The Pioneer Days of Scientific Computing in Switzerland

Martin H. Gutknecht
Eidgenössische Technische Hochschule
CH-8092 Zürich

Abstract. Scientific computing was established in Switzerland by E. Stiefel, assisted by H. Rutishauser, A.P. Speiser, and others. We cover the years from the foundation of the Institute for Applied Mathematics at the ETH in 1948 to the completion of the ERMETH, the electronic computer built in this institute, in 1956/57. In this period, Stiefel's team also solved a large number of real-world computational problems on another computer, Zuse's Z4, rented by the institute. Along with this work went major contributions to numerical analysis by Rutishauser and Stiefel, and Rutishauser's seminal work on compiling programs, which was later followed by his strong commitment in ALGOL.

We have tried to include some background information and to complement H.R. Schwarz's article [Scw81] on the same subject.

1. Getting started: The foundation of the Institute for Applied Mathematics

When looking for a date marking the beginning of computer science and scientific computing in Switzerland one is soon thinking of January 1948 when the Institute for Applied Mathematics at the Swiss Federal Institute of Technology in Zurich (Eidgenössische Technische Hochschule, or, briefly, ETH) was founded under the directorship of Professor Eduard Stiefel (see Sec. 5 for Stiefel's biographical data). Up to then, Stiefel was known in the scientific world as an excellent topologist, who in his thesis written under Heinz Hopf had laid the basis for the theory of vector fields on manifolds. None of the seven papers he had published before 1948 was on numerical analysis, but in his regularly held courses in descriptive geometry he got into contact with engineers and learnt of their need for constructive and computational mathematics. Moreover, during World War II Stiefel, as an officer of the Swiss Army, had to some extent worked on computational problems. When after the war he became aware of the development of computers and algorithms in other countries, in particular the USA, he realized the scientific and economic importance of this research for a highly industrialized country, and, through his personal initiative, he achieved the foundation of the Institute for Applied Mathematics. Its aim and purpose were the introduction of scientific computing on programmable machines in Switzerland. From the beginning Stiefel was backed up in his basic decisions by a Committee for the Development of Computers in Switzerland and by the Board of Directors (Schweizerischer Schulrat) of the ETH.

At that time electronic computers were not yet on the market, but many research institutions around the world were designing and building their own machine. Some relay computers, e.g. Aiken's Mark I (1944), and at least one machine based on electron tubes, Eckert and Mauchley's ENIAC (1946), were already running. In the USA several groups of researchers competed for the biggest and the fastest machine, and the costs of some of these projects exploded. There was no chance of receiving so much money in Switzerland, therefore it was clear that in relation to these American projects a Swiss machine had to be at a Swiss scale. In fact, at the beginning Stiefel's budget was very limited, and the technical equipment of his institute consisted just of a Madas mechanical desk calculator and a Loga drum, a cylindrical instrument combining various slide rules.

But Stiefel was also a very successful administrator, who was able to acquire grant money from public and private sources and to get contracts with private industry and even with the army. In contrast to the situation in the US, the latter is quite unusual. But it is very likely that Stiefel's military career, which ended at the high rank of a colonel, was beneficial for his projects. Later, from 1958 to 1966, Stiefel also played a significant role in local politics: He was an important member of the (legislative) community council of Zurich. Thus besides being a truly innovative and highly competent mathematician in various areas Stiefel fits also into the image of the Swiss establishment as it is colorfully painted in McPhee's "Place de la Concorde Suisse" [McP84]. Clearly, being engaged and successful in so many disjoint activities required to be well organized, and Stiefel could in fact keep things running with seemingly very little effort.

When starting the institute it was of course very important to find good collaborators. In this respect, Stiefel was again highly successful: As assistants he chose the mathematician Heinz Rutishauser (see Sec. 6 for Rutishauser's biographical data) and the electrical engineer Ambros P. Speiser [1], both former students of the ETH. Rutishauser had left the ETH three years before and was working as a high school (Gymnasium) teacher, while finishing his excellent dissertation in complex analysis in his spare time. Speiser was just getting his diploma in electrical engineering with a thesis related to computers.

2. Learning from others: The trips to the USA

Although prototype computers were being constructed in various countries, the USA were clearly ahead in computer technology. Hence, it was decided that Stiefel and his two assistants should visit the USA to acquire some of the American knowhow. The following is a brief summary of Stiefel's report [St49] from the first trip, from October 18, 1948, till March 12, 1949. Rutishauser and Speiser stayed for longer, until the end of 1949.

