Konrad Zuse

Born June 22, 1910, Berlin-Wilmersdorf; German inventor of prewar electromechanical binary computer designated Z1 which was destroyed without trace by wartime bombing; developed two more machines before the end of the war but was unable to convince the Nazi government to support his work; fled with the remains of Z4 to Zurich, which was successfully used at ETH; developer of a basic programming system known as "Plankalkul", with which he designed a chess-playing program.

Education: By 1927 Konrad Zuse had enrolled at the Technical University in Berlin-Charlottenburg and began his working career as a design engineer (Statiker) in the aircraft industry (Henschel Flugzeugwerke) and by 1935 he had completed a degree in civil engineering. He remained in Berlin from the time he finished his degree until the end of the war in 1945, and it was during this time that he constructed his first digital computers.

Honors and Awards: honorary professor, GeorgAugust-Universitdt, G6ttingen, 1966; honorary degrees: Dr.-Ing.E.h., T.U. Berlin-Charlottenburg, 1956; Dr.rer.nat.h.c., Universitdt Hamburg, 1979; Drrernat.h.c, T.U. Dresden, 1981; Drtechn.h.c., Universitat Reykjavik University, Iceland, 1986; Drrernat.h.c., Dortmund, 1991; Drh.c.sc.techn., ETH Eidgen6ssische Technische Hochschule, Zurich, 1991; Dr.-Ing.E.h., Hochschule f. Architektur und Bauwesen, Weimar, 1991; dottore ad honorem in maternatica, Siena University, Italy, 1992; lnldndische Auszeichnungen/Ehrungen: Werner-von-Siemens-Ring, Stiftung Werner-von-Siemens Ring, 1964; Dieselmedaille in Gold, DEV Deutscher ErfinderVerband/Nfirnberg, 1969; Grosses Verdienstkreuz des Verdienstordens der Bundesrepublik Deutschland, 1972, (mit Stern, 1985); Ehrenmitglied der Deutschen Akademie der Naturforscher LEOPOLDINA, Halle/Saale, 1972; Aachener und Mfinchener Preis, Carl-Arthur-Pastor- Stiftung, Kuratorium der Aachener und Mfinchener Versicherungs AG, 1980; Ehrenplakette der Stadt Bad Hersfeld, 1980; Konrad-Zuse-Medaille, ZDB/Zentralverband des Deutschen Baugewerbes), 1981; Bernhard-Weiss-Plakette, VDMA/Verband Deutscher Maschinen- und Anlagenbau e.V., Dfisseldorf, 1983; Bayerischer Maximiliansorden, Bayerischer Ministerprdsident, 1984; Goldener Ehrenring, Deutsches Museum/ Mfinchen, 1984; Cothenius-Medaille, LEOPOLDINA, Deutsche Akademie der Naturforscher, Halle/Saale, 1985; Ernst-ReuterPlakette, Senat Berlin, 1985; VDE-Ehrenring, Verband Deutscher Elektrotechniker e.V., Dfisseldorf, 1986; Philip-Morris-Ehrenpreis, Philip Morris GmbH/DABEI, 1987; Wilhelm-Leuschner-Medaille, Hessischer Ministerprdsident, 1987; Ehrenmitglied: Deutsche Akademie der Naturforscher LEOPOLDINA, Halle/Saale, 1972; Akademischer Verein Motiv, 1982; Verein des Schleswig-Holsteinisches Museums für Rechen- und Schreibtechnik e.V., Altzenholz, heute: MICOM, 1983; Gesellschaft für Informatik e.V., GI, 1985; Verein ishindischer Ingenieure, Reykjavik/Island, 1986; Deutsches Museum, Mfinchen, 1990; Vereinigung der Freunde und F6rderer der Ingenieurschule an der Fachhochschule Schmalkalden e.V., 1992; Ehrenbfiraerrecht: Ehrenbfirgerrecht der Stadt Hfinfeld, 1975; Namensqebunq: Konrad-Zuse-Strasse, in Bad Hersfeld/Hessen, 1972; KonradZuse-Schule, in Hanfeld/Hessen, 1978; Konrad-Zuse-Medaille, ZDB Zentralverband des Deutschen Baugewerbes und GI/Gesellschaft f. Informatik e.V., 1981; Konrad-Zuse-Zentrum für Informationstechnik Berlin/ZIB, in Berlin, 1984; Konrad-Zuse-Zertifikat, Freundeskreis der Berufl. Schulen e.V./Bad Hersfeld, 1985; Zuse-Raum, Berufliche Schulen/Bad Hersfeld, 1985; Konrad-Zuse-Gesellschaft, Grimdung am 6.9.88 in Hfinfeld, 1988; KonradZuse-Haus, Fa. PDS Programm + Software GmbH, Rotenburg/Wfimme, 1989; Konrad-Zuse-Programm, F6rderung v. Gastdozenten ausUndischer Hochschullehrer-DAAD/Deutscher Akademischer Austauschdienst, Bonn, 1990; Konrad-Zuse-Zimmer, Schelztor-Gymnasium, Esslingen, 1991; Zusestrasse, in O-Hoyerswerda, 1991.

