An Interview with

GENE GOLUB

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University of Minnesota, Minneapolis

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Abstract

Golub discusses the construction of the ILLIAC computer, the work of Ralph Meager and David Wheeler on the ILLIAC design, British computer science, programming, and the early users of the ILLIAC st the University of Illinois.

GENE GOLUB INTERVIEW

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McCORDUCK: Gene, we're going to talk today about Illinois; how much you remember about those days, the beginning of the computer science department.

GOLUB: I should say that it wasn't a department but it was a center rather than a department. I think the department, of course, came in the '60s and I left Illinois by 1959 so my early remembrances there are all of the organization of the laboratory and most of the people who were at the laboratory then were in the department when it was formed, with some notable exceptions. We can talk about that. Well, at that time the man who was in charge was Ralph Meager, and he was an engineer who was responsible for the building of the ILLIAC. The University of Illinois actually completed the first computer based on von Neumann's plans.

McCORDUCK: They completed it?

GOLUB: Yes. There was a computer being build in Princeton at the Institute for Advanced Study, but Illinois actually progressed further and faster than the organization at Princeton.

McCORDUCK: Why?

GOLUB: I don't know. Maybe they had more organization or they hired a more professional team. I'm not sure so I better not mess around with conjecture, wild conjecture.

McCORDUCK: Well, that's interesting because von Neumann himself was supervising the building of the IAS machine.

GOLUB: Well, what had happened is some engineers up at Illinois had wanted to see a computational facility at

Illinois and they thought of course going to a large business organization that they weren't very successful, so then they decided to build their own computer and they received financing from the government for doing that. In fact, the idea was to build two computers simultaneously one of which was the ORDVAC and that was actually completed earlier than the ILLIAC. And that computer went to Aberdeen computing grounds. That's where some of the earliest computing was done in this country and indeed there was a whole series of reports that came from Aberdeen that played, for me, a very important role in my education because that was sort of the, they were like texts in numerical analysis. And people such as David Young and Myron Janchosa and Perlis I believe were all at Aberdeen Proving Grounds. Saul Gorman certainly was there and he did some work in numerical computing at that time, too. So it was, the secondary effect for me, incidentally, there was the computer at Aberdeen Proving Grounds built by the University of Illinois and then that stimulated people to work in numerical analysis and those people then published reports which furnished a good part of my education at the University of Illinois.

But then while, after the ORDVAC had been completed and while the ILLIAC was being completed, a man by the name of David Wheeler came to the University of Illinois. And he had had experience at the Mathematical Laboratory in England at Cambridge, probably the first book on programming was the book by Wilks, Wheeler, and Gill. And Wheeler was a very imaginative kind of person and he had quite a bit of experience by that time. They didn't, you know, they used not a Williams tube memory at Cambridge but rather a delay line memory. So Wheeler made a number of suggestions which were then incorporated into the ILLIAC and the ILLIAC was actually a better machine from the architectural point of view than the ORDVAC. Actually, Wheeler had even made other proposals about index registers which were not incorporated unfortunately and it would have really been a very, very modern computer. Nevertheless, it was an excellent computer, the ILLIAC. I guess in May, February or March of 1953 it began to operate. And it was a very successful machine. It had 1,024 words of memory, each word was 40 bits. There was a library that was written by Wheeler to a large extent who had really a wonderful imagination, well, by the way, he's still in England, he's at the computer science department now in Cambridge and I think he's a fellow of the Royal Society, Wilks certainly is, maybe he's a professor now. He's not a man who's published a lot but he's had enormous on the computing field. So the ILLIAC was built in '53 and that was actually my final year as an undergraduate at the University of Illinois. And I was fortunate enough to have taken a programming course under a

