EDITOR: Dag Spicer, dspicer@computerhistory.org

Interview of Ivan Sutherland

Robert Sproull, *University of Massachusetts, Amherst, MA, 01003, USA*
David C. Brock, *Computer History Museum, Mountain View, CA, 94043, USA*

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EARLY YEARS

Sproull: I am Bob Sproull, this is the Third of February, 2017. I have David Brock with me, as a Cointerviewer, and we are interviewing Ivan Sutherland. Ivan, let us talk a little bit about getting things started, with you and your brother Bert, I think in Scarsdale, New York.

Sutherland: Well my father was a Civil Engineer, who had been born in New Zealand and loved mountains. And he decided that the way to be an engineer in the mountains, to build hydroelectric dams. So that is why he became a Civil Engineer. He received a Ph.D. degree from the University of London, what he called "City and Guilds," which later turned out to be Imperial College, London. He had been an Anzac, a New Zealand soldier in World War One. After the war, the New Zealand government arranged that their troops could be discharged in Europe and that the government would pay their fare home after spending a period in Europe to get an education, travel, or whatever they wanted to do. And he took advantage of that, to go to the University of London and get his Ph.D. degree. He also met my mother in France, and then went back to New Zealand, and a few years later she went there, and they got married. So I was brought up in a family for which education was considered very important. And all my young life, there were interesting things. When we would go traveling, there were always things to see. "What kind of bridge is that? Why is this junction done this way?"

Sproull: I think your mother was also instrumental in squiring you and Bert around on various adventures and meeting quite a fascinating collection of people.

Sutherland: My mother was quite entrepreneurial, I will say. And she was interested in something called "general semantics." Which is the study of what the meaning of language really is. And the General Semantics Society had conferences, and she liked to go to these, and occasionally she would take us along. And somehow through these conferences, she met a man named Edmund Berkeley. Edmund Berkeley was an interesting character. He had been at Harvard and gotten I think a Ph.D. there under [Howard] Aiken. Fred Brooks later on received his Ph.D. degree from Aiken as well. And Grace Hopper, of course, was Aiken's number one assistant and had been there during the war when they were building machines. So Ed Berkeley became an early pioneer in the computing business and had a little company he called "Edmund C. Berkeley and Associates, Inc."

He published a magazine called "Computers and Automation," and did other things relating to computing including cofounding the Association for Computing Machinery (ACM). Berkeley had quite a strong influence on both Bert and me in the early years. We used to go down to New York City, he was on 11th Street I think. And we had taken the subway to 14th Street, and then walked the other three blocks. He had built a thing called "Squee," which was a robot with a scoop in the front, and it had a photocell on it. Bert and I made a series of these things, different sizes and different technologies, and one thing and another. And Berkeley encouraged that, he was very supportive and helpful.

Sproull: So the other luminary you got to know in high school was Claude Shannon. How did that come about?

Sutherland: Well Berkeley introduced us... Ed said, "there's these two boys that you should meet" and our mom drove us to Bell Labs to see Shannon several times.

Sproull: Did you and Bert frequent Canal Street, for all your parts?

Sutherland: Oh yeah. Canal Street, New York City, was where all the surplus stores were. We used to go down there regularly. Father would take us down initially. And now that brings up a whole 'nother story. When I was in grade school, father purchased for 50 dollars, I believe, and that was quite a lot of money in

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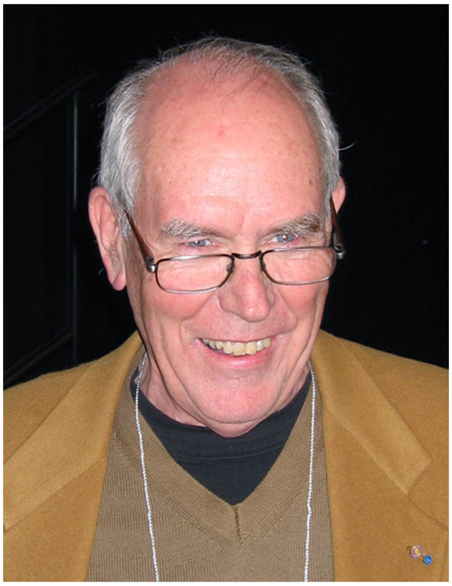

FIGURE 1. Ivan Sutherland at the celebration of his 70th birthday at the Computer History Museum. Photo by Dick Lyon; permission according to creativecommons.org/licenses/by-sa/3.0/deed.en.

those days, a machine. This machine was a hundred pounds or so, full of fine ball bearings, shafts, flexible couplings, cams, handles, prisms, periscopes, all kinds of stuff. I found out much later that it was a Sperry P4 computer. This is all in the interest of the education of their boys.

Sproull: When you were heading off to college, what were your ambitions? Or what did you think you had been doing? Were you looking for an engineering school?

CARNEGIE TECH/CALTECH (BS/MS)

Sutherland: Yeah, I was in engineering school. I studied electrical engineering. I had been a ham radio operator and got interested in electrical things. It was clear electrical engineering was the thing to do, so I went to Carnegie to study that. And I think it was a good choice.

Sproull: Did you do any computing at Carnegie Tech? Was there any computing there then?

Sutherland: Oh, yes indeed. So, [Alan] Perlis was there when I was an undergraduate. And I ran into him a couple times. But I didn't really do any computing as an undergraduate. And Newell was, of course, there. But I did not interact with him much either.

Sproull: Next was Caltech, which you went to right after Carnegie Tech. And by now, you must have had some inkling of where you were headed, yes, besides west?

Sutherland: Well, I was headed for a Ph.D. that was perfectly clear. My father had one and it was no question that that is what I would do. And I do not know if there was ambition, but it was clear. I had been that far west. I went to summer school at the University of Colorado between my freshman and sophomore year, and at the University of Washington between my sophomore and junior year. I was also in Seattle all one summer down at the University of Washington.

Sproull: So back to Pasadena. How long were you there?

Sutherland: I was there one year. They had a one-year master's program, courses only, no thesis. Caltech makes the master's degree fairly easy and the Ph.D. fairly hard. MIT makes the master's degree fairly hard and the Ph.D. fairly easy. I did not know that, but after my master's degree at Caltech, I transferred to MIT. I could not have done it better had I planned it, okay.

Sproull: Any computing experiences?