From 1936 to 1938 Konrad Zuse developed and built the first binary digital computer in the world (Z1). A copy of this computer is on display in the Museum for Transport and Technology (Museum für Verkehr und Technik) in Berlin.

The first fully functional program-controlled electromechanical digital computer in the world (the Z3) was completed by Zuse in 1941, but was destroyed in 1944 during the war. Because of its historical importance, a copy was made in 1960 and put on display in the German Museum (Deutsches Museum) in Munich.

Next came the more sophisticated Z4, which was the only Zuse Z machine to survive the war. The Z4 was almost complete when, due to continued air raids, it was moved from Berlin to Göttingen, where it was installed in the laboratory of the Aerodynamische Versuchanstalt (DVL/Experimental Aerodynamics Institute). It was only there for a few weeks before Göttingen was in danger of being captured and the machine was once again moved to a small village "Hinterstein" in the Allgäu/Bavaria. Finally it was taken to Switzerland where it was installed in the ETH (Federal Polytechnical Institute/Eidgenössisch Technische Hochschule) in Zurich in 1950. It was used in the Institute of Applied Mathematics at the ETH until 1955.

Education and Experience

By 1927 Konrad Zuse had enrolled at the Technical University in Berlin-Charlottenburg and began his working career as a design engineer (Statiker) in the aircraft industry (Henschel Flugzeugwerke), and by 1935 he had completed a degree in civil engineering. He remained in Berlin from the time he finished his degree until the end of the war in 1945, and it was during this time that he constructed his first digital computers.

My First Computer and First Thoughts About Data Processing[1]

I started in 1934, working independently and without knowledge of other developments going on around me. In fact, I hadn't even heard of Charles Babbage when I embarked on my work. At that time, the computing industry was limited to mechanical calculators using the decimal system. Punched-card devices were slightly further developed and able to deal with relatively complex operations for statistical and accounting purposes. However, these machines were almost entirely designed for commercial application. This meant that mathematicians and engineers had to develop computers on their own, working independently from one another. I was no exception.

At the beginning of the 1930s, while studying civil engineering in Berlin, I decided to develop and build bigger calculating machines, more suitable for engineering purposes. I approached the problem from various angles:

First, from a logical and mathematical point of view:

This involved
1. program control,

[1] "Computer Design-Past, Present, Future," talk given by Prof. Konrad Zuse, in Lund/Sweden, Oct. 2, 1987, previously unpublished.

2. the binary system of numbers, and
3. floating point arithmetic.

Today, these concepts are taken for granted, but at the time this was new ground for the computing industry.

Second, from the design angle:

1. allowing fully automatic arithmetical calculation,
2. a high-capacity memory, and
3. modules or relays operating on the yes/no principle.

My research was initially aimed at pure number calculation, but soon led on (1935/1936) to new ideas about "computing" in general. Personally, I believe that was the birth of modern computer science. I recognized that computing could be seen as a general means of dealing with data and that all data could be represented through bit patterns, generally speaking.

That led to my basic hypothesis that: data processing starts with the bit.

At that time, of course, I didn't talk of "bits," but of "yes/no status." On the basis of this hypothesis I defined "computing" as the formation of new data from input according to a given set of rules.

This basic theory meant that all computing operations could be carried out by relays operating according to the dual-status principle just mentioned. The most suitable devices available at the time were telephone relays.

