Computer Oral History Collection, 1969-1973, 1977

Interviewee: Grace Murray Hopper (1906-1992)
Interviewer: Uta C. Merzbach
Date: November 1968
Repository: Archives Center, National Museum of American History

HOPPER:

…well that was the point at which we started keeping subroutines and notebooks, and borrowing each others subroutines. And that's where those first ones appeared that (I didn't know it, but they) are in relative coding, because (you see) they can be put anywhere in a program. And I put the A's and B's in instead of the specific storage locations, and what you had to do if you wanted to use it over again, was you put your argument in A, and so on in B and like that. And those were essentially relative subroutines, though we did not know it (we didn't realize it); in fact, I wasn't aware of it, fully, until I got down to Univac, when I had input-output under my control, and could store those on tape and call them back into a program without having to copy them. You see, we had to hand copy those and we could still make errors in them, and it wasn't until I got the ability to control the tapes and to read from them at will, to search them and pull out a piece of coding and copy it, of the computer _____. But it stemmed, originally, from this business of collecting notebooks full of subroutines, and those that I gave you were in one of my notebooks. There was a notebook which had a lot of those in it, and what became of that notebook I don't know. And any subroutine which might prove useful to others we entered in it, with a description of it, and did use them interchangeably, but we did have to copy them. (Finally…) At first, you know, it would not punch the tape (the computer would not punch the tape) that was fed into the interpolators — that had to be hand punched. You computed your coefficients of interpolation and then you hand punched them over at the tape punch. Eventually we did hitch that up to the computer, so that the computer could punch tape, and at that time we were able to copy coding, but that was just before I left that we got that ability. And the concept of those subroutines was built into Mark III rather than into Mark II. It finally came along and led to the coding machine that appeared in Mark III but they should not be built in, but should be built into this coding machine and used from there. And of course (that eventually), that's part of the thought that eventually turned up in the compilers; those are all threads that led to it.

MERZBACH:

You remarked that in the first volume, the Hankel functions, where you still had to do the typing_____ — now this isn't true for the Beta function…?

HOPPER:

No, the Beta functions were the first ones that (were) actually came right out of the computer and then were photographed. By then, the typewriters had been upgraded and the whole operation was proceeding better. Another thing…

MERZBACH:

What time was that? It must have been around 40… '46…?

HOPPER:

No, I think it was when Dick was doing the planning, in '45. Don't forget when these first things came out, (they just came) we hadn't gotten the idea that you could tell the typewriter to space every — write five and take a space. We hadn't fully learned how to control the typewriter that'd print an amount across a page and in blocks; there was so much of the techniques of handling the typewriter that had to be invented, because when that stuff first came out, it was just coming out a mass of numbers, and all of the dress-up we had to learn how to do. The first time…when we first made page numbers for that Hankel book, in fact…no, it wasn't the Hankel, it was one of the other books. At lunch time, when Aiken was out of the office, I put a routine on which did nothing but add one and print the number, add one and print the number and space, and made it print out just a sequence of numbers. And then, we cut them up and pasted them on the pages of the book, you see. But he came in and found us with all seven hundred and fifty thousand dollars worth of Mark I adding one and printing digits — waste of computer time — oh, he went through the ceiling. But it was much faster than sitting down at the typewriter and printing out those page numbers, and then later we cut them up and pasted them on the pages. Of course, once we'd done that, then we realized we could've put them on the pages to begin with, but it took special plugging in of the typewriters, and so on, which we had to devise. Then of course, there was the day, finally and inevitably that happened, when one of the operators put up tape on inside-out. You know those tapes were loops and they kept going over and over again, and he'd turned it inside-out which meant that all the instructions that were on the left there, that handled all the equipment, went over — they were on the right, went over onto the left and all the regular coding which was on the left got over on the right. And so, when the mechanism read it the interpolators tried to step both forward and back at the same time, which stripped the gears, the typewriters all tried to print and do different things simultaneously, the card punchers tried to step and read and all sorts of things, and it sounded (the crash of that thing sounded) as if a plane had run into the building. You never heard such a crash in your life because everything mechanical tried to act at the same time, and it was down for about two weeks when the tape was put on inside-out. Of course, that's beautifully typical of running a computer, that anything which can happen will happen—Murphy's Law. You don't even have to think it up; if it's physically possible or mentally possible it will occur, and eventually that one did, the paper got on inside out. And another thing about those tapes: you know, if you roll up a tape and take one end out of the center and one end out of here, you may or may not make a moebius strip out of it, depending on how it's rolled. Well Dick, one day at lunch time in a great rush, proceeded to take a tape just exactly like