MIT (PHD)

Sutherland: Well, computing at Caltech was a little backward. But there was aerospace in the area that was doing computing. Digital computing grew up on the East Coast. It is quite clear that the West Coast was a bit behind. So one of the reasons I went to MIT was to do computing. And Marvin Minsky and Oliver Selfridge came out from MIT and I had lunch across the table from them at the Athenaeum. They were waxing eloquent about computing at MIT and about the TX-0 that was there for students to use and how it was all going on at MIT. And I listened carefully to that and said that is what I want to do. MIT had offered me a handsome fellowship to go to graduate school.

So a year later, I wrote them and said I'd like to come to graduate school after all, having turned them down initially. And they said, "Well, we'll certainly admit you, but we can't offer you any fellowship." Fortunately, I had a National Science Foundation Fellowship, which was transferrable, so I went with the National Science Foundation money, and that was a good thing to do.

Sproull: MIT was a foreign territory in terms of who was there, besides Minsky and Selfridge and Shannon, I mean, what was the department like? What were the facilities like? What were other students doing? You worked for Wes Clark at MIT Lincoln Labs, I believe? Wes was a group leader and the TX-2 was sort of his machine. How was that supported and why was Lincoln doing it?

Sutherland: Lincoln was supported by the Air Force to explore the needs of the Air Force for technology. Transistors had recently been invented and what they wanted to do was to figure out what the operating behavior would be of transistors in large numbers. And so they built TX-0 and then TX-2 for that purpose, and the Air Force paid for it for the purpose of not computing, but for the purpose of understanding the behavior of large numbers of transistors. So it did not have to meet any particular computing demands, and so Wes was able to use the computing power in whatever way he saw fit.

Wes did something which I think shows an enormous perception of the future. He said, "We're going to use this machine as a personal machine for individuals to use to learn about computing." And that did not become common until many years afterwards. So Wes took TX-2 and treated it as a window into the future of what computing might be if everybody had one of his own.

Now I could not have done the work that I did for my Ph.D. degree without that access to computing. You simply could not have done that thesis anywhere else. Not only because of the equipment on TX-2 that made that possible but also because of the way the time was allocated. I got hours of time on TX-2 all to myself. Now admittedly, it was at 4:00 in the morning. But never mind. I mean, I had the hours of time when I could just diddle with what I was doing and learn, you know, what it meant to have this kind of interaction or that kind of interaction. And without that time, without that resource, it would never have happened.

Sproull: I presume it was not a great challenge to figure out how to program these computers?

Sutherland: You just figured it out. I mean, I don't know how you learned to. You picked up the manual and read it and it wasn't that hard. It was a pretty good macro assembler that you used. TX-0 had been built by Wes at Lincoln Laboratory.

Brock: Two quick questions. One was, was a security clearance required of everyone who worked at Lincoln Labs or just certain members of the staff there? Did you have to have a clearance to go in?

Sutherland: I do not think I had a clearance. In fact, I am reasonably sure I did not have a clearance. I do not remember whether I had to sign in or and out, or whether I just walked in and out. In the back of the Lincoln building was the blockhouse where there was serial number 1 SAGE computer [XD-1] ... and that was secure territory. You did not go in there.

Sproull: Was there any coupling between the SAGE project and the TX-2 stuff? Or did they just happen to both be at Lincoln?

Sutherland: Well, the big coupling was the memories. The big problem with computing then was how do you make memories? Jay Forrester had perfected magnetic core memory, and it had been developed principally for SAGE.

Brock: In terms of other TX-2 users, I believe in listening to or watching a lecture that you one time gave, you talked about Herschel Loomis, who I think was doing also some screen-oriented work with the TX-2.

Sutherland: Hersch Loomis did the first graphics program on TX-2 and he made basically an "Etch-A-Sketch." You know, he had knobs and when you turned this knob, the dot moved that way, and when you turned this knob, it moved that way. So you could draw using the knobs, but it was pretty awkward and pretty crude.

SKETCHPAD: A MAN-MACHINE GRAPHICAL COMMUNICATION SYSTEM (1963)

Sproull: Is it time to turn to Sketchpad?

Sutherland: We certainly can do so. I think the listing is right there. We can look at it, if you want. It is written in assembly language for the TX-2, as slightly modified by Larry Roberts for Sketchpad.

Sproull: You have spoken earlier about the general motivation in making pictures. But did you walk up to the TX-2 and say oh, I think this is a machine that has the right stuff for making pictures? How did all that get put together?

Sutherland: The TX-2 had a CRT on it. And under the CRT were four knobs. And there was a light pen of some kind. The light pen had been developed for SAGE for targeting airplanes, right? And we got quite a good light pen developed with the right optics in it. Then I made a tracking program for the light pen. It had a little cross that would appear. And as you moved the light pen, the cross would follow the light pen. So, it looked like the light pen was a flashlight, which shone this cross into the CRT.

Sproull: So, was that the first program you wrote to build up to more stuff?

Sutherland: I do not remember the order of things. But I knew that was important to do. Almost immediately—well, I had seen the TX-2 the summer before. And I knew that it had this CRT on it. When I went to Wes and said, "I want to use it," I said, "I want to use it for engineering drawings." I mean I was quite up front about that. I had the idea that it could do that earlier. And so, I proposed that to Wes and he said yes. Years later he said to me—"you know," he said, "I built TX-2 for you." He said, "Of course, I didn't know who you were at the time." But he had hoped, I think, that some person would come along and do something like Sketchpad with it. And I happened to be the guy who did that. But it was fortuitous A, that I got a job at Lincoln Laboratory, and B, the most important thing was Wes's wisdom in saying we are going to use this machine in a way that makes this kind of work possible. If Wes had not done that, it would not have happened. And I think Wes's foresight showed in that. It showed in the next thing he did, which was the LINC, the Laboratory Instrument Computer, a personal computer targeted at biological laboratories. And it had a huge impact on how biological research was done. There were eighty or so of them posted by NIH here and there.

Sproull: I want to come back to Sketchpad. There must have been some "a-ha" moments. There must have been some frustrating moments. There must have been some false starts—where programs got thrown out and replaced. Do you remember any of those that might have lessons for us today or be noteworthy?

Sutherland: I remember an "a-ha" moment very clearly. I wanted to make a condition on three points that they be collinear [all lying along the same line]. And I tried any number of things. The a-ha moment was symmetry: that if you want three points to be collinear, it is important to have an algebraic expression that does not care which point is which. You cannot pick two of them and calculate the third. You have to do some calculation that is based on all three of them in a symmetric way. And what is that way? It is the area of the triangle that they describe. And if they are to be collinear, the area of their triangle is zero. It is as simple as that. Compute the area of the triangle. And if it is zero, they are collinear. If it is not, they are not.

Sproull: How about some frustrating moments for Sketchpad?

Sutherland: Frustrating moments I have disremembered.