Now a link with mathematical logic had been forged. As an engineer I had no idea of the existence of such a discipline. I developed a system of "conditional propositions" for relays-something that corresponded approximately to what is known as Boolean algebra today. My former mathematics teacher showed me that this sort of calculation was identical with the propositional calculus of mathematical logic.

From the engineering point of view, the gap between this and pure mathematical logic was bridged in order to simplify the design and programming of computing machines. At roughly the same time in England, the mathematician and logician Alan Turing was in the process of solving this problem from a different angle. He used a very simple computer as a model in order to place theoretical logic on a more formal basis. Turing's work was of major importance for the theory of computer science. However, his ideas had little influence on the practical development of computing machines.

The theories needed to be put into practice. First of all high-capacity memories had to be designed. At that time (1935) memory consisted of single registers operating a system of numbered wheels using the decimal system. Typical problems were the input and retrieval of information, as well as the choice of counters. Capacity was fairly restricted, although some punch-card machines were able to deal with up to 20 counters. These machines generally functioned on the basis that a number could be "added on."

But a new problem had to be overcome: pure memory was needed without the adding-on facility, but with high capacity and a special selection facility, as well as an elegant way of communicating with the periphery. I thought it was a good idea to base such a memory device on binary numbers from the outset. My idea was to divide the machine up into cells which would be able to hold data for a complete number, in other words, the operational sign, exponent and mantissa (where a floating point was being used), as well as additional specifications. Using the yes-no principle a “word”—as we would call it today—could be formed from a series of bits. The memory elements only needed to store yes-no values.

One device that could deal with this type of operation was the electromagnetic relay, which can adopt two positions, “open” or “closed.” However, at the time I felt that the problem could be better solved mechanically. I played around with all sorts of levers, pins, steel plates, and so on, until I finally reached what was a very useful solution, for those days. My device consisted mainly of pins and steel plates, and in principle could be extended to 1,000 words. A proper machine using telephone relays would have needed 40,000 relays and filled a whole room.

The basic principle was that a small pin could be positioned right or left of a steel lug, thus memorizing the value 0 or 1. Input and retrieval were also effected via a steel-plate construction, and the individual parts could be stacked on top of one another in a system of layers. The address system also used binary code.[1] These machines had the advantage of being made almost entirely of steel, which made them suitable for mass production.

Individual memory elements could be easily arranged in matrix form, which was very useful as far as constructing computers was concerned. Not only was a number memory now available, but it could also be used to store general data drawn from practically any source. Logic studies conducted at the same time had already shown that general calculations with any sort of data structure were possible, and that this data could be made up entirely of bit combinations. That is why I had already called the storage system a “combination memory” in the patent application.

This was something new on the Babbage designs. It was clear that programs could be stored provided they were composed of bit combinations-one reason why programmable memory had already been patented by 1936.

In the course of pursuing the basic principles of mechanical memory, I developed a mechanical relay technology. This I applied to both programming and calculating parts. At the time it was not clear whether all operations could be run according to the yes-no principle, or even whether that was a good idea. That was something that was only discovered later after much hard work. Initially I developed various adding machines for binary numbers, which used elements providing up to three or four positions. This was done using both electromagnetic and mechanical relays. Finally I found a solution which worked on the yes-no principle alone. By this time the similarities between essentially very different technologies were becoming increasingly obvious. I was faced with the choice of using either telephone relays or mechanical technology for my computing machine. As mechanical memory had proved successful (I was able to build a working model in six weeks), and because of the frightening number of relays needed in the alternative system (around 1,000), I decided in favor of the mechanical version, at first.

Inventors are often faced with that sort of decision. Today, I know that opting for relays immediately would have been better. However, working on a completely private basis, with just the help of some friends, I started to construct a mechanical model of the computer. At first I thought it would be possible to produce it quickly. In

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[1] Further details can be found in Patent no. 907 948, K1. 42 m, Group 15 / May 1936 entitled “Mechanical Relay”; and Patent no. 924 107, K]. 42 m, Group 15 / May 1936 “Mechanical Relay Memory.”

fact it took two years to set up a half-way functioning machine that I could present to the experts. Unfortunately the surviving photos are not very good and the machine itself proved somewhat unreliable. In fact, with the help of switching algebra, it proved easy to convert mechanical relay circuits for use in electromagnetic relay technology.