that. He picked up the inside end and the outside end, and we had this clear strip stuff which you put on the tape, and then you put the other end over it and then you ironed it (we had an electric iron and you ironed it) to seal them together, and he did that. And I said, "Dick, you've got a moebius strip, it won't run in the machine," and he said: "it will run in the machine." And we finally unrolled the tape after he'd fastened it together, and with Bob trying to arbitrate, determined that it was in fact a moebius strip. And Dick and I got in an awful fight about it, and the funny part of it was that that argument got up again, and again, and again as to when you would make a moebius strip and when you wouldn't. And two years ago, when we were both on that panel for the ACM of the old-timers, at lunch that day, Dick and I got into that same argument all over again of when you made a moebius strip out of a Mark I tape. That of course, (there it was it) was bound to happen sooner or later. The adventures of running that first computer were out of this world; they'll never happen again, of course, because we met everything for the first time.

MERZBACH:

Was there any discussion at the time — did you pay any attention, one way or another, to the procedures used on the Bell machines at Aberdeen for example? You know, the questions on the difference in coding or anything like that?

HOPPER:

No, very little to the Bell machines. However, when ENIAC came along I was sent down to Philadelphia and I did visit ILLIAC, and find out all about it, and before we went much further with it—before we got into the Mark III. It didn't affect the Mark II; the Mark II was a rush job to be built out of available stuff and was. It was started before the end of the war was in sight and did run in '46, you see. So that, it did not feel the influence of electronics, however, the Mark III, of course, did. And I can remember when just toward…it must have been in '46 some time (because they came from Germany), the first of the cores appeared. Nobody, today, would recognize them as a core — they were picked up by the Army, in Germany. They were about four inches square, of iron (you know) rings but they were square, and they were the first of the coils that had the proper hysteresis loops and could be used for storage — and we had that. There were three of them that came, very preciously, from Germany by airmail. The Navy had located them in Germany, and they came to the laboratory for us to look at and consider. And also, oh, as early as 1945, we were beginning to experiment with magnetic recording. They had single discs, almost like a record but a little bit thicker, and they were recording on the edges of them, and beginning to look into the techniques of magnetic recording. When it came to building the drums (and this was going on, you see, in '45 and '46), the beginning work for Mark III was started while Mark II was being built; (the drums) they were trying to get drums machined — now those were, of course, since been shown you can't use. They were long (about three or more feet long) and about (I guess about) eight or ten inches in diameter. And what happened was, that when you ran them at high speeds, they bulged in the middle. And they were trying to get drums built and machined; they were built down at the Navy Yard in Boston, and the question of how to machine those drums,