man called J. P. Nash. And so at the end of that semester, I was graduating, I wasn't really sure what I wanted to do, but he asked me would I like to be a research assistant. And I liked that computing stuff, it was fun, so I stayed on and began my career in computing really from June 1953 on. I guess I had taken that elementary programming course. I tried to find jobs and I thought, gee, everybody would want somebody who knew something about computing and programming, but actually it was too early because at that time there weren't so many computers around and so it wasn't, you couldn't just waltz into a place and get a job saying that you knew how to program. Actually, after one course you really don't know how to program very well, but nevertheless, I thought I had some experience. So there was a very lively group at Illinois. There was Meager, who was head of the laboratory, a very solid, conservative engineer and he's credited, I guess, with having built the ILLIAC and ORDVAC in such a strong stable manner. Then Abe Taub was there at Illinois and I think he came to Illinois after they decided they wanted to build an electronic computer and he came from Seattle, Washington. He had been associated with von Neumann for many years and I think that's through that connection he came to Illinois. And I gather von Neumann had some connection, too, with Illinois, although I never personally met him. Again, I was, I think I told you I was too young to really understand what was happening at Stanford with respect to computer science. I was just a graduate student at Illinois so I don't know all the politics. Have you interviewed Taub at all?

McCORDUCK: No, he's on my list.

GOLUB: Well, he was there. Nash was the person who did so much for me personally. I mean he taught a course and he encouraged me. He encouraged me to be interested in statistical comp uting and to this day I still have some interest in that. And then there were a number of excellent young people that were there who were in their 20s, I was, of course, 21 and they were 27, old people. And that included such people as Jim Robertson. He's known for his work on computer arithmetic. And it was David Muller. He was a research associate there, had just gotten his degree at CalTech in physics and then came to Illinois. And he was a very clever guy. He did a lot of work in various aspects of computer science, but eventually when the computer science department was formed at Illinois, he moved out of that. He wasn't happy with the administration of that department so he's currently in the math department. But as a sideline, he became interested in finding zeros of polynomials and he devised the method that's known as

Muller's method today and although he has very little interest in numerical analysis, he continued to be known because of the work he did just, you know, it's not an uncommon thing that someone who's very clever does something like one paper it affects a lot of people but then they lose their interest in that area. So there was a wonderful spirit in that group. There were the older people, Nash and Meager, and there was the younger people who were very lively and open-minded. It was a very exciting time. And a number of people subsequently went on to do things in computer science.

McCORDUCK: For example?

GOLUB: Well, Raymond Miller was there, he was a graduate student there, and now he's at IBM. Then there's a man by the name of Abazineus who's down at UCLA. So there were a number of people who were there as students. I think I've missed, you know, I think they've had a long period, but probably their greatest influence was in numerical analysis when as a result of Taub. That is, Bill Geer was a graduate student at the same time that I was a student. Well, he came a few years after I was a student, and he's still at Illinois, as a matter of fact. He went away for several years but then he came back. But Bill Geer and Bob Gregory, who's head of the computer science department at the University of Tennessee, also was part of the computation center. But in the early days what made it particularly interesting is we had those series of Englishmen. First there was Wheeler there who spent probably a couple of years in Urbana, had an enormous impact on the architecture of the ILLIAC and on the library. I mean at that time, you know, you could know everything. And, in fact, I personally learned a lot about programming by learning the codes of Wheeler. You know, that was one way you learned something about programming is reading other people's codes and I knew almost every detail about every program, numerical program. That's the amusing thing. And it wasn't in higher level languages, either. At that time, everything was coded in machine language so you really could understand things quite well because there was such a limited library. And I knew things about the architecture of the machine and, in general, people were much more universal because computing was such a small area compared to what it is today. So Wheeler was there for a long period. And then Stanley Gill. I mentioned Wilks, Wheeler, and Gill and he was there for about a year and he was a very influential fellow, too. He had written or devised a method for solving differential equations known as the Runge-Kutta-Gill method and it really was a very powerful method for

solving differential equations. It was sort of the beginning of people relooking at numerical schemes with the idea of seeing how you would really implement them in an efficient manner on a computer so that some of the old ideas, such as simplicity of coefficients, you know, if you're doing things by hand calculator, you sort of enter things into the register as you do today. So, for instance, it's much easier to enter a coefficient of a half or two-thirds or something, well, that's not so easy, to multiply by two and then divide by three than to have some number that really has an infinite expansion and trunking that is essentially digits at random. But once you had a computer program, it didn't matter whether those numbers were half or pi divided by seven it made no difference to the computer what it was multiplying, you know, what the actual constant was. So Gill had devised this very clever way of solving differential equations, which was an extension of the famous method known as the Runge-Kutta-Gill method. It was really most applicable to fixed-point arithmetic, it was before really there was a lot of floating point arithmetic in use. So he spent the year at Illinois and he had come from Cambridge in England and then following him there was another person by the name of Sandy Douglas, A. S. Douglas. So Douglas was there for a year. But he was the, he didn't have the influence that Wheeler and Gill had, especially Wheeler I would say.

