An Interview with

WILLIAM A. WULF

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Conducted by Jeffrey R. Yost

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William A. Wulf Interview

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Abstract

Computer security pioneer and past President of the National Academy of Engineering William Wulf briefly recounts his childhood, early education, and developing research interests before addressing how he came to develop a strong interest in computing and completed a doctorate (the first computer scientist doctorate) at the University of Virginia under one of the department's founders (and the sole founder of the computer center) Alan Batson. The bulk of the interview is on his years as a faculty member in computer science at Carnegie Mellon University and the University of Virginia, and his founding and leadership of start-up Tartan Laboratories, and his service in directing NSF's CISE and as President of the National Academy of Engineering. Among the topics discussed are BLISS, C.mmp, HYDRA, key meeting with Al Gore on the Internet, teaching, and the digital humanities.

Professor Anita K. Jones also participates in the interview.

Yost: My name is Jeffrey Yost from the Charles Babbage Institute at the University of Minnesota, and I'm here today on Tuesday, June 23, 2015 in Charlottesville, Virginia, at the home of William Wulf and Anita Jones. This is an interview with William Wulf for CBI's NSF-funded project on Building an Infrastructure for Computer Security History. May I call you Bill?

Wulf: Bill, yes.

Yost: Bill, I'll just start off with some basic biographical information. Can you tell me when and where you were born?

Wulf: I was born in Chicago on December 8, 1939.

Yost: Did you grow up there as well?

Wulf: Yes.

Yost: Can you tell me a bit about your parents?

Wulf: Let's see; the relevant fact is that when I was about eight years old, my father, who was a mechanical engineer [who] emigrated from Germany — I'll show you a marvelous ink drawing, which I keep out here to keep me humble [laughs] — but when I was about eight years old he was diagnosed with Parkinson's disease. And so he could no

longer work or bring home a paycheck and so I essentially was raised on welfare. My mother was a native of a small town outside St. Louis, Missouri, called St. Charles. Her father, my grandfather, was a carpenter, and I suppose it was from him that I developed a lifelong interest in carpentry and woodworking. If we have time, I'll take you down and show you the biggest and most expensive room in the house, which is my woodworking shop.

Yost: Great.

Wulf: I built this table, by the way.

Yost: Beautiful table.

Wulf: [Laughing.] I also designed this house, and this study was designed not only for our desks but also we thought we would have students come over and we'd have small, little meetings of no more than six people, which required a hexagonal table. That's why there's a white board on the wall behind you.

Yost: Can you describe yourself as a student, growing up?

Wulf: I think I was a good but not especially remarkable student in grade school and high school. Because my father wasn't able to bring home a paycheck, I went to a community college for the first three years of my undergraduate work. Even though we

had no money, my parents were absolutely adamant that I go to college, and so I went to this community college in Chicago for three years. I did my fourth year, quote, "down state," in Illinois. I got a B.S. in engineering physics and actually, there were two faculty members that had a tremendous impact on me. My first semester of my senior year I wanted to get into a math course in real analysis and the only section of it was closed. So a friend of mine from the community college said he was going to take this computer course and would I like to take it with him. I was skeptical, to tell you the truth, but I did.

Yost: Why was that?

Wulf: I thought of myself as a theoretical physicist and these were these machines, you know? But about two weeks into that course I absolutely fell in love with computers, and that's shaped the rest of my life. I guess I must have done okay because at the end of that semester, the instructor came to me and asked whether I'd be willing to be his teaching assistant the next semester. I didn't know it at the time, but looking back on it, at the time, teaching assistants were graduate students and I was still an undergraduate. But anyway, two weeks into the first course, I fell in love with computers; two weeks into the second course where I was a teaching assistant, I fell in love with interacting with students. And those two love affairs have shaped the rest of my life.

Yost: This instructor was Lloyd Fosdick?

Wulf: Lloyd Fosdick, that's right. Oh, you must have read that already. [Laughs.]

Yost: Can you describe that first course you took?

Wulf: The first course? Let's see, this was a course taught on ILLIAC I, which was a computer built by faculty members at the University of Illinois. There was just beginning to be some commercially available computers, but ILLIAC I was built when there were no commercially available computers. There were no programming languages for it, not even an assembler. I don't know why I remember this, but an integer multiply instruction took 17 milliseconds. We now talk about picoseconds, nanoseconds, but not milliseconds. Anyway, about my education, so having fallen in love with interacting with students, after I got my master's — by the way, Lloyd arranged that too — he came to me in the middle of that second semester and asked where was I going to go to graduate school? Because of my modest background, I didn't even know what graduate school was. He arranged for me to be in the master's program in Electrical Engineering at Illinois.

Yost: What were you thinking, as you were finishing your bachelor's, in terms of career? Had you thought much about that before you got that question about graduate school?

Wulf: Not really. I loved building things. That's why I built this table we are sitting at, why I designed this house, and why I have that workshop down in the basement. So I was just assuming I would be an engineer of some sort, but I didn't have a sharper image than that. Anyway, Lloyd asked me where I was going to go to graduate school. He arranged

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for me to get into the master's program at Illinois. And finishing the master's, I didn't think I wanted to go further — I was just tired of going to school. And so I wouldn't let myself get pushed into a Ph.D. program, but I did want to teach so I applied to every university in the country that said they had a computer — all 12 of them — and the majority of them wrote back saying they only hire Ph.Ds. But I wanted to be a non-tenure track teaching faculty member. One of the two schools that interviewed me was University of Virginia and I came here as a non-tenure track teaching faculty member.

Yost: Before we get into that, did you do a master's thesis?

Wulf: In EE.

Yost: In EE. Can you tell me about that thesis?

Wulf: The thesis, no. [Laughs.] It's so long ago! Okay, where are we going now?

Yost: So you started in a non-faculty instructor post at the University of Virginia?

Wulf: Almost right. I was non-tenure-track faculty.

Yost: What did you teach?

Wulf: At the time, there was no computer science program maybe anywhere, but there sure wasn't at UVA, so I was in the applied math department. So I was teaching math courses but I sort of sidled over into teaching computer courses. For example, I created a course in linear algebra, with a strong computing flavor. And one day in my second year, as I walked out of class, the chair of the applied math department snagged me in the hallway and said that they were thinking of offering a Ph.D. in CS and would I like to be a Ph.D. graduate student. My first reaction was no. My wife and I had just had a baby and I didn't think we could afford it. He scowled for a moment and said what if we reduced my teaching load/salary to seven-eighths time? Seven-eighths, I could live on that and so I said yes. So I got the first Ph.D. in computer science from the University of Virginia, and probably one of the first dozen, or so, in the world.

Yost: Alan Batson was your advisor?

Wulf: Yes.

Yost: You mentioned that wrote to 12 schools that you knew had computer facilities —

Wulf: I don't know that that's all that had one, but they were the ones that advertised the fact.

Yost: And the two that responded, what was the other?

Wulf: Miami University in Ohio.

Yost: Ohio State?

Wulf: No. [Pause.] It's too long ago. [Laughs.]

Yost: Can you describe how — or before I ask that — was Alan the one that responded to you when you wrote to the University of Virginia when you applied?

Wulf: I don't recall. But, when I came here, he picked me up at the airport and took me to his home for breakfast. So it was a very personal relationship from the get-go.

Yost: Can you expand a bit on that and describe him as a mentor?

