Deborah Estrin

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Computer History Museum

Editor: Dag Spicer

Deborah Estrin is a computer scientist who has made major technical contributions to networking, multicast routing, embedded sensing and computing, wireless sensor networks, and mobile and electronic health. She has been a professor her entire career, has served on countless panels and advisory boards, and continues to mentor students in electrical engineering and computer science. She is one of the most accomplished and visionary people in computing today and also the first professor hired at the Cornell NYC Tech campus. In 2012, *Wired* magazine named her one of the "50 People Who Will Change the World."

***David Walden*: Please tell me a little bit about your youth, the places you lived, and your early education, family, hobbies, siblings, and so on.**

Estrin: I was born and raised less than a mile from here, on the other side of the University of California, Los Angeles campus, to Thelma and Gerald Estrin. I have two older sisters, Margo and Judy. From the age of three, I lived across the street from UCLA and went to the local public schools. I then went to UCLA my last year in high school and on to UC Berkeley Engineering and MIT. From my early childhood, I always remember my parents telling the story that I wanted to grow up and get my driver's license and my PhD. This was at the age of six or seven, reflecting both that I was growing up in Los Angeles—where a driver's license was an indication of independence—and that a PhD was the norm with the set of people they always had over to dinner and to various social engagements. It was a time when the UCLA Computer Science Department was first growing. There were a lot of social interactions at my parents' house, cocktail parties and dinners, and what became known as my father's "Probability Seminar," which was, of course, a poker game with Len Kleinrock and other faculty from CS.

My father was very affected by the women's movement, initially through my mother. I used to think both my parents had their consciousness raised in the 1970s while I was in middle school and high school. But recently looking through some of my mother's old letters, I realize that she was a feminist long before that. Nevertheless, although my mother had done her PhD at the same time as my father at the University of Wisconsin, her career had always come second, and I think that was one of my father's deepest regrets. My father was probably the least sexist person I've ever met, of any age or gender. And that was a very powerful way to grow up as a young woman.

What were my hobbies? I did a lot of Israeli folk dancing, and we spent summers and sabbaticals traveling together as a family around Europe and Israel, where my parents both had strong professional connections.

My parents got married when my mother was 17 and my father was 20. They met when they were students at CCNY [City College of New York] and were both active in political movements when World War II broke out. They had married before the hostilities began and were both studying history I believe. During the war, my mother started working in electronics—the Rosie the Riveter phenomenon. After the war, they both decided to go on into electrical engineering and, through the GI Bill, went to the University of Wisconsin together and obtained bachelor's, master's, and doctorate degrees.

Background of Deborah Estrin

Born: 6 December 1959, Los Angeles

Education: BS (EECS), University of California, Berkeley, 1980; MS (technology policy), Massachusetts Institute of Technology, 1982; PhD (EECS), MIT, 1985.

Professional Experience: University of Southern California, assistant professor (1986–1992), associate professor (1992–1998), professor (1998–2000); University of California, Los Angeles, professor (2000–2012); Center for Embedded Networked Sensing (CENS), founding director (2002–2012); Open mHealth, cofounder (2011–present); Cornel NYC Tech, professor (2013–present)

Awards and Honors: National Science Foundation's Presidential Young Investigator Award, 1987; ACM Fellow, 2000; American Association for the Advancement of Science (AAAS) Fellow, 2001; IEEE Fellow, 2004; ACM-W Athena Lecturer, 2006–2007; American Academy of Arts & Sciences Fellow, 2007; Anita Borg Institute Women of Vision Award for Innovation, 2007; National Academy of Engineering Member, 2009.

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***Walden*: The government can do some good things.**
Estrin: Yes, very much so. And after the war, at that time, anti-Semitism was a factor when they were looking for jobs. They ended up with John Von Neumann at the Institute for Advanced Study at Princeton. From there, they went to the Weizman Institute in Israel; Chaim Pekeris visited IAS and wanted a machine for his research and government use, so they brought my father over to run the project and build the Weizac.

***Walden*: After high school, you went on to Berkeley and chose electrical engineering and computer science. Was this because it was your parents' field? Often children run away from their parents' field.**
Estrin: Well, I ran away from them physically and left LA. I was about 17 and I remember my first phone call home to my parents from Berkeley was, "Why did you move to Los Angeles and raise me there?" I felt somehow a little bit more at home in the Bay Area than growing up in West Los Angeles in that era of Beverly Hills and Hollywood and all of that. Now the whole world is like that.

It was a time when many more women were doing things that were not just the traditional things they had done, and I loved math and science. Also, I always had this drive to design and invent things. So with a desire to create new things, engineering and EECS was just a natural; so much was happening in terms of new technologies. And that became even more true—that was really the draw.

