Oral History of Ed Fredkin

Interviewed by:
Gardner Hendrie

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Gardner Hendrie [July 5, 2006]: We have with us today Ed Fredkin, who has very graciously agreed to do an oral history for the Computer History Museum. Thank you very much Ed.

Ed Fredkin: You're welcome.

Hendrie: I would like to start by understanding a little bit about your family background, your father, your mother, any siblings, and where you grew up with a little bit about your early life.

Fredkin: Okay. My mother and father were both Russian immigrants who met in Los Angeles, and I was the youngest child of four. I had a sister who was 14 years older then I was, an older brother, and a sister, also an older sister. We grew up in Los Angeles. My father had started a business in the 1920s and was very successful, but lost everything in the big market crash in 1929. So as I was growing up we were fairly poor, and that was a major factor in our life. We moved around a lot from one place to another as we couldn't pay the rent and had to move out and find another place, that kind of thing. But we managed, and we didn't really need things that much that we didn't get. I had a good childhood, lots of fun. My mother was trained as a concert pianist, was a conservatory graduate but did not perform professionally during my lifetime. She died when I was about 11. My father was always interested in being a writer, but he was in the radio and TV business in the early days, selling parts to people that fixed radios. Later on he specialized in selling educational television equipment to schools, but his business was always a one-man business. So it was a little business and he eked out a living and that was about it.

Hendrie: That must have been traumatic to have your mother die when you were still not even a teenager.

Fredkin: Yeah. It was, of course. She had cancer and was sick for about six months, and caused our family to kind of disperse, in that my father couldn't keep things together all that well at that time. My brother was then about 18, so he was going to school and then joined the Air Force. My sister and I, who were closer in age -- she's a year and a half older then me -- we each moved in with a different family. Then I moved from one family, to another family, to another, over a period of time. Eventually my father remarried, and then my sister and I moved back in with my father and stepmother. That lasted until I went off to college, pretty much. I also spent some time living with my older sister in that period. So I wandered around. I was in a sort of stable situation from when I started in kindergarten, got up to the 7th grade, then moved around a lot, and then finished up back in the same school system that I started with.

Hendrie: Which school system was it?

Fredkin: It was Los Angeles; John Marshall High School, which was a small high school in Los Angeles, the smallest one. It wasn't gigantic. I can't remember right now how may students it had, something like less then a thousand. Meant it was small.

Hendrie: That is small. What were your interests when you were growing up? Were there any precursors to your future career, in terms of things you liked to do, and hobbies you had, that sort of thing?

Fredkin: Yeah. I was always interested in science, just as a little kid. I got very interested in firecrackers and things, and explosives and things like that, so I got interested in chemistry for that reason. I had quite a little chemical lab. I discovered to my kind of surprise that I could go down to a big chemical supply place and buy beakers and Bunsen burners and stuff like that, but also chemicals that you could just mix together to make your home grown fireworks because they'd made them illegal in Los Angeles while I was a kid, which was annoying to me.

Hendrie: So did this when you were...?

Fredkin: While a kid, yeah.

Hendrie: Probably like 7th and 8th grade, that sort of time?

Fredkin: Yeah, or younger.

Hendrie: Or younger?

Fredkin: I would say I started buying things about age ten. An example is that I discovered fluorescent paints, and I found some that were transparent but fluorescent. So I was able to paint all kinds of designs on the walls of my room, which with the lights on you couldn't see anything, but if I turned them all out and turned on an ultraviolet light they all lit up. Stuff like that. I used to do a lot of things that were kind of fun. Occasionally an experiment would turn out badly, you know? But in general I was pretty careful. The other thing I liked to do is, I liked to make money. And so I did various things; as a kid I always had money. I sold things door to door when I was like ten or 11 because I read something in some comic book that said "Sell this door to door and you can get these wonderful prizes." It took me a little while to realize I was being ripped off. I was selling subscriptions, you know? But then I started a little business for myself going door to door and fixing appliances, like lamps or toasters or things like that. I would go into a hardware store and buy cords and light sockets and the plugs that you could wire into a cord with screws and so on. I would stop, knock on a door and just ask "Do you have anything like a lamp or a fan or something that doesn't work?" If it was a simple job, like the cord was no good, I would fix it and charge them something. So I did that. Then I got a paper route. At first the paper route was sort of unsatisfactory because I was very shy and I had to collect the money. Once a month I had to go around to each of my customers and collect the money. Many of them very cleverly either recognized me and then didn't answer the doorbell, or some were rude and when I wanted to collect they'd say "A week ago on Thursday the paper was in the bushes somewhere," or something like that. So I had a lot of uncollected money that way. But later on I got a much bigger paper route, and eventually when I was 16 I had a huge paper route that I delivered using a car. I got up at like 2 or 3 o'clock in the morning every day and worked until like 7, and I made a lot of money. It's hard to translate, you probably have to

multiply the numbers by 20 or something. But I was making several hundred dollars a month. That was interesting.

Hendrie: Now what did you tend to do with your money? Go and buy more chemicals?

Fredkin: No, that was a very minor expenditure. First of all, later on in going to college, I realized I wouldn't get any help anywhere; that my parents couldn't afford anything. I was saving up for that. And I wanted a car, so I bought a car. I ended up buying several cars. In one case I took the engine completely apart and changed the rings and the bearings and everything, put it all together and was completely amazed when it started up and ran. That kind of thing. I always worked -- after school jobs, or weekend jobs, stuff like that -- in order to just have the money. I didn't buy any very expensive things, but basically it was mostly living expenses.

Hendrie: Okay. And maybe some reflection of the difficulties of the family -- that you didn't want to ever be in the same position.

Fredkin: Yeah. I had some terrific ideas when I was a little child and I didn't follow up on them. One is I discovered that if you owned a big building, you would get all this rent; that struck me as a very interesting idea. But when I learned about stock I came up with an idea. I would say I was maybe ten years old, and my idea went like this. My parents would get the bill from the electric company and they'd start cursing, "These robbers, they're cheating us. They charge so much and it doesn't cost them anything, and blah, blah, blah." Then I learned you could buy stock in the electric company. Then they would complain about the water bill, complain about the telephone bill. So I hit upon this idea. Say you think the electric company is cheating people. The thing to do is to buy stock in the electrical company. Now, you should keep buying more and more and more stock until when you get your bill and you discover they're cheating you, it makes you happy because you're the shareholder now, and you're making more money. You should do that for each thing that annoys you, so that you have sort of equilibrium. That was one of my childhood ideas that I didn't bother with when I grew up.

Hendrie: Very good.

Fredkin: When I started my senior year in high school I realized I would not have enough money to go to college, and I got admitted to Caltech.

Hendrie: Did you apply any place else?

Fredkin: No. I just applied to Caltech and got in. There's a funny story to that I'll tell you in a minute, about my being admitted, because, as they explained to me when I left, they had admitted me with the worst high school grades of anyone they'd ever admitted.

Hendrie: Oh my goodness.

Fredkin: Yeah. And they felt they had learned their lesson. Anyway, what I did was I realized that I needed some extra money, so I concocted a plan. A friend and I did this together; we were both going to go to Caltech, and we both had a money problem. The plan was to leave high school a semester early and work. We presented our plan to the school, and they said "You have to have all these subjects." And we said "Well, instead of having free periods we've taken them all, and at the end of the first semester of the senior year, we'll have all the subjects we need." Then they found a rule that said you had to take – this was a three-year high school -- six semesters of gym, physical education. We explained to them that the point of gym is, while you're there is to take exercise. So we argued, and argued, and argued. Finally they gave up and decided, something like four days before the graduation of that class, that we could graduate with that class. One result is we missed all the senior activities that you normally have. There's a whole bunch of things that happen, including the prom and whatnot. We missed all that. But we both got out of school with our high school degree and we both got jobs. I got a job with a life insurance company as an actuarial clerk. One of the things, I needed a couple more subjects to get into Caltech, so I took two courses. It was a requirement to have had some last course I wasn't going to finish in high school, so I took it at LA City College at night. That plan worked. I got to Caltech and I had enough money to pay for the first year. My problem was not just the tuition, which wasn't all that high, but just living expenses.

Hendrie: Yeah, you couldn't commute from home.

Fredkin: No, they wouldn't allow me to, but it was very weird. Because I came from Los Angeles and they had limited housing. They just picked distance as the criteria -- distance of your home, even though mine was too far to commute -- as the criteria for who could get into a student house. So what I had to do was rent a room in a private home near the school. But they made me a member of a student house so I could go there and commune with fellow students or something during odd hours.

Hendrie: Now what was your thought in high school about what you wanted to study? What were your earliest thoughts about what you wanted to do when you grew up, and what were they when you went to Caltech?

Fredkin: Before I even knew what its name was, it was obvious to me what I was interested in was physics. I was completely curious as to how things worked, and I knew, once I learned that there was such a thing as physics, that was what I was most interested in. I was interested in science. My interest was kind of casual in other areas, like chemistry. I was interested in chemistry mostly to make things, you know? Although a teacher organized a team effort to go after the American Chemical Society. They had a competition every year for individuals and teams, and I got drafted for the chemistry team. I was the worst one on the team because I really wasn't interested in chemistry, but I was still pretty good, and I came in something like 23rd in the United States. But our team was spectacular and we won for the United States.

Hendrie: You won for the United States.

Fredkin: Yeah.

Hendrie: So this is a pretty good high school with some good teachers.

Fredkin: What happened is interesting. Our chemistry teacher had a friend, a college friend, who lived in some place like in Minnesota. She went one summer to visit her college friend, who was also a high school teacher and taught chemistry, and discovered that they had an amazing record of doing well in these tests. She learned what the method was and brought it back. The method was: they published all the tests afterwards. I don't know if they published them, but one way or another she came back with a set of the previous tests for the last like 12 years. And while none of the questions from the last 12 years were on the tests we took, there was lots of similarity to the problems and so on.

Hendrie: So the subjects were very...

Fredkin: So what we did was we studied those tests, all of them, and that just got us in tune with the thinking of the test makers. I have to say one other thing that I sort of developed while I was in junior high school. Actually, I'll tell a little anecdote. When I was in grammar school, in probably about the 5th or 6th grade, I had a bet with some friend of mine -- I remember his name, Kenneth McKenzie -- as to who would do better on the math quiz we were going to have. I was always very cocky. I bet I would do better then him. This was a ten question quiz, so that's a kind of risky thing, you know? When I looked at all the questions, I knew all the answers but there was one problem with one question. I was a total nerd then, much more so then I am now. What I realized is that the teacher had said something about this question, whatever it was, and I realized she was wrong, but I didn't mention anything to her. But now there was this question on the quiz and I thought to myself "Which should I do? Should I answer what I know the teacher thinks the answer is, or should I answer what I think the answer is?" And the typical nerdish thought is "Oh, maybe in the days since she told us this in class, she's learned the right answer." I put down what the right answer was. My quiz came back with one marked wrong, that's what my friend had, one wrong, so I was going to lose the bet. I went up to the teacher and I explained to her why she was wrong and I had the thing right. My reaction always was, again, sort of nerdish. I always thought people would say "Oh, thank you for showing me that I was wrong," and I couldn't understand when they would get annoyed. But what I didn't realize was they had this rule in LA to grade on a curve, and they were supposed to take all the scores and calculate this curve, and then pick what's A, B, C, D. Well, if you change someone, then technically they would have to go do this all over again. So she snatched the paper away from me and then gave it back to me with that one marked right. But my score and grade was the same; she put down nine right. So I came back and said "If I got that right, how come my score…?" She says "Look over here, where you put your name. You misspelled your name, so I took one off for that." My response was "Okay, well if you're counting my name that means it's 11 questions." And she just told me in no uncertain terms to go away.

Hendrie: Go away.

Fredkin: That's right. So I lost my bet. Okay, so that made me mad and I resolved from now on, that's it. I'm going to answer the questions the way they want the answers, instead of this sort of honest method I had. I developed over the next few years a kind of amazing ability to deal with multiple-choice questions. I could look at answers, say there were four numbers, and pick the right one almost always.

Hendrie: Really?