Wulf: I haven't thought about that for a long time. He was a Brit; he got his Ph.D. in physics in England; and his personality was a really interesting combination of the more formal attitude of European faculty, and at the same time, we had a very personal interaction. But our relationship was much deeper than faculty/student, it was a personal one as well. Very reinforcing and supportive.

Yost: Can you describe the computing facility at the University of Virginia? I understand it started with a Burroughs 205, and then later a B-5000.

Wulf: Absolutely correct, yes. The 205, I didn't use it for very long. It was in February when I got here, and it was a vacuum tube machine. Perhaps in retrospect one of the strangest things about it was that the primary memory was a drum. I had used the IBM 650 when I was in Illinois, which also had a drum as a primary memory. And if you think about it, the typical organization of computer programs is that you execute one instruction, and the next instruction, using the memory location right after that of the prior instruction. That turns out to be a bad idea for drum-memory machines. You might end up having to wait for a whole revolution of the drum in order for that next instruction to come up. The 205 and the 650 took different solutions to that problem, but both certainly had to face up to that. As a programmer you couldn't just let the software take care of it.

Jones: When you were programming in assembly language, you had to place each instruction on the drum?

Wulf: The assembler helped, but yes, you had to make sure that the next instruction was going to be close to being right under the read head or your program would run a thousand times slower.

Yost: Challenging.

Wulf: Yes. We don't think about such things. Well, people don't think about assembly language anymore for that matter. [Laughs.]

Yost: You wrote a dissertation entitled, "A Notation on Digital Systems." Can you both tell me how you came to that dissertation project and also to describe the dissertation?

Wulf: The notion of high level computer language was just emerging. FORTRAN was a very new, very novel concept and the design of computers, of the hardware of computers, was right down at I'd have to say the vacuum tube level. So definition of machines were drawings of the electrical interconnections and I just felt strongly that we were not going to able to design more and more complex, more sophisticated digital systems — computers — unless we could get the level of the abstraction up from electronic drawings. So I decided that we should have, in essence, a programming language for describing the physical machine and so that's what the dissertation is about; writing, in essence a programming language but where the output of the compiler for that language is not a program but rather in essence a set of electronic drawings. There was another dimension to it and I don't remember how I made these two things up, but there was a general interest in a more formal approach defining what the semantics of a programming language was. And I thought that was particularly important for this, where the output of the "compiler" was going to be descriptions of electronic circuits. So I, in essence, did a formal semantic definition of the programming language, so that one knew exactly what was coming out of a program; a machine description in this programming language. The way that I chose to do that was not to be at all of interest to anybody [laughs] but I suspect that's true of most Ph.D. dissertations.

Yost: Were there other faculty members at UVA in addition to Batson that you also saw as mentors or helped with your work on this dissertation?

Wulf: It was so long ago that I'm drawing a blank on names, but yes, there were several.

Yost: Do you recall if there were any computer scientists working on program language theory that influenced your thought, outside of Virginia?

Wulf: Well certainly one of the things that influenced my thoughts was when we got that Burroughs 5000, the operating system — which was way, way, way ahead of its time — was written in a dialect of ALGOL. You may remember that ALGOL was hoped to be this universal programming language, and as I said, the operating system was written in ALGOL, that's not quite true. It was a dialect of ALGOL because you had you had to be able to get at things like I/O devices. So ALGOL influenced me but this Burroughs version used for writing the operating system certainly also influenced me.

Yost: And as you finished your Ph.D., can you tell me the process you went through in your job search?

Wulf: I wrote to quite a few schools, applying. I don't remember exactly how many interviews. I got lots of offers to do an interview but the one that was just head and shoulders above everybody else was from Carnegie Mellon. At the time, Carnegie Mellon was considered to be one of the three best computer science schools in the world and had

some fantastic people there. So I went there and gave a lecture about my dissertation, and very shortly after I was there I got an offer from them. There really wasn't any contest after that.

Jones: Do you want to tell him the big frog, little frog story about tracking down Batson?

Wulf: I had two offers, one from Carnegie Mellon, and I think this is where Purdue came in, it was the second offer. I went to Alan and told him I had these two offers and the one from Purdue was for substantially more money. Well, for a poor little graduate student, it seemed like a lot more money. So I went to Alan and said, 'I have these two offers. What's your suggestion?' He said, 'Do you want to be a big frog in a little pond or do you want to be a little frog in a big pond?' I distinctly remember saying to Batson, 'No, I want to be a big frog in a big pond.' The big pond being Carnegie Mellon. So I accepted the offer from Carnegie Mellon. It was exactly the right decision.

Yost: When you gave the job talk from your dissertation at Carnegie Mellon, were there any faculty members that you remember communicating and bonding with?

Wulf: As I said, at the time, CMU was considered one of the three best computer science departments in the country, so . . .

Yost: There were a lot of stars.

Wulf: . . . a lot of stars. In particular, Alan Perlis, Al Newell, Herb Simon — and I'm not sure I quite appreciated at the time, what a compliment getting an offer from them at the time was — but they came back very quickly. Alan Perlis, in particular, was very strongly in my court for making an offer.

Yost: As you started in on this job, what did you see as the principal area you wanted to conduct research?

Wulf: Pretty much I thought I would continue my dissertation topic and in particular, I was still very influenced by this experience with Burroughs and their having written their operating system in a dialect of ALGOL. So my first major project there was designing a programming language specifically for writing system software. It was called BLISS, Bill's Language for Implementing System Software. [Laughs.]

Yost: And so your work on BLISS preceded the C.mmp. Can you talk about that work?

Wulf: In preparation for your coming, I was thinking through a bunch of these things and I have this very distinct memory: one of the people who was at CMU when I went there was Gordon Bell. Gordon was there on leave from Digital Equipment Corporation, DEC, and he was the lead engineer at DEC. One day, Allen Newell came to me, who was a superstar in artificial intelligence. He and Herb Simon really sort of defined that field. Alan came to me and he said, you know Gordon and I have been talking about building a multi-processor. Would you like to be in charge of that project? I thought about it for

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about two nanoseconds and said yes! So Gordon actually designed the crossbar switch. The machine would call C.mmp and it was a 16-processor multiprocessor, and the 16 processors were connected to 16 memory modules through this so-called crossbar switch. So the amount of memory that one of the PDP-11s could address at any time was limited to a 16-bit address or 64k. But we could change the settings and the switch, so a logical address space for any processor could be very much larger, and it was easy for two processors to share the same page of memory. There had been a few multiprocessors designed before that but they were mostly, I think they were exclusively two processors, and they did not share memory, or very much memory, anyway. One had been built at MIT, I recall, and I think IBM had built one too, but nobody had built one with as many memory modules or with such a high degree of memory sharing. But anyway, I had nothing to do with the design of the crossbar switch and that sort of thing. I did have fair amount of input into inter-processor communication, the way the interrupts were handled, the things that the operating system really needed in order to exploit this architecture. And then I was principle designer of the operating system.

Yost: As you started working on that, was security a consideration from the start?

Wulf: [Laughs.] Yes, but the way that got started was Anita was a graduate student at CMU at the time, and one day she came by my office and handed me a hand written, penciled piece of paper that defined the notion of typed and capability-based protection and I just fell in love with it. We hadn't gotten very far into the operating system at this point and I just bought that hook, line, and sinker.

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Yost: Had you been aware of Cal Time-Sharing System at that point?

Wulf: In general terms, but, yes.

Yost: Did that have any influence on your thinking about capability systems?

Wulf: Too long ago. [Laughs.] Sorry.

