laptop or cell phone sort of near one of these power transmitters it charges right up?

Alanson Sample: Exactly.

Justin Rattner: Okay. Well that's an amazing technology. I guess something we can look forward to in the next four years.

Alanson Sample: Right.

Justin Rattner: All right. Thanks for being here.

Alanson Sample: Thanks.

Justin Rattner: Alanson Sample, everyone.

[Applause]

Justin Rattner: You saw it here first, remember that. All right, well we've been talking about transistors and photons and wireless communications. Wasn't it supposed to be a talk about machine intelligence and human intelligence somehow coming together at some point in the future?

Well, in fact, that is the subject of the keynote this morning. And I think to talk about how machines are advancing towards human intelligence, it only makes sense to look at robots -- sort of our favorite manifestation of machine intelligence. And to do that we have a couple of robotics experts with us today -- Dave Ferguson and [Sid Srinivasan] from Carnegie Mellon University and Intel Pittsburgh Research Center. Come on out, gentlemen.

[Applause]

Justin Rattner: Dave, good to see you.

Dave Ferguson: Hi, Justin. Good to see you.

Sid Srinivasan: Good to see you.

Justin Rattner: [Rini], good to see you. Okay. Well, Dave, I know you're quite a noteworthy roboticist. What have you been doing recently in the robotics area?

Dave Ferguson: Well, one of the large projects we were working on towards the end of last year was the Urban Challenge where it was a combination --

[Crosstalk]

Dave Ferguson: That's right, the [unintelligible] Urban Challenge. It was a competition, a road race in which none of the cars were allowed to have drivers. So the goal was to develop an entirely autonomous vehicle that drive you to work or drive your kids to soccer practice without you having to do anything.

Justin Rattner: Boy, driving with -- oh wow. Okay. And how did you guys do?

Dave Ferguson: Well, we did well actually. Our team placed first. Intel was one of the major sponsors, and it was an amazing event.

Justin Rattner: We bet on the right horse, huh?

Dave Ferguson: Yeah, that's right.

Justin Rattner: Okay. Well what are some of the challenges you encounter when you try to build a vehicle that can drive through an urban area?

Dave Ferguson: So probably the biggest challenge is trying to cope with the large amount of uncertainty that's involved in human environments. So nothing ever happens the same way twice when you're out on the road or in your own homes or offices. And this is the key focus of our current project, the Personal Robotics Project, which we are working on at Intel. We're trying to free robots from controlled factory settings and bring them into performing useful tasks in our homes and our offices.

Justin Rattner: And they have to be programmed exactly.

Dave Ferguson: Exactly. So nothing is ever the same in my home or my office, and so the robot needs to be able to cope with that change.

Justin Rattner: All right. Sid, what are some of the other challenges?

Sid Srinivasan: Sure. There are a couple of key challenges for personal robots. I think the first one, like Dave was saying, is navigation. Our homes are filled with clutter. There are chairs and tables and moving objects like people. So a robot needs to have a deeper [semantic] understanding of the objects that it sees. And it needs to be able to navigate in a highly-cluttered environment.

So another big challenge for us is manipulation. We want our robots to be able to physically interact with objects in our home, like open doors and cabinets and pick up complex objects like keys, like a coffee mug, or a milk jug.

Justin Rattner: Should I ask if there's a demo coming here?

Sid Srinivasan: Absolutely.

Justin Rattner: All right.

Sid Srinivasan: See the coffee mugs over there?

Justin Rattner: Uh-oh.

Sid Srinivasan: [Herb], why don't you come on out?

Robot Herb: Hi Sid. It is nice to see you.

Justin Rattner: Nice to see you, Herb.

Dave Ferguson: This is our robot, Herb. And right now it's using this blue laser in the front to figure out how it can get to its goal which is in front of the table, and also to avoid obstacles.