McCORDUCK: This raises a question in my mind about the great intelligence of these English scientists and yet the kind of dreadful things that happened with the English computer methods. What do you think accounts for that discrepancy?

GOLUB: I don't know. I guess eventually it became a big business, computing, and money, you know, there was a necessity to have a technological base which would build and maintain computers. And I guess the British, that's one of the places they have fallen down. In the early days, you know, they had a glorious history in computing and then it just fell away.

McCORDUCK: But even the building of the ACE, that took forever and by the time it was dedicated, it was obsolete.

GOLUB: Oh, yea. Well, have you spoken to Jim Wilkenson about these matters?

McCORDUCK: No, I haven't.

GOLUB: Because he talks, he gave some wonderful lectures at Stanford, he gave the first Forsythe lectures and he talks about that and those lectures eventually will be written up. Harry Huskey taped those lectures so you may want to get those, as a matter of fact. But he talks about the pilot ACE and then he talks about the ACE. And the pilot ACE he thought was really a wonderful scientific effort, and then the ACE he felt, by that time, it had, the thing had moved from them. Pilot ACE of course involved Turing and maybe the ACE did too, I don't know the history that well, but it was some fabulous effort. So the British were moving... At several different places, you know, I mentioned the Williams tube that came out Manchester in England and there were people at Cambridge who were doing things and just throughout the country there seemed to be a lot of effort. I guess Cambridge is still important in computer science circles and maybe Manchester, too, but I don't know if they play the same strong [role] that they played before. So England was the great ascender. And another place that played some early role in computing was Sweden, I think they had a computer quite early on. But, well, they never had any desire, I guess, well, they never had any hopes, I suppose, of building an industry where the English really did have a number of different computer organizations and even today I guess they still manufacture some computers.

McCORDUCK: Why do you think these people were drawn to Illinois especially? Or were they in fact coming to the United States all over the place?

GOLUB: Well, those particular English people came because there was a close connection between Illinois and Cambridge. There would have seemed to have been a coming and going. But there were other people that came from other countries. There was a man by the name of Hobblebaum, who's still there, and he was a physicist and he was interested in solid state physics and he came to Illinois and he had a great effect, too, although he was not there at the very beginning. The people that, I think I mentioned several of the people were there early at the beginning, well, there were those senior people, Taub, Nash, and Meager, and then there were these younger people, Robertson and Muller and a lot of other people, too. As a matter of fact, I can't remember all the details.

McCORDUCK: No, I'm really interested in capturing the atmosphere more than just the details and what kinds of things interested you then what kind of issues were you facing?

GOLUB: I personally was mainly interested in numerical computation as then is now. And in fact, it's amazing how one continues, at least I'm certainly narrow in my interest that I've continued to work more or less on the same kinds of problems. So for instance there were some, Eigenberry [?] problems that I was looking at then and people are still interested in numerical techniques for solving those same problems. That is we know a lot more than we do then but some of those problems are still not easy to solve. There's no perfect way of solving those problems. It's very interesting to observe what's happened I guess over these last twenty-five years or so that is, there's been some broad advanced in some directions, but then there are still some problems that are very sticky and as far as I can see, no one has really... They know that the problem, they know more than ever that the problem exists, and they've made headway on some problems, great headway and they understand those problems quite well, but problems that are closely related they just can't get a real handle on.

McCORDUCK: It fascinates me particularly non-specialists cannot guess which problems are hard and which problems are easy.

GOLUB: I think that's true in general. I know a text book in mathematics that is known in particular for it's problems and the author doesn't say which problems are worth ten points or which problems are worth fifty points and when asked, you know, you just mixed all these problems up he said, well, when you're doing research, you don't know what's going to be easy and what's going to be hard. That is a fact. You know, some things that you could state quite simply are very, often very difficult to solve. And the person who wrote that book felt that you shouldn't make people aware of that fact, that you can't easily determine what's going to be easy to solve, that's what research is about. Well, that's one way of looking at that particular problem.

McCORDUCK: For those of us that are used to having the easy problem be number 1, 2, and 3 and the medium being 4, 5, and 6, that's dirty pool.