as perfectly as they had to be machined, went on for months (trying to make those drums, even the first one). They made those early discs for us down there, and then the question was trying to make those drums and a terrific job trying to machine those. The logical design, the circuit design went much faster; for instance, trying to get relays that were fast enough—latch relays, (that were fast enough for Mark II) was a very difficult job. There weren't any relays that were fast enough to attain the speeds that Mark II needed, and those were actually built for Mark II and Mark II only — those fast latch relays and the other fast relays, and much of that had to be invented under pressure. And of course, when we moved to the new building, the new Computation Laboratory (itself), the whole lower floor was working in those areas, was trying to invent the pieces we needed for the next computer. When I visited ENIAC, the tremendous contrast between Harvard and the activities of Eckert and Mauchly was the programming. You see ENIAC was — you plugged the pieces and essentially you built a special computer for each job, and we were used to the concept of programming and controlling it by our program; there was a very sharp contrast between the automatically sequenced and the plug board system of ENIAC. Of course, they had the electronic speeds, and again too, their input-output was nothing but a cardpunch. They didn't have the typewriters directly on the computer; you had to take the cards out to print them. Mark I was a little ahead on that score too, but the big contrast was in the concepts of programming, and by that time we had already gotten to concepts of subroutines and I think a little bit had influenced Wilkes, who had been there from England, and of course he later produced the first book on subroutines, when he was working on EDSAC. And they could not have gotten, you see, the concept of libraries because they had to replug it all. They could have had libraries of charts, but the library of programs — it was something that couldn't have grown down there because of the equipment. I think we tend to forget that many of the developments that have happened have been based on the availability of equipment. We couldn't have had a compiler until we had a computer which did control all of its own storage including its tape storage (couldn't have built it). It had to wait until the computer controlled its own tapes; even when Whirlwind started running, it did not control its own input-output it was manually loaded. So was SEAC when it was first built, it was manually loaded. You loaded the program and the data in, and then you pushed the start button and took off. And then when it stopped and had finished the computation, you unloaded the results. Because you see, Mark I always was printing all the time that she was running. You didn't have to wait until you had finished the computation to get your results out, so that she was way ahead of her time in some of those concepts of controlling the peripheral gear. And many other concepts in software had to wait until the computer could control those peripheral gears. You couldn't (have) for instance, stack up all the different programs you wanted to do during the day, and have the computer locate them at the proper time of day and go to work on them, until you had the tape units attached to the computer — until Univac I came along. And you couldn't have a run-to-run locater, which was the beginning of the operating systems until you were operating in that environment. So that, if they say software lagged, it lagged because it had to wait for the hardware before it could be done. Of course, on the other hand, the software also influenced the hardware, because the minute they came out in England with the "B" boxes…We had been programming on Univac I, you see, with programming the loops,

but as soon as England came out with the "B" boxes the concept of index register was promptly built into the computers from then on.

MERZBACH:

To get back to the I and II, and what you said about the Mark III, is it fair to interpret this that essentially the major differences, or answers if you will, appear in the Mark III whereas the Mark II was not so successful?

HOPPER:

That is right. The big step forward in Mark II and the one which was ignored because she was a relay computer—nobody paid any attention to her because by the time anybody knew anything about her, she was a dead duck, and everybody was going electronic — was the tremendous development of the multi-processor and the multi-programmer which were innately in it, and those concepts were lost until much later. And yet I have found it feasible and useful to go back and read the Mark II manual as I'm working with the 1108, because it gives me clues. The programs that were written for Mark II, using the multi-processor, would give me clues as to what I should try to do on an "8" which is…we don't get another multi-processor until you do get to the 1108 — it's that long gap. So, I think Mark II was neglected because it was built out of relays, and its slow speed, you see.

MERZBACH:

Yes. One of the interesting things about Mark II…what problems arose in setting it up at Dahlgren — Mark I, you had people who'd been involved in _____.

HOPPER:

No, I don't think there were too many major problems except they went down there and set up relay racks, and then fired the big guns to see if it was going to be able to survive down there—whether the jarring, due to the big guns, would influence the computer.

MERZBACH:

But in terms of running it, having people learning to…

HOPPER:

No. I don't think there were any major — they were trained at Harvard; they were sent up from Dahlgren, trained at Harvard, and then sent back to Dahlgren. One thing happened there though: the Mark II had a big bank of constant switches; you could set constants in by setting switch dials and they left it alone one lunch time, and the Admiral came in and showed some visitors his beautiful computer. And he said: "This is where we put the numbers," and he lifted his hand up and twisted these switches, and they came back after lunch and started to continue running the problem and found that all the shelves were gone all over the place. And some of them were practically coming back at them, and they couldn't figure out what had happened to the computer during the time they'd been away from it — some bug had gotten in it — and they finally found out that the Admiral had twisted the switches. After that they put a big plate glass over those; it was kept locked. (Mark II was the one, too) When we were debugging Mark II, it was over in another building, and the windows had no screens on them and we were working on it at night, of course, and all the bugs in the world came in. And, one night she conked out, and we went to look for the bug and found an actual large moth, about four inches wing span, in one of the relays beaten to death, and we took it out and put it in the log book and pasted scotch tape over it, and as far as I know, that's still in the historical log book up at Harvard (we found an actual bug in the computer). That brings up another thing I think is an innate property of computers: the crews that surrounded them in those early days, very quickly became very much welded together as a team, and all kinds of small pranks, inventions and all sorts of things were very current; they were apt to become…they thought of themselves as highly specialized; they ran that computer and they had their own secrets and jokes and everything like that. They were quite an unusual bunch, from time to time, and you'll find as in the case of that Mark I, that most of them are still in the computer industry, somewhere. And that basic training they got was fantastically good—it really was. They became a very select team and they were quite proud of themselves, and of course, unendingly played pranks on each other and on anyone else that came along, because they controlled the computer.

MERZBACH:

How much of a problem was it to learn about applications that you probably hadn't paid particular attention to before? I was thinking on the — looking at the volume on the design of missiles, now how much did you know about missile design before we got into that?

HOPPER:

Absolutely nothing.

MERZBACH:

How did you go about it?

HOPPER:

As we came along, we worked with the people that had the problems, and all the time we began to learn the languages. I learned languages of oceanography, of this whole business of minesweeping, of detonators, of proximity fuses, of biomedical stuff. We had to talk to these people — all we had to begin with was mathematics. We had to learn their vocabularies in order to be able to run their problems. There was a tremendous amount we had to do — that we, as programmers, had to learn in the process of trying to get at these various applications, and what had to be done about them and everything else. Now this one is after we have gone to the new laboratory, I think, this design of missiles.

Commander Blieck, by the way, who was in…I notice his name here again in the Bureau of Ordnance, he was our guide, friend and helper down in Bu0rd; when we needed something, we went to Cdr. Blieck. He's now on the faculty of the Navy Postgraduate School at Monterey. He went back to teaching mathematics after the war was over; he is now a captain in the reserves. He may…I guess he comes up for retirement sometime soon. I notice there are many people now beginning to appear that are all over the computer industry. Yeah, this was one of the earliest things on the design of missiles — one of the very earliest — most of the world didn't know there was such a thing as a missile. Let's see what's the date on this?

MERZBACH:

I think 1958…

HOPPER:

By then, of course, we'd captured German missiles (the German V-2's), but nobody realized, I think, that we had them and were designing and building them — very few people did.

Now I see mention of Albert Wortheimer, in the Bureau of Ordnance. He was the one that was really back of that computer, and of the building of the later computers throughout the whole history of Mark I, and Mark II, and Mark III.

Now this one was printed on the computer. This is one of the one's that was printed on the computer, and then these…this was a mask (this all was a mask) which was put over it. The thing was printed on the computer and then this whole thing was a stencil, a mask, and then it was photographed but that was done on a computer; that's the actual computer typing, and the other stuff was put on a mask. It's a long time since I've seen those books — what else have you got here?

MERZBACH:

Well, this is the…let's see I'll read this, this one we've…this of course, is the Mark II and then this is what…this is a bit later.

HOPPER:

The Hankel functions I was well mixed up with. Yes, (this was) my next job was writing this, and again I drew all those circuits at least once. Now I didn't do…there's one section of this that I did not do, and that's this stuff here on the ? printers, input-output stuff. And the auxiliary tape equipment and the input-output stuff was done by — ah, let me get his name, it's in here somewhere — Dick Woltman did that.

MERZBACH:

One question I had in as far as the actual construction of the various components: now you mentioned that a certain amount of (at least) testing was done in the basement of the lab, however, wasn't mark…

HOPPER:

This was for Mark III.

MERZBACH:

This was for Mark III, I see.

HOPPER:

Mark II was in another building across the street, and I can't remember the name of it.

MERZBACH:

I see. Was this mainly…were the subcontracts to various — for the various parts, or what?

HOPPER:

Oh, no, these were all these employees that are shown here on the staff of the laboratory.