Sid Srinivasan: So right now what it's doing is it has a pair of cameras in its elbow. And it's desperately looking for these black plastic mugs. And the whole demo is completely autonomous. It's hands-free. And it has a model of a mug in its brain, and it's searching for these mugs. And what you see up there is the robot's view of what the world looks like.

And now it's figuring out, completely autonomously, which mug to pick up and how to pick it up so it can [lower it into the] basket.

Justin Rattner: It's got it.

Dave Ferguson: So it's got it, yeah. So what it's doing, as Sid mentioned, is it's figuring out safe, stable grasps for it to use to pick up the mug, and then it's figuring out how it can plan for the entire arm to execute that grasp and pick up the much.

Justin Rattner: Okay. Are we going to go for two of them?

Sid Srinivasan: Absolutely.

Dave Ferguson: It doesn't leave until the job's done.

Justin Rattner: All right, a robotic busboy.

Dave Ferguson: That's right. So Sid and I both have to do the dishes and clean the table at home.

Justin Rattner: Hey, I'm in that camp too.

Dave Ferguson: So one of the big focused reasons for this project.

Sid Srinivasan: A key research focus for us is to be able to execute this at human speeds. We don't want a robot to sit around looking at the mugs for 20 minutes before it picks it up. We want it to act very fast at human speeds. And that's been a focus of our research.

Justin Rattner: Super. Well it can probably empty the dishwasher faster than I do. All right. Well that's great. Thank you, gentlemen, Dave.

Dave Ferguson: Thank you very much.

Justin Rattner: Yeah, good luck with Herb.

[Applause]

Sid Srinivasan: Thank you.

Justin Rattner: Sid, thanks for [unintelligible].

Sid Srinivasan: Thank you.

Justin Rattner: Thanks, Herb.

Robot Herb: Have a pleasant morning.

Justin Rattner: Bye, Herb. I don't know if I'd have one of those running around my house. Anyway, I think that demonstration emphasized the importance of another key robotic capability and that's the ability to sense the position of the object. Now the arm you just saw was using computer vision basically to find the object of interest, doing a little bit of model-based computing to identify the objects. But very precise grasping is a real challenge for robots, and it would be an important advance if we were able to figure it out.

To give us an idea of one such possibility we've invited Joshua Smith from the Intel Seattle Research Lab to tell us about some novel work he's been doing in robotic grasping. Come on out, Josh.

Joshua Smith: Thanks very much.

[Applause]

Justin Rattner: You're a famous guy in two ways.

Joshua Smith: Oh really?

Justin Rattner: I know you invented something that probably saved at least one or two person's lives that are sitting here in the audience. Is that right?

Joshua Smith: Are you talking about the car seat that's in all the Honda cars?

Justin Rattner: Right. So it controls the airbag deployment?

Joshua Smith: Right. It prevents it from deploying in bad situations.

Justin Rattner: Right. And I also read a story about you in the New York Times this morning so you're really getting famous.

Joshua Smith: Wow. I think you were in there too.

Justin Rattner: Okay. Well, I see we've got another robot over here. And really we're going to focus on sensing as a key part of grasping. So why don't you take us through it?

Joshua Smith: Okay. We're going to start up the robot here. This uses a new sense that we've built into the robot hand, the same sense that you mentioned from the car seat. It's called Electric Field Pre-Touch. This is a sense that humans don't use but various species of fish use to sense their environments.

So the robot hand -- there's no camera here. The hand is actually tracking this apple.

Justin Rattner: It wants the apple, Josh.

Joshua Smith: That's right, I know. I'm teasing it. It's not nice.

Justin Rattner: I think you better give it the apple, Josh, or it will get mad.

Joshua Smith: All right. So we'll hold still for it. Yeah. I'm going to take it back.

Justin Rattner: I wouldn't cross it.

Joshua Smith: Yeah, I know because it could grab you or . . .

Justin Rattner: Uh-oh. Oh, it's very gentle.

Joshua Smith: Yeah, it let me go. But we'll give it the apple this time.

Justin Rattner: Okay.