GOLUB: There's a famous book that has the number of points that each problem is worth. You could try all kinds of things. There were a lot of people who came to Illinois because they were interested in developing the knowledge so that they could take it home to their own country. For instance, several Australians were at Illinois in the thought of building a computer just like the ILLIAC In Australia. And that actually happened. It was a computer called the SYLIAC that was built in Sydney, and that computer is essentially, or was essentially, a duplicate of the ILLIAC with probably some minor improvements. I think the person who was responsible for that was John Black. Black had been a physicist at the University of Illinois and left the United States in the '50s, I don't know if he was called, that was the time of the McCarthy era and that was one of the things that motivated him to leave. But I recall sitting around the table and he would say I'm going to Australia, he had a thick Viennese accent, and badger them, I don't know if he used the word badger exactly, until they build a computer just like the ILLIAC. And just about 6 months later some Australian showed up and started to look at the ILLIAC and getting the plans and so forth. And another few years and they had their own copy of the ILLIAC with the library and everything. He had really a desire to see something like that built. And it was one of the early modern computers in Australia. There may have been other computers.

McCORDUCK: Then this is before the time that buying or renting or leasing a commercial computer was simply not feasible?

GOLUB: That's right. I'm told that the motivation again for building the ORDVAC and the ILLIAC was because the engineers wanted some high speed computing device. And in particular a very famous civil engineer by the name of Newmark was the one who pressed for the building of this computer.

McCORDUCK: Arthur Samuels says that when he went to Illinois he was very interested in having a computer there. He did a lot of stomping around trying to get money to build or buy or somehow get one. I guess he first wanted to buy one and then realized that that was impossible.

GOLUB: I don't remember him because I guess he left.

McCORDUCK: Yes, I don't think he was in the lab.

GOLUB: So I have no recollection of him at all. Well, it was a wonderful spirit in those days and, you know, there was an intimacy that you don't have today around those computer labs. So you had, for instance, people came to use the computer at a certain fixed time. There was a code checking time and there was a running time.

McCORDUCK: Really?

GOLUB: And it may have been, I can't get the exact times, perhaps, but something like between four and five-thirty in the afternoon you could come to do a code check and you would take your paper tape up to the machine and put in a photoelectric reader and you would see the machine running, you know. The ILLIAC was not overly large and the lights would flash and you might get some paper tape immediately out and you'd run to the printer and see what information that it had on it. But you'd sit around in sort of a U shape around in chairs and everybody would sit around and discuss their problems with one another. And you might be sitting next to some very imminent scientist, you know.

McCORDUCK: And you being a graduate student at that time?

GOLUB: That's right. And you might talk about your common problem and that's all gone now. In fact, you know, with terminals everybody could be at home, obviously and there's no communication in the way that there was before. So that hour and a half was very nice and you would, you would sign your name up on the black board and then you'd be called in turn. There was a very forceful woman there who knew nothing about computing, but she was, you know, a tough minded kind of person who kept all of us scientists in line. And Ramona Russell was her name. She was famous, you know, throughout the university as this power. If she didn't like you, she was really unhelpful and if she liked you she was very helpful so you had to cultivate her in some way. She still is in the

computing center at the University of Illinois. She's no longer doing the kind of job that she was doing then, but there she was. And so there was a nice atmosphere where people talked to one another and I met a lot of people who, you know, are at other places, not necessarily in computing, you know, they might be in a physics department or some other department. So that was very nice. Well, as a graduate student, I was really interested in numerical computing and even though I took courses in statistics and I spend most of my happy hour just being a research assistant in the computing center.

McCORDUCK: You were formally a student of the mathematics department?

GOLUB: That's right. And about half the students were in the math department, the other half were electrical engineering. So Illinois has always had a very strong hardware orientation and they always had young people who were coming through electrical engineering. And those people were getting Ph.D.s in hardware and some of the people are, again, still at Illinois. That was probably one of the problems that they had in the early days because they were training people and they would often keep their own people and I've always felt that there was too much inbreeding at the University of Illinois. And I guess that tradition doesn't quite exist any longer, but maybe for the first ten years a lot of that went on.

McCORDUCK: Of course, that's very difficult in a new field. How many people are there to go around. You kind of have to take what you can get and if you grow your own then...

