TRANSCRIPT

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)

DARPA ROBOTICS CHALLENGE PROPOSERS' DAY PRESENTATIONS AND WEBCAST

MONDAY, APRIL 16, 2012 12:00 P.M. EDT

EXECUTIVE CONFERENCE CENTER AT LIBRARY CENTER 4075 WILSON BOULEVARD, SUITE 350 ARLINGTON, VA 22203

Good morning everybody, welcome to the DARPA Robotics Challenge Proposers' Day. I am Dr. Gill Pratt, Program Manager at DARPA. We will start by showing you the agenda for our meeting today. So we're going to start up by having some introductory remarks and this is going to be by three different people. The first is going to be John Holdren who is the President's Science Advisor and the Director of the Office of Science and Technology Policy. After that, we're going to have Ken Gabriel who is the acting director of DARPA. Following that, we're going to have Paul Eremenko who is the Acting Director of the Tactical Technology Office. And then, you'll be back to me to begin to talk about the program and what we're really looking for and how exciting I believe that this is going to be. Towards the end of the day, we're going to have Chris Glista who is the Contracting Officer, who will tell you a little bit about how you should write your proposal, things to do and things not to do. And we're going to follow that by the providers of the Government Furnished Equipment for tracks B and track C and that's Rob Playter at Boston Dynamics and then Nate Koenig of the Open Source Robotics Foundation. So let's go ahead and start with Dr. John Holdren who is the Assistant to the President for Science and Technology and the Director of the Office of Science and Technology Policy. Thank you.

[Silence]

Hello, I'm John Holdren, President Obama's Science Advisor and the Director of the White House Office of Science and Technology Policy. And on behalf of myself and President Obama, I want to express our enthusiastic support for the DARPA Robotics Challenge, a creative competition that promises to spur companies and researchers to advance the state of the art in robotic capabilities to aid us in our response to disasters. Through this effort, teams are being challenged to develop a robot that can perform potentially life saving tasks in dangerous environments such as traveling over rubble, removing

debris from a blocked entrance, climbing a ladder, and using tools to replace a broken part. This DARPA Robotics Challenge is exciting for a number of reasons. First, it will advance the goals of President Obama's National Robotics Initiative which he launched at Carnegie Mellon University last June to quote, "Accelerate the development and use of robots in the United States that work beside or cooperatively with people." The Obama Administration believes that robotics technology is approaching critical mass and that teams of humans and robots will soon be able to solve a number of important and complex problems related to manufacturing, health care, space exploration, transportation, and national security. By providing a basic platform of hardware and software to get things started, the DARPA Robotics Challenge will lower the barrier to entry for entrepreneurs seeking to develop new applications for robotics and will attract an expanded pool of innovators. Second, the DARPA Robotics Challenge has the potential to help the Department of Defense achieve the important goal of being better prepared to conduct humanitarian assistance, disaster relief, and other operations. In the same way that DARPA's previous grand challenge dramatically increased the state of the art in self-driving cars, attracting private sector investments, and even changing people's perception of what is possible in that domain, so this grand challenge promises to cultivate revolutionary advances in robotics and perhaps change our assumptions about the potential role of these technologies in our lives. And who better to trigger this shift than DARPA, appropriately famous for making ideas that seem impossible, merely improbable then probable and then inevitable. Finally, the DARPA Robotics Challenge recognizes that robotics can help encourage today's youth to excel in science, engineering, and math and pursue pioneering careers as doers and makers. Hundreds of thousands of boys and girls across the country already participate in robotics competitions and the DARPA Robotics Challenge will support and expand efforts to expand that cadre of future innovators. I know that the robotics community will rise to the occasion. And I hope other governments will join us in this challenge as well. Working together, we can

dramatically improve the ability of robots of all kinds to respond to natural disasters and industrial accidents while paving a path toward high-tech help for humanity.

So I think and I hope that you found that as inspirational as I did. Our next Speaker is going to be Dr. Ken Gabriel, the Acting Director of DARPA.

Nearly 30 years ago, I walked through the doors of a giant glass building in Holmdel, New Jersey to start my career at Bell Labs as a member of the Robotic Systems Research Department. It was a time of great excitement and hope for robots. Robots were seen as helping us manufacture everything from cars to optical fiber switches, even to go into outer space. Back then, robots were seen as working alone in industrial environments, and the robots themselves were the exclusive domain of scientists and engineers working at major research centers and universities. Today with DARPA's Robotics Challenge, we want to explore and advance robotics with a completely different set of drivers. Rather than working alone, we want robots that work together with humans in scenarios like DoD Disaster Relief Operations, sometimes supervised by humans, other times working independently, but always working to human intent. Instead of controlled environments with custom tooling and fixtures, we want robots that adapt to our environments, our tools, working together with humans in shared environments. And finally with the robotics challenge, we want to open the aperture on who and what technologies can contribute to robotics advance. Over the last 30 years, computing, sensing, and communication capabilities that were exclusively at major research centers are now in the hands of hundreds of millions of people. With DARPA's Robotics Challenge, we seek to increase the number and diversity of innovators who are working to realize the dream of making robots partners with humans. Let's get to it.

Okay, that was absolutely wonderful from the director of our agency. And our next speaker in just a moment will be Paul Eremenko who is the Acting Director of the Tactical Technology Office, Paul.

All right, thanks very much Gill. I am delighted to be here and I'll spend just a few minutes talking about DARPA generally as well as about the Tactical Technology Office within which that DARPA Robotics Challenge program resides. DARPA was an agency that was founded in 1958 by executive order from President Dwight Eisenhower in response to the Soviet launch of the Sputnik Satellite. It was an agency that is unique within the United States government and that its charter is exclusively to prevent and create strategic surprise. DARPA serves as DoD's primary innovation engine and is an organization that is, at its very core, is a risk taking organization. One that is designed to have a risk profile that's fundamentally different than the rest of the defense establishment and one that invests in high-risk, high-payoff type investments with demonstrable outcomes over the duration of a limited DARPA effort. Impossible ideas come to life at DARPA, and I have some examples of such impossible ideas throughout the distinguished history of the agency. Impossible ideas don't come from requirements, they don't come from road maps, they come from the imagination of DARPA Program Managers and DARPA Principal Investigators and performers. An example that you see before you is the Saturn V rocket which of course has--perhaps had its roots in a hundred years before the first launch in the writings of Jules Verne, but was catalyzed by a DARPA program to develop the F1 engine. Wireless communications also has its roots both in science fiction and DARPA research in the 1980s. The Internet, of course, is perhaps the best-known development of the Advanced Research Project Agency as DARPA was known for a brief period of its history and of course has transformed society as we know it. Stealth technology, somewhat closer to home, a product of the Tactical Technology Office which began with the concept of what was called the Hopeless Diamond that was made to fly in the course of the Have Blue and Tacit Blue Demonstrator programs and ultimately transformed the arsenal of military aircraft that we have today. The Global Positioning System which has also become ubiquitous has its roots in DARPA's Transit to a Satellite Research program from the 1960s and a number of risk reduction activities that were conducted by the agency over the subsequent decades. Surveillance UAVs and unmanned--and a wide

assortment of unmanned platforms also originated from DARPA programs and in fact DARPA TTO programs.

And looking forward, some of these--some of the efforts that are ongoing that nonetheless have their roots in what was once deemed to be impossible ideas in movies, in popular culture, in science fiction, that DARPA is catalyzing and that may well transform our life in the decades to come. Robotics and automation of course which will be the subject of today's presentations. Multimode mobility which is something that we are currently pursuing and is popularly known as the flying car. And so, those are just some examples of a long record of continuous accomplishment and impossible ideas coming to life. And so as you go through your proposal development effort, don't be shy, think outside the box. And as you go through the ups and downs and smiles and frowns of performing on a DARPA program and participating in a program like the DARPA Robotics Challenge, you will undoubtedly face moments when you believe that what you're trying to do is in fact impossible. And so, I hope that you remember some of the examples that I gave you today and I hope that you're not daunted by the challenge or by the naysayers in the course of developing your ideas.

I want to talk a little bit about the organization of the agency as it stands today. DARPA is organized into 6 technical offices. The Tactical Technology Office is on the right and the DARPA Robotics Challenge fits squarely in the thrust of ground and soldier systems that are being pursued by the Tactical Technology Office. And I want to close by making a bit of a sales pitch if after you engage in the DARPA Robotics Challenge and develop some wonderful new constructs for the future of robotics and the future of the Humanitarian Systems and Disaster Relief Mission, if you have other ideas, please bring them to us and also consider becoming a DARPA Program Manager. DARPA has a fluid workforce, so we hire about a quarter of our program management cadre every year and there's no better way to pursue a good idea than by coming here and championing it. And with that, I will close and yield the podium back to Gill to delve into the details of the program. So best of luck to you.