The first stopover was at the Mathematical Center in Amsterdam, where Dr. v. Wjingarden directed the construction of a relay computer and a mechanical integrator, but provided also a scientific computing service to the Dutch industry. Next, Stiefel spent seven weeks in New York, mainly at the IBM Watson Laboratory for Scientific Computation at Columbia University (Dr. Eckert and Dr. Thomas), where he had a chance to use a large selection of IBM computing equipment. In particular, he became familiar with IBM's Selective Sequence Electronic Calculator, a computer containing some 12'000 electron tubes. In New York, Stiefel visited also the Institute for Mathematics and Mechanics at NYU (Prof. Courant, Prof. Friedrichs) and the Computation Laboratory of the National Bureau of Standards (Dr. Lowan, Dr. Salzer); both institutions were still without electronic computers, though the NBS had already published some 30 volumes of mathematical tables, mostly produced on desk calculators and IBM punched card machines, which were wide-spread computing aids at that time.

In Washington Stiefel spent two weeks at the Office of Naval Research and the National Bureau of Standards. At the ONR, Dr. Mina Rees was then Head of the Mathematics Branch. Her continuing help in the organization of Stiefel's trip, in particular, her importance for giving him access to various computers in laboratories of the Navy and the Army, are gratefully acknowledged in Stiefel's report.

It was, of course, a must to visit Boston, where at the Harvard University Prof. H. Aiken was designing his Mark III, while Mark I was running "24 hours a day and 7 days a week", as he said. During Stiefel's three weeks' visit some of this computer time was consumed by a free boundary problem submitted by Prof. G. Birkhoff. The latter informed Stiefel also of a new numerical method, which is now called successive overrelaxation! In addition, Stiefel had discussions with Prof. S. Bergmann and his group on the use of kernel functions in conformal mapping. Certainly these discussions aroused Stiefel's interest in relaxation methods, which on one hand led in cooperation with Prof. M.R. Hestenes to the conjugate gradient method [HSt52, St52a] and, on the other hand, to a series of papers by Stiefel, Rutishauser, Engeli, and Ginsburg on relaxation methods in general, and their interrelations, see in particular [St58, EGRS].

Finally, Stiefel was for two weeks at the Institute of Advanced Study in Princeton, where he tried to learn from Prof. J. von Neumann, who was at the leading edge of both theoretical computer science and hardware design. Rutishauser was left there, monitoring the work at von Neumann's computer project while Speiser was left in Boston, working on Aiken's Mark III.

Besides the stops mentioned above, Stiefel visited shortly a number of other places, either for information about computers or for giving lectures. He also spent some time in Princeton and in Chicago working on his former research subjects, geometry and continuous groups.

Throughout his trip Stiefel was highly impressed by the wide-spread use of mathematical and numerical methods in scientific, industrial, and military research, and the confidence of government and industry in this approach. He noted that this wide-spread use was not only due to the existence of large electric and electronic computers, but rather to the different American attitude towards applied mathematics. Actually, many of the computations were still done on desk calculators, punched card machines, and analog computers.

Concerning the construction of computers Stiefel had learnt that many unexpected difficulties had appeared with large machines, in particular concerning their reliability. None of the six types of memory he

[1] Ambros P. Speiser (*November 13, 1922; dipl. El.-Ing. ETH, 1948; Dr. sc. techn., 1950; Privatdozent at ETH, 1952; Prof., 1962) became in 1955 the first director of the IBM Research Laboratory in Zurich. He is now Director of Research of Brown Boveri & Cie., Baden (Switzerland). 1965-1968 he was president of IFIP.

had seen satisfied him. In his discussions with Prof. Aiken he got assured that a relatively small and slow but reliable machine could be built with a small budget, and that such a machine could nevertheless become a very useful and cost-effective tool for Swiss science and industry. A first tentative design of this machine called ERMETH (Elektronische Rechenmaschine der ETH) was worked out by Speiser in Boston and, after his return, in Zurich. It is documented in Speiser's doctoral thesis [Sp50].