Sproull: Okay, so let me poke. How did you debug on that machine? What did a bug look like? I mean I realize you probably saw a picture you did not expect to see, or you saw no picture or something. That is always been one of the wonderful things about graphics. But you had a bunch of toggle switches, and what did you do? Was there a DDT [Dynamic Debugging Tool] for it?

Sutherland: I do not remember. There was a wonderful mechanism in TX-2 called the "metabit," which allowed you to stop the machine when it got to a certain instruction that had this bit set. And I forget how that was used in the debugger. There must have been some kind of symbolic debugger. But the code was all written in this macro assembler. And you could—online– change the code and reassemble. The key debugging mechanism was thus that you would set some metabit somewhere at which point the machine would stop. You could see on the lights what was going on and you could single-step [the processor] if you wanted and see what was happening. Of course, my programs never had bugs.

<laughs>

Brock: Could you paint a picture of what it was like to write Sketchpad, you know, where you are working, the process that you went through? Were you working at home on lined paper, and then coming in? And then what was the process for getting the code into the machine?

Sutherland: I would go home and think about what did not work and then about how to fix it. And then I write some code. I often typed the code in myself. But there was also a secretary who would type code for you. If you wrote it neatly enough so she could read it, she would type it in. And so, I often got her to write a section of code, which I had add to the program, edit that in, and then run that. But the thought was definitely all offline.

Sproull: Let us finish up a little bit about Sketchpad. So, there was an endgame involved in writing it up and it becoming a dissertation and some negotiations with your thesis committee. Was there an oral exam or any kind of procedural thing to get through?

Sutherland: I had Minsky on the committee, and Steve Coon from mechanical engineering, Minsky, and Shannon. And I had been to each of their homes and knew them all personally.

Brock: And how was Minsky? What was his role? Did he provide anything that you can recall that was shaping the direction of the Sketchpad project?

Sutherland: There was very little shaping done by anyone. The biggest piece of shaping that was done was when Shannon came by and I had straight lines working just fine. And he said, "This is great, Ivan. I think you should do circles." And now, straight lines are pretty straightforward. Circles are a whole other bag of wax. But Sketchpad could do straight lines and circles. That was it, no conic sections, thank heavens.

Brock: One fascinating thing for me in watching some of your lectures about Sketchpad is how large the drawing space is that Sketchpad represents; what a large canvas is accessible through the small screen. And I was interested to hear how that developed.

Sutherland: It is perfectly straightforward. It was eighteen-bit coordinates. And it was a ten-bit screen. So, the canvas was two hundred and fifty-six times the size of the screen.

HARVARD (1965-68)

Sproull: After discharge from the Army, you moved to Harvard and put together a research project based on this same notion of making 3-D perspective images.

Sutherland: Right, what I called the head-mounted display. There were a variety of grants to fund it, but the interesting one came from the CIA. So I got this research contract from the CIA, totally unclassified. And then the Old Mole got a hold of it. So Old Mole was the leftist rag from Harvard Square. "Harvard University takes filthy money from the CIA." Horrors, oh, horrors, Harvard taking money from the CIA, and there was a scandal about this, and a big fuss about whether Harvard should or should not take CIA money. So Dean Ford set up a debate amongst the faculty of pro and con, and there were to be eight speakers at this debate. I was not one of them but I attended the debate. And it is evidence of the eloquence of the Harvard faculty or the naiveté of Ivan Sutherland that my opinion changed eight times during the debate. And the way it went was against, for, against, for, against—and Dean Ford saved the last slot for himself. And Dean Ford's argument, which I think is a sound argument, was, "There is no such thing as a filthy source of money. There are only filthy conditions of the grant." And he said, "Harvard above all should understand this since a large part of the Harvard endowment comes from the triangle trade."

EVANS AND SUTHERLAND (1980)

Sproull: So I want you to tell a little bit about a Salt Lake City startup in 1968, right after you left a tenured professorship at Harvard. This was before startups were commonly spinning out of university projects. There were a few, but there certainly was not a [Silicon] valley pattern yet about startups and how they were done and what they were like. And so everything ranging from the kind of buildings you were in to who you hired and the relationship with students at the university, I think all of this would be fascinating. Well, first of all, a simple question: What was your role? You had a title, chief scientist, but in a startup, it is all hands on deck. Everybody is doing everything. So what did you actually do?

Sutherland: Well, Dave Evans was the President. It was quite clear that he was the guy who understood most about business. He was 20 years older than I was. He had industrial experience. He had been the leader of the DARPA project at Berkeley, which is how I first got to know him because I was paying for that project while working at DARPA. That is where Butler Lampson cut his teeth and where Bill Joy cut his teeth and so on, on that project. So it was clear he was the boss.

Brock: What was the business plan?

Sutherland: Well, we were going to do graphics for scientific purposes. And we knew how to make line drawings and three-dimensional stuff, and there were some applications that had just been done for chemistry. You could see what chemical molecules looked like and so on. That was basically the business plan. That turned out not to be what made money. What made money was pilot training. That got converted by some people we hired from GE into a pilot training business, which was very profitable and very successful, which I had relatively little to do with, so in some sense, the Evans & Sutherland Company was successful in spite of my best efforts. E&S's first product, which I designed, was the LDS-1 [Line Drawing System]. I was two-thirds time at E&S; one-third time tenured professor at University of Utah.

Brock: Did you have a laboratory in both locations?

Sutherland: Well, I had an office at the university and I had an office and a laboratory at E&S, but there was laboratory work going on at the university. Now, some years later, there was a flowering of computer graphics at the University of Utah. There is no question about it. It had a huge impact. It trained the next generation of graphics people. And the question of why that happened has been asked repeatedly, basically with the question of, how could you reproduce it? That is the important question. How could you reproduce that singular event? The Harvard Business School wanted to do a study of that, which they subsequently published.

My take on it is that a research project of that type needs three things: It needs money to support the research, and that came from DARPA. It needs a worthy project and the project at the university was how to make realistic-looking pictures. There was not enough computing in the world to do that easily, so the challenge was how do we marshal the computing that we do have well enough to do it reasonably well? How do we get the most bang for the computing buck that we have? I have come to call that a worthy technical opponent. And the third thing you need is leadership, and it was perfectly clear at the University of Utah the leader was Dave Evans, and he was a great leader.

Sproull: This is a perfect opportunity to comment on another thing that you have attributed to Dave, which is the willingness to focus the department on a single topic.