***Walden*: Did you focus more on hardware or software there?**
Estrin: At the time, it was a double EECS major but it was more software than hardware. In my last year, I had an incredible class with George Turin on the communication side of things. That really set the stage for my interest in networking.

***Walden*: After Berkeley, you went to MIT. What did you do at MIT?**
Estrin: I got to Berkeley and went through it quickly—I don't know why I was in such a hurry. I had always had a little bit of my parents' politics or activism in me so when I went to MIT, I entered the technology policy program to study the social implications and policy around technology. But I ended up doing my PhD at MIT in EECS (although it was rather multidisciplinary) because in the end I was more drawn to designing and inventing things than to analyzing the implications of what someone else had invented.

***Walden*: You also got a master's from MIT, though.**
Estrin: I did, in technology policy. And then I went on and did my PhD in Course 6 (EECS).

***Walden*: Jerry Saltzer was your advisor, at least for your PhD?**
Estrin: Yes, he was stickler for both vision and detail—quite a combination.

***Walden*: Not for your master's?**
Estrin: Jerry was on my master's project along with Marvin Sirbu.

***Walden*: How did you end up working with Jerry?**
Estrin: At that time, Jerry was starting to have more multidisciplinary interests, so when I went to look at the Laboratory for Computer Science (since merged with the AI lab to form CSAIL) for possible advisors someone directed me his way. He had an interest in cable TV and data over cable—this was 1981–1982. I did my master's around data communications over cable TV. I explored adapting multiaccess communication protocols (such as what makes Ethernet work) to longer distance CATV networks as well as some nontechnical issues. In particular, back then, there were all sorts of technological and institutional questions about whether the Mom and Pop cable operators were going to be able to upgrade their facilities and manage advanced data services. So I started that project with him and Marvin Sirbu, and then I continued on with my PhD with Saltzer.

***Walden*: What was your topic?**
Estrin: The title of my PhD was "Intra-organizational Networks." It was about doing Internet connectively across administrative boundaries and involved topics related to network security policies such as how to define the access control and information flow rules and mechanisms for remote operations inside a different administrative domain.

***Walden*: After graduating from MIT with your PhD, you ended up back on the West Coast at the University of Southern California.**
Estrin: I was hired at USC by then Chair George Bekey. That turned out to be a

tremendous stroke of fortune because, after a year or two, I started spending more time at the affiliated ISI [Information Sciences Institute]. It was actually Danny Cohen who, I think, said to Jon Postel and their group, "We should invite Deborah over and give her an office." I started spending most of my time there and, most importantly, having my graduate students there too, giving them the opportunity to be apprentices on advanced development projects ISI was doing. That was the basis of the 15 years I spent at USC.

***Walden*: For our readers who don't know what ISI is, could you just say a word about how that's distinct from, say, the Computer Science Department at USC?**

Estrin: The Information Sciences Institute was started long before I was there and was affiliated with USC as a kind of research lab, sort of what Lincoln Labs is to MIT or SRI was to Stanford. They did some very early important work related to speech and the Internet. Jon Postel was the person who ran the domain name system and operated a lot of other seminal infrastructure around the Internet; he used to personally give out IP addresses and domain names—he was the name and number czar. He was the governance of the Internet when it was too small to have anything else. The DNS developed by Paul Mockapetris was built and run at ISI. The RFC [Request for Comments] system was also run out of ISI. It was a place where advanced infrastructure was being designed and built and run in production as a way to do computer science research. ISI shaped the way I think about and do research.

That was an amazing time of people doing research and academic work but with output that was not solely academic. One of the last core networking projects I did was related to multicast routing, which was a really interesting design opportunity. I had the chance to work with incredible minds like Van Jacobson and Steve Deering. Ironically, it was also that experience with multicast routing that caused me to move away from core networking because, in the end, multicast didn't get deployed. And since I'm an odd sort of academic—things don't interest me solely for academic reasons—-that was a bit traumatic and I thought, well, if the Internet has become such a critical infrastructure that it's difficult to influence the core technologies from academia, then it's not clear how as an applied academic doing Internet routing I can do relevant work. I wanted to work in areas where I felt there was a chance the work would have impact and where I would have a better chance of learning from deployment and use. It's sort of what caused me to shift my focus to study wireless sensor networks.

In retrospect, I was wrong in general but right for me. Wrong in that many academics have had tremendous influence on the shape of networking through their research in the decades since—Scott Shenker, Dave Clark, Jennifer Rexford, to name just a few. Right, in that I personally was ready for a change because that's how I am.