[Silence]

Okay, thank you very much Paul that was wonderful. So with that introduction, let me go ahead and begin to talk a little bit about some brass tacks here. So what is it that actually inspired me to think about this program to begin with and then inspired my agency to decide to fund it? Well, there have been a number of disasters recently, but of course disasters aren't anything new to mankind. Let's start by taking a look at just a few of them. We have Katrina in 2005 which is well-known within the United States, a terrible disaster caused by weather. We have the Deepwater Horizon, an awful disaster caused by an accident where deepwater drilling went bad. And then finally of course, we have recently, a little over a year ago, Fukushima which was terrible not only for all the lives that were lost, but also the tremendous damage that occurred as a result of the power being turned off at the nuclear power plant and the difficulty with the three reactors that occurred there. So let's focus in just for a moment on Fukushima, not because this challenge is only about Fukushima, but because I think it's a good exemplar of the kinds of robots that we really need and what this program particularly aims at. In disaster response, you can aim at a whole range of things. You can begin with, "Well, what should we do a few minutes after the disaster begins?" You can go to "what should we do during the first day of the disaster?" Excuse me. And then you could go further out in saying, "How do we go ahead and respond to a disaster in order to clean up the site and to try to return things back to normal?" This program is really aimed at that first day. And it's aimed at trying to make the disaster less disastrous, if you would, than it would have been if we had not had robots there. And so, if you read the wonderful summary that was given in IEEE Spectrum about the first 24 hours at Fukushima, you'll see that they show several inflection points, times where in fact if people had only been able to get in there and do what needed to

be done, the disaster could have been mostly averted. In other words, it would have been much less of a disaster. Of course, the difficulty was that after the first explosion at the first reaction--at the first reactor, it was very difficult for people to operate in that environment because the radiation was so high and the contamination was high and there was also debris all over the place. So that's where robots come into play. Can we use robots to go where people can't go to help us damp down a disaster, to make the disaster evolve less? So taking that as the problem to be solved at DARPA, we now take a look at, well, what sort of technologies do we need. What are our programmatic goals? How do we want to advance the state of the art? So let's switch from number one, which I just talked about to looking at number two, which are the characteristics of robots that need to change. We want to improve supervised autonomy. Now what does supervised autonomy mean? It's not teleoperation. That's when operator is effectively telling the robot what to do at every moment. For instance, if I'm moving my hand, I'm saying move forward a 10th of an inch, move forward another 10th of an inch, move to the left, move to the right. It's also not full autonomy. When I tell the robot, "Go do something about that disaster and make it better." Well, robots aren't smart enough to do that now, they still need people. So somewhere in the middle is this idea of supervised autonomy. That's where people give the robot moderate level, low level instructions to be able to say, "Okay, pick up that part, move that rock, grab that handle." And by giving those sorts of instructions, we think that robots can do what they're best at which is operating in this hazardous environments where people can't go and people can do what they're best at which is to use their brains to figure out what to do. So we have experts who know what to do in a disaster, but of course can't go to the actual site itself because it's too dangerous. It's through the symbiosis of those two ideas that we think that robots and people can work together as partners to help make these disasters not so bad, to make the world safer. This idea is actually not very new, it started with a fellow named J Licklider whose picture you see at the top of the slide there, who was an Office Director over at DARPA back in the 1960s and he wrote this very neat paper called Man-Machine

Symbiosis or Man-Computer Symbiosis and I would encourage you if you want to read a little bit about the history of this, turned out he was one of the pioneers of the Internet as well. And so it's really kind of neat to begin back then and to see the perspective. Our idea is quite similar, but now with people and robots working together. So, besides that idea of supervised autonomy, there's a few more. First of all, the robot needs to be mobile enough to get to the site despite the site being degraded perhaps by some explosions or other sorts of things that happen in disasters. Number two, the robot has to be able to do something when it gets there, it has to manipulate the environment, close valves, replace pumps, do that sort of work. And then finally, it has to have the energetic efficiency in order to do all of that without running out of power, and that's a very important consideration, too. So we really want to advance the state of the art in all four of those areas. Let's go to topic number three here, we want to catalyze a robotic industry. We think the robotic industry is really in its infancy right now. And like many industries that are sort of poised for a takeoff, there are a number of stumbling blocks that we would like to help overcome. And one in particular has to do with design tools. How does a person who's designing a new robot figure out what the right configuration is? How big to make the parts? What parts are necessary, what parts are not so necessary? Right now, that's pretty much the Edisonian method. You have to build it, you have to try it, you have to see if it works then you go back and try again. And unfortunately, it costs a lot of money. It takes a lot of time to do all of that. So another idea is to use simulation. And simulators are beginning to be used in a lot of industries, both in mechanical engineering and in electrical engineering as well. There was a very famous simulator called SPICE which really helped the integrated circuit industry takeoff. We're looking for a transformation in the robotics industry that's quite similar. And so, we want to develop simulators that operate in real time that allow for human supervision and operator interaction that have high-fidelity models of the environment that could also operate all the sensors that are on the robot as well. So later on in today's Proposers' Day, you're going to get to hear from the Government Furnished Equipment vendor that we've chosen to

help develop the simulation engine. But we feel that this will be a lasting legacy of the program that it's really going to allow future designers of robots and robot systems to really accelerate the range of progress, the rate of progress that we have in the field. Let's look at number four here, something very important to DARPA is to try to utilize as much of the talent in the world as possible to not narrow our view and only pick some of our usual performers that tend to work for us. So what we really want is "A," for this to be an international effort, and we're welcoming and encouraging participation from anywhere in the world. And number two, we want both traditional and nontraditional DARPA performers. And so, we're looking for different ways and we've arranged for different ways for all sorts of different performers to be part of the effort here. So we really hope that this will be a worldwide effort to help with the worldwide problem. So let me talk a little bit about the word human and why the word human is so important in this effort. Human comes up in three ways here. And first for all, it has to do with what the robots must be compatible with as they navigate around in the environment. The environment that we have inherited on earth here is one that we've then gone and engineered to suit our own bodies. We build doors with handles of a certain height. We build stairs that are spaced at a certain height in order to accommodate the human form. So the world is full of engineered environments that have been built for people. Whatever the robot is that we're going to use in this contest, it needs to deal with that environment. Now of course in a disaster, that environment can be degraded. It can be flooded. It can be degraded by an explosion. All sorts of things might happen. But still, the environment is not truly random, it's actually a human environment with a little bit of change to it. And so the robot should be compatible with that environment. Number two is that we want the robot to be able to use human tools. This is kind of a new idea, but when we thought about disasters, we realized that what human responders do in disasters is that they use all the tools that are around, that have been left around from maintenance and for construction and they also go to different supply stores and rental places in order to get tools to bring to bear on the problem. And disasters have this

wonderful characteristic that those tools tend to be around in the very places where we care about disasters to begin with. So a new idea here is that we want robots to be compatible with human tools. And by tools, we mean everything all the way from a screw driver up to earth moving equipment, some kind of a vehicle that a person would drive. A lot of people ask the question, "Why don't you just use some of the newest vehicles that are built for a computer to drive where you don't need a human driver at all?" And of course, the last few DARPA challenges had been about trying to have driverless vehicles. The trouble is, is that those represent a tiny fraction of the available vehicles in the world and we don't know where the next disaster is going to occur, vehicles are heavy and somewhat difficult to move, particularly the larger ones. And so, we want these robots to be able to adapt to the vehicles, not build vehicles that can adapt to the robot. We know that eventually vehicles will be able to be driven by computer or by robot, but not just now. And so again, the idea is robots that are compatible with human tools from screw drivers to power tools to air tools for instance, all the way up to vehicles. A good example, for instance, of the use of this were the fire trucks and how they were used during the first few days of the disaster in Fukushima. Third big point of human compatibility has to do with the operators. And it's two kinds of factors with the operators. One is making the operation of the robot, the supervision, to tell the robot what to do, something that doesn't require expertise or training in robotics. We know that a lot of the first responders, a lot of people that help with disasters are in fact not experts in robotics. So the human interface needs to be intuitive enough for a person that's otherwise untrained to operate in a natural way. So that's one form of human interface. The second one has to do with planning, when somebody who is an expert on disasters thinks about, "Well, what would it take to go close that valve?" What they often will do is imagine in their mind, "What would it take to send in a person to go close that valve?" Now over and over again in this program, we're going to emphasize that the robots that you build in program do not need to be exact anthropomorphic copies of people, we're not insisting on that. But we do insist that they be compatible with human

