Compiling SIMULA: A Historical Study of Technological Genesis

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This article traces the history of the programming language SIMULA from the 1950s into the 1970s, focusing in particular on the formative years between 1962 and 1967. It offers no technical appraisal of the language per se. Rather, it is a sociotechnical analysis aimed at exploring the broader history of the SIMULA project. The article asserts that technological change should be studied in a contextual perspective. Thus the politics surrounding the project and the prehistory of SIMULA are given ample attention.

The SIMULA programming language was designed by Ole-Johan Dahl and Kristen Nygaard at the Norwegian Computing Centre (NCC) in Oslo between 1962 and 1967. It was originally implemented as a language for discrete event simulation, but was later expanded and reimplemented as a general-purpose programming language. Although it never became widely used, the language has been highly influential on modern programming methodology. Among other things, SIMULA introduced important object-oriented programming concepts like classes and objects, inheritance, and dynamic binding.

This article seeks to explore the wider history of the SIMULA project. By means of a contextual approach to history, it attempts to weave together the technical development of the language with what is normally seen as its social, economic, and political context. Thus, this article is a sociotechnical analysis, where the main concern is to investigate the heterogeneity of technological genesis.

As the historian of technology Thomas Hughes[1,2] has shown in his remarkable studies of Edison and others, technologists often pay little attention to commonly accepted knowledge categories or professional boundaries. He observes that they, in order to accomplish their aims, frequently transcend the limits of what is normally considered technical or scientific, and that they habitually amalgamate matters commonly labeled social, economical, or political with matters technical and scientific. Thus, for Hughes, technologists are heterogeneous professionals, and their interaction with the wider sociotechnical context to which they relate their work becomes the prime focus of interest. His principal argument, in effect, is that one cannot fully comprehend the complex processes of technological and scientific change unless one recognizes that problem-solving technologists see the above analytical categories as going together as a thoroughly integrated whole — that is, composing a seamless web, to use Hughes' own terminology. In accordance with this, he challenges us to "follow the actors" and seek explanations for technological and scientific change beyond the narrow internalist narrative of technical development.[3,4]

As this article aims to show, the construction of SIMULA was indeed an effort that required a high degree of heterogeneous engineering on the part of the two principals, Dahl and Nygaard. The first few sections take us briefly through the prehistory of the language, focusing especially on Dahl and Nygaard's different professional experience — in informatics and operations research in the 1950s. The main portion of the article is largely devoted to a discussion of how the language was constructed and implemented. In line with what has been stated above, the analysis attempts to incorporate a sociotechnical approach to history, and thus several "non-technical" aspects of the project are dealt with in some detail. The closing sections provide a brief survey of some of the most significant SIMULA implementations surfacing in the 1970s, as well as a commentary on NCC's SIMULA engagement in this period.

By the early 1950s, the new technological developments in the field of machine-aided computation and electronic information processing had really begun to show their potential. With regard to computer programming methodology, advances in several areas were about to open up an entirely new field of research characterized by the distinguished American computer scientist Alan Perlis as:

> ...the study of the phenomena arising around computers, and in particular, the study of symbol systems that spring into existence on computers in response to phenomena.[5]

The general opinion was that it was highly essential for Norway to take part in this development, and various measures were taken toward this aim.[6,7]

The Norwegian Computing Centre

Toward the end of 1951, the Advisory Committee for Computing Machinery under the Royal Norwegian Council for Scientific and Industrial Research, NTNF, proposed the establishment of a Norwegian Computing Centre. To a large extent, this initiative was motivated by the desire to constitute a central agency that could coordinate and facilitate the distribution of computing power among Norwegian industry and academia. From a main center of operation located at the recently established Central Institute for Industrial Research in Oslo, the new computing center was supposed to form the backbone in a network of smaller, regional units located at various research institutions throughout the country, like the Norwegian Defence Research Establishment, the Agricultural University of Norway, the University of Bergen, and the Norwegian Institute of Technology in Trondheim.[8]

NTNF, hereafter also called the Research Council, quickly approved the committee's proposal, and in January 1952 the Norwegian Computing Centre was formally established. The reasons why the Research Council gave such a speedy consent probably had less to do with the intentions denoted above, than with the need for an operational unit which could assume the task of running Norway's first electronic digital computer, called NUSSE (Numerical Universal Automatic Sequential Electronic Computer), which at the time was being built at the Central Institute for Industrial Research. This vacuum-tube machine, based on an original design by Dr. A.D. Booth, was completed in 1954 and immediately put to use by the Norwegian Computing Centre.