Let me anticipate that from July 1951 till February 1952 Stiefel stayed once more in the USA, now mainly in Los Angeles at the Institute for Numerical Analysis of the National Bureau of Standards and at the UCLA. In his report [St 52] he again called attention to the great support for and confidence in scientific computing and to the different situation in Switzerland, where only few mathematicians had a chance of finding a job in industry, so that some of the best chose to emigrate to the USA. (Well-known examples are W. Gautschi, P. Henrici, H.J. Maehly.) Further remarks on the few possibilities for applied mathematicians in Switzerland are also found in some of Stiefel's later annual reports until 1956; afterwards the situation started to change.

Concerning Stiefel's research at NBS it is well known that he was working with M.R. Hestenes on the conjugate gradient method [GOL87, HSt52].

On this second trip Stiefel got also new information on some of the computer projects. He noted that quite a few had been abandoned, that only three of the "superfast" machines were working regularly on mathematical problems (namely SEAC at the Computation Laboratory of the NBS in Washington, Mark III at Harvard University, and Whirlwind at MIT, which had been a secret project at the time of Stiefel's first trip). In particular, von Neumann's EDVAC was still not working. (It became operational in 1952.) So, Stiefel was confirmed in his opinion that the ERMETH should be simple and reliable.

3. Computing on the Z4

When in Spring 1949 Stiefel came back from his first trip to the USA he anticipated that the design and the construction of the ERMETH would take several years. In order to promote numerical computations with his institute he needed some other equipment that was immediately available. He first thought of renting IBM punched card machines [St49]. But then he learnt that the German Konrad Zuse had been able to save one of his relay computers, the Z4, through the devastating time at the end of World War II by hiding it in a cow stable at Hopferau in the Bavarian alps. After inspecting the Z4 there on July 13, 1949, Stiefel and Zuse worked out a lease: ETH rented the Z4 for a period of five years for a total of SFr. 30'000.

Konrad Zuse (*June 22, 1910) was a highly gifted civil engineer who had started to design and assemble a mechanical computer called Z1 in his parents' living room in Berlin in 1936. Its logical design was far ahead of the time. Zuse's basic concept, although not yet fully implemented in the Z1, included full programmability and remained the same up to the Z4. The basic number representation was already in binary floating-point. However, due to the limited accuracy of the mechanical parts the Z1 was never fully operational. But after replacing the processor by one built from relays, Zuse had a working computer, the Z2, in 1939. Two years later Zuse finished the Z3, which contained in its processor and its memory some 2600 relays and which many experts consider as the first programmable computer worldwide. The next model, the Z4 rented by Stiefel, was constructed from 1942 till 1945. It contained some 2200 relays and worked with normalized 32-bit binary floating-point numbers with 22-bit mantissa. A multiplication took 2.5 to 3 seconds. The program was read from two switchable punched tape readers. The Z4 was more powerful than the Z3, although it had again a mechanical memory (for 64 numbers). Old movie films were used as tapes, so there was a minimum of entertainment for the people operating the machine. (Although they did not have a projector!)

After 1950 Zuse kept on designing computers and some of them were fairly successful on the small German market. Zuse's work is well documented by his autobiography [Zus70] and the references listed there. The Z4, which is now exhibited in the Institute of History of Siemens in Munich, is also described in [Eng81, Scw81, Sp50a, St53, St54a]. Among the many interesting features we mention the unique handling of the value infinity and the hardware division based on Zuse's own ingenious algorithm, cf. Rutishauser et al. [RSS51]. Zuse made also a seminal early contribution to programming by formulating algorithms in his "Plankalkül" [Eng81, Zus48, Zus59].

Before its delivery to Zurich the Z4 had to be repaired and overhauled. Also, on proposal of Stiefel and his team conditional instructions were included. After its installation in August 1950, which was followed by some further servicing work, the Z4 proved extremely reliable, except for some gradually growing problems with mechanical parts, in particular the memory. Typically the Z4 was running day and night at the ETH, often unattended when working on a long job. The list of 55 projects that have been performed on it until its removal in April 1955 contain an amazing variety of subjects, e.g., a forth order PDE for the tensions in a dam, the eigenvalues of an 8×8 matrix from quantum chemistry determined by inverse iteration, a linear system with 106 unknowns, which came from a plate problem, solved by the conjugate gradient method, ODEs modelling rocket trajectories, and so on. Some of these projects are described in the excellent survey by Schwarz [Scw81], who himself together with Dr. U. Hochstrasser was doing some of the most time-consuming computations, which were related to the design of a Swiss supersonic military aircraft [Hoc55, Scw56].

