An Introduction to Context-Aware Computing

featuring Dr. Anind Dey and Dr. Jeff Boleng as Interviewed by Suzanne Miller

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Suzanne Miller: Welcome to the SEI Podcast Series, a production of the Carnegie Mellon University Software Engineering Institute. The SEI is a federally funded research and development center sponsored by the U.S. Department of Defense and operated by Carnegie Mellon University. A transcript of today's podcast is posted on the SEI website at sei.cmu.edu/podcasts.

My name is Suzanne Miller. I am a principle researcher here at the SEI. Today, I am very pleased to introduce to you to Dr. Anind Dey, director of CMU's Human-Computer Interaction Institute and to Dr. Jeff Boleng, a senior researcher in the SEI's Advanced Mobile Systems Initiative. In today's podcast we are going to be discussing context aware computing. First, a little bit about our guests.

We are very fortunate to have Dr. Anind Dey with us as a guest today. Dr. Dey is an early pioneer in context-aware computing and authored one of the seminal papers in the field entitled *Understanding and Using Context*. We have provided a link to that paper in our transcript. In his research, Dr. Dey uses sensors in mobile technology to develop tools and techniques for understanding and modeling human behavior, primarily within the domains of health, automotive, sustainability and education. One of his projects, dwellSense, uses sensors to monitor daily activities of older people to detect physical or cognitive decline; using computer vision and other tools to detect behavior disorders such as autism; and automobile navigation systems that adapt to an individual's preferences.

Dr. Jeff Boleng is a senior member of the SEI technical staff on the Advanced Mobile Systems team. His interest and experience span a wide gamut of computer science, from network protocols, operating systems, distributed computation, and embedded systems to numerical analysis, scientific computing, parallel processing, and concurrency. These are both very busy people, so I am very interested to see how they interact together. Welcome to you both.

Suzanne: Let's talk about context aware computing. Of course, the first thing that comes up when we do that is smartphones, right? Everybody talks about context aware. I have a friend who

monitors her sleep patterns with her smartphone. I know every new model has an increasing number of these miniature sensors that are growing in power and reducing in size, and they track data from all around the environment. Give us a brief introduction of context-aware computing, and how sensors play a critical role in this.

Anind Dey: My take on context awareness is it is this ability to adapt how an application works with knowledge of what is going on around it. That is, who is using it, information about that individual, information about where they are, what they are doing, and what their preferences are. It is all this information about context of use, and then using that information to adapt how an application works.

Suzanne: So, the complexity of that is that *who* and *where* and *when* are themselves subject to context. This is one of those recursive sorts of things, and figuring out how to filter what the sensor is sensing into something that is meaningful.

Anind: Right. So, the sensors act as a proxy to the information we really want, which is the user's intent. *Why* are they using this application at this time and then how should the application responded in their behalf? The *who*, the *where*, the *when* are some of the easier parts; the *what* is often the most difficult part.

Suzanne: And then, *why*?

Anind: Right. That is their true intent.

Suzanne: Because essentially we are trying to go after, *Why are you steering this way*?

Anind: That is right.

Suzanne: …that is different. Or, *Why are you now going down the stairs when you just when down them two seconds ago. How did you get back up?*

Anind: That inference is the hardest.

Suzanne: All those kinds of things, yes. So, those are the big challenges in context awareness. Let's start with the sensors. So, what is it about perceiving information from the real world with a sensor that is different when you and I perceive that information as humans?

Anind: Well, we have taken a lot of raw data, raw stimuli. We are able to very easily and very comfortably convert it into useful information to act on—actionable information. With our smartphone, it gets the raw data, and it is still up to the programmer or developer of the smartphone or the application to convert that into useful information.

Suzanne: And, filter what is useful and what is not.

Anind: Right, what is relevant and what is not.

Jeff: There are volumes and volumes of raw data coming up from the sensors.

Suzanne: Right. We are getting into the big realm.

Jeff: Right, and it is noisy data.