At this point I would like to mention my friend Helmut Schreyer, who was working on the development of electronic relays at that time. Helmut was a high-frequency engineer, and was completing his studies (around 1936) at Professor Stäblein's Institute at the Technical University in Berlin-Charlottenburg. Helmut, who was a close personal friend of mine, suddenly had the bright idea of using vacuum tubes. At first I thought it was one of his student pranks-he was always full of fun and given to fooling around. But after thinking about it we decided that his idea was definitely worth a try. Thanks to switching algebra, we had already married together mechanics and electromagnetics, two basically different types of technology. Why not then with tubes? They could switch a million times faster than elements burdened with mechanical and inductive inertia.

The possibilities were staggering. But first the basic circuits for the major logical operations such as conjunction, disjunction, and negation had to be discovered. Tubes could not simply be connected in line like relay contacts. We agreed that Helmut should develop the circuits for these elementary operations first, while I dealt with the logical part of the circuitry. Our aim was to set up elementary circuits so that relay technology could be transferred to the tube system on a one-to-one basis. This meant the tube machine would not have to be redesigned from scratch. Schreyer solved this problem fairly quickly.

This left the way open for further development. We cautiously told some friends about the possibilities. The reaction was anything from extremely skeptical to spontaneously enthusiastic. Interestingly enough, most criticism came from Schreyer's colleagues, who worked with tubes virtually all the time. They were doubtful that an apparatus with 2,000 tubes would work reliably. This critical attitude was the result of their own experience with large transmitters, which contained several hundred tubes. Apart from that, conditions were not exactly propitious for the development of a fully tube-operated machine. The war had broken out in the interim, making the procurement of staff and material very difficult. Nothing could be done by private initiative. We therefore proposed the construction of a 2,000-tube computer for special use in antiaircraft defense to the military authorities. Although the reaction was initially sympathetic towards the project, we were asked simply, "How much time do you think you need for it?" We replied, "Around two years." The response to this was, "And just how long do you think it'll take us to win the war?" The outcome was considerable obstruction and delay in the development of a German electronic computing machine. Schreyer was by now fully engaged in other projects. By the end of the war he had constructed a small experimental machine for 10 binary digits and around 100 tubes. But this machine was also lost in the general confusion just after the war.

After the war was finally over, news of the University of Pennsylvania ENIAC machine went all round the world—"18,000 tubes!" We could only shake our heads. What on earth were all the tubes for? Schreyer and I parted company after the war. At that time it was prohibited to develop electronic equipment in West Germany. As Schreyer saw no means of continuing his very interesting research, he emigrated to Brazil to take up a university chair. Schreyer died in 1985.

The English development known as COLOSSUS was unheard of outside the circle of those working on it. It was only much later that the wraps came off this very interesting project. In 1980 Schreyer and I had the opportunity to speak to the COLOSSUS people in England. We compared our circuits and it turned out that there were considerable similarities. The English had also been working on logical operations and other similar design principles.

By the end of 1938 it seemed clear that electromagnetic relays offered the best chance of producing a reliable operating computer quickly. Before I redesigned the Z1 to operate completely with relays, I made a test with a small pilot machine, the Z2. I used the mechanical memory of the Z1 with a low storage capacity (16 words), as well as the card punch and reader to build a simple computer with 200 relays operating with 16 bits and on the basis of fixed-point arithmetic.

Young transmitter specialists, including Schreyer and other friends of mine, helped me design the circuits and choose the appropriate components. But although their advice was a great help, to a certain extent I expressly set out to explore new ground. The most important thing seemed to be to keep the frequency absolutely even, so that one cycle equaled one addition, itself comprising several steps. Frequency was set using rotating disks or rollers, which were covered in alternating strips of conducting and non-conducting material, contact being made via carbon brushes. This principle had many advantages. Tests could be run on the machine at any speed. Another advantage was that spark extinction took place at the brushes and not at the relay contacts when circuits were being shut down. Despite well-meaning advice from some friends, I did not make use of certain well-known telephone communication tricks such as delayed-response relays.