environments, compatible with human tools, intuitive for a human being to operate and also intuitive for a human being who's not an expert to plan. And what that means is that somehow the form cannot be too radically different from what the form would be for a person in terms of its capabilities. For instance, if a robot was very snakelike and have the capability of going through an aperture that was only inch in diameter, that would be somewhat difficult for an untrained person to imagine how to use compared to a robot that was shaped more like an ordinary person. So again, [there is] no necessity for the robot to be just like a human being, but we need compatibility in planning, operation, tools, and environment. So on this next slide, I'll talk a little bit more about what supervised autonomy is as we think about it. So I'm going to take you through a development of human robot interaction as we go from a very, very crude way of trying to handle a disaster to a more complex way. So if you look at this slide here, you'll see that there is an area that's shade--shaded either in orange or pink, depending on your monitor. And that box of shading represents an area in the disaster where the environment is poor and not very good for a person. I'm going to take you down these rows one at a time. And I'll start at the top row of a human being who unfortunately finds themselves in that environment. So that's bad, because the human being can't survive for long in that environment. And yet, they need to do something because that's where the disaster is. So our first urge and the one that's adopted primarily now in trying to get human beings to be able to operate in these environments is to put the person in a protective suit, to have protective gear that they wear. And so in this diagram here that's represented by the white box that surrounds and covers the human being and is essentially a protective envelope around the person. Now what's wrong with that? Well, these suits tend to get very hot. They tend to impede the motion and the perception of the human being. And in general, don't last for very long, the person cannot be in that suit for very long. And then finally, unless the suit is made very well and checked very thoroughly, the reliability of the suit is also difficult as well. So having a human being in a dangerous environment is really just a bad idea. So in the third line here, the third row down, enter

robotics. And we're going to use teleoperative robotics as our first example because historically those were the first that were used and primarily now, that's the robots that are being used. And so we decouple where the human being is from that difficult environment, and we put them to the left here outside of that environment and have the communication link here with the word decouple written on top of it to connect the two of them, both in perception and also control. Now as soon as you do that, the human being is no longer there with their eyes and ears to perceive the environment and they're not directly acting on the environment either, so what they need to do is that they need to create a model in their head, which we call the predictive model that predicts what they believe is going on in that environment. And so through that predictive model, they say, "Well, I can't quite see it perfectly, but I think what's going on is," whatever the case may be. But it's important to think about that predictive model and you see how it comes into play in just a moment. Now in real disasters, those nice blue communication links that you see right there are in fact not as good as you would like them to be. First of all, a robot is not quite as good as a human being at manipulating the environment. It's also not as good at perceiving the environment. So we go from a solid line that's on the right hand side to a dashed line as we go down to row four of this diagram. Also on the left hand side, that communication link between the human being and the robot is not as good as we'd like it to be. And so there, we go from a solid line to a dashed line which is degraded and in fact that communication link tends to vary with time as well. So we have to be careful because our link with that robot may not be very reliable. So again, turning to Fukushima just as an example, there, the radiation shielding and the concrete nature of the buildings made wireless communication quite unreliable. So now, what are we going to do with the situation? Well, one possibility is to try to make that predictive model a little bit better. Can we do better than a human being just sort of thinking about what's going on on their own? Can we do better than teleoperation? Well, let's handle teleoperation first. So here we move from teleoperation in row four to supervised autonomy in row five. What does that mean? Well, instead of telling the

robot, "Move an inch forward or a quarter of an inch forward and then move to the left and then move to right," we're going to say, "Pick up that boulder." We're going to say, "Turn that handle." We're going to give it medium level commands that are supervising its fairly low level autonomy to do things. And so that's the idea. Next, and because of that, we can deal with the fact that the communication link is not so good. Because we don't have to tell it as much as we used to and we don't have to perceive the environment with quite the fidelity that we did before. We don't need the communication link to be as perfect with supervised autonomy as we did with teleoperation. So that's the idea of that one. And then let's finally go down to the last line in the diagram, the last row. In here what we're trying to say is that that predictive model is so important to the operator's perception of what's going on that we really want to do that as well as possible. Human beings are pretty good at imagining what's going on at the remote location, but we have a hard time remembering exactly everything that we saw and we have a hard time keeping track of it all. So why not go ahead and take that predictive model and decouple it from the person and use something like, for instance, a computer simulator running software to give a best estimate of what we think is going on, on the other side, what's actually going on in the danger zone where the robot is.

And so that's the idea of decoupling the predictive model from the operator. Let me zoom in a little bit on this in this next slide. So we have a human being, we have a predictive model, we have a robot that's operating under supervisor autonomy, and then we have an environment, and of course the robot and the environment are in a dangerous place where we can't or don't want to send a person directly. The kinds of questions that you should be thinking about in this program are question one, two, and three. For the kind of robot that you want to design, both hardware and software, what kinds of input and output should go between the operator and with the controller, that predictive model saying, "I want you to pick up that rock," should that be the right level or should it be, "I want you to get the rocks out

of the way?" Well that requires more thinking, more autonomy on the part of the robot. We're not going to tell you the answer. We're going to ask you to find out the answer. Next question you might ask yourself, what sort of messages should be going back and forth between the operator's control station and the robot itself? What should go forward to tell the robot what to do? What should come back in terms of reports from the robot saying what to do? The idea is here that the predictive model at any given time will give the operator a best estimate of the situation that the robot is in. And as it gets more information over that somewhat degraded communication link, it will update its model of what it thinks is going on over there, its prediction of what's going on there. But also, that prediction will be telling the robot what it is that you want to do, again, dealing somehow with that degraded communication link. Question number three, how much autonomy should the system have? What should its mobility be? How good should its manipulation dexterity be and how are you going to handle the difficulty of providing enough energy and power for the robot to do what it needs to do? That's question three. And again, these are the major technical points of what you should be thinking about in terms of coming up with a solution. Question four, task and metrics, that's actually for us here at DARPA to do. We have to figure out what exact task you should be doing in this challenge. We have given eight notional tasks in the BAA and I'm going to talk about them now and actually go through them one at a time. But I want you to think about something very carefully, DARPA does not want you to over fit your solution to those eight particular tasks. And in particular, we're saying that those tasks are not necessarily going to be the ones that we're going to do, and not necessarily in the way that we're saying. The whole idea of disaster response is a robot that is general purpose. A robot that can be adapted to the conditions at hand and those conditions are very hard to predict because we don't know where the disasters going to be and we don't know what the disaster is going to be. So please, please, please, do not over fit those solutions and those are likely to change, those particular tasks. So let's take a look. Here are our eight notional tasks from driving a utility vehicle to the site all the way down to replacing

that pump or component at the end. And on the right-hand-side of this chart are a bunch of robot capabilities and we put in little Xs where we think that that capability is particularly important for that notional task. Again, please don't get wedded to these particular eight tasks. As we get more experience in the challenge and we see which tasks are hard and which tasks are easy, we will likely change the tasks to make them just in that sweet spot of difficult but not impossible. We're also going to be talking to a group of advisors in the disaster response world, we've talked to them before. We're going to keep talking to them more and they're going to tell us which of these tasks are particularly important for disaster response. So we are going to tune this in order to come out with the best. Now, you may ask the question, "If I don't know exactly what the tasks are, how could I possible write a good proposal?" And the answer is we will evaluate your proposals assuming that these eight tasks are in fact what the tasks are. And then when Proposers' Day--excuse me--when the program start day, the kickoff comes around in October, we will then have a much better idea of what the tasks are going to be, but we're going to still be tuning them after that. So again, we're going to give you a lot of help in making sure that your robot is able to do the particular tasks, but don't over fit the solution, don't propose a solution that only works for a subset of tasks, make sure that your solution is pretty general in purpose. So let's talk about these particular tasks, again keeping in mind, I can't say this enough, that they're subject to change. Number 1, drive utility vehicles, now why is this important? Well, energetics is a difficult problem with robots that work on rough terrain. So having a vehicle that the robot could get in, drive to a particular place and then get out of is an important thing. Second, some of the tools that we want to use are vehicles themselves. So allowing a robot to operate a tool at hand that has a standard vehicle interface, being a steering wheel, an ignition key, a gas pedal, a brake pedal, perhaps handles in order to operate, is an important capability. So that's why we're having you do this thing. You need to be able to get in the vehicle. You need to be able to get out of the vehicle. At our present assessment, we don't believe the vehicle will have doors, so it's a matter of stepping into the vehicle, sitting down,