Yost: I understand. There was the beginning of a number of works and publications in the late 1960s, and early 1970s, on computer security starting with Willis Ware's 1967 paper outlining the multilevel security problem at the Spring Joint Computer Conference. Had you followed any of the kind of computer security developments, either with Multics having been designed with security in mind, as well as SDC's ADEPT-50?

Wulf: I would say yes, I was generally aware of, I think, all of those papers. I mean, there weren't that many at the time. But it was not a high priority. I wasn't particularly looking to build a new, novel, better security system. It was when Anita brought me that penciled piece of paper that I really got intrigued by it.

Yost: And so that started you off on the HYDRA project?

Wulf: Yes.

Yost: Can you tell me how that project evolved and the principal members of the team that worked on it?

Wulf: Have you seen the book about HYDRA?

Yost: Yes.

Wulf: The authors of that book are the team that designed it. I felt the only way I could fairly select a set of authors was to include all the people who had worked on it. Some of them had worked more on it than others, but that list of authors is the list of people who worked on it. Almost all graduate students. I don't know where I'm headed here.

Yost: Were there any other faculty members other than yourself who spent significant time on it?

Wulf: No. I mean, I talked to other people and they were generally aware, and I'm sure they critiqued it and that sort of thing, but nobody was really devoted to it.

Yost: As you began working on the project what did you see as the greatest challenges?

Wulf: Boy that's a long time ago. I think that there were two things which in retrospect I think were probably inseparable from each other, but they were separate in my mind. One

was simply building a truly symmetric multi-processor operating system. Every multi-processor before that was a master/slave relationship. One of the processors ran the operating system and simply said to the other processor, you go do this job. I didn't want that. I wanted completely symmetric; every processor could run parts of the operating system. They had to not step on each other's toes, but we could do that with inter-processor interlocks. Part of the design of C.mmp was that at the time [pause]

Yost: And was the unique at the time?

Wulf: Oh, yes. Nothing had ever been symmetric before. I talked a little bit before about my contributions to the design of the hardware, and they all had to do — not all, but — one of the most important things was the set of facilities one needed in order to let more than one processor execute the operating system and not step on each other's toes. So more than one could be running the operating system but as long as they weren't stepping on each other's toes, it was okay. Just had to have the hardware to do interlocks to make sure that that didn't happen. So I saw this building an operating system that was symmetric and could be executed on multiple processors simultaneously, that was one big piece of the HYDRA design. The other piece was the capability-based protection.

Yost: Simultaneous to that project, at the University of Cambridge, Maurice Wilkes, Roger Needham, and David Wheeler were working on the Cambridge Cap or Capablility System. Was there any interaction or communication between this capability systems project and yours?

Wulf: No. We saw each other at conferences and talked informally – but nothing beyond that.

Jones: Well, you would assume; in their book they acknowledge me.

Wulf: Oh, yes. [Laughs.]

Yost: What did you see as the application and the potential impact for developing the HYDRA OS kernel?

Wulf: At the time, I was absolutely convinced that the set of ideas that we were pushing, both capabilities and the symmetric multi-processor, was something that ought to get into commercial service fairly broadly. It's a big disappointment that that basically didn't happen. I don't know whether there's anything I could've done to change that, but it was a disappointment.

Yost: You've written, "the protected subsystem abstraction is very powerful in designing operating system software in a capability environment and that was a key element of the success." Can you elaborate on that?

Wulf: No. [Chuckles.]

Jones: Come on.

Wulf: Okay.

Yost: You've also written in an article that you regret that enough was put into the human engineering side with regard to software interface for the user. Can you comment further on that?

[Pause.]

Jones: The HYDRA interface?

Yost: Yes.

Wulf: Let's see. I remember writing that paper. Thinking back about the motivation for it is a little hard, but I think it's probably fair to say that the whole notion of human interface to computers received much less attention globally than we would do now. We were so enamored of the hardware side of things that the human interface just didn't get the same amount of attention in *any* system. It wasn't just us. And it was reflection upon that that prompted the paper.

Yost: Do you recall what the response was from the computer security research community to when you first started presenting work —

Wulf: Let me turn that over to Anita. She was actually closer to that community than I was.

Jones: There wasn't much of a community.

Wulf: [Laughs.] That was just going through my head, too.

Yost: But was there any interaction with, say, the people that were on the Anderson committee?

Jones: I think you have to kind of get your head around the fact that the notion of computer security was very simplistic. It was, there's the user and there's the operating system. There was only one user, so the extent of computer security was shared files. And since two programs were never executing simultaneously, we didn't do much — at that point — multi tasking. There was *A* [single] program running, and so the extent of computer security was do you have legitimate access to this file, period. And you don't have to worry about another program simultaneously accessing the file and changing it from out under you; something like that. So the attention to computer security by and large was just not there. It was this simple notion of do you have access to that file, full stop.

Yost: What do you see as the legacy of HYDRA?

Wulf: I said before that I was then, and to some extent I still am; I regret that it didn't have more global impact. The notion of computer security is still pretty simplistic and disappointing. I mean, just listen to discussions about Hillary's [Hillary Clinton] e-mail system on her home computer. It drives me nuts, that particular discussion. The broadcasters assume that a government system is going to be more secure than a system at home. Well, we have never ever built any computer program that was secure. Every computer program that I know of has been compromised and so if you want to talk about the security of the system, you have to talk about — with the current system — all you can reasonably do is talk about how much effort it would take to break it and the amount that gets devoted to breaking the system is a function of how valuable the information is in that system. So I think government systems are probably a lot less secure because people are willing to put more energy, more time, into trying to break them. I'm not at all sure that the state department e-mail system is going to be "more secure" than Hillary's system in her basement. I mean, it's possible but I don't think it's a given, by any means.

Jones: He asked about the legacy of HYDRA. Seems to me one aspect was the fact that you had a tiny kernel and everything that had traditionally been in the model that operating systems was outside, and therefore separately protected. You want to talk about that?

Wulf: Well, I'm not sure what I should add to that. Why don't you go ahead. [Laughs.]

Jones: In comparison, it was dramatically differently structured than operating systems, and there was only a small amount of code that ran in privileged mode. For example, the file system, because it's capability-based — I guess we can talk about this now — the file system was not privileged code. It ran outside and it could deal with the disks, and therefore, the files. But it otherwise looked like a user process, really.

Wulf: But if you look at contemporary manufacturer produced operating systems, they're still in the old mode.

Jones: Millions of lines of codes.

Wulf: Yes.

Jones: How large was the terminal for HYDRA?

Wulf: It was less than 64k. I don't remember how much.

Jones: It was what ran in each of the individual processors.

Wulf: Right.

Jones: Another thing that I thought was interesting was that Bill decided what academics do is they let research projects go beyond the time that they should go. Because the minds

of the faculty and students are, you know, one of the critical resources of the nation and so projects should be shut down. So Bill, based on some reasoning that I'm not privy to, decided — because I wasn't close to it at this point — decided to shut it down, bought champagne, and — why don't you tell, Bill? HYDRA sent a message to everybody?

Wulf: We held a party for shutting down HYDRA.

Jones: And C-dot [C.mmp], too?

Wulf: C-dot, too, yes. C-dot was nothing without HYDRA. What you see up there is the last reboot of HYDRA, and then we took it down and shut it off. That's all on display there. And at the bottom are the signatures of all the people who worked on it, mostly graduate students but [pause]

Yost: Were a number of those your doctoral students?

Wulf: All of them. That's true of the people who are authors of the book about HYDRA, as well.