Sutherland: Yeah. When I went to Caltech Dave Evans said to me, "You won't be big enough to do everything. Pick one thing and do it well." That was very, very sound advice. And I think he understood that and he focused the Utah work on that [one] problem: how do we make realistic-looking pictures? That was the focus and it was a clear focus. Everybody could understand that is what we were doing. I do not think it was ever written down as a statement of work or goal. But there were many different ways to approach it and they approached it in many ways. The task of understanding how the human brain works is such a goal. I mean everybody can understand that is the goal. Nobody has the slightest idea how to do it, okay, but there are various approaches. But it is clearly a worthy goal.

Brock: I was interested in your making the decision to leave this tenured post at Harvard for both an entrepreneurial startup and also a different university. Was this a difficult decision for you?

Sutherland: No. You see, you are much more sophisticated than I was. It should have been a very difficult decision. It was a big decision. I mean leaving tenure at Harvard is a big deal, okay? I simply did not understand what a big deal it was. You know, you would have a great deal of courage if you walk on ice if you know it is ice and you know it is thin. Well, if you have no idea it is ice and you think it is concrete and it is thick, no courage involved, okay? I was simply too naïve to realize it was a big decision. I am sorry about that but it is true.

Sproull: Well, so we could move on from Utah. You have said that one of the reasons you decided it was time to leave E&S is that you did not know everybody by their first name anymore.

Sutherland: Well, something like that. The Evans & Sutherland Company got too big for me to be comfortable, you know. I am clearly a small organization person, and now that I understand that about myself I try and behave that way, but I did not understand that initially. And I had done all the things in Salt Lake that I could do. My children were now advancing in grade school, and it was quite clear that the Salt Lake environment in the junior high school was not as good for a non-LDS person as it might have been. I had met a guy called Glen Fleck, who was the number two man to Charles Eames. Glen Fleck was a Designer. He and I started a company, which we called the Electric Picture Company, whose purpose was to make movies using computer graphics techniques. That company failed for a good reason. It was 10 years too soon. But I moved to LA in order to be closer to the center of that business and also to get a more cosmopolitan environment for my children.

CALTECH (1976-1981)

Sutherland: John Pierce was in charge of a search committee at Caltech to find out how to get into this field of computing. And apparently he and Dave Evans had a conversation about this, and I think Dave Evans said, "Make no mistake. You gotta get this guy." I believe that is how Caltech decided to offer me the job. But I think that is what happened, and he recommended that, and sure enough Caltech offered me a position and I took it. After I had been there a little while they gave me the Fletcher Jones chair, so I was an endowed chair with Caltech. And leaving that was a decision that should have been a big decision, but, again, I did not treat it as a big decision.

Sproull: So Caltech had some computing types at the time, but it sounds like you were encouraged or invited to really try to do something new.

Sutherland: Bob Cannon was the dean of engineering and said, "We want you to build a computer science department," essentially, and so I set about doing that. And so I worked with the Caltech Development Office to set up a thing we called the Silicon Structures Project, and it was their idea of how to structure it, but it was a place that industry could put money in. The deal was industry puts $100K a year per company plus a person. A person has to stay for a year and be acceptable to the company and Caltech. So we got six sponsors. They were Burroughs, Xerox, IBM, DEC, Hewlett Packard, and somebody else. We got six sponsors to do that and the six industry guys appeared on campus, so I had an instant computer science department. There they were, right? Six guys who could have been faculty members but were paid by industry and were there.

Sutherland: I said, "We're gonna focus on integrated circuits." [Caltech Gordon and Betty Moore Professor] Carver [Mead] knew how to do that. I was deeply interested in it so that is what we focused on. And I tried to hire a number of people including Bob Sproull, and they got turned down, one after the other. And one of them that was turned down by the faculty as not good enough was a man named Al Perlis, whom I could not get an appointment at Caltech for, okay? And the argument that I was given was he does not have an adequate publication record. And I was too stupid to say, "Would you believe 70 Ph.Ds. as a publication record?" You know, I did not recognize that that was what I should have answered, okay, but I did not, all right? And sure enough, Perlis' publication record is a bit thin. No question about it. What he published was students, most important thing to publish, right?

So after a while I got fed up and quit, and that was probably a mistake, but I was totally frustrated because I was asked to set up a department, then I could not do it, okay? I subsequently thought about that very carefully and realized that I was not politically savvy enough to know how to achieve that in the Caltech environment. I was very unhappy about that and so I quit. I had been very successful. I had raised a lot of money. I had started a great research project. Carver Mead's book was published, and that period of time at Caltech was hugely productive. A whole bunch of students have had a huge impact on the integrated circuit world. I believe that the Caltech activity fueled the integrated circuit revolution by providing the means to train the engineers that were needed to fuel it, but it felt totally unsuccessful to me.

Sproull: So let us go back a little bit to while it was still on the upswing and you were not yet discouraged, because there must have been a lot to getting all that going, and it was not just Caltech. There was ARPA support. There was galvanizing other people. There was the Xerox and Lynn Conway connections.

Sutherland: Yeah, Lynn Conway worked for my older brother at Xerox, and that is how she and Carver met—they met because Bert knew Carver through me and hired him as a consultant and encouraged the Mead—Conway book, which is dedicated to Bert because he paid for it. You know, it is perfectly straightforward. But that period was very productive in terms of educating people about integrated circuits. Carver and I published an article in *Scientific American*, which said essentially "it's the wires that are the problem." You should not count the transistors. They hide underneath the wires. The limitation is how many wires you have, and I think that is as absolutely true today as it ever was, maybe more so.

Brock: I am interested in the Picture Design Group story again, and the idea of using computers to make film. If you could expand upon what your ambition was at that time, what your thoughts were and the business story of that. Was it Venrock again or...?

Sutherland: No, we never satisfactorily got an investment, thank goodness, okay? So the company went broke without losing anybody's money. No, the idea was fairly obvious that computer graphics could be used to make movies, and so in LA we went to visit Disney and told them about it. And Disney, the big technical advance that they had had was xerography to make the outlines of the successive frames that they would have in their movies so that the colorists could fill in the colors and trace the outline. That was as far as the technology they were willing to deal with. So it was just premature, but it seemed fairly obvious that you could make movies using computer graphics, which I think is widely accepted that that is a good technique now, but we were premature.

Brock: Was your idea to provide special effects?

Sutherland: It was pretty vague... the Picture Design Group actually did a number of designs. We did the design of the Museum of Economics in LA, which was paid for by the various the savings and loan companies and the banks, and some investment firms put up some money. And Glen Fleck was a designer of stuff including museums, so I contributed some things to it, and that is how we tried to keep body and soul together, but it was not successful.