Joshua Smith: And bring it over to you. But this is generally a pretty friendly robot.

Justin Rattner: Whoa.

Robot: Please take this.

Justin Rattner: Okay.

Robot: There you go.

Justin Rattner: Gee thanks.

Joshua Smith: So we can also . . .

Justin Rattner: Very good apple.

[Laughter]

Joshua Smith: We can interact with it like this too. We've done a lot of things to make interaction with it safe and human-friendly. So we've stimulated springs here so you can touch it and so forth which industrial robots --

Justin Rattner: That's not actually in the robot. That's programmed in the robot.

Joshua Smith: Yeah, there's no spring. It's completely virtual; we just simulated the spring.

Justin Rattner: So what's next for this technology?

Joshua Smith: Well, there are three things. One is figuring out how to get more geometrical information from the sensing technique. Another, the most important, is to connect it with the previous robot that you just saw and build a complete system. Finally we want to build a personal robotics ecosystem that extends the personal computing ecosystem, and that's the big project that we hope people here will help with.

Justin Rattner: We'll put the hand on the arm and then build out the ecosystem.

Joshua Smith: Yep.

Justin Rattner: It sounds like a pretty big challenge, but I'm sure you're up to it.

Joshua Smith: Thank you very much.

Justin Rattner: Thanks. Josh Smith, everyone.

[Applause]

Justin Rattner: Okay. So we're making machines, robots in particular, more like humans, teaching them to navigate and to grasp and to do other routine tasks that humans do of course every day and have been doing for hundreds of thousands of years, if not more.

What are we doing to make humans more like machines, to give them capabilities beyond the five senses that we use every day?

Well we're going to take a look at some very interesting technology that moves us beyond the keyboard and the mouse as the primary input device, even moves beyond advanced interface technology like speech recognition.

As Ray Kurzweil pointed out in the video segment, machines are talking to each other at billions of bits per second. How do we begin to communicate at this very high bandwidth? And to show you what might be done to use mind control to talk to machines, we've invited Tan Le, who's the president of Emotiv Systems, to show us some of the work she's doing. Come on out, Tan.

Tan Le: Hi.

Justin Rattner: Morning.

Tan Le: Good morning.

[Applause]

Justin Rattner: Glad you're here.

Tan Le: Thank you.

Justin Rattner: Okay, you look pretty normal.

Tan Le: Yeah. I'm pretty normal. [Unintelligible].

Justin Rattner: All right. So what really captured my imagination about your work was this idea of using our brains to talk directly to machines.

Tan Le: Absolutely, because up until now, all of our communication with machines has been limited to very conscious or explicit forms, you know. Whether it's something simple like turning on the light with a switch or even as complex as programming software, we've always had to give machines a command for it to perform any function for us.

And really that limits our ability to navigate through the masses of information that we have now at our disposal. And this information overload is actually becoming more and more complex over time.

So on the other hand, you look at communication between us as humans, it's actually so much more compelling because we take into account so much more than what is explicitly expressed.

Justin Rattner: Right, sort of body language and all that.

Tan Le: Yeah, facial expressions -- we observe that. We observe body language. And then from that we can start to infer feelings and emotions into our dialogue with each other. This is something that doesn't exist today in our communication with machines. So at Emotiv, our vision for the future is that communication with computing has to involve a total form of communication where it starts to understand and interpret your facial expressions, your emotions as well.

Justin Rattner: Okay, now, a lot of people have talked about using computer vision to do that, but you're talking a different approach.

Tan Le: We're taking a different approach. We're taking signals directly from the brain. So we're naturally emitting electrical signals as we're standing here. And we're just taking sensors that measure those fluctuations at the surface of the scalp, totally noninvasive technology, and then basically determine what it is that you're --

Justin Rattner: Should we go take a look at this?

Tan Le: Yeah, let's do that.

Justin Rattner: All right.

Tan Le: So I'll introduce you to Zackary.