***Walden*: Tell me about that.**

Estrin: I ran an ISAT [DARPA's Information Science and Technology advisory committee] study called "simple systems," and it was one of the things that led DARPA to launch the SenseIT program. Over a pretty short period of time, it became the entire focus of my own research projects. Our SenseIT research project at USC/ISI focused on mechanisms for coordinated distributed sensing, and I agreed to chair a National Research Council study that produced a report "Embedded Everywhere."

Through this early work, it became increasingly clear to me that doing experimental distributed sensing without a strong connection to the application domain for which the data were being used just made no sense. For the previous 15 years, I had safely and comfortably been working at a level of abstraction below the application, but now I felt like there was some circuit not being closed. So I had the idea of developing a center that would bring the users and designers of distributed sensing under one roof and decided to apply for an NSF Science and Technology Center grant to make that feasible. Center scale grants are unique in that they have the scale of funding and duration to bring together collaborators for productive multidsciplinary work that would not happen otherwise.

I came to UCLA and immediately began the long competitive application process for Center for Embedded Networked Sensing (CENS) to develop environmental monitoring applications and the underlying sensing systems. UCLA was the prime institution, with USC, UC Riverside and UC Merced as partners. After a long review process, we were awarded the grant. CENS wasn't about funding technologists to have small encounters with applications; there was both the time and the resources to support true

co-innovation between application and technology. The NSF Science Technology Program is fantastic and unique. It gave us a tremendous opportunity to do application-driven research. From 2001 to 2005, I focused on distributed sensor arrays and then, around 2006 or so, became interested in mobile phones as a type of sensing data source, which has led to the work that we ended up doing in participatory sensing and mobile health.

***Walden*: Stepping back for a second, you mentioned that you moved from USC to UCLA. How did that come about?**

Estrin: You know, they asked and it was just at one of those times. I'd been at USC for 15 years, and I was starting to think about this more application-driven work. I began that work with some wonderful colleagues at USC in marine biology, actually. It wasn't something I was seeking, but when UCLA asked, it felt like the right thing to do: moving on from where I'd started at the age of 26 and going to a larger university that had an even larger base of application domains in the sciences and things. It was just time for a change, and it was a change that fit in with the fact that I was a single mom. Being close to my parents was also very important to my son and me so I wasn't looking to leave LA then.

***Walden*: In the sensor area, one of the areas you worked was eco-sensing, putting people with sensors out in the world. How big a thrust of the sensor effort was that, or is that just a little piece of what you did?**

Estrin: Environmental monitoring and developing innovative, multimodal, distributed sensing systems was the thrust of the center. Ecology and ecosystem monitoring was the biggest application domain. I was also very involved with NEON, the National Ecological Observatory Network, which is now an NSF major research and equipment facility. They're building something that will live for 20 to 40 years across the continental US; a set of distributed ecological observatories in which people can do systematic exploration and long-term research around things like the impact of climate change on ecosystems.

It was in that context that we started to look at imagers as biological sensors—using cameras in observations of foliage and their transitions and of birds and using infrared cameras to pick up soil phenomena combined with below-ground soil arrays—trying to enable a kind of full above and below ground ecosystem measurement system for the purposes of modeling.

Initially, we came in with a naive set of notions about what the scientists needed and what were interesting distributed algorithm problems that we could solve. Because of the commitment to actually do things that were relevant to the applications, and a style that involved rapid prototyping and pilots in the field, we became much more flexible in our technical infrastructures and algorithms and much more focused on what would actually make a difference to the scientists.

***Walden*: What is your evaluation of the impact this work has had? Is it ongoing? Has it helped?**

Estrin: Yes, I think that there are two branches of the work. With respect to the scientific domains involved, it did have a lot of impact on our colleagues in those fields and what those fields are doing. We influenced the design of NEON, which is a huge piece of scientific instrument infrastructure for the country. And I am told that we had a lot of impact on the way in which ecologists are using these kinds of distributed arrays and cameras and so forth. In terms of computer science, I think we raised the bar of what it means to do applied and experimental work and engage with real applications.

One of the frustrating things was the fundamental economics of fixed sensing. When you put a sensor someplace in the physical environment, it is measuring that cubic centimeter or meter and that's it. It better be a really important cubic centimeter or meter, maybe because it represents something in a model or it's a hotspot in a server room or on a factory floor. Bill Kaiser and Greg Pottie initiated a project that I was part of on robotic-based sensors where we started moving sensors on aerial cables to be able to cover more of a two-dimensional and, in some cases, three-dimensional area to get a better, fuller model of what's going on and not just be stuck in certain fixed places. The economics for mobile sensing happened to occur at the same time that mobile phones were getting more and more powerful.