grabbing hold of the steering wheel. You have to be able to operate all the controls. Now this is not the other DARPA Robotics Challenges that have been done in the past where we're talking about driverless cars and full autonomy. Rather, you will still have a human being as a supervisor on the loop, is the words that are typically used, which will be able to guide the robot in terms of where it should drive. It shouldn't be teleoperated in terms of having a person in a mockup car and having all of their commands directly translated to the robot itself because we won't allow you enough communication bandwidth to let that work. But it should be at some level where the human being is basically guiding where the car is going to go. The robot needs to also be able to get out of the vehicle as well. Number two, traveling dismounted, and what that means is on your feet, not inside of a vehicle, across rubble. This rubble will not be a very difficult rubble, it will be rubble that's easy for a human being to traverse, but we want to show that the robot is capable of operating on terrain that might be typically found in a disaster without losing its balance and losing its footing, so that's important as well. Removing debris that blocks an entry way. These are not enormous boulders that you and I would have a difficult time picking up, just assume that there's a set of some small rocks that are in front of the door and you need to physically bend down and move them out of the way, each one is not that heavy, in order to unblock the doorway in order to go through. Go ahead and open that door, that's the next task. And that's actually more difficult than you would think. First of all, I want to dispel that there were some rumors on the Internet that you had to use a key to unlock the door in order to open the door. Turns out, we have another program at DARPA, the Autonomous Robotic Manipulation Program which has accomplished that, but that was a confusion between that program and the Robotics Challenge. In the Robotics Challenge, we assume an unlocked door, you need to manipulate the handle of that door, open the door, probably against a spring that it's using in order to close itself, hold the door open, go through yourself, and then let the door close in back of you. That's the difficulty of the task that we want you to do. Let's go ahead to the last four tasks. Climb an industrial ladder and traversing an industrial walkway. An industrial

ladder is a vertical ladder, it is different than a staircase, it's more difficult, but it does not involve doing pull-ups where you have to have the entire strength of the robot being able to lift its body just with its arms. The ladder will go all the way down to the ground, but the key difference here is that you need to identify where the rungs are with enough precision to grab it with both hands and feet, if the robot has that form or whatever the form of the robot is, and travel vertically up the ladder in order to transition to an industrial walkway which is a walkway that has hands on--handle bars on the side of it and then walk across that walkway in order to get to the next stage. The next stage is to locate and close a valve near a leaking pipe. We'll have a simulant gas of some sort that is in actuality harmless, but will be colored, and will also emit a sound, like a hissing sound, and the robot needs to go over and locate the valve and then close the valve that requires two hands to close. Again, this is not in full autonomy, but you can use both visual and auditory clues to help the supervisor that is supervising the robot figure out where the robot should go, where the valve is, where to place its hands on the valve and how to turn it in order to close it. The final task which we've envisioned so far is to replace a coolant pump. This again is notional. The pump will be easily held in a single hand, so this is a pretty small pump. And we will configure the flanges, we'll choose flanges that are such that it is within the dexterity of the robot to do an attachment and detachment through the flanges without needing the sort of fine control that may be too difficult to do. Again, all of these tasks are notional. We're going to adjust the difficulty of the tasks. We may add tasks, we may subtract tasks, we may change tasks, in order to make it hard, relevant, but not impossible. So let me go on to the next slide here on the different tracks, the different ways that you can participate in the program. Track A, we have funded teams who want to build both hardware and software. The hardware and software teams are going to be funded at a pretty high level and they're going to be in charge of all parts of the system. And so, we would--if you want to do track A, what you need to do is send us a proposal for both hardware and software and we will consider that for funding.

Track B is similar to track A in that it will be funded by DARPA through the proposal mechanism. But we will in fact not be asking you to develop both hardware and software, but just software. So track B teams are going to write us a proposal, we'll evaluate that. And then for the number of teams that we choose to participate in track B, you will be in competition through developing some software and simulation for receiving a Government Furnished Equipment robot to use in the remainder of the competition and that we will provide the hardware to you. So this is for teams that are specialized in software that don't have particular hardware expertise or for whatever reason want to do that particular way of doing that, that that's where they feel their talents lie. Track C is an attempt to try to widen the aperture to many, many more teams. We're thinking of perhaps 100 teams participating in track C. In here, DARPA will not provide initial funding, but we will hold out the possibility of significant future funding if you manage to compete against the other teams, in this case track B teams, so that your software beats out their software and you show in fact that your software could perform extremely well, and that will be done in simulation. And if you win in that contest, then we will provide future funding and we will give you a GFE robot to allow you to actually compete in the actual disaster challenges. Finally there's track D, track D is engineered for teams that for whatever reason do not want to get involved in the DARPA funding mechanisms, but still want to compete in our challenges, we want to open the aperture to allow any of those teams to compete and to be a bar for our other teams to get higher than or actually have our teams for a bar for track D folks to get higher than. So we really want the best robot to win, the best team to win, no matter how it's funded. Let me show you a diagram that was in the BAA, but actually I think it really helps us to explain a lot better, and I'll talk a little bit about the timelines here as well. So take a look first at phase one. The entirety of phase one is 15 months. It's broken into two parts. The first is nine months, that's on the left side of phase one and the other is six months, that's to the right hand side of that dividing line which is in the center part of phase one. So

what do we do for the first nine months? Well, let's look at the track B and track C teams. Those two teams are developing software that runs in simulation. We are going to provide a simulation engine which you'll hear about a little bit later, which we believe is going to be the state of the art. It's going to run in real time, have supervisor interaction and have validated models of both the robot and interaction with terrain. And we're going to see who wins. And we're going to pick up to six teams which are the top of performers in that simulation after a period of nine months. And we're going to give them Government Furnished Equipment physical hardware, being the robots. And when we give them the robots, we're also going to give them funding to work for the six months to get that software working on that robot and to perfect it and then to compete in the first disaster challenge that's happening at the 15 month mark, which by the way is December of 2013. So, you can see that on the diagram, in track B, we will choose up to 12 teams via our proposal method which is responding to this BAA. We will fund them at up to 375,000 dollars each for those first nine months to work on software. On track C, we open the aperture and we will provide computing resources on the cloud for up to a hundred teams to compete just in simulation using their own funding for any other parts of the work they need to do, but then we're going to consider them on an equal footing in a simulation challenge, the virtual disaster robotics challenge, that happens at month nine. And then the top, up to six teams there, will be given robots to go forward to the first disaster robotics challenge. Now let's pop back up to track A, that's for hardware and software or system teams if we want to think about it that way. We have enough funding for up to five such teams assuming we find five that are good enough and thus are going to be evaluated by proposal. So that's responding to this BAA.

And you can propose up to 3 million dollars of funding for that first 15 months for phase one on track A. So if you're a hardware and software system developer, you want to choose track A, that's the way to go. Finally, there's track D which is for companies or teams that don't want to get involved in DARPA

funding, but do want to compete in the challenges and you're more that welcome to do so. And so we allow you to be as part of the robotics challenge number one and then robotics challenge number two. Now, what's the result of robotics challenge number one? Is there a prize? Well, I wish there was, but we decided to save the good stuff for last so there's not an explicit prize in DARPA Robotics Challenge number one in December of 2013. Rather what we're going to do is that we're going to choose the top eight teams or up to eight teams, we don't know, we may have fewer, but we will choose those and we will provide them with funding of up to a million dollars each to continue to perfect their robots for another year, working up to DARPA Robotics Challenge number two, which will occur in December of 2014 and will be a sort of more difficult enhanced version of DARPA Robotics Challenge number one. And again, we will welcome teams from the outside that had no DARPA funding at all, but wanted to compete anyway. So that's DARPA Robotics Challenge number two, December 2014, and it's then that we're going to issue the prize and we expect to give it to one team which will walk away with, as we expect and we intend, a two million dollar prize. So that's the program in graphic form. Okay, this slide over here repeats some of the stuff that I talked about in terms of the funding that we have secured for the challenge. For track A, again, up to 3 million dollars for each of--up to five teams and for 15 months to get to DARPA Robotics Challenge number one. For track B, the first nine months, we will choose up to 12 teams at a funding level of up to 375,000 dollars each. Both of those will then compete and after the virtual disaster challenge which happens at month nine, we will give funding to the--up to the six performers, up to six teams, funding of 750,000 dollars to make it to DARPA Robotics Challenge number one, the physical challenge which happens at 15 months. Finally in phase two, which is the difference between our first physical challenge and our second one, there's a year that separates those two and we will provide up to a million dollars of funding for up to eight teams to make it from physical challenge number one, to physical challenge number two, finally ending with the two million dollar prize that we expect to offer to the winner of DARPA Robotics Challenge number two. Okay, so here are some dates