Fredkin: Yeah. I developed a whole family of methods, for every kind of question, that had nothing to do with knowledge of the exact subject, or it took into account what knowledge I had. I would take multiple choice questions and I would typically get them all right, even though I didn't know them all. I might get one or two wrong or something if there were a lot. In the 9th grade they gave a huge three day test called the Iowa Tests to everyone in California, and I was told I had the highest score in California on that test. What's interesting is in the 12th grade, they gave us the same test, and by then I was tired of all my sneaky things and I just honestly answered all the questions.

Hendrie: And so you didn't look for the psychology.

Fredkin: That's right, my little tricks, I didn't use them all. They told me I was the only person in John Marshal High School whose absolute score went down in three years. In other words I had done better in the 9th grade absolutely then I did in the 12th. That was just the difference between cheating and not cheating.

Hendrie: Yes.

Fredkin: When I went into the Air Force, they gave lots of tests. I would get them all right, normally.

Hendrie: That's fascinating. You just switched around and said "I'm going to learn to play the game, and this is a game. Can I psych out the writer of this test?"

Fredkin: This business of playing the game is something I learned at some later stage in life. I never learned it for sports in some way. I was never into sports that much. But when I went into the Air Force, being able to play the game was... I went into a program called Aviation Cadets and there they spent the first six weeks trying desperately to make you quit by every kind of strategy, of hazing basically. The people who couldn't play the game, who didn't understand that it was a big game, couldn't deal with it.

Hendrie: Before we get to that, I think we're jumping just a little bit ahead of ourselves.

Fredkin: Okay.

Hendrie: You said you always were interested in physics, so your plan when you went to Caltech was that you were going to study physics. You were going to major in physics.

Fredkin: Yes, exactly. So the first year, everyone did the same thing at Caltech, there was no variation.

Hendrie: A whole bunch of basic courses.

Fredkin: Right. Then basically the second year, they sort of had a fork: engineering or science. So I went down that fork, but only a little way, because in the middle of the second year I left Caltech. Now, I have to say, in high school I never did any homework. So if there was a course that required homework, [shrugs]. I used to take the books home always intending to do the homework, but never did it.

Hendrie: Okay. You always found something more interesting to do.

Fredkin: In something like math, I would arrive at class and think "Oh, I haven't done the homework." And I would whip it out and try and get it all done before they collected the papers. But in other subjects you couldn't do that. So my grades, since homework counted a lot in those days, my grades particularly in subjects that didn't have multiple-choice tests like English or something, were pretty poor. They were C's typically, the occasional D, the occasional B. In math I almost always got A's.

Hendrie: Because that was something you could figure out.

Fredkin: Well math I just could do quickly. I had a funny experience when I was 14 and I spent the year living with my older sister as I was moving around. They lived in Watts and I went to a junior high school there that was part of LA. When we got the mid-semester grade, the one that didn't actually count, I had a D in mathematics. I thought "I can't believe this." I think I got every question on every quiz right. So I went to the teacher and said "Why have I got a D in mathematics?" She said "Well, there's a reason for that." I said "What's that?" She said "It's because you're Jewish." I said "What? What can that have to do with my grade?" She said "Well, don't you know that there's prejudice against Jews?" Of course I knew about that. I never… In some sense I was always oblivious to things like that. But I couldn't understand what she was getting at. She said "Do you realize what you do? Everyone can see that you don't do any homework. That you don't study, you're not working, but you get good grades on all your quizzes." I said "So what?" She said "Well, don't you realize that getting good grades while just doing nothing feeds the racial prejudice against Jews?" I said "No, I don't realize."

Hendrie: It had never crossed your mind.

Fredkin: No. In any case, I didn't change any of my behavior and when the actual grade came, she gave me a good grade. But I thought that was just a strange sort of thing to run into.

Hendrie: Wow. That is strange. So you left Caltech in your sophomore year. Why did you leave?

Fredkin: I left prior to being thrown out.

Hendrie: Okay. That's always a good move.

Fredkin: What I did was, I met with this committee and said "I'd like to leave, and I want to leave in good standing, and come back sometime." They said "Well, yes, you can come back but you have to prove you've changed by having a year of good results from some other school first."

Hendrie: So you basically had trouble with studying. The studying problem crept up again.

Fredkin: The homework.

Hendrie: The homework problem, yes. In Caltech.

Fredkin: Yes. College was different than high school; you couldn't get by without it. Now, in math and physics I still was good.

Hendrie: You were still doing okay.

Fredkin: Well no, I was much better then okay.

Hendrie: Okay, good.

Fredkin: I had dropped out of all my classes prior to meeting with the committee and there was a semester coming to the end. I decided I would take the physics final. I'd been to only half the classes, and I'd done none of the labs, or any of the homework. But Caltech had a policy that all finals were open book. I'll remember this as long as I live, I guess. What I did was… here's the first problem. I have no idea how to do it and I start leafing through the book like mad. Find this part, read this, recognize what it is, do that problem, and so on and so forth. I went through the whole test like that; I was working like a demon. I got the top score in the class, in the sophomore class in the physics test. But I ended up with something like a D in physics anyway because there was no homework, no labs and whatever. But I had the top score and so I was proving something to myself.

Hendrie: So you knew the material.

Fredkin: No. I knew half the material, but I learned the other half to do the test, right there during the test. So I was proud of myself.

Hendrie: And you should be. You were able to figure it out in real-time, is what I call it.

Fredkin: I was very good at that, yeah. That's something I developed, which is an important skill, and I tried to teach it at MIT. It's how to solve a problem when you don't know the subject. If you find the name of the subject and you get a book on it, how do you solve the problem in any case? In other words, I

realized I'd developed a lot of techniques. I had one other experience which I thought was really funny. At the beginning of the sophomore year we had… This was, I guess, in the freshman year actually. It was the beginning of some semester. We got a new TA. He started out telling us he was going to introduce this subject to us, and he was going to give us a test, and he wanted to emphasize something. What he cared about in this test was the method. Now one of the things I'd developed in math is a sloppiness with numbers. In a math problem I could do math, but I'd sort of developed a habit of sloppy arithmetic, so I'd add 3 and 4 and get 8 or something, or whatever I did. I'm reminded of someone, some relative of, I think, Hilbert's, who said "He only knows numbers up to three," or something, or four. To him it's "one, two, three and then N". There's no need for anything else. I had developed that habit. So this guy, the teacher, emphasized quite strongly, and I wasn't really listening, that "What I care about is that you use the method right. You've done the math right. The arithmetic isn't important." My best friend was in the same class and he knew all the math; he was a mathematician. Everything he took at Caltech, he already knew it all. We both took this test. Later on this TA comes into class and he's beaming, he's just so happy about something. He describes what he has there. He says "I have these two tests."

Hendrie: These two papers?

Fredkin: These two papers, yeah. He said "One of them has every answer right, and has the lowest score in the class." He said "The other has every answer wrong and has the highest score in the class." Or something, I don't remember if it was every question wrong.

Hendrie: Yeah, fundamentally that was it.

Fredkin: Yeah, I don't remember the details. But it was my friend and I. He just wrote all the answers down because he just knew it all.

Hendrie: He could do it in his head, he didn't have to show any method or anything.

Fredkin: Yeah. Well part of it was… I think when you learn calculus you first learn to take a derivative in a long complicated way with some limits and so on, as opposed to just taking the exponent and sticking it in front and reducing it by one -- that kind of thing.

Hendrie: Yes, exactly.

Fredkin: It was a situation like that. Our two papers. I got the best score, and he got the worse. That was just funny.

Hendrie: That is funny. Now you said this was your best friend, at least in the freshman year. Was that somebody you met, or is this the person that you met in high school?

Fredkin: No, that was someone I met, and I never have run into since I left Caltech.

Hendrie: Really?

Fredkin: Yeah.

Hendrie: Do you keep in touch with your friend that you went, and both decided to leave the high school and work?

Fredkin: Yeah, right. And we both left Caltech the same year.

Hendrie: He left too?

Fredkin: Yes. What happened to him is he didn't leave when I did, so he waited to the end of the semester when they threw him out. But he had a similar problem, it wasn't exactly the same. We both went into the Air Force. I went in first and then a few months after I did, he also went into the Air Force and we both became fighter pilots in the Air Force.

Hendrie: Okay.

Fredkin: And our paths crossed a few other times.

Hendrie: So you still know him and you know where he is.

Fredkin: I know him and we communicate by email. He's living on a boat now, retired in the West Coast.

Hendrie: That's fascinating. Good. All right, so you and Caltech are not of the same mind exactly in what you want to do.

Fredkin: Yeah.

Hendrie: So you've got to do something, what are you going to do? You must have had a plan, right?

Fredkin: Well the problem was, then, there was a draft, and you got a deferment for being in college.

Hendrie: Now what year is this?

Fredkin: The year I left Caltech was 1954. This was the tail end of the Korean War. The fighting had already stopped, but it was a cease-fire, and it still is, I guess. They had a draft, and by having ROTC you got a deferment -- that's the military training you took at school. When I went to that committee of faculty members to ask, they said "What are you going to do?" Well one of the people on the committee was the Professor of Air Science and Tactics, as he was called, who was a colonel in the Air Force. When I told them I was going to go into the Air Force, they all looked glum except him. He looked very happy. If I hadn't joined the Air Force I would have been drafted into the Army.

Hendrie: So that was the motivation.

Fredkin: Well, I wanted to fly. And I had already learned how to fly. Actually, that same friend and I both went and took lessons together in Los Angeles, and we both learned how to fly.

END OF TAPE 1 / BEGINNING OF TAPE 2

Hendrie: All right.

Fredkin: I wanted to say one incident that happened when I was about eleven years old, I think. I had an uncle who was a violinist, and he played with the Los Angeles Philharmonic Orchestra. I never got to go to concerts or things like that just because of financial reasons, but I realized they had rehearsals. I asked him could I come to rehearsal, and he said "Sure." So when there was a rehearsal I went down, and the front of the Philharmonic Hall was all closed up but there was a side entrance -- stage entrance -- and there was a guard there. I went up and figured I would explain about my uncle and so on. I started to say something and the guard says to me, "Hey kid, get out of here. What are you doing here?" , and he chased me away. When I saw my uncle sometime later I complained about that and he said, "Oh, I can fix that. I'll give you a note. You show this to the guard and there will be no problem whatsoever." So he gave me the note. Then when there was another rehearsal I went down and went in, and there was almost no one in the audience part. So I sat in one of the front rows and I watched this rehearsal. It was great fun because, aside from playing music, it was fun to see how the rehearsal went and [how] the conductor yelled at people, that kind of thing.

Hendrie: Yes.

Fredkin: In the middle of all this I suddenly had this amazing realization, something that's just like a big light bulb going off kind of thing, right?

Hendrie: Uh huh.

Fredkin: My note was in my pocket and I'd never taken it out. And I'm thinking, how did I get in here? I just suddenly realized I was in there and it was like the transporter room or something.

Hendrie: Yes.

Fredkin: So, I thought about it. I thought to myself, this is a very important thing. Remember everything about this and don't forget it, okay? What I realized is: it had to be something about the way I acted, the way I walked, the way I appeared, because it was the same guard as the previous time. And I had just walked right up and in and waved hi and he didn't stop me.

Hendrie: Okay.

Fredkin: And I thought, ah, there's got to be a big lesson here somehow. What I realized -- I analyzed this in my head -- it had 100 percent to do with how I felt and what my attitude was and how that communicated to the person there. I felt I belonged. He recognized that I felt I belonged, and so he assumed I must belong and in I went. That principle affected all kinds of things in my life from that point on. If I tell you more stories you'll see it at work over and over again, where I end up getting into something one way or another where I have no right or reason to be involved. I just involved myself and the other people assumed it must make sense.

Hendrie: Somebody must have told you to be here, or whatever.

Fredkin: I ended up being able to do kind of a whole series of amazing things, and that's, I think, what--

Hendrie: And that was your first cognitive realization of this characteristic?

Fredkin: This possibility, yeah.

Hendrie: The possibility and how it worked.

Fredkin: Because I sort of felt as a little kid, I didn't have anything. Other people had things, and other people were famous, and other people had money and other things, and I didn't have anything, hardly. But I realized that I had the possibility of doing this thing, and over a period of time I tested it and developed it and it became a kind of natural part of my personality. It still exists, and comes up.

Hendrie: Very good.