Yost: While you were working on the HYDRA project, was it all-consuming or did you have other research that you were also doing at the time?

Wulf: I would have trouble pointing at specific things but I always run things in parallel. And yes, HYDRA was 99.7 percent of where my energy and my thoughts were going but there were always other things bubbling in the background.

Yost: You were continuing to publish on programming languages, next generation programming languages. Can you talk about that line of research?

Wulf: [Pause.] No. [Laughs.]

Jones: Oh, sure you can. When did BLISS start, the BLISS project?

Wulf: That really started when I went to CMU.

Jones: Oh, okay. You already talked about BLISS?

Wulf: Bill's Language for Implementing System Software, yes.

Jones: Did you talk about NOGO, too?

Wulf: Oh, no. Let's see, Dijkstra wrote a paper, a very short paper, that was published I think in *CACM*, pointing out that the GO TO was a factor that complicated the logic of computer programs and consequently was a contributor to program errors. I bought into that and decided that we should design this language, BLISS, without the GO TO

statement. It was clear theoretically that you could do without it as long as you had other control constructs, like if/then/else and then various iterations statements, and subroutine calls. But it wasn't clear that as a practical matter that was going to be a good idea. So when we set out to design BLISS, we decided not to include the GOTO, but had the attitude that this was an experiment and if things went bad we could put it back in. But it never got the GO TO. We used BLISS for writing HYDRA, for example, so on a large operating system, and it worked just fine not to have a GO TO. It was another thing that was a disappointment, that that didn't get propagated into other more practical languages because I thought we conclusively demonstrated that you could use this for large, sophisticated, complicated software without the "go to."

Yost: So this is the first completed programming language that did not —

Wulf: It certainly was the first. It may still be the only. I'm not sure.

Yost: Did you have any interaction or communication with Dijkstra?

Wulf: Lots of informal communication. We were at the time going to the same conferences, from time to time. He had me come give a talk. I was at some modest number of his talks. But yes, we interacted.

Yost: As you finished the HYDRA project, how did you see your research especially, at that point? Did you see computer security as an area that you would want to have continuing involvement with or were you also captivated by other areas of research?

Wulf: [Laughs.] Let's see. I think I moved on to other things. Not sure I could tell you what those things were.

Jones: Are you going to talk about Alphard? You did a lot in languages. You can talk about optimization, but also Alphard was an example of the implementation of ADA that was modest and lean, etcetera.

Wulf: Language broadly has always been on my interest list. How can I say this? Expressing the ideas of computer science in an executable way is what was, and to some extent, still is an interest of mine. I never thought of myself as a programming language researcher. I did think of myself as there are these ideas and I wanted to get them into executable form, but I can't say them very well just in languages so I would branch out into these other things, like BLISS.

Jones: Did you talk about DEC picking up BLISS and your copyright on it, how it affected me?

Wulf: The implementation of BLISS that we did — the principal one, anyway — the compiler ran on a DEC PDP-10 and produced code for the PDP-11. So I actually

collaborated fairly closely with some people at DEC, and they did pick it up — but this is part of that disappointment — it didn't go beyond that. Oh, yeah, that's the BLISS compiler. One of the; maybe I can talk to you about omitting the GO TO. One of the benefits of that, it turns out, was we could optimize programs better than we could optimize programs that had a GO TO in it. If it had a GO TO, you can't always tell what information is communicated or is modified by a particular control path, whereas if you only have four IF statements, at compile time, you can characterize what the state of the program is or would become. So the BLISS compiler was damn good.

Yost: When you published on BLISS in *Communications*, do you recall the responses you got from the computer science community and programming language specialists?

Wulf: It's a long time ago. I don't know how to answer that. I always had good relationships with other people in the related fields that I touched on. Nobody picked up my work and took it to the next step, and I think most academic researchers would take somebody else picking up your work and moving it to the next stage as an indication of real deep interest, and I didn't have that. My students carried on some of my work but [pause]

Yost: Are there any examples that you want to highlight, projects that are carrying on your work?

Wulf: It's been so long.

Yost: I understand; a long time ago. Was Alphard the beginning of work that in part was connected to ideas with what you did in starting Tartan Laboratories?

Wulf: No, the BLISS compiler was what led to that. I thought we had developed a technology for building optimizing compilers that was head and shoulders above what other people were doing. So the idea of Tartan was to build optimizing compilers for other machines and that was successful enough that we grew it from three employees and no income, and in about eight years we were up to over 100 employees and about $20 million a year in income. Then we sold it to our biggest customer, which was Texas Instruments. We had started on venture capital, and the venture community got their money back with plenty of interest.

Yost: Can you tell me about that thought process that you and Anita had, in terms of moving from, taking a leave from, CMU and launching a company, and taking a different career path with that entrepreneurial venture?

Wulf: Branching out from a university when starting a company was perhaps even more in the air [then] than it is today. It was unusual in the eastern part of the country but very common on the West Coast. Lots of my former students were out on the West Coast and a lot of people we interacted with were faculty members at Stanford and Berkeley. So the idea of starting a company kind of arose from that and it just sounded like a marvelous, exciting idea. In retrospect — you know, Anita and I had been very involved in the

interface between technology and public policy — we both worked for the government, we both had been on many industrial advisory committees, and a lot of interaction with technology and public policy. Part of the reason why we'd done that, I think, fairly effectively is that we have experiences well beyond just our academic experiences, and starting the company was just a piece of that, working for the government — we'd both worked for the government — we'd both been advisors to the government on various kinds of science advisory committees. So that richer background has, I think, lead us to be able to be more valuable at that interface. So I feel very good about having done that.

Yost: You mentioned that the company went from three to over 100. So it was you, Anita, and who was the third individual at the start?

Wulf: Joe Newcomer.

Jones: John Nestor.

Wulf: Oh, and John Nestor. So it was four then.

Jones: No, Joe was not a founder. It was you and me and John.

Wulf: Oh, okay.

Jones: But Joe was there.

Wulf: Oh, yes. Do you remember Joe building the computer room? When we started the company, we rented some space for our offices, which was an old warehouse. The majority of the space remained a warehouse; there was nothing in it.

Yost: Where was this located?

Wulf: It was in Pittsburgh. That close enough?

Yost: Yes.

Wulf: Probably a mile or two away from the CMU campus. But anyway, this guy we mentioned, Joe Newcomer, when we rented the space we wanted to have a computer like the computer that they had at CMU, which was a DEC PDP-10. This was in the days when you had to have big space, and air conditioning, and all that sort of thing. Joe came to work with us and he was just totally enamored with creating this space for the PDP-10 and getting the air conditioning working, all that sort of thing.

Yost: From the start, was there the goal of developing an optimizing compiler for ADA?

Wulf: For anything.

Yost: Did you see more of a government market or a commercial market, or both?

Wulf: Primarily commercial. That's when I met Steve Jobs. He had just started Apple, and we set out to sell him an optimizing compiler. He didn't buy one. [Laughs.]

Yost: Can you tell me about early attempts to seek clients and what was the first I guess bite?

Jones: Do you remember the contract with Intel? This was to produce non-assembly language code, which is what most compilers produce, but to produce micro code. And the contract said that it had to be so many percent better than the micro code . . .

Wulf: Hand written.

Jones: . . . than the hand written micro code, and they had collected a body of hand written micro code.

Wulf: I'd forgotten all about that.

Jones: I think it was five percent better or ten percent better.