Suzanne: When you say noisy data, say what you mean by that.

Jeff: Oh, well, this is a commodity cheap device; I am holding my cell phone up. The sensors, they are getting better all the time, but they are not perfect. The accelerometer data might have noise in it and show spurious movements that are not really there, so you have to be able to filter that as well.

Suzanne: So, noise is really spurious information that doesn't relate to the actual information you are trying to get from that sensor. I think this is one of the areas where big data has actually contributed to this whole field because we have techniques we did not have even 10 years ago for allowing that noisy sensor to actually be able to be helpful to us, right?

Jeff: Then there is the other challenge of combining multiple sensor streams in meaningful ways.

Suzanne: That is what humans do.

Anind: That is exactly right.

Suzanne: Right? That's what humans do really well.

Anind: Multiple sensors.

Suzanne: We are not even conscious of how we are synergizing all, and synthesizing all, this information. That has all got to be done manually…

Jeff: Programmatically, yes. Algorithmically.

Suzanne: With the computers, so that is a big challenge. OK.

When you address that kind of synthesis with some of the computing that you are doing with the smartphones, how does that mobile environment play into that? Because, as you say, different programmers are dealing with different aspects of the context information they are getting. Synthesizing that has got to be a little different than when you have got a super computer at hand that you can just do anything you want with. It is a constrained environment, right?

Anind: Yes, you have low-powered processors. You have limits on your power budget, so you only do so much computation on the phone. You have limited storage and, as Jeff pointed out, the sensors are not quite as good as what you want if you could dedicate thousands of dollars to your sensing platform. So, you have to deal with all these constraints.

I think still the key is whether you are able to send information up to the cloud, whether you are able to do all sort of things to protect your battery budget. The key is still, *How do you as quickly and efficiently as possible create this idea of what the intention is, what that context is, so that you can act on it.*

Jeff: Then, there is that other challenge that we can gather all the data, we can train the machine learning algorithms what a person was doing at the time or what a group of people is doing at the time. But, then, how do you individually personalize it? That is a big challenge. We can create nicely trained models that represent a large population but could be useless for an individual because we are all so unique.

Suzanne: Yes, we are. Some of us actually see a computer trying to do something that we think we should be doing, and we get a little bit recalcitrant about giving it the data it wants.

Anind: That is absolutely true.

Suzanne: Not that I would ever be that kind of person. You have people that are aware of the computing that may have motivations that are not consistent with the application.

Anind: That is right.

Suzanne: You may also have people that are even malicious in terms of wanting to use that information in a way that was never intended in terms of when that sensory data was gathered. So, those have to be challenges that add in to that constraint space that you are dealing with.

Anind: Yes. For a lot of the applications that we see out there, there is a desire to keep all the data on the phone, so it is your personal data, it is on your personal phone and the data never leaves. But for practical purposes—one, because the data is actually valuable, and two, because the computation may not be enough on the phone to do all the processing there—you are going to ship it to the cloud. That is where the issues [arise] of who really has access to the data and how is it going to be used.

Suzanne: Right. So, some of the other podcasts that we have had that deal with cloudlets and all those sorts of issues, they come into play with this too, which is why Jeff works with all of the other folks that we have talked to.

Jeff: A whole gamut of things, yes.

Suzanne: So, what you have been focusing on together is on technologies that help warfighters and emergency personnel operating at the tactical edge. We have defined that before, and we still define that, as environments constrained by limited communication connectivity, storage availability, processing power, and battery life. We have talked a little bit about how context-aware computing relates to that. But, give us a couple more examples about how each of you sees that particular environment as both a challenge to context-aware computing and an opportunity. Start with you Anind.

Anind: The question was about the warfighter domain.

Suzanne: And warfighters and emergency personnel at the tactical edge.