Fredkin: It's also related to another thing, which is [to] learn to assume I would be successful. An example of that, that affects me today, is when I'm going somewhere in a car and there are other people in the car, my method of driving, say, to the theater is different than other people's, in that I'm always finding parking places right next to where I want to be, while they're stopping five blocks before they get there. They spot a space and they grab it.

Hendrie: Okay.

Fredkin: What I realized is, if you're driving to a destination like a theater, the optimal strategy is to drive all the way to essentially there, and if there's a space right there to take it, and then look for spaces while you're driving away, as opposed to looking for them while you're driving towards it. Okay?

Hendrie: Okay.

Fredkin: In general my strategy of assuming I'm going to get a great parking space works about 95 percent of the time, because there's five percent where I end up back in some parking lot. Other people I travel with are much more, I don't know what the right word is, they don't have a methodology and they end up parking far away.

Hendrie: Far away. Well it's so logical to start where you want to be and drive away and find the first one driving away.

Fredkin: That's right.

Hendrie: Rather than guessing that you won't find one; making the presumption.

Fredkin: Yes. And there's lots of principles like that that are taught to some people. Like a principle of landfall. Which is, if you're a sailor and it's the old days before GPS and you're heading for a shore, a distant shore, and you want to get to, say, Boston after sailing across the Atlantic, do you aim for Boston? The answer is no. If you know how to -- this is again using the sextant or some old kind of navigation -- you aim off to one side by an amount that's going to be greater than any possible error. Then when you hit land you make a turn. Say you aim to the right.

Hendrie: Yes.

Fredkin: Then when you hit land you turn to the left and sail until you get to Boston. Okay? The alternative is you sail until you see land. You were aiming for Boston but you didn't get to Boston, so now you sail a little bit to the right. You don't see it. You sail to the left. You don't see it. You sail to the right. You sail to the left.

Hendrie: Right, yes, exactly, you don't know which way to turn.

Fredkin: You go back and forth. That's right. So, the principal of landfall makes it certain that you know which way to turn. That's the idea. So, there are things like that in life, aside from just sailing boats.

Hendrie: Ok, very good. We're at the point where you're going to join the Air Force and learn to fly, but you mentioned that you had learned to fly already. So, maybe you could tell me a little bit about how you got interested, and when you first thought about it might be fun to learn to fly, and all of that.

Fredkin: Okay. As a child I was totally taken in by machinery, in particular by cars and trains and streetcars and boats and airplanes and so on. Operating something like that just was my kind of thing. So, I dreamt about driving a car all the time. When I would ride in a streetcar I would sit up right next to the motorman to watch exactly how you drove the streetcar. In those days the power was applied by having a big handle that you turned around like this and if you let go of it, it would apply the brakes automatically. You have to push down on the handle and then you'd go around and it was a big switch box that switched in various resisters and different field windings so as to give you staged power to the electric motors and so on. And the brakes were pneumatic with an air compressor and made hissing noises, and you could let the air into the brakes or position it so it held that pressure or let go of the pressure and so on. And I, by watching very carefully and trying to understand things, would figure out exactly how you drive a streetcar, exactly how . So I was always interested. I wanted to sail boats and things like that. I felt that sailing had to be logical. I could just figure it out from first principles.

Hendrie: Right, okay.

Fredkin: I tried in every way to get someone to take me sailing, but by the time I was 14 I had never been in a boat other than a little thing in a pond, a little pedal boat or something like that. So I just decided to travel down to Newport and rent a sailboat. I got to someplace where they rented sailboats. I was on Lido Island in Newport and the guy asks me a number of questions. He said, "Have you ever sailed?" I said, "Oh, sure, yeah, sure. I know how to sail" and so on and so forth. So, just watching me he realized I probably had never seen a boat before up close.

Hendrie: Okay.

Fredkin: So then he started asking me some specific questions and I kept trying to answer them just based on first principles. Then he asked me a particular question. He said, "Okay, say you're sailing and you're sailing this way and the wind is coming this way and a puff of wind -- a very strong puff of wind -- comes in and it's starting to tip you over. What would you do?" So I figured, well, it's pushing on the boom, so I said I'd let the boom out. And he says, "Yeah, that's kind of right, but guess what? If you're starting to tip you know what's going to happen when you let the boom out?" I said, "No." He says, "It's going to go a little way and it's going to run into the water and stop. Then what will happen?" I said, "Oh, well it might tip over." He says, "Yes." So then I said, "I could turn into the wind." And he says, "Yes, that's the right answer." So, he decided to let me go.

Hendrie: Very good.

Fredkin: But I didn't get it on the first try. So in any case I just sailed around there and taught myself how to sail, that kind of thing. And I read books. I read how-to [books]. Like one thing I taught myself: I like to cook, and as a kid I liked to cook. When I discovered some pretty good cookbooks, I realized that

this is like chemistry. If I can learn to do the following: read a cookbook and understand exactly what they're getting at, I can cook anything in the cookbook and it will come out good all the time. I was used to people saying, "Oh, I knew I shouldn't have made this cake on a rainy day because…" or, "The moon was full. That was a bad time to make such and such a thing." People had excuses for why the food they prepared didn't come out. But when I watched them cook it, they were always very sloppy about measuring, or ….

Hendrie: The measurement, and the time.

Fredkin: …the time. Or, "I don't have that ingredient. We'll just use this other thing" and so on and so forth. So, to me cooking was, as I say, something like chemistry. And if you did it right… You can use your imagination and make changes but still you can make good things by seeing what a cookbook says, that kind of thing.

Hendrie: Okay, good.

Fredkin: So, the Air Force--

Hendrie: So now when did you start flying?

Fredkin: When I was about 17 or 18, Bill Fletcher and I went down to--

Hendrie: Now he's your friend, yes?

Fredkin: That's right. We went down to Glendale Airport, which doesn't exist anymore. It was too windy to fly that day, but we found out the information. It cost so much an hour for a lesson, so you can save up that much money and then get a one hour lesson, and you'd need so many lessons to solo, and then so on and so forth. You could go on and get your pilot's license. So we both came back. What we used to do is ride our bikes from Caltech in Pasadena out to Glendale and get a lesson. I think we only went down together on that first trip, because we had to schedule things and we'd always get different times. But I would just ride my bike down and take a lesson whenever I saved up enough money and it was a nice day.

Hendrie: Oh, wow, okay. So you learned during that year at Caltech?

Fredkin: Yes, I learned to fly. I didn't get my pilot's license but I had soloed and knew how to fly. So, when I went into the Air Force I had a little bit of flying experience.

Hendrie: All right, good. Tell me about your experience in the Air Force. What were you doing?

Fredkin: The first interesting experience was going for the physical. When I applied, the first thing I had to do is go and take a written test and a physical in L.A. which was very simple minded. This was just a pre-screening thing. Then, since I was applying for Cadets to be a pilot, I had to go up to San Francisco area and take a real complicated physical test, lots of questions. They were flunking people right and left saying "You're out. You failed", and so on. I recall that they had eye tests. My vision was very good then. They're giving me one-eye tests. This guy just puts a card right in front of me and starts moving it away, so I started reading it, “AQZ”, whatever. He puts the card down and says "You failed. You're out." I said, "How did I fail?" He said I was too far away. I said, "Well, I started reading it and you kept moving it." He says, "Yes, but you didn't tell me to stop." I said, "You didn't ask me to stop." So, I said, "Do it again." He says, "Okay, I'll do it again." So, this time I tried as soon as I could make the things out, like he's this far, I said "Stop" and I read them. He says, "You flunked again." I said, "Why?" He says, "You're too close. You read it too close. You're not supposed to read it that close."

Hendrie: [Laughs] You read it too close.

Fredkin: Wait, yes. So I said, "What am I supposed to do?" He says -- I don't remember the details -- he said something like, "Between 8 and 12 inches." I said, "Okay, do it again" and I'm thinking 8 to 12 inches. I say "Stop." I read it and he says "Okay, you passed." I thought that was strange.

Hendrie: Yes.

Fredkin: Then I had to meet with the psychiatrist. He asked me lots of questions. He said something like "Are your parents divorced?" I said, "No." My mother had died. Okay. Then I'm sitting next to someone, and he says, “I'm washed up. They told me I'm—“. I said "Why?" He said "Well, they asked were my parents divorced, and I said yes." He said, “My father was divorced before he met my mother.” And I thought, oh, I interpreted that question differently. I thought the question was, “Were they divorced, did they divorce during your life”, which would be meaningful.

Hendrie: Yes.

Fredkin: The fact that a divorced person married your mother didn't seem meaningful to me. But he was washed out for that. And my mother was divorced when she married my father. In other words, she was married previously.

Hendrie: Yes. She had been married previously.

Fredkin: Yes, right, and my oldest sister had a different father than I had. I was being honest but I couldn't imagine they were asking a question that stupid.

Hendrie: Yes.

Fredkin: But the whole thing was like that.

Hendrie: Just irrational.

Fredkin: There was one kid there who had flunked the urine test and somehow he asked for another chance. And his “second chance” was he got someone else to pee in the cup for him, okay?.

Hendrie: Okay.

Fredkin: I thought that was interesting.

Hendrie: Yes.

Fredkin: So it's all over with, and I'm flying back to Los Angeles. On the airplane I'm flying on I see one of the guys who was one of the airmen doing the testing. The plane was fairly empty so I went over and started talking to him. I said "You know, this was a very weird experience, like they were trying to make me be disqualified". I knew I had passed. I said, "Do you know how many passed?" He says, "Yes, I know exactly." I said, "How many?" He said, "Three." I said, "Three? How many were there?" He said 155. I said, "Only three passed?" and I'm thinking, boy, they must be the best physical specimens in the whole world. I said, "I just can't believe it. That's so strange." He said, "It's not strange at all. You don't understand what's going on." I said, "What do you mean?" He said, "Orders came. We have slots for three at this time. Flunk the rest." Oh, interesting system.

Hendrie: Exactly. Of course. No way you would have guessed it was anything like that.

Fredkin: That's right. And so when I got to Texas in the Air Force, who do I see? The guy who borrowed someone else's pee. He was one of the three too. Who probably didn't belong actually.

Hendrie: Right. Oh, my goodness.

Fredkin: So that started my Air Force phase of life. I was obviously different than all the other cadets, because I was sort of more of an intellectual than anyone, and interested in science. Whenever they talked about airplanes I would understand what they were talking about and I would do very good on tests. In the military, if you have to tell someone a rule, he's going into the army. The first rule I would say is: don't let the sergeant learn your name. Because the only reason they'll use the name they've learned is for some purpose that you're not going to like. I was pretty easy going and could deal with stuff they dealt.

Hendrie: …tried to do to you?

Fredkin: Yeah, right. And I got my demerits. I'll give you an example, of when you were allowed six demerits a week. Then all in excess of six, you had to walk one hour in a dress uniform, what they called “walking at attention”; carrying a rifle, go back and forth for an hour. And if you had eight extra demerits you had to do it eight hours, whatever it was.

Hendrie: Whatever the number was, yeah.

Fredkin: That's right, yes. Although there was a special thing for some offenses they called a “6 and 12”: they gave you 6 demerits and 12 hours of walking. This was punishment. You were marching and it was 100 and some degrees in San Antonio. So you didn't want to get these demerits. Also, after you had been there a while, on the weekend you could go into town only if you had six or fewer demerits. Here's an example of demerits. One of the crimes was when you had an inspection, if there was dirt anywhere around your bunk, your locker, or anything -- that was three demerits, called “Dirt, General”. Everything was said in weird ways. They would say "That's dirt comma general", that kind of thing. So I had six demerits, and the inspection was going on, and as soon as the inspection was over I'm free to go into town, right?

Hendrie: Yes.

Fredkin: Okay. So there's this team going by inspecting, and they'd go down from one bunk to the other. They look at things. They do things like… Here's what they do. Everything had to be in exact order in your footlocker. You had to have a tube of toothpaste, okay? And the tube of toothpaste had to be clean, and the inside of the cap had to be clean with no toothpaste on it. They would pick this toothpaste tube up like that, giving it a hefty squeeze, then undo the cap and say "There's toothpaste on this cap. What's that mister? That's dirt, comma, general: three demerits." Or, they would step on your shoe and then come back and, “Look, you're supposed to have that shoe shined." And they'd say "What the hell is going on here?" Here's what you have to say, "No excuse, sir." You were allowed five statements: "No excuse, sir," "Yes, sir," "No, sir," "Sir, may I ask a question sir," or "Sir, may I make a statement, sir." If you ever said those last two you were doomed.