that we plan on for the entire program. The ones that are near the top are the ones that we're the most sure of. As you go further out into the future, things will become a little less certain, but here's what we're planning so far. So May 31st the BAA closes, you must have your proposals in by then in order to be considered for funding for track A and for track B--or for track B. In October of 2012 that's when we anticipate those performers that we've selected to have the best proposals for track A and track B to be on contract and will have the program kickoff and that's where we expect that your work will begin. This date is a little less certain because we don't know exactly how long it will take to get all the legalities of the contracts set up with you. In June of 2013 that's the nine month mark after October of 2012, nine months later, we'll have the virtual disaster robotics challenge and the whole idea there is that we will be testing, in simulation, which of the track B and C teams do the best and we will take up to six of those and we will fund them for continued work and we will give GFE robots, give them the hardware in order to run their software on, going forward to the first challenge. And then a year later, after the first physical challenge, we're going to do the second physical challenge in December of 2014. Okay, so those are all the comments from me introducing the program. Let me talk just a moment about questions and answers and how we're going to handle those. The BAA had an e-mail address and I believe that the website does as well that you're watching this on of where do submit your questions, that's the place to do it, we're not taking questions any other way. And what we're going to do is we're going to review the questions, both while you're listening to other people and when we take a little break a little later on. And from that review, we will come up with answers to the most frequent of the questions. We're going to give those today. I'm going to read them out. But then we're going to take the other ones and we will post them to the frequently asked questions part of the program website and you'll be able to see your answers there. So you'll be able to continue to ask questions and to get answers, but please don't look for other ways to ask questions because we want to make sure that

everybody gets to see all the questions and all the answers that are provided, so as to keep the

competition for funding as fair as possible. So, next up is Chris Glista, who is our Contracting Officer for the program, Chris.

Hello, I am Chris Glista. I am a Contracting Officer in DARPA's Contracts Management Office, and I'm here today to talk a little about the Broad Agency Announcement process.

The letter "p" shows up after process.

First off with some specifics, obviously the BAA is currently on the street and these future amendments that are posted to the BAA will also appear on FedBizOpps where the current BAA is. It will cover all of the information you need to propose. We are going to make the slides publicly available, but, you know, should you never read them that shouldn't be a hindrance. Time period, the BAA is open until the end of May. The fourth bullet here should be self-explanatory, but please read the instructions in the BAA closely. Again, it should seem self-evident, but you'd be surprised. Some of the responses we get sometimes indicate that the BAA wasn't read as closely as it should have been. The reason that's important, even if you get through the selection process, if you did not read the directions closely, you make it through the selection process, but didn't provide all the information that was asked for, it is going to take the contracting officer significantly longer to get you on contract. So again, it helps both of us out. And the last point, send all questions to the BAA e-mail address inbox, one of the reasons I'm up here is to prove that there is a real face behind contracts. However, please don't e-mail me or don't email Gill directly, we like to have the e-mail at the BAA e-mail address used so we have a central repository of all questions and we don't miss anything. Okay, those were the specifics. A little bit about the BAA in general, this is the primary instrument DARPA uses to solicit proposals. It's taken from the Federal Acquisition Regulation part 35 and I actually put a link up there in case you want to a check it out. Believe it or not, it's the shortest part of the Federal Acquisition Regulation. You can probably read

it in about an hour. So, if you want to double check that everything I'm telling you today is true, feel free to do so. The definition taken from part 35, BAA is a general announcement of an agency's research interest including criteria for selecting proposals of all offers capable of satisfying the government's needs. The last point is important. It's for the acquisition of basic and applied research, that's why we use it here at DARPA so much. And it is specifically not related to the development of a specific system or hardware procurement. So the robotics that come out of this, we are going to have robots at the end, they're not going to be turned into a weapon system or handed off directly to the military for fielding. So again, we're in the basic and applied research realm. Okay, and why do we use broad agency announcements, well here, we do have a clearly defined goal. However, it's going to be expected that we're going to get significantly varying technical and scientific approaches. So it really doesn't lend itself to comparing ranking proposals as is traditionally done with hardware procurements because that would really be like comparing apples to oranges. Again, there's no common work statement, we have a broadly defined goal, but you're not getting a performance spec that you're going to be building to. Primary basis for selecting proposals, this should come as no surprise, is technical merit. After that, importance to agency programs and funds availability and we mention funds availability, it's conceivable that every proposal that we get in would make it a contract award and is selectable. However, obviously, as the numbers in the BAA indicate, we are budget constrained. And the last point, kind of a cost realism shall also be considered that kind of dove tails with that. We did put the budget targets in the BAA, that does not mean that we expect every proposal to come in, in exactly that number. Whichever number you choose to propose to, we are going to evaluate the realism of that number. In other words, can they do what they say they're going to do for the amount of dollars that they propose, so that's cost realism and that's one of the evaluation criteria. Okay, this is also important, it's to be expected that many of you will be members of teams that one performer won't do the entirety of the work. You shall not subcontract technical or scientific work without the Contracting

Officer's knowledge. In other words, we discourage the bait-and-switch type approach. If you're selected because you have one team member that has outstanding expertise in a particular field, you're not going to be allowed once you're on contract to switch that person out without getting the contracting officer's explicit permission. So again, if you read part 35, the composition of your team, the strength of your subcontractor team is one of the bases upon which you would be selected. Okay, I talk about FAR part 15 here. This is--if you've never done government contracting before this--you could probably tune out for a little bit, but for those of you that are somewhat familiar with government contracting framework, part 35 is different than part 15. Part 15 is again, what's traditionally used to buy a traditional weapon system, a piece of hardware. Some things that occur with part 15 that you won't see here is there'll be no competitive determination. In other words--I mean, actually, that's what's going to happen during the competition itself, but that won't happen upfront before you're selected for funding. There are no mandatory discussions, that means when you put your proposal in, that's your best shot. You're not going to have an opportunity to submit a final proposal revision. Cost and pricing data, if you are submitting a FAR-based contract proposal for greater than 700,000 dollars and I know that many of the team A proposals would be for that amount, you're going to have to certify to the accuracy and completeness of the cost and pricing data. Meaning, that from the time you submit the proposal, if new information has become available prior to contract award, you're going to have to disclose that upon penalty of law. And as I mentioned before, subcontract consent and key personnel clauses will be included in all awards. So you're going to be selected upon the strength of your team. If that changes, we have the right to, you know, choose to terminate the contract or not select you.

Okay, communications, again, please use the BAA e-mail address for all communications. After--you know, pretty much after today, we're getting questions and answers right now. The communication is going to become more one way. After we get your proposals, we do have the right to come back if there's something that's not clear, we can ask for a clarification. Don't count on the fact that we'll do that, this gets in to the last point after your--you know, you received your decision whether or not you're selected or not. You can request informal feedback. There are no rankings, so no ranking will be provided. But one of the things I often hear during these informal feedback sessions is when we provide reasons for, you know, why you may not have been selected. People say, "Well, if that was unclear, why didn't you come back and ask me?" Well, you know obviously, with the volume of proposals we get, we attempt to do that, but it's--there's no guarantees so really when you submit your proposal, that's the time to put your best foot forward. Okay, applicant eligibility. This is fundamental research so really-everybody is really--that's interested can respond. You know, unless you're--had been disbarred previously from federal contracting, there's really no restrictions. International participants are welcome. And lastly, small business participation, non-traditionals are definitely encouraged. Teaming is not required and I think the scope of the effort pretty much lends itself to this, small dollar amounts. We're also making the GFE hardware available for people that may not have the wherewithal to purchase their own. So there's going to be no set aside, no preference given to small businesses, but we have definitely gone out of our way to make it as easy as possible for them to participate. Okay, eligibility continued. If you're a government agency or a laboratory or a federally funded research and development center, you cannot propose unless you present proof of your statutory authority to purpose and you provide a statement stating that the work is not otherwise available from the private sector. In other words, the government doesn't like to compete with private industry. If you are from one of these entities and you don't know if you have the statutory authority, you know, please consult with your legal folks, I'm sure they will be able to tell you. Organizational conflicts of interest. Big thing