GOLUB: And there was great pride in the people for whom they had produced so that they kept those people on. J.P. Nash was a very fine person and he was at Illinois for, let's see, until about I would say 1957. And then he went to work at Lockheed and he sort of rose in their administrative ladder until he became vice president in charge of research. And then he actually had even a higher position than that. Seven years ago, he went to Cape Kennedy to watch a shot and then during that week, you know, he got some food caught in his throat and he died. It was rather sad. You know, you've heard of this classical problem with choking. And for me it was a great loss because it was just a few weeks after the death of George Forsythe. And so it was unfortunate. He was very sympathetic to

students and supportive so a number of them, us, remember him very fondly. I don't think he actually was a thesis advisor of many students, but he actually was, you know, someone whom students could talk to fairly easily. He, I guess at that time, he organized the schedules and such things. It's amazing how those things became professionalized and how that, at that time, a professor wrote down who got what amount of time on the computer, you know, you can't imagine Bill Traub doing that sort of thing whether someone gets seven minutes or twenty-two minutes. A man by the name of Snyder was deeply involved in computing. So Jim Snyder was a physicist who used the ILLIAC quite extensively. Jim Snyder was a physicist who used the ILLIAC extensively for a number of computations. There was talk of building an accelerator at the University of Wisconsin and Snyder was involved in that. And later he went to Wisconsin for a while and then he returned to Illinois, now he's the head of the computer science department at the University of Illinois. And Lloyd Fosdick was also there, he had been maybe a post-doc at the University of Illinois originally in physics and then he was involved with Snyder and then went to the University of Wisconsin for a while, came back to Illinois, but now he is head of the computer science department at the University of Colorado. So you can see a lot of people passed through that center at the very beginning.

McCORDUCK: Stanford's department grew out of a very mathematically oriented, in fact, it grew out of the mathematics department. In good academic fashion, would you like to compare and contrast the two kinds of sources, one department growing out of a mathematically oriented environment and the other having a real strong hardware component?

GOLUB: They're quite different and I don't know if it's easy to compare it. Stanford grew out of the mathematics department because George Forsythe was in the mathematics department so it was natural for him to become a subset of the mathematics department, the computer science...

McCORDUCK: [Principally, for the mathematicians' use?]

GOLUB: Yes, exclusively for that purpose.

McCORDUCK: So, already somebody had decided that should be a mathematically oriented field.

GOLUB: Although George was a pragmatic in his outlook, he was always interested in solving problems. I think that was one of his great strengths was being a problem solver. But Illinois, the computing center was not part of the math department or engineering department, by the way, although it was, the original leadership came in part out of engineering. But rather, it actually was set up under the graduate college. So it was, today, I believe, it's part of humanities and sciences. You know, in a way, well, I would say, since the math department has had a greater turn towards the more theoretical aspects of computer science. It is rather peculiar in that fashion. But there is this notable difference that at Illinois there was this heavy emphasis on hardware and I guess that's because of its early origins. You probably know it's actually for ILLIAC but they come out, in one form or another. The original ILLIAC and then there was an ILLIAC II and then there was an ILLIAC III, but it wasn't called ILLIAC III but it was another, it was a special purpose device, and then the ILLIAC IV, which is essentially situated at Sunny Vale. So there have been four computers designed at the University of Illinois. The ILLIAC IV, I don't know, some of its components came from elsewhere, I guess, I gather. Stanford has never been in the hardware business. Now at University of California they also tried to build a computer and it wasn't so easy, they didn't succeed.

McCORDUCK: I didn't know that. I didn't know they tried to build their own.

GOLUB: Yes, there was a drum machine that they wanted to build and there was man I believe by the name of Morton who was associated with it. That perhaps explains some of the, you know, they've had great problems at Berkeley over the years and I think it started out in a bad direction and I don't recall all the details, but it had to do in part with the fact that they wanted to build a computer there and it was never very successful and they never seemed to bring, the people they brought in weren't the right personnel and it has never had a great history.

McCORDUCK: [One of the people they brought in was Traub?]

GOLUB: That's right. He was brought in to organize the computation center and then they formed a department.