Hendrie: You were doomed.

Fredkin: At first they'd say no, but they'd be really mad at you then. Their point was to blame you for something you didn't do and see if you could take it. That was the whole game.

Hendrie: That was the whole idea.

Fredkin: Right, yes. But most people didn't understand that that was the game. So, I'd breathe this big sigh of relief. They passed me. Suddenly I see they've turned around and they're walking back, slowly, in a very peculiar way. By the way, we were supposed to have our eyeballs locked, as they called it, looking straight ahead. If they saw that you were looking to the side, that was a no-no. Okay. But I could see they were heading my way.

Hendrie: Your peripheral vision told you that.

Fredkin: Right. What they're doing is, they're following a moth that's flying around. There's a moth that's flying around, flies around, flies around, lands on my windowsill. This guy comes up to me, "What's that, mister? That's dirt, dirt general. Give me…" You had these little slips in your pocket. You had to hand him a slip. He wrote down three demerits “dirt, general”. So I had to stay and march three hours back and forth. It was typical.

Hendrie: A typical thing. All right.

Fredkin: I don't know whether there's some purpose to it. I think their idea is, if you can do all of that, when they tell you, “you've got to make this run” and you know you're going to get killed doing it, you'll go do it. I probably wouldn't, but someone else might.

Hendrie: All right. So you got through flight training?

Fredkin: Yes.

Hendrie: Now you learned… you flew in the trainer?

Fredkin: Well you started out in a Piper Cub in those days, for 20 hours. Then you went to the T6, which was a World War II trainer. Then, it was an interesting thing. Then after the T6 you had a fork in the road. You went to what they called multi-engine training, or single engine training, which was a strange way to describe it. Basically it was: Were you flying a big airplane with a crew? In those days a big bomber would have a pilot, a co-pilot, a radio operator, a navigator and a bombardier and then three or four gunners manning guns. The Super Fortress, things like that, okay. I knew for sure I wanted to be a fighter pilot. I didn't want anyone else in my airplane. I just wanted to do whatever I did. The first part, up through the T6, everyone was together and then you split off. I went down the fighter pilot path. Then we went to the T28, which was a modern propeller-driven plane that was like a World War II fighter. From there into the T33, which was a jet fighter that had a two-place version, which was the most popular trainer in the world for jets. I finished all that. Then what happened is, after I graduated the next step was to go to what was called “gunnery school”. This is where you learn to shoot, and drop bombs, and all of that.

Hendrie: Yes, right.

Fredkin: I had a lot of fun with the T33, because I was still kind of like a scientist and I did experiments. I probably had a T33 to a higher altitude than anyone had ever done. I know the cabin was probably at a higher pressure altitude. I did an experiment once. I went up, and I had nothing to do, so I decided to see how high I could make this plane fly. I got to a point where it had stopped climbing, which was I was about, I don't know, 47,000 or 48,000, something like that. I then started experimenting with the flaps. I

lowered a little bit of flaps. It started to climb slowly again. By fiddling, I got it up higher and higher, somewhere around 50,000 feet. Then I had an explosive decompression in the cabin, as it's called, -- the cabin pressure went poof. There was an altimeter for the cabin. When I say cabin, it's a cockpit.

Hendrie: Yeah, the cockpit, right.

Fredkin: So the cockpit had its own altimeter, and I looked at it. It had gone to 56,000 feet, and that's because whatever leak developed was in a low pressure area of the airplane. I think it was behind the canopy or something where dynamically the pressure was lower. So I had to switch my oxygen. Normally the cockpit is pressurized and the oxygen mask we had, had a setting for high altitude, which is called pressure breathing where instead of your breathing in normally, the oxygen is under pressure. So if you relaxed it would just inflate your lungs, and then you have to strain to breathe out. That gives you a few extra thousand feet of consciousness.

Hendrie: Yes.

Fredkin: Okay. We were close to the limit there. There was someone else in the airplane who was basically along for the ride, and he was plump, somewhat. You wore gloves. When you fly a fighter you wear gloves. They're these very thin, very nice gloves, and you have a flight suit. But he could see this much skin, and he developed what's called aero embolism. The lymphatic fluid in you starts to boil, because the pressure is so low. What I noticed, that was interesting, is that this is a very bizarre thing. When I opened my mouth to say something, my saliva started boiling in my mouth. It was a very strange thing.

Hendrie: Very strange.

Fredkin: Yes. It was the slight difference in pressure between when I'm pressure breathing, as it were, it didn't boil, but as soon as I would say something it would go bubble, bubble, bubble in my mouth like mad. We had to figure out how to get the plane down as fast as possible, which was hard because at that altitude, idle on the engine was full power. In other words, it had an adjustment. Upping the idle would have gotten to the point where it was at full power anyway. I got the plane down fast.

Hendrie: How did you do that?

Fredkin: Well, basically I did everything to create drag. I put the gear down, and I put dive brakes down, and so on.

Hendrie: Ha, all right. Even in that thin atmosphere it did something?

Fredkin: Oh, yeah, right. The other thing is, I think I was the first person to do a bunch of zero G experiments, because there wasn't any…. I had read an article in some magazine about the idea of flying zero G curves in an airplane. This article was written by someone who was discussing how to design an instrument for the pilot that would read zero Gs. They had a G meter, but the G meter we had just went, here's zero and one, two, three. But if you want to be on zero to within 100th or a 1,000th of a G, it wouldn't show up on that meter.

Hendrie: Yes, of course.

Fredkin: The article discussed how difficult it was to build a meter that could read accurately near zero, because there would be so much friction compared to the forces involved and blah, blah, blah. A kind of learned article that was nonsense. My zero G meter worked perfectly with no errors whatsoever in three dimensions. What I did is, I had a little pink rubber eraser. I'd put that on the… There's this part of the cockpit in front you, sort of a little cowling like over the instruments. I put it there, just sitting. Then I flew the airplane to fly that into the air, and then I flew formation on it.

Hendrie: Okay.

Fredkin: In other words, if it came towards me I'd slow down, and if it went the other way I speeded up. You could fly formation on another plane. This was much harder because I was dealing with inches instead of feet.

Hendrie: Right, exactly.

Fredkin: But when you're flying next to another plane in formation you have to be adjusting things within a foot.

Hendrie: You're constantly adjusting.

Fredkin: So I would fly formation on this eraser, which was right in front of me. That was a zero-error zero G meter.

Hendrie: That was a brilliant idea!

Fredkin: Yes, right. I mean, it was pretty simple minded. I got to be pretty good at it. I did this over and over. There's one thing I tried to do which I never succeeded at. I wanted to fly at zero G and then roll the airplane around it. I was never able to do that successfully. The other thing I tried to do is, I took water up with me in little containers, because what I wanted to do…. I'd have a little paper cup and I'm flying this jet. It's a one man airplane, no auto pilot, and I'm trying to pour this into something, and then I'm going to go fly zero G. Which meant I had to dive down, pull up sharply and then nose over like that.

Hendrie: Right, yes.

Fredkin: Okay. Then when I get to the zero G -- I've got my eraser I'm trying to keep -- and I want to spill some water out of this thing. I wanted to see a blob of water just floating in front of me.

Hendrie: Oh, that would be fascinating.

Fredkin: The astronauts have seen that up in space. To make a long story short, the number of times I tried it, I never succeeded. Because if I'm at zero G and I go like this, it doesn't exactly pour out, and then when I try jerking the cup away, it would tend to follow the cup to some extent.

Hendrie: Oh, yeah, you gave it momentum.

Fredkin: Even though it's the part that could spill out. In any case, various amounts of water got sprinkled in the cockpit there, but I never was able to get the blob of water there.

Hendrie: Never able to see the blob.

Fredkin: No, but I used to do all kinds of things like that. Another thing I did that was great fun for me is the Air Force. I viewed the Air Force as a kind of vacation for myself. The training period, then three years in the Air Force, and I figured I'll be more grown up. Everything would be better then. Suddenly, just after I graduated they said, "Oh, we want everyone to sign up for an extra year. And if you don't do it, we won't send you to gunnery school." I didn't want to sign up for the extra year, so they didn't send me to gunnery. Instead, they sent me to a school where I learned to be an intercept controller. This is guiding an airplane to shoot down a bomber by radar. It's like air traffic control, except we're trying to get them to the same place at the same time.

Hendrie: At the same time.

Fredkin: As opposed to keeping them apart.

Hendrie: The other way, yes.

Fredkin: In those days they didn't have any good simulators, so people had to fly. Some airplane would be up there pretending to be a bomber, and some would be pretending to be an interceptor. Then you'd be on a radar looking at these little blips and telling instructions to one, to go intercept the other, okay?

Hendrie: Right, okay.

Fredkin: So they needed pilots to do that. Of course, I was a pilot.

Hendrie: Yeah, they needed somebody that understood what was going on.

Fredkin: Yes. They divided the days in half, so this was sort of a nice, easy going course. Normally you just had half a day of lessons, and they figured that's as much as you can swallow. The other half you had nothing to do. One week you'd have your half be in the mornings, and the other week you'd have your half be in the afternoons. What I did was when I had my intercept controlling half in the morning, I flew the fighter, normally the interceptor, in the afternoon.

Hendrie: Oh!

Fredkin: And when I had my class in the afternoon, I flew the interceptor in the morning, so I saw both sides of this every day. It was unusual because almost everyone else there was either a pilot flying or they were an intercept controller who had never flown an airplane. But I get bored easily. So what happened to me is that I'm up there flying, and the way they would issue commands was interesting. They had these four things: right and left and starboard and port. Right and left were directions you could look. Look to the right, or look to the left, to see the other airplane or something. Starboard meant you were going to turn. When the guy on the ground… Say you're going north which is 360, and he wants to turn you to the east. He would say “starboard zero-niner-zero”, that being east. Well, when you heard starboard you started your turn. You didn't know what to yet but you needed to have quick reaction. They'd say starboard and you'd start your turn, “0-9-0”, and you'd roll out there, okay?

Hendrie: Yeah.

Fredkin: Jets going fast took a long time to turn. In other words, the faster you go it takes much longer to turn. So, as I say, being bored and understanding the whole system, I hit upon an interesting idea. When I was going north and they said “starboard”, instead of turning, I just started to pull up. I pulled up until I was vertical. And they said “0-9-0” and I would roll over this way and continue pulling up this way, come down this way, roll out and then go that way.

Hendrie: Oh!

Fredkin: Okay? Now, the normal thing that happened on the radar, is there are these little sweeps. Every 15 seconds the radar would be turning around. Once every 15 seconds. So what you see on the radar screen, you'd say to the guy "Starboard 0-9-0" you'd see this little trace going “trace, trace, trace”, and it made this gentle curve.

END OF TAPE 2 / BEGINNING OF TAPE 3

Hendrie: Right.

Fredkin: Okay. So you would see this track slowly, trace after trace, making this curve like this. But the maneuver I made didn't work like that, because I pulled up vertically. And at that point the radar picture of me just came to a stop, and then I rolled over this way and came over this way. The main point is my track on the ground made an exact 90-degree thing. Exactly.

Hendrie: Or whatever the angle was.

Fredkin: Whatever the angle, it was exact. It just went click-click. And there was this afterglow on the screen, so you could see the whole track. What happened is that after that first time I did this, there was a long pause…

Hendrie: From the controller. Yeah.

Fredkin: Right. So he gives me another turn, and I do the same thing. After a while I can hear there's some confusion and talking, and then one of the instructors takes over.

Hendrie: Okay.

Fredkin: So he says, "Port 270!" Gives me this order. I do my same little trick. And he gives me one thing after another. Then I hear more confusion going on. Finally they say, "Attention all aircraft in the area. We're scrubbing the mission for the rest of the day. There's something wrong with the radar." <laughs>

Hendrie: Oh, no. <laughs>

Fredkin: Anyway, I always was a bit of an adventurer of sorts.

Hendrie: Well, yeah. Nobody told you that you had to… There wasn't a standard…

Fredkin: Well, they did tell me what I was supposed to do. I mean I was just have--

Hendrie: You were just having fun.

Fredkin: Yes. I was having fun. Now it could have, you know… They never figured that out.