Wulf: It was a non-trivial [pause]

Jones: And you put your best people on micro code, not on assembly language code. So that's how good this optimizing compiler technology was. Let's see, you once opined that it was hard to sell compilers and the reason was that companies believed they had to own that technology, that it was so crucial — why don't you elaborate?

Wulf: You go ahead.

Jones: Okay, well this is something you once opined long after we left, that a company that sells a product has got to believe that, or prefers to believe that it is totally in control of what it crucially depends on. And at that point, companies crucially dependent on compilers — in a way they don't think about it now — and so they were loath to depend on anybody else, much less a small startup company, to provide what was absolutely crucial to the working of the software that they built. So it turned out to be hard to sell compilers to the large companies because they felt like they had to have it in-house.

Yost: Was that in part the risk of dependency and being held up by a supplier, or a supplier going out of business and being out of luck?

Wulf: Both.

Jones: Both. If they depended on that and all of a sudden, if that compiler was not there, was not producing code that worked, there was nothing they could do. Going and getting a replacement — I think this is another Bill phrase — compilers for a language had to be

bug-for-bug compatible with a definitive implementation of a language, even if; well, why don't you talk about this?

Wulf: No, you're part way into it. Go on.

Jones: There was the C language and C was a very large target market for Tartan because so many people were using C. C was defined by some documents of specifications but it was also defined by the Bell Labs implementation or the Berkeley — [I] think it was the Berkeley implementation.

Wulf: It started out at the Bell Labs.

Jones: Right. I think the definitive implementation was; oh, I think you're right. The Berkeley implementation, except that it had bugs. But we came to understand that the Tartan compilers had to be bug-for-bug compatible because if they weren't, when you substituted in a much higher performance Tartan compiler, it had to produce code that worked. But in order to work, it had to reproduce the bugs in what was being replaced, and that was the Berkeley. I forget, there was a name for it. Anyway. The Berkeley C Compiler. So that was another wrinkle of building compilers at that time because if you sold them to somebody, it had to produce code that worked.

Yost: How far in after you started in 1981 were you regularly getting contracts and when did the company became profitable….did it grow quickly?

Wulf: When did we leave? The company was marginally making money when we left and [pause]

Yost: And that was 1987.

Jones: That's what our timeline says here.

Wulf: It really took off after we left.

Yost: While you were there, one thing you were you working on was optimizing compilers for ADA?

Wulf: ADA never took off and so I don't know that we ever produced a commercial ADA compiler.

Jones: Except for Alphard, when you stood outside and showed it was possible to build an effective compiler.

Wulf: There was a lot of concern that a programming language at too high a level would produce poor code. There was just this very strong feeling that you really ought to write at the assembly language level if you wanted efficient code. But if you were going to use a higher level language; the higher the level the worse the code. And we said no, ain't

true. [Laughs.] The one interaction that I had with the design of ADA was I tried to get them to remove the GO TO and they wouldn't do it. And I said you've got this programming language here that produces marvelous code, and no, it's not at exactly the same level as ADA, but couldn't get them to buy it.

Yost: You were the president of Tartan those seven years. Can you describe to me your management philosophy and style in leading the company?

Wulf: Jeff, it was a learning experience. Nothing in my academic background prepared me for being a CEO of any kind of company. I think my management style, if I had one, was an outgrowth of my interaction with students and pretty much was I got really good people working for me, listened to them, and yeah, there are some things which really required command decisions, but first listen to them. And I think that worked really well. These were really smart people. None of them, except for Nestor, had any experience in a commercial company either, but they were smart and they were good at generating ideas. And so I was more of a traffic cop, I think, than a do-do-do-do-do person.

Yost: Can you tell me about how you recruited these excellent people?

Wulf: Most of them were from CMU. After we grew a fair amount then we started advertising outside and we started getting people from industry, but the vast majority of them were from CMU. Do you remember how many people we had when we left? It was like 20.

Jones: Or 30.

Wulf: Or 30, yes. But it grew to over 100 people in a spurt after we left.

Yost: Did you remain at all involved as a consultant or did you retain a partial ownership?

Wulf: Yes, we retained partial ownership. We did very well when it was sold. I don't recall that we had any kind of formal relationship. We were very close to the people and so we very much stayed in touch.

Yost: What were the keys that led it to take off?

Wulf: Do you have an answer for that?

Jones: I think it was corporate maturation that the development processes got stronger, they were well understood, they were debugged. Tests, had you know, year after year gotten developed. I remember late in the time, you built some kind of program that would actually automatically generate tests for a language. So in effect, you were still doing a little bit of research or advanced technology development. And the product software, the optimization code buried down inside was shared by all the compilers so every compiler product, whether it was C, or Modula, or whatever, would mature it further and so I think

there was a strong base, and maybe the market got looser. People were more willing to buy. Now, TI, Texas Instruments, was a special case because they were using it to generate code for signal processors, right? So what language did they do that in?

Wulf: I don't recall.

Jones: I don't recall either.

Wulf: At least one of the compilers that was built for them was SIG.

Yost: Had they become a customer before you left?

Wulf: Yes.

Jones: Yes.

Yost: And they ultimately became your largest customer.

Wulf: They loved us.

Yost: And it was in 1995 that you sold the company to TI?

Jones: That seems awfully late.

Wulf: It does, doesn't it.

Jones: I think it has to be earlier. The reason that they cared so much is again, along with general purpose computers they built signal processors. And what you want a signal processor to do is scream, I mean really run fast and so any even slight optimizations were high priority. And again, like for Intel — I mean, we could build better code than their good micro coders could build manually and so it was a product differentiator, the optimization technology.

Wulf: Let me just elaborate on that and explain why that's the case. People writing micro code have blinders on. They look at small chunks of code and that quite simply becomes. A human being cannot maintain a large context in their head, and so what the compiler could do is maintain that larger context. And so know it's probably true that if you take a small enough chunk of code, maybe the Tartan compilers were not as good, but they were given large chunks of code. And we had some techniques as well for doing clever things; small pieces.

I visited Tartan on one occasion that I can remember, after it was sold to TI, and one of our former employees commented that TI believed that a certain compiler creation technology that they had developed was something that Tartan should adopt. And he commented that their technology was just nowhere as good as the Tartan technology, but the TI senior management did not understand that and so they imposed the TI technology on Tartan.

Yost: Did TI use the acquisition solely for its own purposes or did it also sell to the outside, market the technology?

Wulf: No. They did note sell it, but used it solely inside

Yost: Can you tell me about your decision to leave Tartan to return to the academic world?

Jones: It was just time.

Wulf: Yes, I think that's a good way to say it.

Jones: It was difficult.

Wulf: It was. It was difficult to leave all those people that we cared a lot about, but yeah, we were academics at heart.

Yost: In 1988, Anita and you joined the faculty at UVA. She as chair. Can you tell me about that decision to come to UVA?

Wulf: I got a call from I don't remember who, but somebody at UVA, asking me to come be the chair of the CS department. And I had to say no because I, just shortly before

that I agreed to go spend two years at NSF. And I couldn't do both things and I'd already made a commitment. But the idea came up and I think I generated it but I'm not sure, that maybe we could come and Anita could be chair, and they bought into that. And so we came and, you know, I had this background at UVA and loved living here. So we came and I went up to NSF, and that all worked pretty well. I still think Anita is the best chair the department's ever had, but I'm biased. [Laughs.]

Yost: Prior to your arrival at NSF, to direct CISE, NSF had funded regional networks and started to fund supercomputer centers and connect these centers. Can you describe NSF and CISE when you arrived and what your thoughts were about it?