And I guess when the department was formed that he was not asked to be head of that department and he seems to have resigned from the computer science community in some way. The man whom everybody respected tremendously at Illinois was Meaker. He was just one of these very solid scientists, or engineers, I should say. But he seems to have gotten bored by the job. He was sort of an early drop out because he, after some time in 1957 or '58 he just dropped out of computing. He resigned, he was a full professor at the University of Illinois, and he had a summer house, I believe in Michigan, and he went to Michigan and he said, well, I'll be a consultant now, that's what I like to do. So, he left. A rather remarkable situation. Well, another person who was there at a fairly early stage was Don Gillies. I don't know if you know that name at all. There's the Gillies lecture now at the University of Illinois and Gillies had gotten his master's degree at Illinois and then gotten a Ph.D. in Princeton in mathematics and then spent some time in England and then after that he came back to Illinois. And he was a very clever man, very clever at programming. As you can imagine, you don't hear this so much any longer, there were people who were renowned for their programming ability and, you know, just like chess players. And there were people who's programs were just unusually clever, they had clean thoughts and they knew how to work things out, in a way. They made things quite simple and obvious today but at that time, all those ideas had to be devised. And so Don Gillies was noted for that, for his programming. There were people in England who were especially good at programming. Who's the man who was at Oxford and died just...

McCORDUCK: This week?

GOLUB: He was considered, you know, sort of a great programmer, too. But there was some challenge to it. Even today, of course, computing and programming, they're given fancier names than what you might do in your programming effort, but basically boils down to cleverness. And there was some very clever people around at that time. Well, a lot of people, as soon as they saw what the game was like, they got very intrigued by the whole computing business. But that's, this cooperation between engineers and scientists in general was very strong at Illinois. And that was very nice. That was a very fruitful cooperation.

McCORDUCK: Yes. Is there any other institution you can think of where that exists?

GOLUB: What about Carnegie-Mellon?

McCORDUCK: Quite a different flavor. There was a strong cooperation between computer science and say, psychology or perhaps the school of medicine, but not electrical engineering.

GOLUB: For instance, one thing that they missed out on at Illinois was work on programming languages. That the engineers didn't see the usefulness, I guess. And there were simple developments in assemblers, but there was no great effort in languages. So that was unfortunate. And I think that may have been attributable to the engineers. And I think Taub understood the importance of the computer very early and had a feeling for how important computers could be in solving, in doing large scale scientific computing. He had very good connections with, he had a good connection with sort of the scientific community. I'm trying to think of what areas were particularly heavily stressed. So the chemists were heavily involved in computing. There was a man by the name of Wall who later went on to the University of California, Santa Barbara. He spent a lot of time computing in the student years, did a lot of computing. I don't know if you're aware of it, a number of people who were, Illinois was a great center of solid state physics and Bardeen was at Illinois. He had been at Bell Labs, but he was one of those coinventors of the transistor. And he was at Illinois. And his group had lots of computing problems. And I feel pleased now to report that I programmed for someone who got a Nobel prize, actually Bardeen has gotten two Nobel prizes. So there were really a lot of high quality people who were quickly involved in computing. It's funny, sometimes I only realized after many years what was going on. For instance, there was a method known as Norsick's method, and Norsick was a physicist at the University of Illinois and everybody spoke very highly of him. He's been dead now many years, he died in the '60s of cancer, but only recently have I realized that his work had such an important influence in the numerical solution of differential equations. Maybe that's often the case, you know, something goes on nearby and you hear that it's important, but you don't really become aware of what's going on.

McCORDUCK: Sometimes it's very hard to tell; things seem very important because you're there and it's the middle of the landscape and how can you miss it, but over time [events recede into the memory].

GOLUB: Another group of people who used the computer at Illinois were the agricultural statisticians. They understood, you know, the importance of doing some statistical analysis and very early on there were some people who had large systems just for solving statistical problems. And they were heavily involved. I guess... It's hard now, it would be interesting now to look at those records, you know, see who used the computer in the early days, but it's probably not very easy to find out. One thing that might be interesting, for instance, to see look at the IFIP meeting that took place in Paris in 1959 and see how many papers were presented by people from different institutions. I think there were two or three papers by people from the University of Illinois. Gillies, for instance, did submit a paper and some others, too.

McCORDUCK: You left there when?

GOLUB: It's twenty years now. In fact, I guess, well, I actually left there in April of 1959. I went to England for a short time.

McCORDUCK: Was there in fact a department then or was it still a center?