Of course, numerical experiments related to the basic numerical analysis research performed at the ETH at that time were also run on the Z4. For example, after Stiefel had returned from his second US trip, Lanczos's eigenvalue method [Ru53] and the conjugate gradient method of Hestenes and Stiefel [HS52] were coded. One must further mention Rutishauser's early investigations on the stability of numerical methods for initial value problems of ODEs [Ru52a], Rutishauser's qd-algorithm and LR-transform [Ru57], and H.J. Maehly's polynomial root finder [Mae54].

For some sparse matrix problems the code for the Z4 was extremely long (up to 6000 instructions) since there was no provision for address computation and thus the actual addresses of the nonzero elements in the matrix had to be used when calculating a sparse matrix vector product. To simplify the preparation of such codes, Rutishauser developed a program for computing these addresses and for producing the corresponding section of the code, see Schwarz [Scw81, Sec. 4] for more details. This, however, was just the beginning of his seminal work on "automatic coding" ("automatische Rechenplanfertigung"), the first peak of which is Rutishauser's Habilitation thesis [Ru52], in which he described in full detail a method for compiling the machine code for a certain problem by the computer itself from the mathematical formulas. He allowed for expressions with arbitrary levels of brackets and for loops with bounds depending on the data. Moreover, he discusses the loop unrolling (which nowadays receives much attention on vector computers). His examples include a program for solving a linear system by computing the LU decomposition column by column and then substituting forward and backward. Except from the fact that the keywords are in German, the program looks already like the body of an ALGOL procedure.

4. Constructing the ERMETH

While all this basic research and all these computations on the Z4 were going on, Stiefel's gradually growing group was also working hard on the design and the construction of the ERMETH. Speiser, since 1952 also Privatdozent (his habilitation thesis [Sp51] was on analog computers), was the technical director leading a group of five engineers and three mechanics. On the other hand, Rutishauser worked on the logical organization and its interrelation to his "automatic coding". It was in early 1953 only that it was decided to go for the electron tube technology instead of using relays. But by the end of the same year, the year when Rutishauser also worked out the qd-algorithm, the basic logical organization and the design of the arithmetical unit were close to being completed, and so was a prototype electronic memory, which was attached to the Z4 to replace the no longer satisfactory mechanical memory. However, to work out all the details of the ERMETH, to have the electronic and some of the mechanical parts manufactured by private companies, and to actually assemble the machine took another two and a half years. In July 1956 it was running for the first time, but still with a second prototype memory. In 1955 the Institute came in difficulties since Rutishauser had health problems and Speiser left for taking over the IBM Research Laboratory in Zurich. The electrical engineer Alfred Schai became the new director of the technical group completing the ERMETH; he is still the director of the Computer Center at the ETH. There were in particular problems with the large magnetic drum memory, which finally was installed in 1957. At the end of 1958 the cost for the ERMETH had accumulated to one million Swiss francs.

The ERMETH worked with 16-digit decimal words, each of which contained two instructions, one 14-digit fixed point number, or one floating-point number with 11 digit mantissa. A floating-point addition took 4 ms, a multiplication 18 ms. The magnetic drum could store 10'000 words. Hence, for the time the machine was not very fast, but it had a remarkably large memory. The machine contained some 1900 electron tubes and some 7000 germanium diodes. For more details see Schwarz [Scw81], who also discusses some of the applications and numerical investigations that were run on the machine. Schwarz moreover describes the most important development of the programming language ALGOL, in the basic design of which, I think it is fair to say, Rutishauser had a leading role. Schwarz himself wrote the ALGOL compiler for the ERMETH.

Among the contemporary articles on the ERMETH we mention [Sca57, Scl54, Sp54, S54a, Sp56, Sto54, Sto56]. There exist also a few copies of a manual [ERM58].

The ERMETH was in use at the ETH until 1963. The machine is now on display at the Technorama in Winterthur.

We conclude this article with short profiles of the two distinguished numerical analysts involved: Eduard Stiefel and Heinz Rutishauser.

5. Eduard Stiefel (1909-1978)

Biographical data: Born April 21, 1909, in Zurich. 1928-1932 student at ETH, 1932 diploma in mathematics, 1932/33 visiting positions at the universities of Hamburg and Göttingen, then assistant at ETH, 1936 lecturer. 1939 marriage with Jeannette Beltrami. 1942 Privatdozent, 1943 full professor at ETH. From 1948 director of the new Institute for Applied Mathematics at ETH. 1956/57 president of the Swiss Mathematical Society, 1958-1966 community councilman, city of Zurich, 1970-1974 president of GAMM. 1971 Dr. h.c. of the University of Louvain, 1974 Dr. h.c. of the University of Würzburg and the University of Braunschweig. † November 25, 1978.