at DARPA, you cannot be a scientific performer and a SETA support, technical performer at DARPA without a waiver approved by the DARPA Director, which I don't believe has ever been granted, maybe once throughout the history of the agency. So if you are--if your organization is providing SETA support to the government, you're basically ineligible. You should also check if you're going to be to be teaming your subcontractors. Some of them may be providing that type of support unbeknownst to you. So it's good to ask that before you submit your proposal so as to avoid a nasty surprise. You know, lo and behold, one of your subcontractors has been doing this type of work and you're now ineligible. Okay, award instruments. We pretty much left it wide open in terms of what type of award you can receive. Obviously, contracts, traditional contracts, the way the government normally buys stuff, is allowed. Grants, we use those often for fundamental research. Cooperative agreement, which is much the same thing, and other transaction which is pretty wide open. Rather than focus on this extensively, I provided, and again, we'll make these slides publicly available, some links where you can find out more about the different contract types. I just want to stress the last point that in the end, it's the contracting officer's decision as to which type of award gets made. So for example, you may propose a cost reimbursable FAR-based contract and we come to find out that you're accounting system is not, you know, it's not equipped for that and we can't get it equipped for that in time to make the award, we may push you over to a for sure over to a firm fixed price type contract.

Obviously, you have the ability to disagree with our determination and walk away, but--so again, everything is wide open. There's some information you can access there. If you have questions about the contract type, in the mean time again, please send us an e-mail and we'll try to answer those. Okay, rights to technical data and computer software. This is important. We ask for you to layout any restrictions you're going to be asserting on the technical data that will be delivered to us. There's actually a table, I believe it's the last two pages in the Broad Agency Announcement, this applies not only to the prime contractors, but also to any of your subcontractors. The government really does like

to know what it's going to be able to do with the technical data after the program is over. And I believe there's a statement in the Broad Agency Announcement basically alluding to the fact that we are looking to the extent possible for unlimited rights so that this program can live upon its completion. So if you're not going to be providing unlimited rights to everything, please let us know so we can take that into consideration in making our selection calculation.

Okay, thank you very much.

[Silence]

Okay, thank you very much Chris. Next up is going to be Rob Playter from Boston Dynamics and Rob is going to talk about the Government Furnished Equipment hardware platform which are the robots that the team B--track B, and track C teams are going to compete for, Rob.

Thanks Gill. I'm going to provide an overview of the Government Furnished Equipment for this program. So this is an image of the PETMAN robot. It is--we're building two robots at Boston Dynamics right now. The first was PETMAN which is being developed to test protective equipment for soldiers. The second is ATLAS which is a DARPA funded program that we're building, leveraging the PETMAN design and emphasizing rough terrain mobility. Both of these robots are the humanoid form, taking about a 50th percentile anthropometry to scale the robot. It's a hydraulically-powered robot. It has 27 actuated degrees of freedom. It will have two onboard computers. It will have a power tether. It will have-again, the robot for the GFE will have a sensing head. And it will also have a modular wrist. So we will provide mechanical, electrical, and data connections at the wrist for a government furnished hand. And it will also have protective shells to protect the robot in the environment from collision. The video we

are about to show is of the PETMAN robot operating in our laboratory. Here, you see the PETMAN walking on a treadmill in the laboratory maintaining dynamic balance. So this robot was, again, designed to test protective equipment, and so it needs to perform a range of lifelike motions. Here you see it a maintaining stability even when subjected to a small disturbance. So the robot uses it's on board sensors to provide reflexive balance. We're creating a small repertoire of behaviors, things like this, stimulated jumping jack or a squat, all which are designed to test chemical protective suites for their integrity. This robot has been operational at Boston Dynamics for about a year. And you're seeing the repertoire of behaviors we have developed for it in that time. It's a relatively strong robot, the hydraulics give it a large strength-to-weight ratio which we think will be very important for performance in the DARPA Robotics Challenge.

What you're looking at here, the skeletal image in the middle of the screen there, is a map of the joints that we expect we'll be delivering with this robot. Again, these are all hydraulic powered actuators. Starting at the top of the robot, at the neck and working down. The neck will have two degrees of freedom allowing the neck to move in pitch and yaw. And we anticipate that the terrain sensors will be mounted to that neck. The back and shoulders each have three degrees of freedom. The elbow has two degrees of freedom, flexion and then internal rotation much—will really serve the purpose of wrist rotation. And then, there will be an additional flexion degree of freedom down at the wrist. The hips each have three degrees of freedom. The knee will move in flexion as will the ankle. Again, the hands will be attached to the arm through a standard interface. We don't know exactly what hand is going to be delivered yet, but that will be included as Government Furnished Equipment. What you're looking at here are some data describing the capabilities of the robot. So in the top table for each joint in degree of freedom, we're showing what the range of motion for that joint is provided. So these were design specifications for the PETMAN and ATLAS robot and you'll see a minimum range of motion, a maximum, and the range between those two for each degree of freedom of the robot. The lower table similarly for

each joint in degree of freedom, we described the strength of those joints. And these strengths, these are maximum torques are--were judged sufficient during our design process to enable the robot to perform, again, a range or behaviors some of which you saw in the previous video. Here you see a breakout of some of the mass of the robot. We expect the robot, the ones we've built already, weigh about 170, you know, to 175 to 178 pounds. And we expect this robot to be very similar. We are expecting to add a power plant to this robot. It's going to enhance its mobility capabilities. But we don't know exactly what that power plant is going to weigh yet, we're expecting in the range of 50 pounds and this will be mounted to the back of the robot and it will be able to carry it as it perform its tasks. So for the total weight will be around 227 pounds give or take. Here you see the conceptual description of how we expect this power plant to work. So there will be a power plant that mounts to the back of the robot that will be probably have a small hydraulic pump and an electric motor, the motor driving the pump and the pump which in turn provides power to the hydraulic actuators. Now you see the draped line from the power pack to the laboratory electrical power supply. We expect that to be an electric tether providing electrical power to that motor. Also, it will likely include a cooling water supply in return, which will be used to cool that motor and cool the hydraulic fluid on the robot. So between the two of these, we should have a relatively portable power supply for the robot. And here, we're summarizing the computing architecture for the robot. There will be two computers. Starting from the top, there will be a computer available to the user. This is where you will provide your software for high level motion control, terrain sensing, and communications to a workstation where the human supervisor will be provided data and will have both Gigabit Ethernet and Wi-Fi connections to that computer. A second computer onboard will--the robot computer will run low level control software and in turn communicate via digital bus, a CAN bus, to the sensors and actuators on the robot. Sensors like an IMU. The terrain sensing tools like a LiDAR or a stereo camera, the government furnished hand and the

individual actuators where we typically we provide position and force data at each joint. And that concludes my remarks on humanoid robot.

[Silence]

Okay, thank you very much Rob. Our next speaker is going to be Nate Koenig from the Open Source Robotics Foundation. Thank you.

[Silence]

Thanks Gill. I'm going to talk about Gazebo which is an Open Source robotics simulator that's going to be used during this Robotics Challenge. So I'm going to cover a few of the features and how we're going to go about facilitating development in the robotics challenge. So about 10 years ago, Gazebo was first started down at the University of Southern California where projects at the time--we did simulator capable of modeling outdoor environments.