Hendrie: Did that maneuver in fact allow you, if you, say, had a 90-degree turn or more, did that actually allow to turn faster?

Fredkin: No.

Hendrie: Okay. You weren't going the correct direction sooner because of that?

Fredkin: No.

Hendrie: It just looked really funny on the radar.

Fredkin: If you had to do a 180-degree turn, it would be the fastest way. But for a [regular] 90-degree turn, you had to do one 90-degree turn. I had to do one 90 degree, another 130-degree turn and then another turn out. Now, I would have done it in less space, but I would have been further behind.

Hendrie: Right.

Fredkin: So it wasn't the better way to do an intercept. My point was they just had a 2-D picture. They didn't have any altitude information in those days of any kind.

Hendrie: Okay. Yeah. There was no transponder.

Fredkin: There was a transponder, but it didn't say the altitude. It was called IFF. It just said "identification friend or foe".

Hendrie: Oh, that's fascinating.

Fredkin: So those were just things I did. I always had a kind of a slight practical joker streak in me. But I never bothered explaining that to anyone. They were happy the radar worked the next day.

Hendrie: Wonderful. That's a great story.

Fredkin: Then I was based at Eglin Air Force Base after the training, and I just flew. Eglin Air Force Base was a huge operation with more than 20 airports on this big Air Force base. Little ones and big ones, aside from the main airport. They had a big payroll, and they paid in cash. A little convoy had to go with one truck to bring the cash -- nothing bigger than a $20 bill. Had to go to Pensacola, Florida and bring it back to Eglin Air Force Base, which is Fort Walton Beach, which is, about, say it's 90 miles. They had two trucks with troops, airmen with guns. They didn't want to be robbed with all this cash. They used

to have a helicopter and a fighter, a jet, flying cover. So they're driving along at 50 miles an hour, and I have to circle around watching them.

Hendrie: So you got this duty too?

Fredkin: I used to do that on occasion. That was fun. Then they invented the SAGE system, and this was computerized air defense. Since I was a trained intercept controller, and I was at the air proving ground command, where I was at Eglin Air Force Base. When they got a new pair of shoes in the Air Force, they would send some down to Eglin and people would walk around in them and see whether [they] got blisters or not. So they got this new air defense system [and] they needed to test it. Very naively they put together a team of people, and one of them was me, just by happenstance. They sent us up to Hanscom Field (near Boston)…

Hendrie: This wasn't something you volunteered for particularly or anything?

Fredkin: I don't remember if it was a volunteer thing, but it was just a matter of some peculiar luck. It might be that they were tired of me and were sending me away, or who knows what. I don't know. So when we got there, which was in May of 1956 -- I think that's when it was, I have to think. It was either then or '57. I can't remember right now.

Hendrie: All right. That's okay.

Fredkin: The senior guys, the majors and colonels, came up. They sent a complete assortment of people, from some airmen -- that's the lowest rank -- and sergeants, and then some… I was a lieutenant. And they had some captains and colonels and majors and what not. So they sent this whole assortment. All the senior officers bought houses instantly. That was sort of the Air Force way; when you were transferred someplace, you bought a house, figuring it will appreciate. [We] were there just for one month, and it got announced that there's going to be a one-year delay before it becomes ready for testing. They announced this like the month before testing was supposed to start. None of the officers wanted to go back; they'd just bought houses and such. So they made a case for, "Oh, this system's more complicated than we thought. We could use this year to get ready and train", and so on and so forth. This was a funny thing that happened. They estimated it would take them a thousand man-years of programming effort to write the SAGE program.

Hendrie: Now where was this being written?

Fredkin: It was being written at the Lincoln Laboratories, and the System Development Corporation, which was then part of Rand System Development Division.

Hendrie: Out in L.A.?

Fredkin: Yes, although a lot of the people were located out here too. When they started work on this computerized air defense, there were five hundred programmers in the world. So they mounted a massive training program because they would hire people who maybe had a degree in math, and try and teach them programming. They were teaching people about computer hardware: logic and everything else. All the people that came up from Florida were enrolled in this course. The first part they enrolled them in was digital logic: flip-flops, and how you design, stuff like that. After one week all of them dropped out but me.

Hendrie: You thought it was fascinating I'm sure.

Fredkin: First of all, none of them could get it. They didn't have any background or something. It's simple stuff, but they didn't know the best way to present things back then and explain it. But still, I just sopped it up like a sponge, as it were. I stayed for about a year. I was in various courses: programming courses, courses on every aspect of computation that was known then. So I got this sudden education in computers. There hadn't been a computer course taught at a university yet. Like, there hadn't been one taught at MIT yet.

Hendrie: So this was not at MIT. This was part of--

Fredkin: MIT was involved because Lincoln Laboratory was doing the development.

Hendrie: Was part of MIT.

Fredkin: Yes. But what I mean is, as an academic course. It was just at the point where they were about to teach something about computers. There's this funny thing that happened to me. When I finished taking the courses, the question is: what's to be done with me now?

Hendrie: Now, you're still in the Air Force, right?

Fredkin: I'm still in the Air Force. So the Air Force assigned me to Lincoln Labs. What that meant to me is, one day a guy came around, and he said, "Hey, I'm the guy who the Air Force has assigned you to work for me. I'm your Lincoln Labs boss." I said, "Okay." He says, "I want to show you what we need done." And he brought me to some room, and it had a bunch of file cabinets in it. There were these Air Force bases involved, like in Truro, Mass. On the cape there was a radar. The radar information fed into the SAGE system automatically. They invented the modem, for instance, as part of this project. The guys who ran the radar were supposed to send a report in once a week, and it was supposed to end up in this file cabinet. The guy explained to me, "You know, we tell them to send it, but they don't send it. What we need is an officer with authority who can order them to send it." They had some weird idea of how things worked. When he finished explaining what he wanted me to do, which was to check this file cabinet and whatever's not missing, follow up on it, and so on, I realized I would be terrible at doing this kind of clerical work, and I'm not the organized type anyway. So I said to him, "The job you've described is totally inappropriate for me." And he said, "Oh!" And he went away, and he never came back. Now--

Hendrie: Now, was this an Air Force officer?

Fredkin: No. This was a Lincoln Labs person. Meanwhile, I was going around making myself generally useful, and having immense fun because there were the biggest computers in the world there, and I could use any of them. People just assumed, "Oh, he's the Air Force guy. Of course he can use them."

Hendrie: Because the Air Force is paying for all of this.

Fredkin: The Air Force is paying, yes. I got to observe all kinds of fascinating things. Lincoln wanted to buy an IBM 709 computer, a vacuum-tube computer that had built-in hardware floating point arithmetic capability. They wanted it because the XD1 computer that they developed had 16-bit words, and it was a straight binary. To do data analysis was a pain. It didn't have Fortran, which the 709 was going to have as soon as Fortran was ready-- and stuff like that. They tried to convince the authorities they need this 709, and the authorities, whatever, didn't go along. Then we have the visit from the big general in charge of everything. He comes. There's all these demonstrations put on for him, the tour and everything. I'm just hanging around watching all of this. Some guy-- one of the Lincoln Labs guys-- suddenly has the idea: let's see if I can convince this general that we want this computer. He starts to describe the situation, that we want this other computer to do the data analysis and so on, and the general interrupts and says, "Hold it, hold it. I understand exactly. It's a deal. Get the computer." I was just amazed! This guy was so quick, and he's a general. So I went up to him after the meeting, and I said, "You know, I really was impressed by how quick you made that decision. I was wondering if you could elaborate to me a bit of what you consider the important issues." He says, "This was a very simple thing to decide." He says, "If we let that XD1 analyze its own data and it makes mistakes, it's going to cover them up. Of course we have to have another computer analyzing the data." So that was the basis of his decision, a very, you know….

So I went around, and I was a very fast coder. When someone told me about some problem, they would just tell me, "Oh, we have this problem, we can't seem to get the code to do such and such." I would just go write a program and I'd give it to them. I sort of wandered around doing things like that. I got a reputation for it. When Sputnik went up, two guys came to me and said, "We need a program instantly. The Air Force wants…" They were both from Bell Telephone Labs. They needed so many scientists so quickly, they just went to Bell Labs and said, "Send us thirty people." And they went to various other [organizations], just to get them all working on it. So these two mathematicians came and said, "We need a program. We've got to calculate the orbit." I said, "Okay. What do you want it to do?" And they said, "We need a program that can do double interpolation." I said, "Double interpolation?" This is where you have a table and you look up this [row] and this [column], and you find the entry and you want to interpolate both sides and look at all the other values. I said, "Oh, well what are you trying to calculate?" They said, "We need this." They had this famous German math book that all mathematicians knew about, called "Jahnke & Emde" [Tables of Higher Functions]. If you find an old, old mathematician, he would recognize that name. Because you used to have to have log tables, and trig tables, and God knows what. So I said, "Look, you don't need double interpolation. I'll just write a program to compute the function." They hesitated, and they said, "No. I'm sorry, but you can't write a program to compute the function." I said, "Why?" They said, "This is a function that can't be done in a computer." I sort of laughed. You have to understand that in those days all kinds of people had ideas about computers that weren't true about them, because they didn't really know how they worked. They didn't understand it. They heard about a computer, and they'd think, "Okay. They've made an electronic version of a Marchant

desk calculator that can add, subtract, multiply and divide, except it does its own pushing of the buttons or something. They thought you told it which buttons to push. They had built a model up like that. Then they'd imagine that's what the computer was. So I said to them, "Look, someone calculated this damn table. It's a function. It's a mathematical function." They said, "There is no function." I said, "Of course there's a function." I'm arguing with them. They said, "The problem is there's two functions. You have to use one function for one range of variables and the other function for the other range." I said, "Well, that's the easiest thing in the world with a computer." They said, "No, a computer can't do that because there's not one function." So I said, "Look. I will write the program, and it'll do it." They looked at me, and they said, "Will you write the double interpolation program, or won't you?" So I said, "Okay. I'll write your double interpolation program." So I wrote that program for them. This was the kind of thing that you were up against all the time.

Hendrie: Oh, my goodness.

Fredkin: So I'll tell another anecdote.

Hendrie: So did you end up writing it as double interpolation, or…

Fredkin: I just wrote the program they asked for and gave it to them. And they used it in the table, and they were able to calculate the orbit. By the way, the method of calculating the orbit was… this is so funny. The whole U.S. was shocked by Sputnik, shocked to death, right? They had a Russian ham magazine. You know what a ham is, a radio amateur. It was dated like six months before Sputnik went up. What it talked about was, it said "If there were a satellite in orbit, and it was broadcasting a steady tone, and you listened to it as it flies over, and you measure the Doppler shift, you can calculate the orbit. It went through the whole process of telling you. And Sputnik had a tone that it broadcast. It was going, "beep, beep, beep," but it was a tone. Then when it passed you, the frequency dropped. So by measuring that on a number of orbits… There was process, and it was all in this magazine that they happened to have. They didn't have to figure anything out. The point is, if anyone had had any brains, they would have realized from reading that magazine that this is being written because they're going to send up a satellite. They shouldn't have been surprised. Anyway, some time later we sent up our satellite. I was still in the Air Force when they launched a rocket to the Moon called Pioneer. Here's how primitive things were. It needed mid-course correction. At MIT Lincoln Labs they had a thing called the Millstone Hill Radar. It could bounce signals off of Venus or the Sun. So a rocket is launched from Cape Canaveral. When it comes over the horizon from Massachusetts, the Millstone Hill Radar locks onto it and starts tracking it. It's a great radar. There was a computer connected to this radar, and it's supposed to calculate the correction. They had little rockets on the last stage, and they could fire an extra two, four, six or eight of them. So all that Millstone Hill was supposed to say is, to the guys… the guys down in Florida had a button for each pair of rockets. And they could push this button, or push two of the buttons, or three or four. Okay? That's how primitive it was. And it's on the telephone to each other. So the Millstone Hill Radar tracks it and then prints out, "Fire ! Rockets." So the guys down in Cape Canaveral say, "How many, and what are we supposed to do?" They say, "Wait a minute." They reloaded the program with paper tape, started it up again, okay? And it said "Fire # Rockets." And the guys down in Florida are getting frantic. "You gotta tell us now! How many?" They said, "Wait a minute." And they reload the program and it says, "Fire * Rockets." Okay. So they didn't fire any. The rocket went up 80,000 miles, turned around and fell into the ocean. Now, it turned out, actually, if they'd fired them all it would've gone

up like, 120,000 miles and fallen into the ocean. But nevertheless, the people at Canaveral were totally livid and insanely angry. Okay? And so someone finds me, and says, "Something screwed up at the Millstone Hill in their software or something. Go find it and find out what's wrong and fix it." So I go up, and it was very funny because I'm the lowly lieutenant or something, but still people were very intimidated. I say, "Can I have the manual for this computer?"