Anind: Right. So, in both these cases there is a tremendous amount of information that could be valuable to an individual or a group of people in that space. So, it is partly the problem of, *What information is valuable and then how to direct it to those individuals.*

The use of the context is critical for one, trying to understand what this group of individuals is experiencing, so that you know what information is relevant. But, also, determining what is the best way to get that information to the individual—whether I should be sending something to some heads-up display, whether I should be sending it in a more visual iconic way, all make a difference depending on what their state of alert is.

Suzanne: There is also the goal.

Anind: That is right.

Suzanne: Because the goal of an emergency responder early on is to find all of the people that are still alive. Later, it changes a little bit to gathering evidence and other things. The goal is going to affect the context as well.

Suzanne: What about from your view point, Jeff?

Jeff: For me, this whole thing started and it was all about information delivery and delivering the right information at the right time. When you are in one of the edge environments—especially a combat situation or, think of a firefighter fighting a wild fire—it is a dangerous situation. Probably, utmost in your mind is personal safety. So, if a threat emerges, an adversary or a fire near you, you want to know about that, you don't want that paralysis of too much information.

Suzanne: Right. You don't want to suffer from alert fatigue.

Jeff: Yes. You want something to prompt you and help spur you into the right action, so that you can preserve your own safety and also achieve the goal that you are going after.

Suzanne: OK. So, you are more about the delivery side, and Dr. Dey, you are more about what is the right information to get to that person or group.

Jeff: Yes.

Suzanne: To simplify it way down.

Jeff: That sort of defines our collaboration.

Suzanne: This is very important. Personally, I have done work with the Joint Fire Science program and have had contact with some of those folks that do end up on those front lines. It is very fast moving. Like any of these edge situations, it is very fast moving. So, that time constraint is going to be the other thing. We don't have forever to sit and analyze all this data and figure out what is the right thing to send when.

Jeff: Or, stare at my 300 apps on my phone and decide which one I want to open at this point. If I can model my activities and mission so that the phone knows what I am doing, it can present the things I need. It can be predictive, which is sort of the Holy Grail.

Suzanne: That is a holy grail and predicted in a way that is also not intrusive.

Anind: Not creepy.

Suzanne: Dr. Dey, Anind, looked at me, and he saw what I was thinking about.

Jeff: What is that called?

Anind: The Uncanny Valley.

Jeff: The Uncanny Valley, yes.

Suzanne: Yes. When it is too uncanny it reduces the trust to a certain extent. It is like, *Well, what is on the other end of that, and what else do they know that I don't really think they should know?* So, those are all issues that come up with this. So, that is going to be one of the interesting issues for you is getting acceptance of these kinds of technologies with groups that are suspicious…

Anind: Right.

Suzanne: …of privacy, security, and technology in general.

Jeff: We see some of that now with Google Plus and some of the other things that are going on. I sometimes pull up my phone, and it tells me an event that I am glad it told me, but I never asked [for] it, and I am surprised how it knew that that is what I wanted to know.

Suzanne: That's the creepy part.

Jeff: I am one of those fairly transparent people that I am OK with it, you know what I mean? Give them all my data. If I am shopping for something, show me the exact right one that I am going to be happy [with], so I don't have to spend much time shopping. So, you can have all my data.

Suzanne: Not everyone is quite as forthcoming as you are, Jeff.

Anind: Our current approach—and I think the current approach of a lot of researchers in the field—is to pick vertical application areas that are so valuable that people are willing to give up some information, and they think, *My health? I am willing do that. I am willing to give you this information.*

Suzanne: Yes. For my father's safety, I am willing to do this.

Anind: Right, exactly.

Suzanne: For the safety of the firefighters that are protecting my home, I am willing to give up some location data.

Jeff: In this domain, I say we have a cheat. I call it our "big cheat." With first responders somewhat, but definitely with military personnel, if you give them a device, you can tell them you don't have any privacy on this device, we are going to share all that context data. And, that is going to aid you enough, and if it doesn't aid you then let us know. That is what we are working toward.

Suzanne: Yes, but if you have a contract with them it's a little different than the general public.