All in all, I was able to gather enough experience with the Z2 in order to convert the complete Z1 design for relay operation. What emerged was the Z3, which I consider to have been the first properly functioning computer in the world. In order to make fast progress the memory was also given a 64-word capacity, making use of relays.

The Z3's basic specifications were:

- a binary number system
- floating point arithmetic
- 22-bit word length, with I bit for the sign, 7 exponential bits, and a 14-bit mantissa
- 2,400 relays, 600 in the calculating and program section and 1,800 in the memory.

The calculations possible were addition, subtraction, multiplication, and division, taking the square root, as well as some ancillary functions. Construction of the machine was interrupted in 1939 when I was called up for military service. It was typical of the attitude prevalent in Germany at the time that I should be later released from active service, not to develop computers, but as an aircraft engineer. However, in my spare time, and with the help of friends, I was able to complete the machine. By 1941 it was working and I was able to show it to the aircraft construction authorities. The German Aircraft Research Institute in Berlin-Adlershof showed the greatest interest. Professor Teichmann, who had been working on the problem of wing flutter, was particularly attracted. Unlike aircraft stress, wing flutter results in critical instability due to vibration of the wings, sometimes in conjunction with the tail unit. Complex calculations were needed in order to overcome this design problem. The most difficult part was calculating the so-called “Küssner determinants” based on complex numbers and unknown quantities in the main diagonal. I achieved a breakthrough, using my equipment for this calculation. Unfortunately the Aircraft Research Institute had not been given a high enough priority for me to be released from military service. Only Professor Herbert Wagner, who was working on the development of remote-controlled flying bombs, and for whom I worked as a stress analyst, was in this enviable position. However, Wagner was very understanding, and helped as much as possible by allowing me to use some of my work time on the project. By then I had already set up my own small engineering business, the “Zuse-Ingenieur-Büro,” in Berlin. The Z3 was later destroyed after bombing raids. Because of its historic importance we rebuilt it 20 years later; a replica now stands in the Deutsches Museum in Munich.

Around 1942 it was decided to build a more powerful, improved Z4. We thought that we would be able to have it ready within one to one and a half years. It was to have a mechanical memory with a capacity of 1,024 words, several card readers and punches, and various facilities to enable flexible programming (address translation, conditional branching).

Construction of the machine started well but it was not long before the war imposed its delays. In the end, construction was not completed until the close of the war. Procurement of staff and materials became increasingly difficult, and around 1943 the Berlin blitz began, with heavy bombing raids nearly every day. Several times we had to move the location of the machine. During the last few weeks of the war we found refuge in Göttingen. The Z4 was the only model we were able to save, and this in the face of considerable difficulties. On the 28 April 1945 we were able to demonstrate the Z4 to Professors Prandtl, Betz, and Küssner. But the Western and Eastern fronts were drawing closer daily and nobody could say whether Göttingen would be bombed or not, or whether the Z4 was safe there. The Ministry of Aviation ordered us to take the machine to the underground works in the Harz. It was there that we first learned of the terrible conditions under which the so-called reprisal weapons-the V1 and V2-were being built. We refused to leave the machine there and, with the help of Wernher von Braun's staff, we managed to get hold of a truck to transport it elsewhere. And so the Z4 odyssey continued. We then moved south, ending up in a small Alpine village called Hinterstein in the Allgäu, where we were finally able to find a good place to store the machine.

Around 1950, after a number of modifications, the machine was set up in the Technical University of Switzerland in Zurich, where it remained for several years, the only working computer in Continental Europe. Today it is a historic model and can be seen in the Deutsches Museum in Munich. Unfortunately it's no longer in full working order.

Another offshoot of computer research ought to be mentioned here, too. By that I mean process control. At the Henschel Aircraft Factory Professor Herbert Wagner, for whom I worked as a stress analyst, was involved in developing remote-controlled bombs. To this end, the tailplane and wings, which were constructed of metal with a relatively low degree of precision, were subjected to detailed measurements, using gauges at some 80 different points. The necessary adjustments were then calculated to allow for manufacturing inaccuracies. This required a rather complex calculation. Initially I constructed a special-purpose computer for a fixed sequence of operations using around 500 relays. This machine replaced a dozen calculators and worked very reliably for two years, two shifts a day. The procedure required a mechanic to read off the gauges. The values were then recorded and operators entered the figures into the computer. This led me to build an improved model, which could read the gauges automatically and transfer data directly into the computer. The heart of the machine was a device that today would be called an analog/digital transformer. Perhaps this was the first process control system in the world.