The Norwegian Defense Research Establishment

Whereas the NCC pretty much remained a conventional computing center throughout the 1950s, significant contributions in informatics research were already being made at the Norwegian Defense Research Establishment (NDRE). Here, a group of young students and research scientists under the leadership of Jan Garwick came to be highly instrumental in the inception of informatics in Norway.

Jan Garwick had come to NDRE from the Department of Astrophysics at the University of Oslo in 1947.[9,10] Before the war this department had been the country's leader in scientific computing, due to the efforts of Professor Svein Rosseland who, in 1934, had initiated and supervised the construction of the first Norwegian differential analyzer, and who, for many years, would be a sustained driving force for the adoption and use of computers in Norway.

When Garwick came to NDRE in 1947, his assignment was to build up a mathematics section and a military computing center. To this end, he wanted modern digital computing equipment and, in collaboration with researchers from the University of Oslo and the Central Institute for Industrial Research (in 1949), he offered to work on plans for the development of a relay calculator. Although there clearly was a need for such equipment in Norway (for example, in nuclear engineering), the project was never carried through. This was partly because of problems in acquiring reliable relays and partly because the electromechanical technology soon came to be regarded as out of date, compared with the emerging electronic designs like the EDSAC. Inspired by a Dutch design based on the decimal system, he then devised plans for an electronic digital computer called UNIDECA. The plans for this project were first presented in 1952, but for reasons that we shall return to shortly, the project was later discontinued.

In parallel with these projects, Garwick and his team also engaged in a number of other activities, among them the construction of a card-programmed electromechanical computer based on an extension of a regular Bull punched-card calculator. When completed in 1953, this machine was in fact the first programmable computer in Norway, and as such it contributed significantly to early insights into the problems and methods of computer programming.

In 1954 the Norwegian Intelligence Service and the British computer manufacturer Ferranti entered a contract on a delay-line computer to be installed at NDRE. Against this new background, the rationale for Garwick's own project changed completely, and it was later abandoned altogether. When the Ferranti Mercury computer was ordered in 1954, it was still in the design and construction stage, and would not be operational until the summer of 1957. In the meantime, Garwick and his team commenced work on developing systems and software for the new machine. On several occasions he went to England to present his ideas for improvements of the Mercury instruction set, and together with Dahl, a young mathematics and physics student who in 1952 had come to NDRE as a soldier (conscript), he later developed and implemented an assembly system for the Mercury called DIP (Decimal Input Programme).

Toward the end of the 1950s, Dahl had become one of the leading Norwegian experts on computer programming, and with the advent of high-level programming he was soon enticed into this line of research. In cooperation with Garwick, he started developing plans for a high-level programming language, and encouraged by the first Algol reports, he subsequently built a compiler called MAC (Mercury Automatic Coding — not to be confused with the British project of the same name).[11-13]

Operations research and the advent of Monte Carlo simulation

While in England during World War II, Gunnar Randers had come across the new field of operations research, and after his return to Norway, had made a few unsuccessful attempts to establish this field of research at NDRE. In the early 1950s, Garwick restlessly moved on to other projects, and in 1952 the operations research project was handed over to his assistant, Nygaard.[14,15]

Like Dahl, Nygaard came to NDRE, in 1948, to do his military service as an assistant to Jan Garwick. One of the first contracts he received was to plan for the future, and this gradually came to be the basis for many of the ideas which later resulted in the conception of SIMULA. At the Institute for Atomic Energy Research (IFA),[16] a team directed by Gunnar Randers was in the process of constructing Norway's first nuclear reactor called JEEP-I (Joint Enterprise Experimental Pile). This large and prestigious project involved numerous complex calculations — among other things, calculations of resonance absorption — and during 1949 and 1950 Garwick and Nygaard were enlisted to work on this project. After having invested a lot of time and effort trying to solve the problems through traditional numerical approaches, Garwick eventually suggested that they instead should try the new Monte Carlo simulation technique. In subsequent efforts this new method soon yielded results, and to everyone's surprise, with a few months of "game playing" the task was successfully accomplished.

In 1952 Nygaard left the computing center and became a full-time operations research analyst. His experiences using Monte Carlo simulation had shown him the applicability of this approach, and during the 1950s he devoted a lot of time to this technique. In 1956, he was also put in charge of operations research at NDRE and had, by 1960, become one of the foremost operations research specialists in Norway.