Wulf: Let's back up a little bit. What we now call the internet was designed by two guys in the Department of Defense, Vint Cerf and Bob Kahn. The reason they designed it is that DoD woke up to the fact that 90 percent of their communication between the Pentagon and the service personnel was by telephone. They realized that telephone networks are very, very vulnerable. If you want to call from Washington, D.C., out to the West Coast, it goes to a hub in D.C. to a hub in Chicago, to a hub somewhere in the mountain states. And anyone could blow one of those up and totally ruin D0D's communication. And so the design of the net was to be reliable, not to support all the things that we now think of as being the Internet. Anyway — my immediate predecessor at NSF was Gordon Bell and he had negotiated with the DoD people to shift responsibility for the operation of the Net from DoD to NSF. DoD was unhappy because the net had become a major communication for research between people at various

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universities and DoD believed that they funded research not infrastructure, so control of the net was given to NSF to support the infrastructure. But at that point in time, the network was completely funded by the U.S. government and so there was a set of, quote, "Acceptable Use Rule". In essence, the only people who could use the net were government employees or people who contracted with the federal government. Anyway, so NSF was running the net when I arrived and it reported to me. The guy who actually did all the work was a man by the name of Steve Wolfe, W-O-L-F-E. One day Steve came to me and said, wouldn't this net be a lot more valuable if just ordinary citizens could use it? And that hit me like a ton of bricks; of course it would be!

But, he said, there's a problem, we would have to get an act of Congress because the design and implementation at that point was all funded by the government. We have to actually get Congress to allow this to happen. Because of NSF, I actually testified to Congress about the research we were funding a fair amount. I had gotten to know some of the staff members on the science committee, which is where I testified. In particular, I got to know quite well one of the staff members for Al Gore, so I went to this staffer and said, 'We need this piece of legislation, can you arrange for that?' He said, 'No, I can't but maybe Al can, let's go talk to him.' So that's when I met Al Gore; well, he fell in love with the idea. In fact, he was the sponsor of the legislation which makes the network available to you. There's all this talk around [interrupted]

Yost: Do you recall any specifics from that meeting?

Wulf: I just have a general impression that it was a very positive; I mean, he fell in love with the idea very quickly. You know, people poke at him because it's reported that he said he invented the internet. I don't know what he actually said but what I do know is he sponsored the legislation which makes the net available to the general public. I don't know where I was headed.

Jones: Then you had to spin it out so that NSF wasn't running it, you had contractors. So it went out to some . . .

Wulf: Somebody.

Jones: . . . to the north; Michigan or somebody. I forget the name.

Wulf: I think Boston maybe. Or was it BBN?

Jones: I don't think it was BBN, I mean, they were there in the early days and then at the end. Because that was larger than the National Science Foundation, and it should not be in the business of running infrastructure for the entire United States.

Wulf: Oh yes.

Jones: So then it also had to become financially self-sufficient and so it's all that.

Wulf: It was exciting times.

Yost: Yes, that's an amazing contribution and story.

Wulf: Well, I'd like to be able to say that we foresaw all of the things that happened [but] it ain't true. [Laughs.] We couldn't see about that far ahead.

Yost: Being someone that had made a major contribution in the era of computer security, was there thought about a public internet and security at the time?

Wulf: I remember some very general discussions but… Do you remember anything, Anita, I don't?

Jones: Did you tell him —

Wulf: We had no concept that the net would become anything like what it is. I come away from that and some other related experiences, believing that as new technologies develop, your first instinct is to do what you already do but a little bit better. I have a distinct memory of somebody from ARPA came to CMU when I was there and said we've got this network and we're going to connect CMU to the net. I think we were like the sixth installation in the world. So we've got all this fabulous faculty sitting around the table — you know, Al Newell, and Herb Simon, and Alan Perlis — and we basically said we're going to connect you to the net, what are you going to do with it? And all these

high falutin' faculty members didn't have a clue! And finally somebody poked up and said well, you know, ISI, which is part of USC out on the West Coast, also has a PDP-10 like we do and they're three hours later than we are so we could use their PDP-10 in the morning and they could use our PDP-10 in the evening and, you know, we'd get about three hours more computing time and not very much conflict for the use. That was our only idea of how the network would be used. We had absolutely; it's just given major new developments, technology developments, your first instinct is to say we'll keep doing what we're doing but it'll be better. Absolutely nobody. I can also remember when the first browser got built and systems names, like mumble mumble dot com didn't exist and got invented. What has happened, I mean, it's been incredible living through this whole experience and seeing a) the technology develop; but b) the societal impact.

Yost: Of course, NSF funded a supercomputer application center at Illinois, which developed Mosaic.

Wulf: Yes.

Yost: Can you tell me about priorities you saw at CISE, outside of the networking area?

Wulf: You already mentioned the supercomputer centers, and that was clearly a major impact.
I'm not sure I can articulate this, but CISE made what I think is a really important contribution to NSF. NSF was created to support basic research and that idea was down

to the toenails of every staff member, every program director, that's what NSF did. We support basic research. Well, CISE came along and all of a sudden, it was funding these facilities — the net for one, the supercomputer centers for another — and so we introduced into the Foundation that there is at least this one other kind of activity that to be sure is supportive of basic research, but supportive of a much broader thing. So a) NSF looked out at the horizon a little bit and you can have a major impact on society by doing that; and I think that was a pretty major contribution during my tenure there. I would not claim that those were my ideas, necessarily, but during my tenure, that happened. And that has continued and only strengthened, I think.

Jones: Can I comment on that?

Wulf: Yes.

Jones: NSF did have a history of supporting infrastructure, like telescopes. But they were associates with a single discipline, whereas the supercomputer centers had to balance demands for usage across many disciplines, and had these computer scientists. In telescopes, they had engineers that knew the physics and engineering, but it really was from bottom to top astronomers. Whereas the kind of infrastructure that Bill was talking about, the networks, the shared high performance computing facilities, served the research community broadly. That brought on; that is a more sophisticated, more difficult thing to manage and it caused relations between the disciplines that hadn't existed before.

Wulf: And consequently, communication.

Jones: Yes.

Wulf: And that strengthened the whole enterprise beyond the simple, "here's a facility you can use," this elevated collaborations that would not have arisen otherwise.

Yost: And throughout the research community, as well as, I imagine, among program officers.

Wulf: Oh, yes. I was really addressing the research community but your comment is correct, too, because collaboration between program officers; the funding when I got to NSF was all stovepiped, you know, a program officer had this narrow set of disciplines and activities that they supported and that just got much, much broader.

Yost: This kind of relates to a different project, actually a completed one, Tom Misa and I just completed a book on the history of NSF FastLane. I was wondering if electronic proposal submission was something that you at CISE were involved with at all, early discussions about it?

Wulf: I believe the majority of that happened after I left.

Yost: The formal project certainly did, but I think there was a precursor research project, Xpress, that was funded by NSF to investigators at both Michigan and CMU for electronic proposal submission.

Wulf: Could be.

Jones: Do you want to take a break at some point?

[BREAK IN INTERVIEW]

Yost: You had a lot of experience testifying before Congress and seeing policies that were made at that level. In some material that you sent to me, it indicated that you were quite disappointed with some of the policy decisions regarding science and technology. Can you talk about that?

Wulf: Well I just did. [Laughs.]

Yost: But not in the recording.

Wulf: Oh, okay.

Yost: Please don't hesitate to say everything you just said, again. The recording was off during our break.