Outline of his work: Stiefel's list of publications is published in a memorial issue of the Zeitschrift für Angewandte Mathematik und Physik, Vol. 30, No. 2 (1979). This issue also contains Stiefel's own comments on the list and a profile written by J. Waldvogel, U. Kirchgraber, H.R. Schwarz, and P. Henrici. In his comments on the bibliography, Stiefel devides his work into five periods:

1. Topology
2. Group theory and representation of groups
3. Numerical linear algebra
4. Numerical methods in approximation
5. Analytical methods in mechanics, especially celestial mechanics.

In all of these areas Stiefel made truly original and fundamental contributions. In fact, even as a newcomer to a field he was able to find a solution to some important basic problem, and in retrospect Stiefel's solution was simple and surprising at the same time.

With respect to scientific computation period 3 is the most important, but periods 4 and 5 must not be overlooked. The paramount contribution to numerical linear algebra is of course the conjugate gradient algorithm introduced in the joint paper with M.R. Hestenes [HSt52] and further investigated in a series of papers, in particular [St52a, St58]. However, one should also mention Stiefel's promotion of using variational principles for deriving the linear system from the physical problem [EGRS]. With this approach he put difference methods on a common basis with the finite element method.

Stiefel's period in approximation theory, although considered "less fruitful" by Stiefel himself, features the introduction of the single exchange version of the Remez algorithm and the proof of its equivalence with the simplex method, if the latter is applied to the discrete linear Chebyshev approximation problem [St59, St60]. The highlight of the fifth period is the introduction of the KS-transform (jointly with P. Kustanheimo) for regularizing Kepler's differential equation of celestial mechanics [KSt65].

6. Heinz Rutishauser (1918-1970)

Biographical data: Born January 30, 1918, in Weinfelden (Thurgau). 1936-1942 student at ETH, 1942 diploma in mathematics, 1942-1945 assistant at ETH, 1945-1948 Gymnasium teacher in Glarisegg and Trogen. 1949 Marriage with Margrit Wirz. 1948/49 New York and Princeton, 1949-1955 research associate at the new Institute of Applied Mathematics at ETH. 1951 Privatdozent, 1955 associate professor, 1962 full professor at ETH. From 1968 director of the computer science group at ETH. † November 10, 1970.

Outline of his work: Rutishauser's list of publications is contained in Research Report 82-01 of the Seminar für Angewandte Mathematik at ETH.

Rutishauser has come up with several of the most important ideas in numerical analysis and programming. In his Habilitation thesis [Ru52] he described the automatic compilation of a suitably formulated algorithm and thus introduced the concept of what is now known as compiler. Later his ideas on how to formulate algorithms have left traces in the design of ALGOL, for which he committed himself strongly [Ru67].

In numerical analysis Rutishauser's name is first of all forever linked with eigenvalue computations: The qd algorithm [Ru57, Ru63b, Ru76 (Appendix)] was meant for it, and so was its generalization, the LR transform, the basic principle of which reappeared later in the QR algorithm of Francis. This is also true with respect to spectral shifts, where Rutishauser found a cubicly convergent variant of the LR transform [Ru60]. Another truly original proposal is his algorithm, based on Jacobi rotations, for the reduction of band matrices to tridiagonal form [Ru63].

But Rutishauser contributed also to a number of other areas of numerical analysis. We mention his early work on the instability of methods for solving ODEs [Ru52a], his general definition and survey of "gradient methods" for linear equations [EGRS] (in this paper he also introduced a preconditioned conjugate gradient algorithm), his application of Romberg extrapolation to the notoriously difficult problem of numerical differentiation [Ru63a], his thoughts on the regularization of the nearly rank-deficient least squares problem [Ru68], his contribution to a survey of interpolation, quadrature, and approximation [SaS68 (Chapters H and I.II)], and his ideas on finding polynomial zeros [Ru69]. (These ideas have been completed in Kellenberger's dissertation [Kel71].) Finally one should mention Rutishauser's unfinished pioneering work on axioms for a reasonable computer arithmetic [Ru76 (Appendix)].

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