Pulling the threads together

Since he first started working with operations research back in 1952, Nygaard had been constantly concerned with ways to conceptualize complex real-world systems. One of the major problems he encountered was how to describe the heterogeneity of a system and its operation. In the 1950s, modeling of such systems was usually done through means of symbol notation, that is, flow diagrams accompanied by an account of the rules governing the operations of the system.[17] Monte Carlo simulation had proved to be a serviceable tool for analysis of these models, and when the Ferranti Mercury was eventually installed at NDRE in 1957, Nygaard and his team immediately started to write simulation programs.

Encouraged by the promising prospects of computer-aided simulation, Nygaard soon started to think about how he could formalize the procedures for systems description in a way that would allow standardized concepts to be easily processed by a computer. In 1961, a fragmentary and rather vague set of ideas, also referred to as the Monte Carlo compiler, began to take shape, and, as we shall see shortly, the technical basis for the SIMULA language was molded.[18]

As SIMULA was intended from the very outset to be simultaneously a systems description and a programming language, its construction would require both systems reasoning and programming skills. Even though Nygaard had some experience with computer programming at NDRE (before he was assigned to operations research in 1952), he did not have sufficient experience or knowledge to undertake a task like this on his own. He was compelled to recruit programming expertise from outside, and one of the best allies he could get, besides Garwick, was Dahl. During the spring of 1962 they joined in a series of discussions, which in May 1962 resulted in the first formal language proposal.

SIMULA — A language for the description of discrete event networks

The early approach to SIMULA was, to a large extent, based on Nygaard's ideas of a mathematically formulated network consisting of active stations serving a flow of passive customers. These stations consisted of a queue and a service part; the actions associated with the service part were described by a sequence of formalized statements. The customers possessed no similar operating rules, but were instead described through a sequence of variables called characteristics. A customer was supposed to be generated by the service part of a given station, then be transferred to the queue part of another station, and subsequently to the service part of that station. Here the customer was "served" and then passed on to the next station in the network, and so on, until it ultimately disappeared by not being transferred any further. The actions taken by the stations were regarded as instantaneous, occurring at discrete points in time, and accordingly, this class of system was called a discrete event network.[18]

Dahl and Nygaard realized that, if SIMULA was to become a real programming language and not just a "paper language," they would have to join forces with one of the dominant programming languages.

The intention was to build the language around a fairly general mathematical structure. A salient point at this stage was whether they should construct their language structure from scratch or adapt their concepts to an already existing one. Dahl and Nygaard realized early on that, if SIMULA was to become a real programming language and not just another academic "paper language," they would have to join forces with one of the dominant programming languages. In the early 1960s, Algol 60 was the leading programming language in Europe. The elegant and powerful concepts of this language appealed to Dahl and Nygaard, and made it, in their opinion, the perfect match for SIMULA.[12] The crucial decision of linking SIMULA to Algol 60 was made during the spring of 1962, and would later prove to be both an enormous strength and a serious obstacle. We will return to these issues later on, but for the time being let us just establish that Algol 60 came to constitute a decisive technical stronghold for the SIMULA project.

A new deal for NCC

While NDRE established itself as the leader in Norwegian informatics research in the 1950s, NCC was on the sidelines. From 1954, NCC's primary task had been running NUSSE, but when the far more powerful Ferranti Mercury came to Norway in 1957, this machine became obsolete. As for the intended network backbone function, this never really amounted to more than a modest effort, and thus the whole idea petered out. For these reasons, NCC needed to be revitalized and, when the Central Bureau of Statistics acquired a Deuce computer from English Electric in 1958, NCC was given the task of running this machine. The new assignment led to a reorganization and a new mandate to function as a contract institute for computing — doing numerical and statistical computing for public agencies and industry.[19]

Around 1960, however, it became apparent that NCC was not capable of fulfilling these obligations. The amount of work had increased rapidly, whereas the utilization of the Deuce did not live up to expectations, due to a combination of technical problems and a profound lack of qualified personnel.[20] It soon became apparent to the parties involved that something had to be done. In the spring of 1960, as a first step in strengthening NCC, its board decided to restate the center's objectives and impose a more researchlike profile.