Wulf: All of my experience, sort of sitting at the intersection of public policy and technology convinced me that as a country, we make some really dumb public policy decisions because neither the people making those decisions, nor the general public, know enough science and technology to make the right decisions. I just gave you the example of which is better for the environment: electric or gasoline car? The answer is that the electric car generates about three-and-a-half times more CO_2 than the gasoline car, and it's because you have to generate the electricity and so you burn coal to do that, which is dirty. That burning coal generates heat, which is used to make steam, which is used to drive the turbine, which generates electricity, which then you have to store in a battery that goes on board the car, so it goes back to chemical energy in the battery, and that chemical energy is turned back into electrical energy, which in turn is used to drive the car, to create the kinetic energy of the moving car. And each one of those conversions is subject to the second law of thermodynamics; that is, it's never a perfect conversion, there's some loss at each one. In the gasoline car, you only ever generate or change the chemical energy in the gasoline into kinetic energy in the car, so you do very little conversion and there is very little application of the second law. That's why overall, you have to burn a lot of coal to ultimately move the [electric] car, and as I said, generate about three-and-a-half *times* the CO_2 as a consequence. In the book that I'm writing, or the course that I taught, I give a lot of examples like that where the conventional wisdom is just wrong, and it's wrong, again, because the people making the decisions and the general public don't know a relatively small number of relatively simple ideas. I

characterize the second law for them and that makes sense, nothing works perfectly, nothing. And that captures the idea.

Yost: And this is a course that you designed to teach, when you returned from NSF?

Wulf: Right. I introduced the course in the liberal arts school at UVA, it's called a college, and I didn't advertise it. The first semester I had 12 students, the second semester I had 30, the third semester I had 70, the fourth semester I had 140 and 140 on the waiting list. This was all word of mouth from one generation of students to the next, so it was fairly popular. I take that as a measure of that the ideas were simple and I could communicate them in a way that these liberal arts students, language majors or history majors or whatever, could understand and could remember. Even better, the examples I used all affected their day-to-day lives, so they *wanted* to remember!

Yost: I was an undergraduate history major, and took a technology and ethics course, and that turned me into a historian of technology.

Jones: Several people have come up to him when I've just been with him in parking lots and said your course changed my life.

Wulf: Unfortunately, I came down with this medical problem so I had to stop teaching the course.

Yost: From 1996 to 2007 you're president of the National Academy of Engineering, a great honor and an important role. Can you tell me about what stands out most to you in those many years in an important role?

Wulf: First of all, let's say a little bit about what the Academy is. There are three: National Academy of Sciences, Academy of Engineering, and Academy of Medicine. Actually, the Academy of Medicine for years was called the Institute of Medicine.

Jones: It's changed.

Wulf: It finally changed. Oh, I didn't know that they'd actually done it. Okay, so it's now the National Academy of Medicine. Anyway, they're all part of the same 501(c)(3) not-for-profit corporation so that they're private, they're not government, but they were created by an act of Congress. Virtually every country has a set of academies and they are mostly honorific societies. It's about as hard to be elected to the Academy as it is to win an Oscar. Just doing the numerics, it's actually a little harder. Congress gave our academies two jobs; one is to be honorific, but the other was to advise the government on issues of science and technology as they apply to public policy. So I really was sitting right at the nexus of science and public policy, for those 11 years. That had much more impact on me than the honorific side of the business, I think. It really was great to be involved with all of these *really* smart people. I don't know why they let me in, but anyway, having to think carefully through all of these science and technology issues and how they impact public policy was just an incredibly enlightening experience.

Yost: Were there a number of committees that were formed in particular areas that advised in particular areas?

Wulf: At two different levels. There was a set of committees — the Academy is divided into a series of sections. There's a section for chemical engineering, and a section for mechanical engineering, and so on. There's an advisory committee for each one of those sections. But whenever the feds come to the Academy and say which is better for the environment, gasoline cars or electric cars? We appoint a committee specifically to address that question and the people that we get to serve on the committee are not necessarily members of the academy themselves but they are the best people in the world on that particular topic. They are spectacular and may write a several hundred page report that is *the* definitive answer to the question, but then that committee gets dissolved. We do about 200 of those reports a year, so it's a fairly busy [schedule].

Yost: Are there any initiatives or structural changes that you introduced as president that you'd care to talk about?

Jones: You created the ethics center.

Wulf: Right. I have always been, at some level, quite interested in the ethics of using technology, using engineering, using science in a way which enhances the ethical setting, not just obeys the ethics but actually enhances it. We didn't have any activity associated

with ethics when I took over and so we created an ethics center. Turns out NSF has had an ethics program for a long time and I absolutely, totally lucked out. I got the woman who ran the ethics activity for NSF to come run our ethics program and she has done a super job.

Yost: Is that Rachelle Hollander?

Jones: Yes. And they just won a grant to support it. I'm on the NAE Council now so I follow NAE.

Wulf: The Council is the Academy's board of directors.

Jones: Yes, they put in a proposal, and they were funded. NSF asked to extend it from just being engineering to being engineering and science, which I think is a huge vote of confidence. An interesting aspect of that is that ethics for engineers is particularly interesting because one can talk about — I don't know where these terms came from — micro ethics, meaning the ethics of the individual doing their work, and macro ethics of organizations or nations, and such. Because individual engineers are so critical to the project that they work on, they in fact can have insight and ethical views about what they as individuals should do within the context of the larger end. So for example, in a voting citizenry, they can vote on whether a nation should do something or not but no individual citizen is empowered. For engineers who are engineering a project, the individual is such an immense contributor that there are micro ethical issues. I always thought that was very

worthwhile exploring. You taught that Frontiers of Engineering; you really developed that.

Wulf: Well it is exactly what it sounds like. Again, I think . . .

Jones: You going to describe what Frontiers are? It doesn't tell you what it is.

Wulf: It's a program of conferences, and the notion is that we're very bad as individuals. I mentioned to you before that people, when new technology comes along, the first reaction amongst people is to assume you're going to do the same thing but do it better. And really, what Frontiers was about was not doing that, was looking beyond that. What can you do differently or what can you do that changes the ballgame?

Jones: And who comes to Frontiers?

Wulf: I don't know; I don't remember. [Laughs.] My memory is getting terrible.

Jones: It targets mid-level engineers and so people who have gotten tenure but may not be full professors, if you look at the academic world. It strives to bring together the 50- maybe best engineers at that middle level there; they've hit their stride but they don't have gray hair yet. And so there is a U.S. Frontiers, which is just U.S. people, part industry people, part academics, and you want them to come together. You want them to come together and talk about their own activities but they're from all kinds of different

disciplines so it's not a conference in a stovepipe discipline. And then there are a set of

bilateral, so two country engineers. There's one with Japan, Germany, what other

countries? England. There's one that's starting with India . . .

Wulf: And China.

Jones: . . . and China. So half of the people are that age and that full of achievement from

that country and half from another. And one of the things that Bill really exercised a lot

of stewardship of was having relationships with engineers in other countries. Sometimes

scientists and engineers both because especially in the developing countries, those people

are often from the families that are politically in power, or some of them are influential in

different ways. And so it builds because they're both engineers they talk the same

language, they have the same value systems, it all comes down to their education, and by

the way, many of these people are educated in the U.S. So it builds very lasting

relationships between people who will be more and more influential in their respective

countries, and it builds a basis for citizen diplomacy that is very hard to do otherwise.