Sproull: I have a question related to the Silicon Structures Project. So as you mentioned, people came and spent time with you. How did you get good people from those companies? I would think there had been a problem, that they would not want to give up their best and yet you really wanted their best.

Sutherland: And, the other hard part was that the assignment was hard on a person's career because they were then out of sight and out of mind for promotion and so on. I do not know. It was magic. I mean the IBM guy that we got stayed for three years, and he was really good.

Brock: One final question I have at this juncture is about the Caltech and Xerox PARC connection—with two Sutherlands deeply embedded in both organizations. We already have talked about some of the connections between Mead and Conway and that VLSI design revolution, if you will, that is a result of that mixture of the Caltech and PARC contacts. I wonder if it was broader or there were more dimensions to that PARC/Caltech relationship in this period.

Sutherland: Well, I think PARC recognized that Caltech people were unusual, and there were many summer interns from Caltech that went to PARC, so there were a lot of connections at various levels between Caltech and PARC, but those connections were not unique to Caltech. There were connections between PARC and Berkeley and connections between PARC and Stanford, and it went on and on and on.

Sproull:. After Caltech, you headed to CMU. Talk a little bit about why you went to CMU and what the new project was going to be.

Sutherland: My friend Bob Sproull, who is here today, had decided to take a teaching position at Carnegie Mellon. So that is why I went to CMU the second time ... to do robotics. So projects can be wonderful fun. In fact, I have the attitude that if research is not fun, why are you doing it? Are you exploring the unknown, and why in the world would you bother doing that? You cannot do it for rewards, because you do not know what the rewards are. You do not know what you will find, so you do it because it is an adventure, because the spirit and the camaraderie of a research group is one of the things that makes research worth doing. I think that is important. An important thing to know about research is that if the researchers are not happy, there probably is not much research going on. It is hard enough wrestling with nature that you do not want also to have to wrestle with management.

SUTHERLAND, SPROUL ASSOCIATES (1980)

Sproull: I had like to move on to Sutherland, Sproull & Associates, which you and I set up as a consulting vehicle I think in 1980?

Sutherland: Yes.

Sproull: And this was discovered because I had gone to CMU and would do a little bit of consulting and sometimes you and I had similar opportunities and we discovered it was a lot nicer to do it together than by oneself. The pressure was lower, et cetera. But aside from some consulting clients, the main Sutherland, Sproull project was we decided to try to fund a research program in asynchronous systems by signing up some corporate sponsors and agreeing to teach them the results of what we learned. So tell about how we got that started.

Sutherland: Well, this was well into the period of Sutherland, Sproull & Associates. Our principal client in the early days was a venture capital firm, ATV. And we did due diligence on deals for the venture capital people, which was what basically supported the firm. We incorporated. After a while I started getting interested in the asynchronous world. How could we make things self-timed so that each thing would happen when it was ready to happen, not before, and communication delays would automatically be accounted for? So while I was lying on the beach in Australia I thought, "Well, if we hooked up a bunch of Muller C-elements in series we could make a FIFO, a first-in, first out device," and I puzzled about it and figured out what the latches should be and so on, and I thought, "This can't possibly work," because there was no asymmetry front to back. The input end and the output end were perfectly interchangeable. So how could it know which way was first-in and which way was first-out? And I could not believe this thing could be made to work. It was, it just, it was ridiculous that you should think that a symmetric thing could be able to provide FIFO action, and so when I got back to Pittsburgh I got one of the assistants that we had to actually build one out of some little chip things that we had and a protoboard. That was David Douglas. David Douglas is now working at Sun Micro at Oracle, in the computer business, and he built it and, by God, it worked. Was really strange, and that became the basis of the paper that was published called "Micropipelines," which the Turing Award people called me up and said, "Would you accept a Turing Award?" This is like asking, "Is the Pope a Catholic?"

Not a question to which you likely say "no." They said, "On the other hand, you're going to have to give a speech and you're going to have to write a paper," that we're going to publish in the ACM communications, with no reviewers.

Sproull: So we will come back to that, but you also gave a talk as part of the Turing Award.

Sutherland: Yes.

Sproull: And I recall you had a favorite way of engaging the audience in talks about micro-pipelines.

Sutherland: Yes. We did what I subsequently learned was called a KLA, a 'kinetic learning activity.'

Sutherland: Okay. This is the proper pedagogical term for this thing. It is basically a demo using people as the demonstrators, okay? And my favorite [part] of that was to get each person to emulate a Muller C-element. I had the great pleasure of giving this demo at the University of Illinois in a lecture I gave where Muller himself was present, and Muller at that time was, you know, of retirement age. But I picked the row to demonstrate this in which Muller sat, of course. And so I asked him, "I know that you invented the Muller C-element, but have you ever before *been* a Muller C-element?"

Sproull: So okay. Let us go back to Sutherland, Sproul Associates. You talked about the ATV connections. We have talked a little bit about the async project. So somewhere in there Bert [Sutherland] came aboard.

Sutherland: Yes. Bert decided to leave the Xerox Corporation, where he was working at PARC, and Bob and I both knew him well and said, "Bert, will you join us?" And he said, "Yes," and he grumbled quite a bit at how much money he had to put in because the company was bigger than when we had started it. He stopped grumbling when we finally sold it to Sun and he got a major return back from selling the consulting company. But it was good to have Bert in. Now, yes, it was a strange company. It was an incorporated company, but it ran like a partnership, and the partners all knew each other very well and so it was an odd partnership. Most partnerships, at the end of each year, have a big fight over who should get the bonus, and in Sutherland, Sproull & Associates we had a similar big fight at the end of the year, but it was over who should have to take the bonus.

And it was really quite a remarkable place because the three founders knew each other and cared for each other enough that we were interested in the welfare of everybody and it worked out very well, so for 10 years in the partnership and for some many years afterwards, I got to work with Bob Sproull, my favorite student of all time, and my older brother, the two men from whom I have learned the most, and one of the joys of my life is that I had that experience of working closely with people that I care for deeply.

SUN MICROSYSTEMS LABORATORIES (1990)

Sproull: You mentioned we sold SSA to Sun, and we were part of a founding nucleus of Sun Microsystems Laboratories. Why don't you talk a little bit about that, why we did that and how that progressed?

Sutherland: Well, a consulting firm is consumptive of intellectual capital. You work with various people and you have intellectual capital, which you bring to the table, which is why they pay well . . . But there is not an adequate mechanism in a small consulting firm to generate new intellectual capital and I think after a decade we figured out that it would be good to be generating intellectual capital and so we went and talked to the Digital Equipment Corporation. We talked to a number of other places and talked to Sun. I think Eddie Frank was key in bringing us to Sun's attention, and Sun elected to buy us. We started the Sun Laboratories and Bert, I think, had a major hand in formulating the policies that made Sun Labs an interesting place to be.