Hendrie: What was the computer?

Fredkin: It was the CG20. No, this computer was called the CG24; I think that was its name. It was designed by the radar guys, and was actually the first transistor computer in the world. They completely designed it themselves, but they knew nothing about computers, hardly. When I open the manual-- I'll never forget-- like the first sentence, it says, "The most important design principle in the architecture of a computer is that every field in the instruction must have a multiple of three bits in the field."

Hendrie: Okay. All right.

Fredkin: In other words, the instruction part could be either three bits or six bits. And it was six bits in that machine. And the address part could be, say, nine bits or twelve bits, but it couldn't be ten. Why? They programmed in octal. So they didn't know how to write it down--

Hendrie: -- if it was ten bits. They only knew how to write it down if it was nine or twelve.

Fredkin: That's right. They could figure something out, but it would be very clumsy and so on. In this computer the sine routine was in a particular location. You know, they put their energy into weird things. This computer was the only computer I've known, even since, [that] had a square root instruction. And then it had index registers. Did you ever do programming?

Hendrie: Yes.

Fredkin: Okay. They didn't understand. They heard of an index register, [but] didn't know how it was supposed to work. What happened is, they had no way to read the contents of the index register out. But, okay. Also, whenever they used the index register, they decremented it. And they had no instruction-
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Hendrie: Automatically.

Fredkin: Automatically. They had no instruction for decrementing it, or changing it by anything, but just whenever you referred to it. If they wanted to know what was in an index register, they only way they could find out was to have a table and to read the table indexed. Okay? But that changed it! So they now had to set it back to what it was. It was full of completely hair-brained aspects, and I remember them all.

But the worst thing was… Wait, here's what caused the actual problem, which I found out. They calculated this number, which was supposed to be zero through eight. Took what you might think of as the ASCII code -- it was before ASCII -- for the zero on the typewriter, and added the thing they calculated to that code. Which [worked] because they had been thoughtful enough to make the digits be successive numbers. This would have worked if the answer had come out any number between zero and eight. But their program calculated the number like 15 or 20, which was how many rockets were needed to make the move.

Hendrie: So it calculated the correct number!

Fredkin: Yes, it calculated the correct number, but when it added it to the code, it just got some random letter on the keyboard, of course.

Hendrie: Of course.

Fredkin: They didn't think to see if it's bigger than eight, then just say “too many”. They didn't think that way. They just assumed-- these stupid programmers, you know-- which is it, from zero to eight. So they just added to that. So that's why it printed out these random characters.

Hendrie: Okay.

Fredkin: I decided they had to have an assembler. There was a great assembler for the 709 computer, which was there by then. A guy called Roy Nutt wrote it and I'd looked at his code, and it was the most beautiful. He was at United Aircraft, and it was called SAP (Symbolic Assembly Program). The guy was a terrific programmer. What I did was I made a way for… I was able to go into that assembler, redefine a bunch of things, and make it assemble CG24 code. What it did was, it sort of thought it was making binary code for the 36-bit word IBM computer. Then I wrote a little program that took the bits and reshuffled them into the CG24 positions. Now, the only trouble is the CG24 needed paper tape. So I actually, to my knowledge, I invented the cross-compiler. I don't believe anyone had ever done such a thing before: compile on one machine for another. But it took me, like, one day to write this code. What did was, I punched out an IBM card. On the card were eight of the rows of the twelve, were the picture of the paper tape, the same holes.

Hendrie: The same holes.

Fredkin: Yes. Then I took an 026 card punch, which had a card reader. It had-- relay type machine-- it had the wires for each one. And I wired that to a paper tape punch. So what you did is you wrote your assembly code on the-- compiled it on the IBM computer, got a stack of cards, put them in an 026 punch, and said "duplicate." And the cards were read by the thing, one after another, automatically, and it punched out a paper tape, which you could now read into the thing. I had the whole thing done in three days. Lincoln Labs was wonderful. I'd go to the parts room, and I'd say, "You got a paper tape punch?"

“Yeah.”. They had sort of everything anyone wanted. It was all so simple to do. That was a typical thing I did.

Hendrie: Oh, that is great. That's a great story.

Fredkin: Yeah. I don't know if they used it actually, but I tried. People argued that it was wrong to program in symbolic code. I tried to teach a course once there at Lincoln, where I was trying to explain to programmers why they should use symbolic code. “No“, they said, "We're used to octal. We like it. It's better. You're closer to the machine."

Hendrie: <laughs> All right. Lots of strange reasons.

Fredkin: Yeah.

Hendrie: Most having to do with, “we don't want to learn something new”.

Fredkin: Something like that. Yeah. Well, [it] took a while for them to learn what's right and what's not right.

Hendrie: Yeah. And what really is more efficient. Okay.

Fredkin: I had a wonderful time, and I had lots of ideas. One of the funny ones was I dreamt up an idea while I was in the Air Force of a kind of storage mechanism. I wrote a little memo describing it, and then I wrote a big program for the IBM 709 to test this idea. Then I left Lincoln Labs and went to work for Bolt, Beranek & Newman. While I was there, the guy who was my boss, J. C. R. Licklider, convinced me to… He sort of did what a referee might do. He read my paper and made lots of suggestions for things I needed to do to make it into a better paper: do this, that and the other. —See, I'd never written anything. I was not the writing type of person. There was this funny thing that happened to me. I forgot to mention a really important thing, which was, while at Lincoln Labs, I met some people. I met Marvin Minsky almost right away, so we became very good friends. I met John Cocke.

Hendrie: How did he… I didn't know he was involved at all.

Fredkin: He wasn't. He wasn't, but he came up for some visit, and I had a birthday party for my-- I'm trying to remember who it was for-- I think it was for my daughter, who was one year old. And Marv Minsky came, and John Cocke was visiting him. In any case, Marvin brought John with him. John and I became very good friends from that point on. The way I met John McCarthy was, I took this idea I had thought of, and I'd explain it to people. And they'd say, that doesn't make any sense to them or they don't know what it's good for or not. But they said, "There's a guy with similar ideas you should talk to, and that's John McCarthy." Because my idea looked like list structure to them, and John McCarthy had done

LISP, which was a list structure language. So I found John McCarthy, and I explained this. I remember I found him in Building 26 at MIT, and I introduced myself and started to explain this idea to him. And he got angry. I thought, "This is strange." Then he said, "I've had the exact same idea, but I didn't do anything. I didn't write it up or anything." And I realized, "Oh, he's angry because this is a good idea."

Hendrie: And you published first.

Fredkin: Well, I didn't publish yet. But nevertheless… There's a funny thing about that idea. We ended up publishing… I ended up publishing it in the *Communications of the ACM*. That ended up taking a couple of years to do that.

Hendrie: Yeah. So are you going to tell us what the idea was?

Fredkin:. It's called TRIE memory. I called it "TRIE." I just looked it up on the Web; you get about a half a million hits now. But, the idea disappeared off the face of the Earth when I published this. In other words, some years later I looked to see if there were any citations. No. No one had. No interest. This was appropriate for machines with large memory.

Hendrie: And people weren't building machines with large memory yet.

Fredkin: I remember that by 1968… This was an idea from, I think it was published in 1960 or something like that. It was still a totally dead idea. I know that because that's when I went to MIT. It was the only publication I had, but it was one that had been of no interest.

Hendrie: Oh, my goodness. So you're still in the Air Force?

Fredkin: Well, I got out of the Air Force. I worked--

Hendrie: This is when you finished your… Your time was--

Fredkin: Three years. When I applied to get out, the Air Force suddenly woke up and said, "Fredkin -- what's he been doing all this time?" So they called up my Lincoln Labs boss.

Hendrie: Oh, the one who you said this is inappropriate because they were filing cabinets, I'm not good at this.

Fredkin: Yes. They hadn't had any contact with him. So he said, "I don't know. I haven't seen him. I saw him once, and he said what I suggested was inappropriate, and I never saw him again." So they assumed I had done nothing the entire time. They're reaction to that was, they had no idea. They didn't say

anything to me. But they decided to punish me. Because they assumed that I had really been just drawing my pay and doing nothing.

Hendrie: Yes. You might've been on the beach for all they knew.

Fredkin: That's right. So here's how they picked to punish me. It's a typical Air Force thing. They assigned me to a tour at Resolute Island. Resolute Island is… You know where Point Barrow, Alaska is?

Hendrie: Yes.

Fredkin: It's the most northern part of Alaska. Well if you swing over into the Canadian part, there's islands that go much further north. And 350 miles north of Point Barrow there are still these big northern islands, much closer to the north pole. And one of them had a radar station at it, you see.

Hendrie: Ah, undoubtedly in the DEW [Distant Early Warning] line probably?

Fredkin: This is even before the DEW line, but it was a radar station there. In those days it was serviced by a ship that came once a year, usually, if it could get in. They dropped off a bunch of people with a year's supply. Hopefully they could come back if the ship got in the next year, otherwise they waited or something, I was told. I thought to myself, "Ah. I'm gonna get out in, like, three weeks. What the hell?" So I went to some sergeant to get processed to get out. And he said to me, "Hey, you've got a very interesting problem here." I said, "What's that?" He said, "Well, there's a regulation in the Air Force that says that if you've been assigned overseas"-- that used to mean combat-- "that you're not allowed to submit an application to resign." Because they didn't want people resigning because they're being sent to combat. This was left over from that. I said, "Well, you know, I have a three year contract. And I'm just getting out after it." And he said, "Yes, well I'm sorry, but this regulation supercedes that. And what it means is you have to go to Resolute Island." I said, "There's gotta be some way." This guy was being very helpful. He says, "Well, you know, there's very, very few exceptions of any kind. You just have to go." He says, "Sometimes it can be delayed." I say, "What could delay it?" So he's going down a long list: no, no, it's not that. Finally he gets to one that says, "If the officer's wife is pregnant between X months and Y months, then he can apply for permission to be taken off of overseas assignment until the birth, and then he's put back on the assignment." He says, "Well, is your wife pregnant between that?" I said, "It happens to be true. Yes. But it says I have to go afterwards." He says, "No, it doesn't work that way. Once you're taken off, then you can apply to discharge, because you won't be on overseas assignment, and you'll get out, and you don't have to go to Resolute Island. So all I had to do -- my daughter saved me -- is to get a doctor's statement, and I got out.

Hendrie: Wow!

Fredkin: So that was interesting. I've been lucky in a lot of ways.

END OF TAPE 3 / BEGINNING OF TAPE 4

Fredkin: I have to explain one thing. I kept having ideas, and I would just tell people my ideas. This got to be quite a thing. I gave talks at Lincoln Labs. I got an invitation to Harvard -- would I come and give a talk about something or other, about computers -- and I gave a couple of talks at Harvard. And I'm just a lieutenant in the Air Force. When I got out of the Air Force I wanted to go back to California, but I applied to the System Development Corporation and they said, "Yes, we'll give you a job". I said, "What will I be doing?" and they wouldn't tell me. They said, "We don't know. Just come out here and you'll find something to do." That unnerved me somewhat. I also applied to Lincoln Labs and they said well, yes, you can stay here at Lincoln. That would be great. But because you don't have a degree, the only job they could give me was an appointment as an administrative assistant. This is a file clerk or something like that. So they gave me that job and I took it. I just kept doing the same thing I was doing. In other words, I don't even know if I had a boss, or whether I had one or not. I just was a free floating person and no one seemed to mind. I just did whatever I did.

Hendrie: Right, and you'd go around and do things people wanted done.

Fredkin: Yes, whatever occurred to me. At some point I decided I wanted to start a company and I wanted to buy a computer. There was a new desk computer, as opposed to desktop, called the LGP-30, which was sort of like a desk in size. I ordered one. It was $50,000. I didn't have any money at all, but I figured out I'm going to order it. I'll start a company. I'll line up a bunch of business and then I'll be able to pay for it somehow. I was very confident, or something.