Justin Rattner: Hi, Zack.

Zack: Hello, Justin.

Justin Rattner: Welcome to IDF.

Tan Le: So here is the first interaction point. And what you see here on the screen are spirit [wisps]. And what they generally do in a normal game paradigm is you would press a combination of buttons --

Justin Rattner: Before you do that, he's got some thing on his head.

Tan Le: That's right. He has the headset on his head, which is picking up electrical signals measured at the surface.

Justin Rattner: So is that actually directly coupling his brain activity into this computer?

Tan Le: That's right, wirelessly transmits the signal to a USB --

Justin Rattner: Far out.

Tan Le: Pretty wild. Okay, so Zack, if you get to the interaction point -- so here, he can just simply make a scary face and scare the spirits away instead of having to -- very intuitive, very natural, nothing he has to learn. And what you can also notice also is the color of the sky. The color palette actually reflects his mood. So as we're [walking] through this demo --

Justin Rattner: The background is changing color.

Tan Le: Yeah, that's right.

Justin Rattner: Wow, you really have to want to share your thoughts with the world here.

Tan Le: Absolutely. But here he's actually moving the rock with the thought of lifting it, and once he's lifted the rock --

Justin Rattner: Use the force, Zack, use the force.

Tan Le: He can actually walk across and apply that lift action to other obstacles in the game as well. So here he's come up to a bridge and what he'll need to do is maintain the thought of lift over a longer period of time in order to trigger that action and hopefully repair the bridge to allow him to walk across.

Justin Rattner: Focus, Zack.

Tan Le: May the force be with you.

Justin Rattner: Not quite there. Well, this is what happens when you're at the bleeding edge of technology. I've seen this work.

Zack: Yes, the force in front of 4,000 people.

Justin Rattner: Yes. Yes. All right.

Tan Le: It's done. What did you want to do --

Justin Rattner: Oh, he wants to do something else. Okay.

Tan Le: Okay.

Justin Rattner: All right, that's fantastic. So is this something you can buy?

Tan Le: Yeah, you can buy it in several months, and we're actually also working very closely with developers now, so if developers are interested in working with us --

Justin Rattner: I'm sure the game developers will be really interested in it.

Tan Le: Yeah, definitely.

Justin Rattner: So kind of a stocking stuffer for this Christmas.

Tan Le: Yes, absolutely.

Justin Rattner: All right. Tan Le. Thanks.

Tan Le: Justin, thanks very much.

Justin Rattner: Thanks, Zack.

Zack: Thank you, Justin.

Justin Rattner: You have the force, Zack. Wow, mind control. This is getting scary. All right? But, you know, as impressive as some of these demonstrations have been, they're not as far out as the one we're going to show you next and will be our last demo for the day.

In fact, when I first saw this technology, I thought of that famous quote from Arthur C. Clark that says any significantly advanced technology is indistinguishable from magic. And I think you'll agree that that quote applies very strongly in this case.

What we're about to talk about and demonstrate, at least in early form, is this notion of programmable matter. Many of you may have read the Michael Crichton book Prey, where he talks about these shape-shifting entities that consist of millions or billions of tiny, intelligent nanobots working together to create objects of various shapes and sizes. It's pretty mind-boggling, and it's sort of harder to describe verbally than to see it in action, so let's watch this short video.

[Video plays]

Justin Rattner: Shape-shifting materials. Sounds pretty fantastic. But let's actually take a look at some real shape-shifting material that's in development. I'd like to bring out Jason Campbell from the Intel Research Center in Pittsburg. Jason?

Jason Campbell: It's great to see you.

Justin Rattner: Good to see you. Thanks for coming.

Jason Campbell: Yeah.

Justin Rattner: I trust you're not going to change shape on me here.

Jason Campbell: You never know. I could be still in Pittsburg.

Justin Rattner: Oh, gee, that's scary. First I've got robots handing me apples, mind control --

Jason Campbell: You're the one who set the agenda for the next 40 years.