So we stitched together a physics engine along with visualization and interfaces to create Gazebo. At that time, we were focused primarily on using the Player interface. However we since moved on to also integrate with ROS and also maintain a public API for your own control code. In addition, Gazebo provides some other benefits. It can reduce your development time by operating it faster than real-time environments. We highly recommend using it as a regression tool to maintain a stable and robust code

base. And in this case, in the Robotics Challenge, used as a competition tool. So, all these things show the flexibility of Gazebo and its ability to handle wide range environments and tasks. Some of which are shown in this slide and I'm going to highlight a few other use cases that Gazebo have seen over the years. One of the first use cases was done by a few students who were in machine learning class and they developed a learning algorithm for gaits. So they used Gazebo to visualize these gaits and collect some statistics about their learned algorithms. In another case, researchers developed a mobile manipulator for using factory environments. And again, they used Gazebo to analyze the performance of the research. And beyond the use of single purpose robots or single robots in environments, swarms of robots have been developed and deployed for things such as coverage analysis and use in robot soccer. And one of the more interesting use cases, students wanted to manipulate eggs. So rather than wasting food and potentially damaging hardware, they created a model of eggs and used the force feedback and sensors within our Gazebo to develop control paradigms to handle and manipulate eggs. So at a high level, Gazebo is constructed of, as I said, three main architectures. Physics engine for doing rigid body dynamics, visualization which allows you to see what's going on in simulation and also to generate sensor data, and finally a set of interfaces which lets you control various aspects of Gazebo. So being an open-source project, we have utilized a variety of open-source libraries to fulfill these different use cases. So from physics, we have used Bullet and ODE. In visualization, we're taking advantage of the OGRE Rendering Engine, and to provide inter-process communication and plug-in support, we're utilizing Google protobufs and boost. So with these tools in place, it's possible to create a wide range of robot models from very simple platforms that are constructed from a series of shapes and joints to complex mobile manipulators that utilize high definition meshes, dynamic properties, and a wide range of joints. And of course you can integrate full sensor suites from the Kinect sensor to laser range finders and stereo cameras.

And so these robots need environments in which to operate. So if you're focused on a very particular and simple use case, you can create very constrained and simple environments for things such as manipulation and perception. If you're developing aerial robots or outdoor manipulators, outdoor mobile robots, you can use the terrain features to create realistic environments. Or if you're operating indoors, you can extrude blueprints such as what we did here or develop your own environments for the home or office-like space for path planning and mobile manipulation. So the video that's going to play next will highlight some of these features that I've been talking about. So this first part is demonstrating the terrains within Gazebo and the new animation engine that's currently available. So this--in this case this quad-rotor is animated which lets us bypass the physics engine. And now we move on to a Pioneer robot being driven through the Player interface operating in a typical office-like environment. And finally, we get to a PR2 interacting with boxes and a Kuka youBot using the ROS Interactive Markers. And some new work that is pretty much fresh off the presses is character animation using skeletal animation tools typically seen in games. So this demonstrates the use of leveraging man and technology and GPUs used to bring more realism to Gazebo. So in addition to the core features of Gazebo, there's a set of tools that you can use to get statistics about a current running system and also manipulate various aspects such as insert models, plug-ins, remove models in plug-ins. As well as graphical tools lets you debug what's currently going on in simulation from visualizing joints and joint angles to mass properties and seeing how sensors are operating in the running simulation. So all these models that I've been showing you have come from a variety of sources from online sources such as Google's 3D Warehouse to hand-created models that have used free packages such as SketchUp or Blender. And we're developing a method to better share and distribute these models and plug-ins to all users in Gazebo. So if you need help creating your own models, feel free to go to our website, there's a lot of good tutorials and information about how to get your process and your robot into Gazebo.

So Gazebo 1.0 has been released this past weekend and so in the near future, we're going to be looking at supporting the robot challenge. So this involves integrating vehicles, tools, more realistic outdoor environments into Gazebo as well as supporting cluster-based simulation engines, so this will essentially allow you to use Gazebo as a cloud-based service. And further down the road, we're going to integrate other physics engines, develop multi-floor structures, and wider range of sensors including sonars, GPS, WI-Fi models. And even further down the road, there's going to be support for large environments, both indoors and outdoors, and more robust models for vehicle suspension, friction models, and noise models. So this is a community-supported effort, there's a lot of people involved in the Gazebo project. If you're interested in contributing back, we highly recommend you visiting our website and see what current technology exists and how you can best help. There is also a Wiki available which has a lot of tutorials, examples, a lot of information about the internals of Gazebo and how everything connects together. And of course you can download a source code yourself from our KForge project. So finally, I'd like to thank everyone involved with the Gazebo project, John Hsu has been our physics lead and has been making great efforts in maintaining a fast accurate and stable physics engine and really spearheading the effort to develop the ROS API for Gazebo. Mihai Dolha has been a great contributor in terms of sensor models and physical--character animation tools, and of course our co-founder, Andrew Howard, who has influenced the project over the years in a great way. So thanks everyone involved and we look forward to supporting the Robot Challenge in the near future.

[Silence]

Okay, thank you very much. So, that's our set of talks for today, but don't go away, what we're going to do now is we are going to review all the questions that have come in both before our performers

workshop and actually up 'til now, we'll formulate some answers, we'll check those answers, and then select the most frequent and most important of those questions and I'm going to read off the answers after a short break. Those questions that I don't answer here and I believe the ones that I do answer here as well, we're going to be posting in text format up on the website, so you'll be able to see all of your questions answered one way or the other. Now, if you don't see your exact question answered, please look to other questions that may be quite similar because what we're going to do because so many questions come in is we will coalesce ones that are similar to each other and write a summative question that we think represents those sets of questions well, and then we'll post the answer to that. So be back soon.

Hi there, so we are back and I'm going to over some of the questions that have come in. We've had over 100 questions come in and probably close to 150 now and we've gone over some of them, pulled the most important ones and the most common ones and I'm going to read off the answers 'til I get tired. And you'll get to see the textual answer to all the questions or summaries of those questions that are--will end up on a program website. So let me start, for teams that are given government furnished equipment, will they be able to continue using the GFE after the competition either through transfer all of ownership or long term loan to the performer? So, we wish that we could give away the robots in that way, I think that would wonderful, but in fact, unfortunately the answers is no. We do in fact expect the teams to return the GFE platforms at the conclusion of the program, they represent a significant investment by DARPA and we may want to use them in future programs as well. Question number two. If a team starts on track A and is in a top eight thereby making in it into phase two, but then determines that their software and--that their software would be more competitive in the GFE hardware, can the team switch to using the GFE platform for phase two?

In other words you're a system designer, you make the hardware and software, you do well enough to get through, but then you decide you'd rather run on the GFE hardware. Can you do that or do you have

to stay with your original robot hardware that you had developed? And, we aren't sure. It's not likely that we'll have enough robots to pass out for that, but it's possible. So what we're going to do is we'll handle that on a case by case basis. Question number three. For self-funded teams, can you purchase the GFE platform? And if so, what will the price be? So lots of people really seem to like the GFE platform here. Self-funded teams, only those in track D, can contact the GFE platform supplier directly which is Boston Dynamics, and DARPA is neither going to determine cost nor provide support for those platforms. Notice however the track A performers are expected to develop their own hardware as well as software. And so, those folks must not use the GFE platform or use the GFE platform provider as a sub-contractor. What are the rules of the competition? Question number four. How will the scoring be done? And the answer is that the rules and the scoring approach have not yet been determined, we have of course some ideas, we talked about the general guidelines for those ideas in the BAA, but the particular rules are going to be announced no later in the program kickoff day which is in October. It's planned for October. Question number five, when is the program kickoff meeting? Presently planned for October of 2012. Okay, some contractual questions. Contractual question number one. Are foreign organizations eligible for funding? If so, can they be a lead or just a sub-contractor and are there any limitations in funding amount or percentage that can go to the foreign organization? So the answer to that very clearly is yes, foreign organizations are eligible for funding and they may be either a lead or a sub-contractor. Question number two. Do any additional rules apply to non-US led organizations? And the answer to that is that, under this BAA, no additional rules apply to non-US led organizations. Some technical questions. Some of these, I've addressed in the talk, but I'll say it again. Question number one on technical. Must the robot be humanoid? Answer is emphatically no. DARPA expects the robot to operate in human environments and use human tools, but DARPA does not require a humanoid form. In other words, with two arms, two legs, one torso, and one head. A system for example, that had three arms, four legs, and two heads, that would be kind of cool, is acceptable so long as it performs all of the