Hendrie: You could work this out.

Ed Fredkin: Yes. So I made up a list of companies and put it in alphabetical order and went to see the first one, which was Bolt, Beranek and Newman, and who did I go see, Licklider. We had this long talk and Licklider kind of figured me out fairly quickly as someone who was smart and so on, but also missing a lot of education. He came up with a counter suggestion. He said, "Look, instead of your starting the company and getting this computer, we'll take the computer and you can come here and teach us all about computing." There were no computer people at BBN. The nearest thing to it was Tom Merrill, who was a friend of mine -- and that's how I even knew about BBN -- who worked at Lincoln Labs and had gone to BBN. But he had a PhD. He was Licklider's PhD student and his field was psychoacoustics, so he was in the acoustics end. So I went there with my mission being: teach them all about computing. I ended up learning a tremendous amount from Licklider, who in some sense taught me to be a scientist, how do to scientific experiments, and he helped me get that paper done on TRIE memory. I had a kind of mandate to hire people. I'll give you an example. Licklider's rule was: always hire someone who improves the average intelligence of the group. He started out saying hire people that are smarter than you are, but then he realized he had some very smart people around, so he came up with this other criteria that was a little weaker.

Hendrie: It's the same idea, but more practical.

Fredkin: The same idea but a little weaker, right. He said "hire computer people", so I just got the word out that I was hiring. The first thing I did is I arranged for them to hire Marvin Minsky and John McCarthy, who were friends of mine as consultants, so we got those two guys. Another friend of mine, whom I met at Lincoln Labs, we got hired, Roland Silver, who ended up being a very creative, good guy. Then I interviewed some guy. So I'm interviewing this young guy and he wanted to be a computer architect. So I went to Licklider and I'm all enthusiastic and say, "I just interviewed a great guy we should hire." So Licklider says, "What's he do?" and I said, "He wants to be a computer architect." And Licklider says to me, "Is he the best computer architect in the world?" I was sort of shocked. I said, "He hasn't designed anything yet, so it's sort of hard to tell. <laugh> He says, "Well who's the best one in the world?" I said, "Well my opinion is I know two people, Wes Clark, who was at Lincoln Labs, and John Cocke. He said, "Hire one of them instead." So I went to this guy and said, "Sorry." So he went off to Digital [Equipment Corporation] and got a job. Do you know who that was? Gordon Bell.

Hendrie: All right! This is Gordon Bell, back from Australia.

Fredkin: Yes, right. He'd just come back from Australia. Of course, when I contacted both John Cocke and Wes Clark, they had no interest in coming to BBN, <laugh> so we didn't get anybody. So his [Licklider's] ideas didn't always work that well. John McCarthy explained the idea of timesharing to me, which he thought of in its whole… in other words, he'd really thought it through. He had the whole thing figured out. It was a fantastic idea, except that it was insanely expensive to do. I figured out a way when I discovered the PDP-1. Were you at the PDP-1 thing?

Hendrie: Yes, I was at the PDP1 lecture. [May 15, 2006 at the Computer History Museum]

Fredkin: When I discovered the PDP-1, I realized I could come up with a kind of cheating way to make it act like it was doing what John McCarthy wanted. John McCarthy wanted there to be enough RAM so that everyone lived in RAM, which I agreed was the right way to do it. But RAM was very expensive, in those days a dollar a bit from IBM. I came up with the idea of this fast swapping drum.

Hendrie: So you had it in RAM for a little bit, and then you'd go put it away in a cheaper storage.

Fredkin: Yes, but the system I designed didn't follow that scheme. If you typed a key, the time it took to swap out the person who was running and to swap you in to replace him was 20 milliseconds and it had no latency. In other words, normally, with a disc or drum, you have latency. This was zero latency. I invented all this, and it was so efficient. Here's how it worked. The memory was 4,096 words. The drum that I designed, it had 4,096 words around it. If you looked at the detailed timing diagram of the drum and you looked at the detailed timing diagram of RAM, you discovered you could do this amazing thing, which is what I discovered. You do the read cycle on a word in RAM, so you read this word out, which clears this register. And normally, you're going to write it back-- read/write, so you still have the memory. Meanwhile, while you're reading this out, you're reading a word off of the drum. Now, instead of writing this word back, you write the word back that you got off of the drum, and write this one on the drum in

another field. So what you could do is, every memory cycle of the PDP-1 core memory, you would swap one word. Now the reason there was no latency, is that there were 4,096 words around the drum, so when you said "swap", it looked and said oh, the drum's on register 2,007, so we start there in RAM. And we just went once around the drum, and we filled our RAM always, so there was no latency, and it was 20 milliseconds. Anyone who copied this idea, swapping, missed that point of it being fast, and they ended up with swapping being an algorithm to make people wait, because they didn't have fast drums. They did nothing. No one ever did it that way again.

Hendrie: They had not figured out how to synchronize the drum, which is what you did.

Fredkin: My criteria was, the thing had to be able to respond to every character you typed. So what does IBM do when they copied swapping? They came up [with the scheme that] the computer will pay attention when you hit the carriage return. See, we had a kind of philosophy that was every character. We wanted interaction, so that if you're typing, it's coming up on the screen. They made it so you type a whole line and hit the carriage return. You hit the carriage return and then you wait. I'm sort of a fanatic on making things work fast.

Hendrie: So that was your idea at BBN.

Fredkin: Yeah.

Hendrie: Did you build this swapping drum at BBN or did DEC build it for you? Were you ever able to implement that?

Fredkin: I designed it. And I have to say, BBN bought the first PDP-1. You probably heard me mention that. I got to design all kinds of aspects of the machine, like the character set, and the codes for the characters, and the I/O system and so on. All were my designs.

Hendrie: Because Ben Gurley, he didn't care what the character sets were; he needed a customer.

Fredkin: Oh no, he cared desperately what they were. But the point was, he and I thought alike on all kinds of things. When I would tell him, and I did, what I thought was a good idea, he thought it was a good idea, too. So I told him about the swapping problem. Meanwhile, John McCarthy was enthusiastic about it, and there was a PDP-1 at MIT. This funny thing happened. There was some meeting at MIT, and Ben Gurley was there. John and I and Ben are in a room, and John says to Ben, "Listen, we want to do this swapping drum. Will you build it?" Ben was a sort of interesting guy. He says, "No one's given us a purchase order." John says, "If you had a purchase order, would you build it?" He [Gurley] said, "If I had a purchase order right now, yes, we'd go build it right away." So John runs out and finds Professor Zimmerman, who is head of RLE, and makes him make MIT give him a purchase order right then. He comes back in the room and says, "Here's MIT's purchase order number." I called Licklider and I described this thing to him and I said, "Get someone to call me with a P.O. number." What happened is

in, like, another 15 minutes Ben Gurley had two purchase order numbers: one from MIT and one from BBN. That's the way business should be done sometimes.

Hendrie: Yes, exactly.

Fredkin: We had been hounding them for like six months, "will you do this", and they had other commitments and they were busy doing their own things and so on. It was a major thing to do, because this was a very innovative design. So it was built, yes, and that was part of the BBN timesharing system, and part of the MIT timesharing system they did.

Hendrie: Are you aware of who actually ended up designing it?

Fredkin: No.

Hendrie: Gordon Bell.

Fredkin: Yes, I can believe that, of course.

Hendrie: He designed that swapping thing that swapped in one revolution.

Fredkin: It has one little bug, which was discouraging to MIT, which is if you had an error in it, this error went by you. There was no error checking. Say you had an error in the RAM or whatever; it then got onto the drum and so on. So there was a problem that they felt that the swapping thing sort of corrupted. Let me see if I can explain it differently. They would read routines, when you brought in the whole core image. The way they organized this is they had a copy of some subroutine. If somehow an error was made when you swapped it out, you've then corrupted your subroutine somehow. This could have been solved by their organizing the data a little differently or something.

Hendrie: Correct. They could have had procedures and data.

Fredkin: In any case, that discouraged them, the fact that errors got stuck onto the drum again.

Hendrie: And of course, Digital did not believe in parity in their core memory, so there was no parity. If there had been parity, they could put parity on the drum and you would have detected most single-bit failures.

Fredkin: That's right. The point is that that idea, which was a pretty good idea, went nowhere. And IBM… The degree to which someone can screw something up is so great. I always have somehow accessed information most people don't get, but when IBM released their timesharing system for the 360,

it was incredibly slow. A couple of weeks before release, some IBM guy said, “Hey, we have a terrible crisis. I’ve just discovered something.” Each block that could be swapped in or out had two bits associated with it. One bit said its okay to swap this now. It won’t cause any crash of the system if you swap it now. The other bit said our fancy algorithm for determining who should be swapped next says this is someone that should be swapped as soon as possible. So they had those two bits. The program that swapped them looked at those two bits, right? Well, it didn’t. It looked at the same bit, ”is it legal to swap it” for both cases. What it did was, it swapped everything as soon as it could be swapped, whether it was wanted or not. So this programmer discovers this. They’re about to release the thing and he’s told, “Listen, IBM has a procedure for reporting bugs.” He says, “No, you don’t understand. This is an impossible bug. You have to fix this.” They said, “We have this procedure for good reason. People often introduce problems when they think they’re fixing a bug.” So in any case, it went into some process that took like a year and a half before they could fix that bug. Meanwhile, their timesharing thing got a reputation for being extremely slow. It was just programmed to thrash, as they say.

Hendrie: That’s a disaster.

Fredkin: I’ll tell one other while I’m on IBM. I should tell the story of... I’ll leap ahead and say I got to MIT and I was director of the Laboratory for Computer Science, which was then called Project Mac. John Cocke came around one day. He was visiting at MIT and he said, “A lot of things were learned in the Multics effort. You guys have had experience with interactive systems and so on. IBM has a really big project and I’m afraid they don’t really know what they’re doing in a lot of cases. It would be good if there were a lot of cooperation between MIT and IBM on this. If you could bring a bunch of professors who knew somehow to work with IBM to help them not do stupid things, that would be really a good thing.” At that point, there was a lot of bad blood between IBM and MIT, because MIT sort of totally mishandled the core memory patent. MIT got nothing for that patent when they should have gotten a billion dollars or something.

Hendrie: They got nothing?

Fredkin: Nothing. Because they thought they were smart. They created a company with a bunch of lawyers and gave the patents to that and said, “Here, do the best you can.” They looked at what IBM charged for core at $1.00 a bit and they wanted $0.08 a bit in royalty. The cost of manufacturing of core memory was like $0.02 a bit, or 3, or no… It was fairly low and they charged that price for various reasons, because they could. That’s one of the reasons that Digital could get started in the memory business. But in any case, they [MIT] kept wanting and saying prices, and they didn’t understand the kind of growth that would happen in the volume of bits. They didn’t understand anything like that. So the whole industry decided in a plain way that an infinite legal battle was cheaper than paying this insane pricing, and so everyone just started a big battle. And they came up with a pseudo-inventor at RCA, and claimed to invent core memory. He had had some ideas, but they basically knew they were just fighting a big battle.

Hendrie: That was Jan Rajchman.

Fredkin: Yeah.

Hendrie: And he actually did…

Fredkin: I know, but still, there's no two ways that the MIT invention was…

Hendrie: But he was late. He was late. In the end, his earliest documentation was dated like 2 ½ weeks later than Forester.