Sproull: So you, from a research perspective, continued, with me and others, your asynchronous systems work and building ever more chips and so on, but you had to build the new research group.

Sutherland: Well, I was interested in the asynchronous business and I had become interested in integrated circuit design from interacting with Carver Mead at Caltech, and so I was interested in how we could do that, how we could build self-timed chips that would make use of the notion that things could happen when they could happen in order to gain speed and to not waste energy when it was not necessary to do anything, and so the group that I headed was called the Asynchronous Research Group. But its name was subsequently changed to the VLSI Research Group, I think appropriately, because there's much more to VLSI than just asynchrony.

Sutherland: Sun was sold to Oracle, and at that time I elected not to continue with Oracle or was asked not to continue with Oracle. I cannot tell quite how that was done but—and my wife, my new wife, decided that she wanted to live in Portland, and so that was okay with me. Portland's a fine place to be.

PORTLAND STATE UNIVERSITY (2009–PRESENT)

Sproull: So let us talk a little bit more about Portland State. You mentioned you walked in and just volunteered to start a new center.

Sutherland: Well, I like this notion of being associated with a university, especially if you get the finances right so that they are not paying you. So we wandered in to the acting dean, who was a man named Dick Knight and Knight had been an executive at Tektronix before going to Portland State and he did various jobs at Portland State. He is a fine man, and he set up in the engineering school a thing that we call the Asynchronous Research Center.

Sproull: So, talk a little bit about what you consider some of the highlights of the Portland State research operation.

Sutherland: Well, I think the biggest single highlight was in 2015. Marly published a paper in the Asynchronous Conference. And I forget what the paper is titled. But it is Roncken et al[1]. There is half a dozen authors. And basically, it describes self-timed systems in a very simple way. It says there are links, which are communication channels that cover distance. And links provide storage. They store data. And they transmit data. That is their job. They do not compute.

And the important part of a link is that a link can be either empty or full. In a synchronous or a clocked system, whether a register is empty or full is known only to the designer. The register itself is no different when it is empty than when it is full. So, you have to know on any one clock pulse whether the data in this register is useful. In a self-timed world, you do not have that luxury. So, each link has with it some additional storage that says whether it is empty or full. And at the input end of a link, you can say, "Here's some data. Accept this data and become full." Now, because a link has physical length, it may take time before it announces, at its output end, that it has data and that it is full. That is the latency of the link. And at the output end, you can accept the data, make use of it in whatever way you want, and then tell the link that I no longer need these data, so you may become empty. We call that draining the link. You tell the link to drain. But you do that at the output end whereupon the link becomes empty. But it takes time before the link will announce, at its input end, that it is now empty and can accept new data. And those delays caused by physical distance are automatically encompassed in the link. Links are connected together with joints. And if you think of this as a graph, the joints become the nodes of the graph. And the links become the edges of the graph. And the job of a joint is to coordinate the fullness and emptiness of links. And a joint acts, under certain circumstances where some or all of its input links are full and some or all of its output links, the ones it wants to use, are empty. And part of the action is to make use of input data, compute on it, deliver that data to output links, declare the input links to be empty and the output links to be full. That is an atomic operation of a joint. Now, there is a wide variety of kinds of joints you can imagine. But thinking of self-timed systems in terms of links and joints makes it all perfectly understandable. And more important than that, it ignores totally the question of what is the interface protocol between joints and links. It is just fullness or emptiness, fill and drain. It does not matter how that is encoded in wires electrically. It is all the same.

[1] Roncken, Marly; Mettala Gilla, Swetha; Park, Hoon; Jamadagni, Navaneeth Prasannakumar; Cowan, Christopher; and Sutherland, Ivan, "Naturalized Communication and Testing" (2015). *Computer Science Faculty Publications and Presentations*. 151. http://archives.pdx.edu/ds/psu/16860

GOVERNMENT WORK

Sproull: So one of the things that you do not do so much anymore, but used to do a lot of, is service on government committees of various kinds. You were on the Defense Science Board for a while. You were on several National Academy committees. And you co-chaired a somewhat famous one, the Brooks—Sutherland report. This was the report that became the origin of the fabled "tire tracks" diagram?

Sutherland: Yes.

Sproull: . . .that showed how interweaving of government and industrial research and other activities would ultimately lead to substantial economic activity? But it took fifteen years or so for research ideas to make it to the marketplace? How did that become the focus of this review?

Sutherland: I was at a meeting in Washington. And the executive secretary of the National Academy Committee on Computing, whatever it is called. And of course, I gave my impulsive "no." I said, "Of course not. Don't be ridiculous." And on the way home in the airplane, I realized that this was an important thing, that this would be a guiding principle for the next decade of what we do in computing. I figured this was pretty important. So, I called Fred Brooks. I said, "Fred, I've been asked to chair this committee. I'm not willing to do it. But if you'll do it, I'll do it." And he said, "Well, I'm not willing to do it. But if you'll do it, I'll do it." And so, we agreed that together we would chair this committee, co-chairs. And so, it was.

Butler Lampson was on it. It is a matter of record. It was a remarkable group. And we decided that we needed to show how industrial research, government-sponsored research, and academic research—the interplay between them—how that had an impact on the field. And essentially, the collective memory of the committee, Butler recorded. How did this happen? How did that happen? Who went from here to there? Who went from Berkeley to PARC? Who went from PARC to somewhere else and so on? And we recorded that as a chart. And that became the racing stripe chart. And it shows, over a period of time, the growth of I think eleven billion-dollar industries from first seed of idea to multibillion-dollar industries. And it is a remarkable interplay that there is some of it done by government sponsorship, and then some of it is commercial. Some of it is academic. And there is a flow between them.

Now, I think the marvelous part about the US research establishment is that it has this flow of people from one place to another. When Fred Brooks and I were briefing, this report was shortly after the implosion of Thinking Machines Corporation. Thinking Machines was an MIT spinoff that built big machines. And it had gone broke. It had a lot of DARPA sponsorship, and then it went broke and disappeared. And somebody in the audience asked the question, "Isn't this a giant waste of government money?" And I said, "Well, as far as I know, the knowledge that was gained in that research program was largely in the minds of the people. And as far as I know, not one of them has left the United States." They have all gone to different employment in other places. At Sun Microsystems, we hired several of them. And we got our fair share. And other companies got their fair share. And this is technology transfer at its very best. You take the people who know the stuff, and you move them to some other organization. It is a very high-bandwidth technology transfer. I said it is too bad for the shareholders. I mean the shareholders of the company lose money. But in terms of the national welfare, it is research money invested well and now transferred to where it can do some good. And I thought that that is, in some sense, a unique property of the way government research and private industry research and so on interplay in the United States. It's the strength of the research establishment. We're sitting here in Silicon Valley, which is traditional for doing this kind of thing.