The machine itself had its own history. It completed trial tests on a production line in Sudetenland, but never reached full operational use as the war forced the whole factory to be relocated. The exact fate of the machine is unknown—it's possible the factory fell into the hands of the Russians, who must have been the only ones at the time to own a fully-operational computer. The Z3 had already been destroyed, the Z4 was not completed, and the first US machines, Mark I and ENIAC, were not operational at that time. However, it is unlikely that the Russians would have known what to do with the machine even if they had found it in an undamaged condition.

Alongside my practical work with various computer models I started to consider certain theoretical aspects. The breakthrough to a new computing age went hand in hand with new scientific ideas and the development of new components. Today we talk about hardware and software. These expressions were really only introduced much later by the Americans, although the terms have now become established. It was apparent that a special branch Initially I worked on my own, but towards the end of the war Herr Lohmeyer, an outstanding mathematician, was assigned to assist me. Lohmeyer was a product of Heinrich Scholz's school in Münster, the latter himself a famous logician. The link with mathematical logic had already been established. As a civil engineer I was attracted by the prospect of drawing on predicate and relational calculus and exploring the possibilities they offered as a basis for computing. Take the frameworks used in building construction for example-were they not similar to the graphs used in relational calculus? Using pair lists, it was relatively easy to digitalize the structure of a framework with the aid of relational calculus, in other words, to break it down into its component data. This could then be entered into the combination memory, which had been invented by this time, and serve as a basis for combination calculations. This ought to mean that not only purely numerical calculations could be dealt with, but construction design itself. Up till now only the human mind had been capable of this. The same idea applied to frameworks and other types of building design. I became extremely preoccupied with this new aspect of computing. I even went as far as learning to play chess in order to try to formulate the rules of the game in terms of logical calculus. Chess offered a mass of data structures within a limited space. A symbolic language (the expression “algorithmic language” was unknown to me at the time) that could describe chess problems seemed to me to be suitable for all computer machine problems. Plankalkül was later (1945) devised with this principle in mind.

This led to my first confrontation with what is known today as “artificial intelligence.” Naturally I realized my computer would never be able to run that sort of calculation. But combination memory and the general circuitry were a step in the right direction. Many developments were predictable; of course, others were still in the realm of fantasy. I remember mentioning to friends back in 1938 that the world chess champion would be beaten by a computer in 50 years time. Today we know computers are not far from this goal.

But even in those days quite a lot was achieved at the drawing board. A diary extract from 1938 describes various principles of program control (starting with Babbage and the Z1 to the storage of numerical values, general data, and programs, all in the same memory). Today we call this computer architecture. The latter type of machine is known as the John von Neumann computer, after its name sake, who first produced it 10 years later together with Goldstine and Burks. We now know this was a very elegant solution.

The question is why I did not use this concept in 1939 if I already knew about it. Well, at that time it would have been senseless to try to build that sort of machine, as the necessary facilities were simply not available. For example, storage capacity was not big enough to cope; an efficient program memory needs to be able to store several thousand words. Speed was also too low. It's true that floating-point arithmetic can be performed by simply following a series of single instructions (as is the case today). But that means giving 10 to 20 times as many instructions. As long as the electronic prerequisites were not available, it was a waste of time. Two things were needed first: high storage capacity (around 8,000 words), as in the first magnetic-drum memories, and electronic speed. Towards the end of the 1940s this seemed possible, but as Germans we were not able to participate in this development at the time.

The possibility of a computer being able to deal with numeric calculations and logic organization was so exciting that I gave serious thought to a “logical computing machine.” This led to the “program compiling machine” project. Work was to be split between numerical and logic computers. That included such areas as:

- construction of extensive programs made up of subprograms according to specific parameters
- address translation necessary for these programs

- capability of dealing with engineering structures (e.g., frameworks) using pair lists from which a numerical program could be developed.