Fredkin: So there was all this bad blood, so the idea was to get over all of that. What I ended up doing was I worked out a deal where IBM gave me, in essence, $5 million to spend over four years for anything I wanted. MIT taxed this money. The provost took a cut, as it were. In exchange, we had a complete licensing agreement that they had a license to use any MIT technology in computer science at a prearranged royalty, which was sensible, and we were going to do all this consulting for them. Later on, as this thing got started, I pointed out to them hey, we forgot to think about the professors you want to consult, that it won't work unless you pay them something, and so they had to do that, too. So I brought down 23 people to Yorktown. We came down on Sunday and Monday morning. They started giving us overhead slide discussions, which lasted for an hour. We got eight of them on Monday, Tuesday, Wednesday, Thursday, and on Friday, only four, where they described something called FS, "Future Systems". This was to replace everything they made. About half of the faculty were really interested, that came down. They realized that there was a lot of real help they could give IBM, and they got involved in some ways. There was on exception to this, which was me. My conclusions were completely different than everyone else's. The MIT people just divided right in half. Half just wasn't their interest. The other half thought this was very exciting. They wanted to get involved. I came to the conclusion that this was a form of group insanity; that their goals were so far out of reach. By the way, if you wrote those goals down today, they're not achievable. I'll just give you an example of one goal. It's this. They had in mind that if a business enterprise installs one of their computers, that it should run and keep running while you did things like upgrade processors, upgrade disk drives, upgrade operating system. And all of that should be done without any down time. That was just one feature. It was a multiprocessor concept, but they didn't know… They were blowing smoke, in my opinion, in a lot of areas. Big as they were. And they had every piece of IBM research focused on this, major work going on in Switzerland and everywhere they had resources. This was it, Future Systems, everything, giant, secret. As I realized this, I started cornering people at IBM and trying to explain to them, "Hey, this isn't achievable and if this is all you're doing"-- which is what their plan was-- "you're going to be left in the lurch with no product." After a little while, this got to the attention of people. They were very disturbed by this, because this isn't exactly helping their morale or their program or something like that. What got decided was that the leader of this project, whose name was Bob Evans, and I would have a debate, which was to be held down in IBM's headquarters in the board room. And the sort of moderator was going to be Manny Piore, who was the guy who created IBM Research, and we would debate this issue. Bob Evans' point of view is: this thing has to continue. He described it as a locomotive heading downhill at 90 miles an hour and being fueled with $100 bills or something. They were going to spend a billion dollars or something back then. God knows what. So I argued why they had to kill it. So finally, we finished. I'll never forget. Piore says, "Look, Ed." He says, "This is our company. If we want to do this project, we can do it. It's our company. Even if you think we shouldn't do it, we still can do it." I said, "Yes, I know that's true." He said, "Okay, but now that we're going to do it," he said, "can you please stop talking up killing it, because it's just

causing us mischief". I said, "Sure, fine, okay." So that's that. So we're walking out of the room and John Cocke comes over to me as we're walking out and he says, "Don't worry, Ed, it'll fall over of its own weight." In any case, two weeks later, it was cancelled. It had to do with that meeting, of course.

Hendrie: Of course, yeah.

Fredkin: But they're not going to tell me that. In any case, that was cancelled. A few of the ideas got into one product, just a few of them. But let me give you an example of sort of the madness of it. They had seen a CRT display on a computer. No one there had any experience with it. Now, Licklider had spent time at IBM for a while. When he left DARPA he went to work for IBM, and he wanted to buy a PDP-1. And they refused, and he tried to insist, and they said, "We'll build you something just as good as a PDP-1, but we can't, at IBM, buy a competitor's computer." They just couldn't do it. They never did build it for him, anyway. But see, if they'd done that, they would have had some experience with the display. But they had none. So they're architecting this computer, which is to have everyone working at display screens. No one had ever used one. Now they had invented all kinds of nomenclature in this process. One of them was "architected feature", which was a feature of the computer which was beyond the control of a programmer, but might have been implemented as software. They imagined lots of microcode, millions of lines of microcode. Here was an architected feature. On the screen, whatever you typed, showed up on the left half of the screen, and whatever the computer put up was in the right half of the screen. That way, you would always know whether you typed it or the computer typed it. As I say, this was "architected". In other words, there's no programmer that could do anything about it. This was this half of the screen, this was the other half of the screen. You see, the fact is, designing without any experience.

Hendrie: Ideas that if nobody knows anything, may sound good. But if anybody has ever tried and used something… It's intellectually interesting.

Fredkin: Now what's interesting is… So I killed the largest computer development project in the world. Strangely enough, I did the same thing again. This one involved more people. I killed a 140,000 person enterprise. It's a talent of some sort of mine. It was called Ryad. Ryad was a copy of the System/360 made in the Soviet Union and other socialist countries. They had 140,000 people working on Ryad. I had a lot of involvement. This is such a big story. I can't tell you this whole story right now, but for a later session or something. But basically, I discovered facts about it that were secret, real, real secret in Russia. Who are they secret from? Not just the outside world, but they were secret from all very high level people in Russia who didn't know these facts. The main fact was they couldn't manufacture the machines in anything but toy quantities and a few systems being made in Czechoslovakia and in East Germany. But basically, the main effort in all the big machines, they could not manufacture them and they weren't going to be able to manufacture them. What was wrong is very interesting. They built that machine and they designed it to go together exactly the way machines are built today. My son started a business when he was like 14, building servers. He'd order a motherboard, power supplies, disk drives, a cabinet and so on, and just plug them together and it worked. In those days, if you went into Digital Equipment or into IBM… Take IBM, and you have a system 360 there. It's in systems checkout for six weeks, eight weeks, where they plug the pieces together and try to make it work, because there was no way to tell if the pieces worked until you plugged it together and ran software. That was just the nature of things. So you had to put this computer together and then make it work. System integration.

Hendrie: Right, and then find out what was wrong with each subsystem.

Fredkin: Yes, right. And it took a long time. The Russians said okay, we'll make the core memory at this plant in East Germany, and we'll make the disk drive in Hungary, and we'll just ship all those parts to the customer and put it together and let them have his computer. Which is the way it could be done today.

Hendrie: But they had no technology or understanding of what had to be done. And the testing, the automatic testing and all of that.

Fredkin: That's right. They didn't have the practical experience, really, to understand that. They just imagined that they could it do it their way and they couldn't. If that were the only problem that wouldn't have been… But there were so many other problems, and it was hopeless. The case that I made was that their only hope to stay out of the dark ages was, for the time being, they had to go and buy computers.

Hendrie: Okay, that's what they needed to do.

Fredkin: I managed to convince the Soviet Union of a whole bunch of things I could never do in the United States. So I managed to make that happen. I was in Russia just recently and I was in the Ryad software building. This is [now] a building full of lots of companies. It's the most amazing building on the outskirts of Moscow. It's about a kilometer long. I think it's like eight stories high, quite wide and it runs along a highway for this insane distance. It's a gigantic thing. It was just part of Ryad. It was full of people working on Ryad stuff. It's [now] just full of small companies, all software companies.

Hendrie: Rolling back to BBN a little bit.

Fredkin: And the PDP-1, yes. Digital had in mind that they would sell machines with just 1,024 words of memory, 18-bit memory. So when I proposed to write an assembler for it, they said, well we want it to run in the 1,000 words of memory. That's 2K bytes. And oh, by the way, they wanted what's called a linking loader type of assembly, which is so that you could punch out tapes and then load them in wherever, and features like that. So this had to be the minimalist assembly. I wrote an insanely clever assembler. There's a funny story about why it got tossed by MIT; I was talking to Kotok about that. As I started to write it, I perceived a strange general principle which is this: when you make a rule, you need code to enforce the rule. So say, in those days, every assembler in the world started out, there's a card. They had these cards preprinted, and they had coding sheets preprinted. And here were the characters where you wrote down the label, if there was one. And then here you wrote the opcode, and here you wrote the address, or the index register, whatever it is. So on the punched card format thing it had for SAP, which was the IBM assembler, and for FORTRAN, six characters per symbol. All programming on the LGP-30, or whatever machine, had these fields, as they called them; the fields from IBM cards and so on. The paper tape things just copied it. So I'm starting to write this assembler and I suddenly realized that I'm going to have to do some really amazing tricks to get this to work, because I have to have a symbol table. There's no auxiliary storage. My code has to be like half of the thousand words. So I realized that, hey, if

I would get rid of a rule, like the 6-characters per symbol, I could save some code. That sounds insane, because normally, you think six characters per symbol, I know how big each symbol is. But a variable length symbol? So I kind of invented the idea of variable length symbols. What I did was, when it was reading the tape in and it read the symbol in, there was only one place it would write the symbol, and that was at the end of the symbol table. And no symbol was ever moved. It was a very strange concept. Of course, [also] in the symbol table were the symbols for the instruction opcodes. So now, all it could do was read characters in at the end of the symbol table. Now the search routine was a linear search, because the machine was very fast and had small memory. So it started at the beginning and it had to find it in the symbol table. You know why? Well, it either was there already, or since it was just read from the paper tape into the end of the symbol table, that's where it was. So just coming down, it always found it. It either found it in the middle, in which case there was a meaning, or they found it at the end, in which case, there was no meaning, because it was just read in. So the only thing that had to be decided was, do I move the pointer for the end down, meaning I'm adding a symbol that wasn't there? But if I found it in the symbol table, I didn't move the pointer.

Hendrie: You left it there and it got written. The next symbol got written, bingo.

Fredkin: Yeah, exactly. So tricks like that. I made this thing with a linking loader and everything. And let me just give you an example. I had so many wonderful ideas that are all lost. Here's one I really liked. When you're assembling, normally you have multiple passes. Why? Because it says jump to this tag, but you haven't seen that tag, so you don't know what to say. I didn't want multiple passes. I wanted one pass, but I couldn't save things up. So let me tell you what I did. If it came down and the thing wasn't in the symbol table, I'd put it in. But it doesn't know the value of it. On the paper tape as it was reading in, it was punching out a paper tape for the loader. So if you said jump to A, it said "jump to" and then it had a little code that meant I don't know what the value of this symbol is, but it's at this location in the symbol table, since nothing ever got moved in the symbol table. Okay fine, so that's all it said.

END OF TAPE 4 / BEGINNING OF TAPE 5

Fredkin: Okay. So what would happen - I'll just recap a bit - is that if it encountered a symbol that had a definition, it would use the definition. And if it didn't, it would just have a pointer to its place on the symbol table. Okay. Now, one of the things when I first saw the PDP-1, it had a paper tape reader, but it had a roll. I decided to use fanfold. So now, as this assembler is running, it's punching out a paper tape. It's got compiled code, except every so often it says, "Symbol such and such in the symbol table," because I didn't know what it was, with a little code to indicate that. So it gets to the end of the program. Now you've got your paper tape. Now you want to read it in. What you do is you turn the fanfold over and read it in backwards. Okay. Now, it turns out, by the time you got to the end of the tape, everything was defined, of course.

Hendrie: Yes, of course.

Fredkin: As we go backwards, each time we come to an undefined thing, it's now defined. So all you had to do was to punch it out. You put in your symbolic tape and as it went in, it punched out a linking loader tape. You put the linking loader tape in, it just loaded in and you were all set.

Hendrie: Wow. That is pretty clever.

Fredkin: Yes, that worked. And all this was to squeeze it into 1,000 [words]. Now the mistake was, that in that case it ran very fast. But when they tried to use this in 4,000 words and they got bigger code, it ran a little bit slower. Well, what that meant was as it was trying to read the paper tapes, since there was no buffering of that thing, the paper tape chattered like mad because it would start and stop all the time instead of going smoothly, since I didn't read it into a buffer. That chattering bothered the poor people at MIT. So they said, "Let's copy the TX-0 assembler." So that's the way the world went.

Hendrie: That's what happened there. I never heard…

Fredkin: Yes, well, Kotok explained that to me because I never knew exactly what bothered them. I just know that they didn't like it and it was that they were sure it was going to break the tape reader. But on the little machine

Hendrie: Yes, with a very small memory…

Fredkin: With a smaller… Yes, right. Anyway, that's--

Hendrie: That's fascinating because I interviewed Kotok and heard that side of the story, but I didn't know that you had written the assembler.

Fredkin: Yes, I wrote it. See, I called it "FRAP," which meant "Free of Rules Assembler Program".

Hendrie: All right. That's cool.

Fredkin: It was fun to write. There used to be contests people would have, like "Who can write some code in less space, or who can do this, that or the other?" I basically was very competitive and any time I heard of such thing, I would do something better one way or another, or try to.

Hendrie: Shall we--?

Fredkin: Yes, I think that's about it for now and that's much more detailed than I've done before.

Hendrie: Well, I think that's very good. We thank you. It's wonderful stories. The detail is what makes something. It gives all the color to most stories. Thank you very much, Ed.

Fredkin: Okay. You're welcome. I think the thing that Gordon was most interested in had to do with most of my Russian adventures and stuff like that, which are--

Hendrie: Well, we'll get to that, won't we?

Fredkin: They're funny.

Hendrie: Exactly.

Fredkin: Especially in today's context.

Hendrie: All right.

END OF INTERVIEW