These people speak a common language because one's an electrical engineer, and another

from another country is a chemical engineer, and so these have been extremely successful

and it's really a legacy that I think Bill has left.

Wulf: There's another which I think is harder to quantify, but the Academy of

Engineering grew out of the Academy of Sciences. Academy of Sciences was the original

one and then medicine and engineering split off of that; medicine just within the last few

months. The Academy of Sciences, the membership is almost exclusively academic. It's where you do science, and so when I first went to the Academy, the Academy of Engineering was largely academic. I came in and I said where do you do engineering? You do engineering in industry, not in academia, and so I put a big push on to increase the representation of industrial engineers. Caused a hell of a fuss [laughs] but I think it really strengthened the Academy.

Yost: There were some that wanted to maintain [pause]

Wulf: Yes, almost all. [Laughs.]

Jones: Bill has also been very outspoken and has had a great deal of influence in creating a more diverse research community when he was at NSF, and engineering community when he was in NAE. He won the Habermann Award for that, and we just mentioned that he just won last Saturday, the Karlstrom Award in education from ACM.

Yost: Congratulations.

Wulf: Thank you.

Jones: He has pushed that, and the number of women in National Academy of Engineering [pause]

Wulf: If I remember correctly, when I went there, there were either six or 12, out of

1800? You know, you can't change it instantly because we only elect 65 or 70 every

year. But it's getting up there.

Jones: It's a two-digit percent now.

Wulf: Oh yes.

Jones: Around 10 percent?

Wulf: I think even more than that.

Jones: Great.

Wulf: And more and more women, like Anita, are being moved into leadership roles in

the Academy, which is a very positive thing.

Yost: In addition to industry, are there very many in government that are [pause] . . .

Wulf: I don't have the number in my head [pause]

Yost: . . . I guess a lot of engineering that gets done in government are contractors.

Jones: Especially military, and the Department of Energy have labs that have first rate people in them, and there are a number of people in the Academies from that. The National Academy of Engineering has paid special attention to what since you've been president has come to be called the "Secrets Veterans," which means the people who have made just amazing technical contributions but it's classified.

Wulf: You can't tell anybody what they are.

Jones: People that know about it are the people who have the right classification, and so when they're doing nominations those are all, of course, unclassified. But some of the people who are making the selection of who to put forward, in fact do have access to that, translate it, generalize it, and say this was really important and this did this, but they say it all in an unclassified way because they can't say anything else. And so there are a number of people in government and in industry whose contributions are not completely known in the unclassified world but are recognized by their election.

Yost: You have just an amazing list of honors. Are there particular ones that stand out as being especially important to you?

Wulf: Every single one of those is important to me because somebody did a lot of work to put all the information together, so I appreciate that. I guess I've been particularly tickled by the Karlstrom Award. You know, Alan Batson and Lloyd Fosdick had this incredible impact on me and made me realize the impact that an individual faculty

member can have on the whole life of a student. Ever since I became a faculty member, that has sort of been my gold standard. I would like to do the kinds of things that Lloyd and Alan did, so they kind of rise above the Karlstrom Award, those two individuals. But that doesn't mean that I don't think the other ones are important; I think every single one of them is. They're called honorary degrees and awards, and I feel honored by them all.

Yost: Before we conclude, are there topics I haven't brought up or questions I haven't asked?

Wulf: I actually wrote down a list of topics. Let me see. This is a very small item but you notice that one of my items in my history is that both of us actually have the title of University Professor Emeritus. And just so you know, University Professor is a title above that of Full Professor. You know? Okay.

Jones: We don't know whether there's any other couple that have both in any university.

Wulf: Of the 3,000 faculty at UVA, there are about a dozen University Professors at a given point in time, and we are two of the dozen.

Yost: We have that designation at the University of Minnesota, too, and I think there are maybe 15.

Wulf: I don't think they set a limit at 12, but that's [pause]

Jones: It's usually just a handful, wherever you go.

Yost: Yes.

Wulf: I don't see anything that jumps out at me.

Jones: A thing you might want to talk about is the Library of Alexandria.

Wulf: Oh [laughs]. One day — I think this was when I was at the Academy — I got a telephone call from a guy that I'd interacted with a little bit at the World Bank. He asked me whether I would become a director of the Library at Alexandria. Now you know, the Library at Alexandria is this incredible thing from roughly 300 BC to 300 AD. Well, the Egyptian government decided to recreate the Library at Alexandria, so I was one of the founding directors of the New Library at Alexandria and it was an excuse for making a trip to Egypt once a year for about a dozen years. They built it and it's absolutely exquisite. They built a building with an exterior which is all white limestone. The building is; if you look straight down, it's circular. If you look at it from the side, it's a cylinder but cut off at an angle. The roof is all glass and so if you go inside, go at the high end, look down across a set of stepped floors — absolutely exquisite. The outside I said was white limestone; it has carved into it the letters from every alphabet on earth. Anyway, the guy who is the librarian, I met him at the World Bank. That's where he was when he was asked to become the librarian.

Jones: Ismail Serageldin. So how is he going to build a library that competes with the Library of Congress?

Wulf: [Laughs.] In that very first telephone call, I asked him about the collection and he said look, there is no way that I can compete with the U.S. Library of Congress, or the British Museum, or a whole long list of national libraries, so I won't try. Instead, we're going to be an all-digital library from day 1, and that's why he invited me to be on the board of directors because he thought that I knew what that meant.

Jones: So Bill, tell me what that means.
[Laughter.]

Wulf: But anyway, yes, pretty neat and it's in Alexandria. Have a long-standing interest in Acient Egypt, so it was a great gift to be involved!

Jones: You can surf nice images on the web and it really is beautiful. When they had the uprising in Egypt — chokes me up, actually — a bunch of people got around the library and held hands to keep other people from breaking in and just being vandals, like they were being vandals in other places because they valued this.

Wulf: Yes. These are not people having any formal link to the library — they weren't employees of the library or affiliated with it in any way except as users. That was pretty neat. Choked up Ismail, too.

Jones: Always chokes me up when I describe it. So what have you done, some other things? Because of your visibility you've been part of things like that. I can't think of any; I think that was a very special one.

Wulf: Yes.

Yost: Anything else?

Jones: Do you have any reflections on CMU? It, MIT, and Stanford were clearly the three best in the 1960s and 1970s and I think for systems it always was number one among those three for that particular area, maybe not for theory but for systems, which is where we both worked. Are there any observations about the early days with Newell and Simon?

Wulf: Habermann.

Jones: And Habermann and Wulf, because there are things that we weren't involved in like the complex information processing, which the MIT people relabeled as artificial

intelligence; like speech recognition, which Raj Reddy ran. In the early days, you had this triumvirate of Allen Newell, Herb Simon, and Alan Perlis.

Wulf: Right.

Jones: And you were there with them.

Wulf: Oh yes.

Jones: And so how did they guide the department to maintain its fighting strength?

Wulf: You know, I've thought about that a little bit; just enough to have myself confused, I think. But one thing that stands out is that they set a standard, they didn't necessarily contribute ideas but they set a standard of quality and I wouldn't be able to begin to tell you how many times Al Newell, in particular, would [say] oh, that's interesting, where is the major contribution? Those kinds of questions. And it was quite remarkable being on the faculty with those three guys. They just set a standard. They contributed ideas in their own areas, but they set a standard across the department. It was a pretty heady place to be, at the time.

Yost: I can imagine.

Wulf: Yes. [Pause.] Nothing else jumps out.

Yost: Okay, well thank you so much. This has been terrific.