This project was commissioned towards the end of the war by the Ministry of Aviation. However, the work soon proved to be too broadly based and the ideas never left the drawing board. Since then, the concept of dividing computers according to numerical or logical operation has failed to find favor anywhere. The dominance of electronics made this unnecessary. The high speeds obtainable meant that such operations could be carried out by a single machine. However, one aspect became clear to me in view of all this research between 1936 and 1946. Some means was necessary by which the relationships involved in calculation operations could be precisely formulated. My answer was “Plankalkül---today it would be termed an “algorithmic” language. However, in those days, known mathematical and logical forms were not advanced enough. There were also several other differences compared with today's languages:

1. Plankalkill was not conceived as a means of programming the Z4 or other computers available at the time. Its true purpose was to assist in establishing consistent laws of circuitry, that is, for floating-point arithmetic, as well as in planning the sequence of instructions a computer would follow-what we would term “hardware” and “software” today.

2. It was meant to cover the whole spectrum of general calculating.

By contrast, the program languages developed around 10 years later were relatively one-sided. They were designed specifically for existing computing machines, in other words, for the first really flexible electronic computers. In the first instance, these languages were concerned with conditional branching, address translation, and suchlike. There was hardly any demand for logical operations, such as the application of predicate and relational calculus for engineering constructions, chess programs, and so on. That also applied to the breakdown of data into yes-no combinations. In other words, mathematicians did not consider my principle of “data processing starting with the bit” to be of any fundamental importance. Plankalkül's weakness was that it went into too much depth with regard to difficult calculations, which seemed better left to the future. The importance of my chess program, as an example of applied logic, was simply ignored. In addition to this, in the early 1950s, I was completely absorbed in building up my business at a time when program languages started to become more relevant. This meant I could not participate in the debate on Algol and so on. Plankalkül was later published out of historical interest (in English, too, although it is now unfortunately out of print).

As has already been mentioned, 1945 was a hard time for the Germans. Our Z4 had been transported with incredible difficulty to the small Alpine village of Hinterstein in the Allgäu. My group and my Berlin firm had been dissolved. All of us who had managed to get out of Berlin were happy just to have survived the inferno there. Work on Plankalkül now continued in the wonderful countryside, undisturbed by bomber attacks, telephone calls, visitors, and so on. Within about a year we were able to set up a “revamped” Z4 in full working order in what had once been a stable. Unlike research going on in the US, where every possible facility was available, our means were very limited.

There was no body or organization able to support our work at that time in Germany. Nevertheless, word got out abroad that some sort of machine was operating in South Bavaria. IBM/USA instructed the German firm Hollerith GmbH to see what this was all about. All sorts of promising discussions ensued about possible applications for computers in various areas. But as everything was decided on the other side of the Atlantic at the time, no contract was signed. Interest was only shown in the industrial property rights. It wasn't even possible to secure a promise that I would be able to continue work on development. At that time computers were simply not that important.

However, we did have more success with Remington-Rand, who commissioned us to continue development, initially in a special project dealing with mechanical relay technology. People didn't trust electronics fully at the time and wanted to have a second option. We ourselves were convinced that the future lay with electromagnetics and electronics. This meant working against our own convictions. Nevertheless the machine was interesting, as it became the first pipeline computer in the world—a punched-card machine with a series of mechanical adding devices using mechanical circuits incorporated between the card reader and the card punch. Multiplication was carried out by a series of adding operations. This resulted in a reasonable degree of accuracy despite the relatively slow mechanics. But the development of electronic alternatives was progressing; it was soon not worthwhile continuing with mechanical designs.

However, we were able to produce an interim solution based on our relays prior to the introduction of pure electronic machines, prototypes of which were being prepared by Remington-Rand in the US. The production run consisted of around 40 additional units for punched card machines, most of which were exported to Switzerland. About the same time, we had been able to set up the Z4 as a scientific machine in the Technical University in Zurich. Both contracts helped us reestablish the ZUSE KG company, which I founded near Bad Hersfeld in 1949 with two other partners.

The German market slowly began to develop and we started to receive orders from German companies. One of our first clients was Leitz, which, thanks to the world-famous “Leica Camera,” had the necessary financial means to purchase a computer for optics calculations. Later other optics firms followed suit, so that by the mid-1950s we had a virtual monopoly in the field of scientific computers in the optics industry in central Europe.