Sproull: So, this is a great segue to the next topic, which is your various roles over the years in venture capital. I had now like to know your thoughts about venture capital, the various roles you played, ranging from an advisor to a limited partner with ATV, to an angel investor, to running one of the portfolio companies for a while. So the various ways in which you were part of the venture community seem to me quite fascinating and broad.

Sutherland: The period around 2000 was very hard. The dot com bubble burst. There were no initial public offerings for four or five years. It just became very hard. Teddy [initial partner] died leaving a huge gap in the venture capital partnership. And by then, Bob and Bert had been participating. And so we did due diligence. We thumped the tire, so to speak, of deals to see whether the people were sound and whether the ideas were sound. I managed to keep ATV out of a number of integrated circuit deals involving gallium arsenide. Gallium arsenide integrated circuits had promise because they could be faster than silicon circuits. But there was an important defect in them. It is not widely known, but silicon is an important integrated circuit material in part because if you oxidize it, it makes glass. And glass is a fantastically good insulator and fantastically dimensionally stable and all that good stuff. And neither gallium nor arsenic have that property, which makes making gallium arsenide integrated circuits quite hard. And we stayed out of a bunch of gallium arsenide potential deals, I think wisely. Now, I do not think I am very good as a venture capitalist actually. I see the promise of a technology much more clearly than the difficulties. The difficulties involve: will the products that it makes be useful? And I can imagine all kinds of uses that simply aren't. And so, I think that there's a role in venture capital for dreamers like me. But it's not the central role. The central role is how do you make wise investments that, in fact, will return money, which is what the venture business is all about. And fortunately, in ATV there were partners who were better at that than me. And ATV managed to be a moderately successful venture firm. It was not wildly successful, but it was moderately successful.

"WORK HABITS"

Sproull: Okay, so I want to change the topic now and talk a little bit about something I have labeled "work habits." It seems to me that over the time I have known you, there are certain invariants in the way you work. And I want to talk a little bit about all of them. Maybe I should give you a brief outline. So, one is the daily dose of technology. Another is writing things down. And another, perhaps, is starting and finishing things. So, let us talk first about the daily dose. You have been quoted as saying, "When denied my minimum daily dose of technology, I get grouchy. Without the fun, none of this would go on." So, talk a little bit about why you need your daily dose.

Sutherland: Bob, I don't know why. I think it's Bert who first coined the phrase, "Ivan needs his minimum daily dose of technology." But it is certainly true. And one of the pleasures of my life now is I have contact at the Asynchronous Research Center at Portland State. And I go there every day. And I do things. And sometimes, I get up early in the morning, and I do something technical on the projects that we are working on. And that somehow makes me happy.

Sproull: I had like to move on now to writing things down. And again, you have been quoted as saying "it's not an idea until you write it down."

Sutherland: Hmm. I have no idea how it started, Bob, no idea. It is a major asset to a person with a weak memory <laughs>. But what I find now is I can tell you that there are many, many, many times when I have sat down to write down an idea, and as I write it down, it turns into garbage. And that is when I realize that the idea is no good so I cannot write it down. And by articulating the idea by writing it down it makes it possible to look at it and question it. If you do not write it down, and it remains part of the folklore like fishing stories, it may grow in length with the telling. It may grow in value with the retelling. But if you write it down, you could find the defects. Until the computer program is written down, it has no defects whatsoever. An unrecorded computer program is flawless. I know any number of people who are the nonauthor of the perfect novel—"Okay, I have the perfect novel."

Sproul: How do you put together a good group?

Sutherland: Well, the most important thing is to have very smart friends and relatives. None of these things are my fault or my creations. They are the creations of groups of people that have been assembled. And one of the good fortunes of my life is to meet and work closely with and like a large number of incredibly bright people. I do not know why it is happened that way. Okay? I am a grumpy old man. But people seem to tolerate me for whatever reason. Maybe I am just bumbling enough that they say, "Oh, this guy needs some help. Let's see if we could help him," right?

I see the direction. I can articulate the direction clearly enough that you can understand it. And then, let us get together and make it happen. Eisenhower is famous for a grin. And he is famous for the Eisenhower jacket. And it is clear he is a human being. And it was clear to everybody that he was. Churchill smoked a cigar and was equally famous for his victory sign. But he was a human being. And he allowed his humanity to show. So, that is one characteristic that leadership has. And I have allowed my humanity to show. The people who have worked with me know that I am a person. Sometimes, I am grumpy, and sometimes, I am not. Sometimes, I am happy. And sometimes, I am sad. And I am not afraid to allow the people that work for me to see that. And that is important.

I think a second aspect of leadership that the military describes is articulateness. And I think over my career, I have selected for articulateness amongst the people that I have counted as friends. My mother, bless her soul, was big on speaking with correct diction and correct grammar. And I had lesson, after lesson, after lesson. I had to memorize poetry. And I had to give speeches with correct enunciation and correct grammar and so on. And thank you, Mom. That has been a huge asset over my career. The ability to express in English what I am thinking I think is important to let other people join the trip. How are they going to join up if they do not know what the trip is?

Sproull: One quote that I remember from an earlier discussion on this is, "Cherish and develop young minds." And so one of the things that I think you do very well at is bringing very junior people in who may not have much experience or confidence and not only are they able to join and function in the group, but you give them room to become a specialist at something, to become unique, to become the go-to person would be the Sun cliché, about a certain aspect of what is going on. So you do not crowd them out by deciding what works and what does not, or what is most important or least important, or what needs to be done tomorrow. You know, the group has room in which to grow.

Sutherland: We have got a couple of young people involved in the ARC now that are pretty good. And what is it about them that is good? They are interesting people. Dave Evans said, "You know, when you admit a graduate student to a graduate program, you should always admit some outliers." And Alan Kay was the typical example of a Dave Evans outlier. <laughter> Okay? Alan Kay was clearly very clever and very bright, but he did not have the kind of track record that would get him into a graduate school without any question. But he was clearly a good pick! I did not do that. Dave did that.