For example, phones were newly programmable, knew where they were thanks to GPS components, and were something that people plugged in and recharged at the end of the day. So we started to do something we called "participatory sensing," a combination of automated and human input. It was a

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natural next move to conclude that not only was the environment in which the people are moving around of interest but so were the people themselves. It was a natural, not premeditated, progression from distributed sensing to mobile sensing, to mobile phones, to participatory sensing, to mobile health.

***Walden*: Was mobile health still happening within the CENS center?**

Estrin: Yes, being a NSF Center, CENS allowed for a lot of flexibility. We added participatory sensing to the existing domains of seismology, environmental engineering, marine biology, and ecology. That included mobile health and came toward the end of CENS.

We pursued the participatory sensing and mobile health work with applications that would produce benefit for users even on a small scale, rather than starting with applications like epidemiology that require large-scale usage before they can deliver results. When it comes to scale, you can't iterate experimentally in the context of some future situation that doesn't yet exist. I learned through distributed sensing that it's hard to do meaningful applied experimental work when it is all contingent on a posited future (such as the massive distribution of sensors) that isn't yet buildable. I wanted problems that scaled down as well as up. Because if a problem doesn't scale down, we can't build and use it. I can't experiment with it; I can't explore it and then build up from the successes if it doesn't scale down in number.

So our work in mobile health started at the scale of the individual. By them running an application, there's an intensity of information, a time series, and a temporal resolution that you can understand about them as an individual. We focused on applications where even one person at a time benefits from the innovation. Over time, as the approach proliferates, we can benefit from the opportunities that come at scale as well (population based models, discovery, and so on)

Now, this approach has its downsides; it made my focus more short term. It's very important to the field that we take a range of perspectives, so while this was the right path for me, I am not suggesting it prescriptively. We need a full spectrum of research styles.

***Walden*: Could this work be used, say, in treating diabetes?**

Estrin: Yes. In fact, we had a showcase in December 2012 at which one of the scenarios we demonstrated was for Type 1 diabetes; our use case was an individual who needed more information to better manage her condition. We demonstrated the insights she and her clinician gained by integrating diverse data streams: blood glucose measurements, physical activity monitoring, and data from apps for journaling sleep and mood. The ability to bring all those streams together to inform self-care and provide clinically actionable data is what mobile healthcare is about.

***Walden*: Since NSF Centers only last 10 years and now that CENS has closed, please tell me what you think might happen next. Will you bring some of what you've been doing to that?**

Estrin: I'm delighted to be continuing and growing my work at Cornell NYC Tech. Cornell Tech is a bold vision inspired by a New York City initiative under then-Mayor Michael Bloomberg and enacted by Dan Huttenlocher, dean of the Cornell NYC Tech campus. The vision was to draw on an academic institution with great depth and history, Cornell, and create a new center for digital innovation rooted in the urban context. The three initial research hubs are in Healthier Life, Connected Media, and Built Environment. When I first looked at the proposal back in 2012, I thought, "They're singing my tune, singing my song, whatever it is, humming my tune." When they asked me if I would be interested, it was really just such a clear cultural match in the way they wanted to see the work done there.

I'm excited about doing that kind of enmeshed entrepreneurial work. We are about commercial entrepreneurship as well as social entrepreneurship, so my work with Open mHealth (http://openmhealth.org/), a

nonprofit startup that is all about catalyzing commercial innovation and being a part of the open architecture world, is very much applicable.

Walden: What part has teaching played in your life?

Estrin: The best part of being a faculty member is working with fantastic colleagues and incredible students. Sometimes it's more PhD students and other times it's more master's students, depending on the mix of problems. In my last few years at UCLA, I'd been working with undergrads and high school students to add to that mix. I really like teaching through apprenticeship, where students become experts through scholarship and building, and we are bringing that culture to our formal classes as well as independent research work at Cornell Tech.

Walden: Is there anything final you'd like to say?

Estrin: Well, for a complete picture of things, I have a 27-year-old son and I spent a lot of time being a single parent. We're very close and part of what stimulated me to embark on new endeavors (like distributed sensing), earlier than I might have otherwise, was that I liked having exciting things to tell my then young son about. Being a mother and having this young man as my close friend has been a very important part of my life as well.

Reference and Note

1. This interview of Deborah Estrin was initially conducted by David Walden on 19 Nov. 2011 in Estrin's office at UCLA. This original interview was 7,400 words long, and it was edited down to the length of this column by Dag Spicer with the approval of the approval of the interviewee.

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