challenge tasks. Remember, it's the tasks that matter, it's the generality of the approach that matters, and it's that compatibility with human environments, human tools, and human operators, both in actual operation and in planning, those are the key elements. Must the robot be bipedal? This is a very similar question, can it have legs or tracks or wheels? The answer is, it need not be bipedal, the robot can use non-bipedal locomotion as long as the system performs all of the challenge tasks. Question three, and again, if you're getting hung-up on well which task must it perform, then your robot isn't general enough for us to think that it's the right kind that should be used. You need to keep in mind, don't over fit to those particular tasks. Question number three on technical. Does a robot need to perform all of the challenge tasks or can it do only some of the challenge tasks? The answer is that we expect the robot to do all of the challenge tasks. And for those that it doesn't do, it will score poorly of course on those particular ones. For teams that receive a GFE platform, can they modify the GFE platform? I'm sure it would be fun, but our answer is that, in general, no. And our reason is not that we don't believe that you might not have some great ideas, but if that's the case, you should really be in track A. The reason for giving out the GFE platform is for teams that have expertise mostly in the software domain, however, DARPA may consider rare exemptions to modification of the GFE platform on a case by case basis. An example of this, if you discover a particular sensor that you really want to use, and we find that it can be added to the robot without affecting the other parts in a bad way. We may consider that. But in general, the answer is no. Question number five on technical. For teams that receive a GFE platform, can they perform maintenance of the GFE platform? The answer to that is also no. There it is a hard "No," we will be supplying the maintenance through our GFE platform supplier. Question number six on technical. Must a single robot perform all of them, or can a kind of team of robots cooperate while each robots specializes on one single task? So our answer to this is that a single robot must complete all of the challenge tasks, however, the robot can break apart and come back together in any number of ways as long as the entire robot moves from one event to the other. You cannot leave

pieces behind. As an example, the robot could be a marsupial, it could be re-configurable, but you need to bring all the parts back together as you travel from one event to the next. And that's to avoid the easier solution of having a robot that's specialized to each of the particular task. Again our desire here is for a general purpose solution. Will the GFE platform have an open design? Is the question. Question number seven. The GFE platform software application will have--excuse me--the application program or interfaces, the APIs to the GFE platform will be open, however, the hardware design will not be open. Must the robot accomplish the challenge task autonomously without a human in the loop? The answer to that is no. DARPA expects an operator to be on the loop not in the loop providing supervisory control. The scoring approach will favor autonomy. So if you look at section I.D of the BAA, what it says is for two systems to perform the scenario equally well, the scoring approach will favor the system that has the lower data rate. Question number nine on technical. Must teams release their software as open-source and make it available to the public after the competition is complete? The answer to that is no, DARPA encourages, but does not require open-source software. Technical question number ten, when will DARPA release details of the communication specification? And the answer is no later than the program kickoff meeting which is scheduled for October. Can we use a wired communication link between the robot and the mobile base vehicle? What in general is the communications going to be like? If you look at Section 2.D of the BAA, it will say the commands and data must be able to be communicated both wirelessly and wired, both through a wireless link and through a wired link. So if you have an approach that only works with one, that's not good enough. Particularly if it's only wired, that may not work very well in real disasters. Next question, is this program related to DARPA's HACMS program? The answer is no, the DARPA Robotics Challenge does not have official ties to any other particular DARPA program, but it expects to build on technology that we've developed with many different programs in previous efforts. Next technical question. Can the hardware design that you are using in track A be open-source or must it be open-source? And the answer is that we encourage, but

do not require track A participants to make their hardware designs open-source. So I want to make sure that I said that right, I think I may have said that wrong. We do not require, but we encourage opensource both in hardware and in software. What is the position of DARPA regarding open-source? That looks like a duplicate, so I won't read that one. Is there an approximate date for the Virtual Disaster Robotics Challenge? That approximate date is June of 2013. Is DARPA separately awarding funds for the development of a GFE simulator? And the answer is we are, that is with DARPA Special Notice 12-34 and that's how--the people that you just heard from are going to be awarded a contract or it's our intention to do so. Could you please explain the publication policy? So for that, you should look at Section 6.B.4 of the Broad Area Announcement. Next question, are there arrangements for teaming opportunities? So having done this a lot, we decided not to establish a particular teaming website, however, we strongly encourage teaming through other informal means. We are going to make the list of e-mail addresses that were registered for this meeting available that you can use in order to get a hold of that. Actually, I don't think it's going to be e-mail, but we'll have names. I think that is correct. So look at the BAA Section 3.D.1. Are there any suppliers that track A is restricted from purchasing offthe-shelf software components or parts from? So in other words, are there certain places where you can't buy things from if you're within track A? So the answer is the only providers that you're restricted from are the suppliers for GFE equipment. And so if you look in the BAA, you'll see a specific ban on them being a subcontractor to any of the other teams in track A, B, or C. However, they could be a supplier for track D. Otherwise, there are no restrictions that DARPA has made on track A, B, or C other than the GFE providers. Next question, at what point during the process, the BAA challenge, the kickoff, will the final details of the challenge be available? And again, no later than the program kickoff date which will be on October. Will time limits on the challenge be applied to the entire challenge or to individual tasks? So, for the DARPA Robotics Challenge one in particular we're going to apply time limits to each event, we haven't yet determined exactly what that limit will be, but we expect it will be under

one hour, that's our expectation now for each event. Are there restrictions in power space or environmental on the operator and controller of the robotic platform? Can it be assumed that the operator and control system are indoors with air-conditioning and house power? The answer to that is that the operator will likely be indoors and provided with reasonable space and power. Next question, what are the specification and resolution, range, field of view, frame, rate, et cetera of the sensors on the GFE platform or the stereo et cetera? And so, we will provide details on that no later than the program kickoff day in October. We don't have them right now. Is tactile feedback going to be included on the GFE platform? The answer to that is yes, on the hands they will have some sensing, but we have not yet decided exactly which of the hands we're going to use and so we don't know the exact specification of that sensor. Does the GFE platform include a neck to move the sensor head? If so, what are the degrees of freedom of the neck? The answer is that the GFE platform does have a neck, but the specifications beyond what were describe by Rob Playter will be provided no later than the program kickoff date. These answers are sounding kind of familiar. Does the GFE platform include a torso? If so, is there a waist joint and what are the degrees of freedom of the GFE platform? So, it will have a torso, I think this question came in before Rob's talk about the different degrees of freedom and what their ranges are, so any specifications beyond what Rob provided will be again provided by the program kickoff date. What is the sensing included in the GFE simulator? The simulator will include sensors on the GFE platform as well as other sensors, the platform sensors like we said before have not quite been selected but will be by the kickoff day, the GFE simulator will also enable users to define their own sensors. Will the simulator include models of the tools like vehicle, ladder, human tools, et cetera, and the disaster environment that's required? The answer is yes. When will the GFE hardware be available for test for track B? How many months after contract award? Will the hardware with all necessary test equipment be available at each performer site or will this be run at a government facility? The track B and track C teams with top performances in a virtual disaster response challenge will receive the GFE

platforms approximately in July of 2013 and you'll get to take them home. So you get to actually test them at your own place. We are currently looking into providing government or GFE test facilities or at least plans for building them so that each of the performers can have a similar facility for checking their systems. How long is a tether for the GFE platform? We actually have not decided on that yet although we're talking certain numbers now, it will be sufficient to complete the challenge events and we haven't quite decided on the length. What we will do is probably put the power supply for the GFE robot on the back part of the utility vehicle that it drives around in and have the tether go between the vehicle and the robot itself. What level of access will be provided to GFE platform software? Will providers, willexcuse me--will performers be able to modify GFE platform software or will access be only through the publish API's? So we are expecting that access is going to be through the API's. Can Track B performers add additional computing capabilities to the GFE platform, what type of operating system or--is provided on the GFE platform? What type of memory, CPU, IO capabilities, et cetera? We're going to handle that on a case by case basis as I explained before. In general, we want the teams to feel quite satisfied with the GFE platform, there will be a second processor as Rob discussed before that the teams will be able to use that is not necessarily for low level control of the platform. So, final couple of question here. Will the GFE platform provider also contribute a robot model for using the GFE simulator? And if so, will it include close loop controls? The answer to that is yes. The GFE simulator will include a model of the GFE platform. And the final question is, will Track B performers have the opportunity to influence the GFE hardware design? And the answer is unfortunately no. We are developing the GFE at the same time that the Track B performers will be working on their software and the design for that will actually be fixed by the program kickoff day. So there will not be the opportunity to--for Track B performers to influence the hardware design.

So those are just a few of the questions that we have received. I encourage you to please send more questions into our BAA e-mail address and make sure that you send all questions there. Do not send the

GFE providers questions because they're just going to tell you to send them to us. This is a very official way that we do things and again the reason is, so that every potential proposer gets to hear all the questions and gets to hear all the answers and that we ensure fair and open competition. So thank you very much, I'm tremendously excited about this program. I think it's going to make a real difference both in disaster response and also in advancing the state of the art of robotics. So I look forward to your proposals and to your participation. Thank you.