I am also not the sole source of ideas. I mean, this is one of the issues about where research happens. And I think Bill Joy had it right. He said, "New developments will happen in the computer industry. Most of them will happen elsewhere." We do not have any monopoly on brains. I do not have any monopoly on brains. Okay, I think in a certain way, and I have some good ideas sometimes, but other people's ideas are as good or maybe better than mine.

TECHNOLOGY AND COURAGE

Sproull: I had like to use that as segue into the last piece here, which is to talk a bit about "Technology and Courage," and this is, of course, the title of a little monograph you have done—which I think is under-circulated and under-appreciated—which talks a bit about the fact that it is often hard to summon personal courage to work for long periods of times on these projects, and the tradeoff between making them tractable, and having them be important, difficult enough to be worthy problems. So perhaps you might say a little bit about all that?

Sutherland: Well, I can define a worthy problem. A worthy problem is one which will sustain the interest of the people working on it for a long period of time. The paper about "Technology and Courage" itself, okay, I thought, "Who will care about this? This is a bunch of musings of a guy who's done some of this research, but it's not of any value." And so with great trepidation, I finally published the paper. And a lot of people have said, "This is an important paper to read." So it is a nontechnical paper. In this discussion, I have had a fair number of nontechnical things to say. I do not know if they are any good or not. I mean, history would have to say. But there are some places where the view that I have had of what the national scene is makes sense to me in some important ways. And what makes sense to me is that the research establishment in this country is not run by a research czar. It is run by a diverse collection of people who have all kinds of ideas about what the right thing to do is. And so there is no way that any one individual can block progress. There is no veto in the research establishment in the United States. And the lack of a veto is perhaps *the* most important thing.

Brock: You describe selecting a challenge as being able to see through the problem, to maybe some sort of tractability of some kind. And I was wondering if your long-standing commitment to the self-timed paradigm, if I may call it that, is typical of the way you choose problems?

Sutherland: I think it is unique, because a) it is a selection of a problem, which is really a long-term problem, and which I cannot see a way to the end. There are these insurmountable barriers, okay? In order to let the engineering community deal with asynchrony in a friendly way, one needs the tools to make it happen. One needs the education to train the engineers that can do it. And one needs the management courage to actually adopt these ideas. And any one of those is insurmountable. The three of them together are clearly insurmountable. So I consider what I am doing kind of like Don Quixote. Okay? I am tilting at windmills, and I will lose repeatedly.

But the importance of the problem and the central physical correctness of it is so obvious to me that it seems to me a worthy thing to work on. And besides, it is interesting. The notion that you could design a machine without a clock is heresy in many circles. But it is perfectly doable. It is just hard. And it is hard, in part, because you have no idea how to do it. And it is hard because how do you test the damn thing? Okay, well, I think we have solved that problem. And there is all these pieces that are hard. But you keep working on it, and it starts coming together. For the first time, I feel confident that we know what the ingredients are, to make a testable system.

Brock: To follow-up on that, I have learned that William Shockley used to exhort his group not to fight the physics, but to go with the physics in the same way that the self-timed paradigm, as you describe it, is kind of going with the special relativity rather than fighting the special relativity. But you know, I wonder in fighting this impossible fight, is there a vision that you can articulate of why you think the fight is worth fighting. If it is successful, what do you see as the consequence, broadly conceived?

Sutherland: Well, I think DOD's reason to be interested is that the first thing you do when you design a clocked system is you look at the technology use you have got, and you decide on the clock frequency. Okay? And clock frequency has been increasing over time, and now they have met the heat barrier, and the clock frequency has flattened out at a few gigahertz. And so you have to think of every pause in the operation of a modern computer as an opportunity to cool off! Because what limits its performance is the general rate at which it generates heat. Asynchrony has some property that you only do things when there are things to do. And so you do not waste energy "pedaling in place." Right? I met a guy who worked at Intel, and he was an expert in formal verification. And he was applying formal verification to the—what do they call it? The circuits that avoid clocking unnecessarily. There is a word for that.

Sproull: What do you mean, like conditional? Conditional clock—

Sutherland: Yeah, well, in modern synchronous systems, to save energy, you turn the clock off if you can figure out when it is not needed. And that occurred to me as a very strange thing to do. Why do not you do it the other way around, and turn the clock on only when it is needed? And the self-timed stuff generates clocks only when they are going to be used.

Brock: It strikes me in this review of your career that all of your engineering projects were experiments to learn something new. Which I do not think is maybe the case for all engineering projects or maybe most engineering projects. I was intrigued by this idea of an engineering project as experiment, engineering for new knowledge. Does that resonate at all? Does that sound like a fair description?

Sutherland: Oh, I think so. The Evans and Sutherland Company built products to sell. There is a little different game. Engineering projects, you know? I do not know. In Hollywood, they do not talk about *making* a movie. They talk about *doing* a movie. "We're *doing* a movie." And I think that is a very interesting choice of verb, because it says the activity is something interesting in and of itself, independent of the result. Now I think research is like that. You know, Salk set out to do a polio vaccine, more power to him, and he had a target in mind. But I will bet that the course of reaching that target had its own rewards and problems. And I think that what we are doing is *doing* research, not making research, not making—we are *doing* engineering projects, not making engineering artifacts happen.

Brock: Right.

Sutherland: The *doing* is in some sense the reason for being engaged. I have said many times and I think it is true, if you are doing the right thing in research, it should be fun! I mean, we have a number of strange things in the ARC offices. And so the place where we work tries to be fun. And I think that is valuable. It makes people more willing to be open about their weird ideas.

Brock: I was struck by your comments when talking about leadership and also within your own research groups, about revealing your humanity. And I was wondering if there were any particular things you might care to share about your humanity outside of research in other parts of your life, things that you have found particularly important or activities that you have pursued?

Sutherland: I do not know. What I do professionally is a very large part of my life. There is no question of that. And my wife, Marly, is like that, too. She is really devoted to what she is doing. She is a terrific role model for female students, and she is very approachable, and so many people go to her and ask her things and so on. And we recognize that in some sense we act *in loco parentis*: in part as parents to some of the younger people with whom we are involved. And that is a valuable part of the research group, that there is a humanity to it. Now leadership comes in different ingredients, okay? If I have been successful as a leader, it is been successful in groups of half-a-dozen or so people. Much less successful as a leader of many, many people.

You know, if people will pay you for doing exactly what you want to do, what could be better in life, right? And in some sense, I have never done things—certainly have not done them well—that I did not think were fun. Now I do some amount of, you know, the garbage stuff that you have to do to stay alive.

Sproull: Maybe this is a good place to stop. You know, we have just heard that there is a happy man who has been paid well to do what he loves.