MERZBACH:

No, I mean now just the basic construction; it was done at the laboratory?

HOPPER:

That's right, that's right. Now let's see, of these people…some of these people were Mark III only, and some were Mark II only. Now the starred ones are the people from

Dahlgren, but, for instance, Way Dong Woo was on Mark III entirely; Singer was a programmer; Connie Rawson was a programmer, I got her from Vassar; Ben Moore was the senior engineer in charge of the building of Mark III, whereas the starred crew, here, was the Mark II group. But you can see the beginning of the Mark III people are here.

MERZBACH:

In other words, the components were the only part — you mentioned the fact that the relays were a custom there.

HOPPER:

That's right. Then the racks for Mark II were built as a subcontract, but the whole thing was put together, there at Harvard, by the Harvard crew.

MERZBACH:

I see, put in together and the specifications, too, would have been developed at Harvard?

HOPPER:

At Harvard — that was entirely Harvard. The racks (the relay racks) and the cases were contracted out and, of course, we had Western Union typewriters and those things, but the actual putting it together - the actual wiring was done by the Harvard crew, and the same thing was true of Mark III; much of the stuff for that was built, as I said, at the shipyard; some work was done by Western Union, but this is the crew that put it together. (This) Most of the Mark III crew is in this volume (is in this Mark II volume) the names. Ben Moore was in charge and Way Dong Woo was with him (worked with him on that), though quite a bunch of These are still Mark I programmers — John Hard, Kincaid, Rawson, Singer were people programming Mark I, so this is a combined crew, Mark I, II, and III.

MERZBACH:

When did…at one point people began to come to the laboratory, I understand, specifically to get some training to take back to other places.

HOPPER:

They began to appear as early as Mark I — in the earliest days of Mark I. The major Navy laboratories sent people; that's how A.E. Smith, (Gene Smith) now in Bureau of Ships, came. He came with problems from the Bureau of Ships, and then stayed with us finding out how we were doing and then he took that information back with him. And they came from Dahlgren; they came from the other Navy laboratories (Naval Ordnance

Laboratory), and so on. Then they began showing up from MIT, and then from some of the other major universities. Fairly early in the game, some Air Force and Army officers turned up, too, in that first summer, to find out what this was all about and what we were doing. And then, later when we moved to the new building, (by the time we got to the new building) this was so important that a classroom was actually built in, so that we could give lecture series. It was built (a lecture room was built) in the new building because this had become such a frequent process, this training and giving seminars — three-day seminars, one-week and so on; I did a lot of the lecturing in those because I had been a college professor. And at first, it was entirely within the government — (it was almost) toward the end of the war there, in '46 it was almost entirely government, but then afterwards it began to be more general, and they began to come from the other universities and everything.

MERZBACH:

And then you also started getting people from abroad _____.

HOPPER:

Well they appeared even in that first year — at least from England, we had visitors (from England) as early as the first summer we were running Mark I. I think Wilkes was there very early in the game and — what was his name from London? the very famous one…

MERZBACH:

Boothe?

HOPPER:

Boothe came, but, no — there is someone else—he died some years back. I'll think of that before I get through; they came very early in the game, from England. We didn't see the other nations, I don't think, until after the war — until in late '46, at least, when they began to appear from Europe; Canadian, yes, quite early. And of course, eventually, Rubinoff joined us; he comes from Canada.

MERZBACH:

Well, of the others, you had Swedish visitors, and then I understand Zuse came to visit at one time, but he didn't spend any length of time.

HOPPER:

Yes, he did. He didn't spend any time; he just came and looked at it all. I can remember talking to him but that's all; we had some difficulty communicating; his English wasn't of the best, even though he was working in Switzerland.

MERZBACH:

Did the other — how about the Swiss?

HOPPER:

Well they came later. Because they went off you know, and built a machine which was a direct derivative of Mark II. They spent, I guess at least one of their men was there, six months or longer; he was in residence and worked right with them on building it. And their first machines were direct out-growths of the Mark I, Mark II line.

I think it's almost time for me to wander off.

MERZBACH:

Yes, I think maybe it's…