By that time everyone was talking about electronic machines, but their reliability still left a lot to be desired. The first were built by scientific institutes for their own special purposes, as the commercially available machines were not good enough. We were able to bridge this gap with our relay computers. One thing in our favor was land consolidation, which was in full swing in Germany at the time. Computers were needed to calculate how fields and land were to be reallocated. To this end we developed the Z11, which was later further refined and used elsewhere in urban and agricultural surveying, optics, and so forth. This machine corresponded to what the users wanted-namely, to always know how the calculation was progressing, and to have everything under complete control. In the course of time full automation led to a maze of branches and impenetrable procedures, and software became an increasingly urgent problem. We also experienced and influenced this (not always happy) development with our machines.

After some years, electronic components achieved a degree of reliability that warranted their production in large numbers. Initially we developed a tube model, the Z22, moving later to the transistorized versions Z23, Z31, and Z25. These were based on analytical code, which meant they were extremely flexible as far as programming was concerned. These were the first types of machine where general calculation using any desired data structure and program storage could be carried out. The machines were very popular with scientists and engineers, as they were excellent to play around with, and all sorts of models for the most diverse problems could be tried out. Sadly, in most cases our machines could only serve to whet people's appetites. While our clients were very short of financial means during the early years of the electronic computer, research departments were later much better funded, allowing them to purchase much bigger, more expensive equipment. Unfortunately, my firm hardly profited from this, as we were oriented towards small and mediumsized companies. Nor did we have enough capital to take part in the development of larger machines. Our Z11, Z22, and Z23 are now sought after only as collector's pieces for museums and so on.

One development, which received much impetus from specialists working in the surveying field, was the automatic drafting board. The aim was the automatic representation of various maps which had been calculated beforehand by computer. It is interesting to note that the surveyors were looking for a very high degree of accuracy and initially only wanted to plot polygon vertices. From this emerged the Graphomat, the first computer-controlled automatic drawing board. Many others were interested, too. These were our first tentative steps in the direction of CAD (computer-aided design). Little is known about this side of our work. Here, too, we found out that it is not always a good idea to be the early bird. As early as 1964 1 was involved in negotiations with a major European carpet manufacturer to build a computerized control system for a large weaving machine. I proposed that we start at the design stage of the carpet pattern. The intention was not to make the artisan redundant, but simply to give him a new tool. But this suggestion met with complete opposition from all parties concerned, and the contract failed to come off.

Competition in the computer sector became increasingly tough. Not only were the costs of hardware constantly rising, software development costs were also growing. My company with its thousand-odd employees faced growing capital shortages, making it necessary to bring in new shareholders. This led, step by step, to the company being completely taken over by Siemens.

Today, this leaves me free to devote more time to purely scientific problems, and I still work on a free-lance basis for Siemens AG, Munich. I am currently involved in computer architecture, and am particularly interested in the parallel operation of machines. Back in the 1950s I designed a machine for the meteorological office that today would be termed a “cellular computer.” Here, too, however, I was guilty of trying to run before I could walk.

Let me review a few of the ideas I have examined on paper without ever being able to turn them into reality.

“The Computing Universe” is based on the idea that the whole cosmos is a kind of cellular computer, something that some physicists are seriously considering today. This theory has yet to be confirmed, due to the lack of experimental evidence. A paper on the subject under the same title has also appeared in English.[1] I am sure the idea will gain considerable significance in the future and might help theoretical physics to solve a number of problems.

Another idea of mine was “The Self-Reproducing System.” I approached this concept differently from John von Neumann, who dealt with it using pure mathematics in the context of cellular computers. As an engineer I was more interested in setting up the conditions necessary for actual construction. In essence, the idea envisages a tool factory which is capable of reproducing its own essential component parts. This idea has met with complete opposition. People have been reluctant to consider such a radical solution for all sorts of reasons. Today traditional means of production are being automated step by step. We have yet to build the factory of the future. But one day these farsighted developments will become reality, leading to a complete revolution in the production process throughout the economy.

[1] International Journal of Theoretical Physics, 21st ed., Nos. 6-7, June 1982, p. 589.

QUOTATION

"Of one thing I am sure-computer development has still a long way to go. Young people have got plenty of work ahead of them yet!"

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UPDATES

Konrad Zuse died in 1995 (MRW, 2012).

Portrait replaced (MRW, 2013)