That is a really good thing because that gives an environment for field testing that allows you to sort of do the technical feasibility of some of these things, the adoption feasibility. Then you can have other research streams that sort of dealt with that once you understand what the technical feasibility is. So, those are good things.

So, we sort of previewed the fact that you are collaborating on some research. Just give us a little bit of that because we are going to do another podcast on that one that we want people to listen to because we will get into that project a lot more deeply. What is a little bit about what you hope to accomplish with that collaboration.

Jeff: So, lot of context research is about opportunistic context when people come together. *How can we share information that we both may need because my sensors may have something that you might want, et cetera?*

Suzanne: Sure.

Jeff: We started a line that is more of a collaborative group context sharing.

Suzanne: More intentional.

Jeff: More intentional because squads and soldiers are together, they have got a shared mission and a shared goal. We want to be able to do, recognize, the activities of the individuals and the group as a whole to help share information amongst the group for a variety of reasons: one, just for better situational awareness. Another one might be to better distribute the power demands on the mobile devices throughout or alert someone that somebody is injured, that kind of thing.

Suzanne: What is your part in all of this, Doctor Dey?

Anind: It is actually very similar. So, we have collaborated a lot on trying to understand what is going on at the individual level. Now, we are starting to look at, *How do we identify what groups of people are doing together?* So, when groups are coordinating together, can we identify those and provide situational information for them?

Suzanne: And provide information, for example, about conflicts and the kinds of information you are getting from, say, six people and one of them is an outlier in terms of the data…

Anind: Exactly.

Suzanne: …because that could be meaningful.

Anind: Right, because that could be an injured first responder in the field, and that is why that person [has] not responded.

Suzanne: OK, so that sounds like we will have a really good discussion about that in a little while. Just a little bit about the future. We have talked about problems about security, privacy. This area is often called the internet of things. What are some of the other research challenges that you see in this area coming up in the next five years?

Anind: For me, the holy grail is to try and understand human intent when somebody picks up a piece of technology. Right now, if the only thing I have available to try and figure out intent is a mobile phone, it is a constrained space. With the internet of things, that constraint goes away. Now, we are talking about hundreds, thousands of devices that are going to potentially give me information about this individual. My ability to process and compute on all of that data just seems like a challenge were are not quite ready for.

Suzanne: Agreed. Anything from you, Jeff, or from your view point?

Jeff: Yes, just building on that. As spaces get instrumented, and sensors become not this brick of a phone, they start to be integrated into our clothing or a piece of jewelry that I wear, the sensor data is going to be so rich…

Suzanne: My eyeglasses.

Jeff: Yes, the eyeglasses absolutely. The sensory environment is going to be so rich that I actually think one of the key challenges is trust and adoption. People may rail against it, and it may be too creepy. They may say, *How in the world does my environment know so much about me?* I think it might be even a generational thing. You might have to be nurtured and grow up in that kind of environment to be highly accepting and even dependent upon it.

Anind: I can also see what happens if we reach that point, particularly if you have a generation that grows up with this kind of technology, because then you will wonder, *Is every device, like this pen I am holding, is this device full of sensors and is it able to compute? This one is not, but this water glass is. What is actually part of the internet of things, and what is not?*

They are not going to have glowing red stickers on them. It is not going to be clear what is playing the role and what is not.

Suzanne: Then we get back into the trust issues. So, there is a big sociological aspect to this is as well as the technology aspect coming up.

Jeff: Absolutely.

Anind: That is right.

Jeff: Which is the part I don't research in--on purpose.

Suzanne: That is a very complex area in and of itself, absolutely.

I want to thank both of you for joining us today to talk about these issues. This is a wonderful topic for me. I have an interest in this area, especially in the first responder arena. We are seeing a lot going on in this. So, I thank you very much.

For more information on the research that Jeff's team is doing in pervasive mobile computing, please see sei.cmu.edu/mobilecomputing/research/.

For more information about the Human-Computer Interaction Institute that Dr. Dey leads, please visit www.hcii.cmu.edu.

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