Justin Rattner: I've learned my lesson. So tell us a little bit about this technology and how we're actually at work trying to create it.

Jason Campbell: You know, it's a really challenging vision. It's sort of not incremental research vision, but we're making steady progress on it, and so I'm becoming more and more convinced we're actually going to do it.

Justin Rattner: That that video will be reality.

Jason Campbell: My estimates of how long it's going to take have gone from 50 years down to a couple more years.

Justin Rattner: Ah, that's the exponential -- moving towards the singularity --

Jason Campbell: And that's been over the course of the four years I've worked on this project.

Justin Rattner: Okay. So should we take a look at some of the artifacts?

Jason Campbell: [Unintelligible] some hardware I brought with me.

Justin Rattner: Okay.

Jason Campbell: And a lot of these things we're looking at, we built in concert with our collaborators at Carnegie Mellon as well as AFRL.

Justin Rattner: All right.

Jason Campbell: So give credit to them where credit's due.

Justin Rattner: Sure.

Jason Campbell: You know, in the video we saw [catom] depicted as spheres. We call each one of the elements that form these shapes a catom.

Justin Rattner: Okay.

Jason Campbell: The C comes from claytronics, I guess, which is another one of the names we have for this technology. This is an example of one of our --

Justin Rattner: Electronics, photonics, playtronics.

Jason Campbell: Yeah. Really programmable morphology, the ability to change shapes on command.

Justin Rattner: Okay.

Jason Campbell: So this is one of our early research prototypes. You know, I said we're aiming for spheres eventually. In order to make the task easier to start with, we took a cross-section of a sphere, so we have cylinders.

Justin Rattner: Okay. So this is really a 2D --

Jason Campbell: This is a 2D equivalent -- it has a microprocessor, it has some memory, and it has a bunch of electromagnets around the outside here. Now, if we look at two slightly later prototypes here, you can see they've got a large number of electromagnets around the outside and the magnets let them roll around each other's perimeter. And that's the fundamental sort of actuation mechanism, the way we get these things to move, is rolling across each other's surfaces.

Justin Rattner: Okay. Now, electromagnets may make sense at this scale. What happens if we go smaller?

Jason Campbell: That's absolutely the right question. Electromagnetics let us build something else at this scale. But really we want to move to electric fields, so we learned as much as we could here, and we went -- if you'll go to the next slide, I think, that we have, we built a number of tubes that I didn't bring any with me with. Each one of these tubes is actuated by electric fields. And, in fact, right now, we're trying to build a tube that will carry the control circuitry that allows it to move itself around. And hopefully this fall we'll have a tube with electric field actuators and control circuits rolling around.

Justin Rattner: And size-wise this is --

Jason Campbell: One millimeter across. These are about 10 millimeters long, but 1-millimeter diameter for the round part --

Justin Rattner: That's already getting pretty small.

Jason Campbell: Already quite small. For electric field actuators, you need things to be small, you need the dimensions to be small, so we don't have an option, we have to get small.

Justin Rattner: With all this nanotechnology, you can pack a lot of smarts.

Jason Campbell: We can pack a tremendous amount of, for instance, transistors into that space. I'm not as worried about the number of transistors we fit on it as some other issues.

Justin Rattner: Okay.

Jason Campbell: But let me show you something now that we have never shown anyone in public before. We're starting to learn how to build the geometry behind 3D catoms, and these are silicon-dioxide hemispheres. You can see a hemisphere in each square opening on this substrate here. As I move the flashlight around, you can see the reflection of the flashlight in the sphere surfaces. These were built by [Igel Cherko] in one of our Jerusalem fabs. And what's important here is we need to get the geometry right as well as getting all the components like a processor and actuators together.

Justin Rattner: So this is a small glass hemisphere.

Jason Campbell: Let me give you a sense of just how small. These are a little bit thinner than half the thickness of a dime, but if I zoom out in this camera view, you can see we've put next to that array of hemispheres, a penny here on the side.