GOLUB: It was just a center. Well, the business about the department was that it, the department formed after the department at Stanford in the late '60s. But for many years they functioned as the department essentially. People had appointments either in mathematics or in electrical engineering but they spent their time, basically, in the laboratory, computing laboratory. There weren't so many courses offered then, of course, maybe an elementary programming course and a logic course, some numerical analysis courses. Some of those courses were probably mathematics, well, by people in the math department like the very elementary numerical analysis course. Taub was already teaching an advanced course in numerical analysis and he was beginning to have some graduate students. So there was a development, you know, towards computer science.

McCORDUCK: It was just about that time that Howard Issakson's book was published on experimental music. Were

you aware of what they were doing?

GOLUB: Remember I mentioned these chemists. Well, Isaakson was a chemist.

McCORDUCK: Oh, really?

GOLUB: And I believe he lives there in this area, at least until a few years ago he did. And I'm fairly sure that Hilliar was also a chemist with some very strong background in music. And they were very involved, of course. And I don't know if you saw the famous picture in ~~Life~~ Magazine of the ILLIAC quartet. They had to produce some music on the computer and then that music was transcribed and four mu sicians were sitting in front of the ILLIAC playing a piece. I knew that and of course, if you were very interested in that, amused by it. Now, of course, electronic music is a very important area. But it's done, I don't know where the centers of that are. I know it's done at Stanford to some extent. Do you know where else?

McCORDUCK: Bell Labs?

GOLUB: Bell Labs. But I believe Hilliar, I mean Isaakson, works for Standard Oil or one of the large companies like that. At least when I first arrived in northern California he was up here.

McCORDUCK: Well, that shouldn't be too hard to find.

GOLUB: But there was a lot of innovation. You know, people were just beginning to figure out what to do. I guess the physical sciences were the ones that were most heavily emphasized, with I mentioned, the agricultural statisticians.

McCORDUCK: Do you remember any particular field being very resistant to computing?

GOLUB: Well, I suppose mathematics. Although if you recall, the fall color problem was recently solved at Illinois by two mathematicians who used extensive computer facility. But there was none of the hostility that you would find at Stanford towards computing. I think people just realized that the computer was there but they didn't, there was no anger in their attitude towards computing. And the physicists were really very supportive and the engineers. I mentioned Newmark who was a civil engineer. A lot of people were interested in computing. Of course there were, you know, I suppose in a day's time you only ran maybe a hundred different, no not a hundred even, just a few jobs, maybe twenty jobs really. If you had sufficient time on a computer to get 60,000 places of *e*. This was again a program of David Wheeler who kept all the digits of e. The reason for this was that von Neumann had seen the first two thousand places of *e* and the digits occurred almost in two regular patterns. By that I mean, if you took the first two thousand digits of *e* and counted up the number of zeros, the number of ones, the number of twos, and so forth, that they were just too close to ten percent. And so von Neumann conjectured that maybe *e* isn't very random. So then Wheeler ran a program that printed *e* to 60,000 places instead of [two thousand].

McCORDUCK: [A higher number of incidents?]

GOLUB: Yes, that was all part of the task is to get the number of incidents of all the numbers. So that ran a hundred hours on the ILLIAC and it was sort of like background stuff if you didn't have anything else to do then you would do that. There was a lot of, I don't know if the word pioneering is right, pioneering work on using programs for testing the machine itself.

TAPE 1/SIDE 2

GOLUB: Paper tape was used extensively and one quickly learned how to manipulate that. Again, because Illinois was a big hardware place, people built special pieces of equipment for duplicating paper tape. You couldn't buy equipment like that easily for checking whether or not two tapes were identical or not, you know, because it was a mechanical device there was always the possibility that you made some error. So you would duplicate your tape, and oh, not only could you duplicate your tape, you could stop your tape at a certain point, insert some tape, then sort of

stitch the two pieces of tape together and then continue on. You learned all kinds of tricks.

McCORDUCK: It sounds like a world - paper tape.

GOLUB: Well, one thing, of course, you know, people tend to like whatever they're brought up on. So we were all keen on paper tape and the argument was made that after all, if you dropped cards, they can get out of order whereas tape if you dropped a roll then the computer instructions don't get out of order. So there was a whole technology associated with this paper tape. You could handle it just like you could handle anything else after a while. It's very nice.