Justin Rattner: Wow, they're really small.

Jason Campbell: And that'll give you a sense for the scale that we're working at now. And you should have a real impression that if we built something out of millions of these, like pixels on your display screen, the individual dots would disappear. And you'd see the whole.

Justin Rattner: So how big would an individual catom be?

Jason Campbell: Probably on the order of a tenth of a millimeter, 100 microns or so is a good initial size. Now, it's sort of like your television screen. Over time, you'd like it to get better, you'd like them to get smaller, higher resolution.

Justin Rattner: But, again, even at that scale, plenty of room for logic, for transistors.

Jason Campbell: Tons of room. In fact, some modern processors, we can already fit in that.

Justin Rattner: So the video had, you know, this powerful vision of objects -- big objects that change shape. What are the sort of things you're looking at?

Jason Campbell: Well, in the near-term, sort of high-value applications might include 3D visualization for things like medicine, where you've got some fundamentally 3D data, say, from MRI scanners or CAT scanners or ultrasound. Allow practitioners to really touch it, to prepare for, say, a surgery they're about to do or to make a diagnosis. So it's not just that you're looking at slices of that data. You're actually seeing it in 3D. You can change its scale.

Justin Rattner: Sure. And how about more everyday --

Jason Campbell: On the everyday side, one of the things I'm most excited about is replacing the electronic devices I carry with me. You know, my cell phone is always too big to fit comfortably in my pocket, and it's always too small to fit comfortably on my head when I'm making calls.

Justin Rattner: Uh-oh. I can see where this is going.

Jason Campbell: Really too small to do email or texting with, so I brought a couple of shapes with me to talk about that today. These two -- let me grab the blue one instead -- these two shapes here are --

Justin Rattner: They're just made out of plastic right now, so they're not about to move on you.

Jason Campbell: They're not about to change shape. But they could be made out of the same number of catoms. In both cases, 2 million catoms, each one of which is 200 microns across. So at their smallest, packing them all the way together, I could have a small shape like this that fits easily in my pocket. If I'm getting ready to send an email, I might pull it out of my pocket and convert it into a large sort of midsize device where I have a keyboard and a screen.

Justin Rattner: And as we saw in the video, you could give them the ability, I guess, to turn on red, green, or blue.

Jason Campbell: Absolutely. There are a number of ways to control their appearance, so you can think of them like pixels on a device. So this would actually be a 720p display.

Justin Rattner: Okay, sounds good. It would just sort of, I don't know, not even unfold. Just sort of reshape itself.

Jason Campbell: That's right, more fluidly. And when you're done with it, maybe you morph it into a sphere and drop it into your backpack or into a bracelet and put it on your wrist.

Justin Rattner: So I just have one bracelet. It can say live strong or whatever.

Jason Campbell: You know, and it can say something new every day.

Justin Rattner: Every day. Just what I wanted. Okay. Programmable matter, Jason Campbell, thanks so much.

Jason Campbell: Thanks very much.

Justin Rattner: Well, as you can see, we're making steady progress toward Ray Kurzweil's singularity. And, you know, humans and machines are indeed starting to cross the chasm and move closer together, to ultimately reach that point where machine intelligence exceeds human intelligence.

We saw programmable matter, intelligent matter that can change shape and form and move and change color and do all sorts of amazing things. You know, another part of that vision for the next 40 years.

To get another view of the next 40 years, and I think one you'll find is an interesting contrast to the various demonstrations and examples you've seen today, we asked children around the world who participate in the Intel Computer Clubhouse program to give us their thoughts about technology in the next 40 years. Let's watch the video.

[Video.]

Justin Rattner: I love the quote from the kids, "Making the unthinkable possible." That's what we at Intel, as a company, and all of us as an industry have been doing for the last 40 years. And with your help, that's what we intend to keep doing for the next 40 years. It should be quite a ride. See you all in the future.

[End of recorded material.]