McCORDUCK: [Question unintelligible]

GOLUB: Pretty much so. There was a very, very simple assembler, basically machine code was used. And, of course, fixed point, the ILLIAC was a fixed point machine. Before David Wheeler left he did assign an interpreter for doing floating point arithmetic and then David Muller had then done something with complex numbers, that was something that he was very interested in. I'm trying to think of non numerical kinds of work that would and not so much, there was a little non-numerical work but basically I would say ninety percent of the work was numerical in some fashion. So the ILLIAC had 1,000 words of memory, 1024 words, but then after a while a drum was developed which gave us 12,000 words of memory. That was enormous, we could really solve much larger problems then. Then you had to rethink. Well, having secondary storage immediately changes the quality of the computer. But you really got enamored with this idea of saving an instruction, you know, you thought about your problem very carefully, there were some people who I would say have been around a long time that it was really great when you did six point computations and there was something, you really understood your problem in a way that maybe you people don't understand, you know, as detailed as they do, in a detailed manner, that they don't today. There weren't many books available then, you know, each book that was published was of great interest.

McCORDUCK: What did you use for textbooks?

GOLUB: As I said for myself, these reports from the Aberdeen Proving Grounds and reports in general played an important part in our education. They came here with some frequency. Then there was the book by Wilks, Wheeler, and Gill which, you know, if you could sort of look up some of the early programs. There was a book by Householder very early on and there was a very good book, and even today I look back at that book and find it a very useful book. Reports played really a fundamental role then as they do today, of course. People read reports extensively.

McCORDUCK: I remember when I first came to Stanford the librarian complained to me that this was a very hard place to be a librarian because there [was so] much [in reports].

GOLUB: Well, in numerical analysis there had been some papers that are enormously famous that they've never been published, they were just records. Well, maybe they appeared in some proceedings, but there was, for instance, a report by Wallace Givens and that paper never actually was printed. I mean it was printed, of course, the report was printed, but I don't think it appeared in a scientific journal and it's sort of, you know, a very famous document.

McCORDUCK: What kind of an association was he in?

GOLUB: He was at Argon. He was at Oak Ridge, but I don't think he did anything but pass through Illinois at best. Householder came through probably once of twice. A lot of people, you know, as they do today traveled about. I'm trying to think of what other people, I mean, I know of other people who were there as students when I was there, a man of Glitka who's subsequently written a book on APL. And most of the people I know did not continue, you know, in the same areas that I've continued in. They've gone into other areas of computer science. But maybe that's an old story.

McCORDUCK: It's of interest of me when people are trained in a field what makes them decide to go and do something else whether it's a big dramatic thing or whether it's just, you know, if they're better off with something else.

GOLUB: By the way, Meager - he consulted - he just decided not to continue with the pressure of academic life, although I don't think he felt he had to publish or do anything, he was really the head of the laboratory and I don't think he had the same academic pressure. I met Varga for the first time when I was a graduate student. My advisor invited him to come to Illinois and we discovered that we had similar results and decided upon a joint paper. So just as a graduate student you had the opportunity of meeting a lot of people. Well, even today, of course, that happens to some. I personally feel in my life those were just wonderful years and I've tried to keep the same spirit that I felt as a graduate student then at Stanford and I don't know if that same spirit exists at Illinois any longer. In fact, the times I go back looking for it I don't see it so much. But it was special. I can't tell you. You know the hundreds of people you'd see around the Stanford computer science department I'm talking about twenty-five people or so. So if we had a party at Abe Taub's house, it might include the technicians, from the technicians to the professors. And everybody sort of associated, graduate students. That was really a home-like spirit and that just doesn't exist any longer.

McCORDUCK: In fact, that division is very clear to me because I was at Stanford when that took place. It was a very formal, almost political boundary in the form of a picnic and I don't remember whether computer science department or the computation center but in any case, it was the first time one entity had had one separate social function. They were just both so big it would have been impossible.

GOLUB: Well, you see we were, the computation center there, and that meant everything from computer science to computing. So you had a wide variety of talent and then everybody seemed to work together and it was exhilarating in many ways. If you wanted to find some detail out about the machine, why it performed one way or the other then you could easily, you know, there was no great problem in doing so.

END OF INTERVIEW