Toward the end of the 1950s, Nygaard had found working at NDRE increasingly difficult. The main reason was that the management had wanted him to reorganize the operations research activities in a way that he, from a professional point of view, strongly opposed. As time went on, this controversy evolved into a bitter personal conflict between Nygaard and NDRE's director, Finn Lied. Thus, when Nygaard was offered a new post at NCC in May 1960, he quickly accepted. In line with NCC's intentions, his new assignment was chiefly to build up a civilian operations research unit, and to accomplish this he brought along six members of his previous operations research team from NDRE.

To NDRE, this initially came as a severe blow, since a large number of its operations research specialists suddenly disappeared. NDRE had realized that some staff would be leaving and, as soon as matters were settled, expanded its operations research efforts relatively quickly. In the long run, however, this event resulted in far more serious consequences for the institute's informatics research activities. At the same time as Nygaard and his group left in 1960, Dahl gradually became associated with the SIMULA project at NCC, and Jan Garwick later moved to the US. Thus, much of the expertise that had been built up disappeared. The effect of these changes in personnel was that NCC took over as the leading milieu in informatics in Norway in the 1960s.[7,15,21]

As stated above, the Deuce had seriously affected NCC's ability to execute its commissions, and by 1961 it was clear that this had a decisive negative impact on the center's financial credibility. Notable financial deficiencies had been recorded in both 1959 and 1960,[22] and the prospects for 1961 did not indicate any immediate improvement. What this demonstrated was the necessity of a highly qualified and professional staff, and in this respect the introduction of operations research in 1960 soon proved to be a step in the right direction. Furthermore, it had also revealed NCC's profound need for a new computer that would improve the institute's capacity to fulfill its mandate.

The computer question

The event that would eventually represent the solution to NCC's hardware problems occurred in 1962, and would incidentally also finally propel the SIMULA project from a paper to a real environment. In April 1961, the NCC received an informal proposal from the Danish Computing Centre in Copenhagen regarding possible future cooperation.[20] At the time, the director of the Danish Computing Centre, Nils Ivar Beck, had ideas for a large network of Scandinavian computing centers called the Scandinavian Electronic System. According to the Danish proposition, NCC could, within a few years, become part of this network, and would, in the short run, benefit from such cooperation in several ways. From the point of view of NTNF and NCC's board, the Danish proposition seemed to offer the ideal solution to NCC's most immediate problems, and after a few preliminary meetings during 1961, informal relations between the two computing centers were established.

From Nygaard's point of view, it was tacitly understood that when he and NCC's director, Bjørn Ørjansen, were given the task of drawing up a report on NCC's immediate computer needs, they would conclude by recommending a GIER computer from the Danish Computing Centre.[15] The GIER was a recognized medium-size computer, but in their opinion not the ideal solution for NCC's immediate needs, nor a major benefit to Norwegian informatics in the long run. What they wanted was a real mainframe like English Electric's KDF-9. However, this computer was far beyond NCC's financial reach, and consequently they settled for the GIER. Based on the conclusions in the Nygaard and Ørjansen report, NTNF decided in February 1962 that NCC should order a GIER from Denmark, and granted 2 million NKr ($280,112*) for this purpose.[23]

This was roughly the situation when another important actor, the Univac Division of the Sperry Rand Corporation, entered the stage toward the end of May 1962. In connection with the marketing of their brand-new computers UNIVAC III and UNIVAC 1107, the company arranged an executive tour to the United States for prospective European customers. Nygaard was invited to participate on behalf of NCC.[24]

At this point, let us briefly recapitulate the status of the SIMULA project. As mentioned earlier, the SIMULA concept had, by May 1962, reached a state of semimaturity, and Dahl and Nygaard felt that they now had a presentable language concept in hand. The preliminary groundwork was done, and it was time to seek out financial resources. As reported by Dahl and Nygaard in 1981,[18] there was no initial enthusiasm for SIMULA in NCC's environment, other than the valuable moral support given by the board of NCC. The main objection was that there would be no use for a programming language like SIMULA, and if by any chance there was, such a language certainly existed already. Furthermore, it was asserted that Dahl and Nygaard's ideas were not good enough, and that, in general, they lacked the competence needed to embark upon such an extensive project, which for these reasons would never be completed. Finally, it was maintained that this kind of work should not be performed in small countries like Norway. From these statements, it should be evident that gathering financial support from the Research Council would indeed be a difficult and protracted mission.

Fortunately though, other options existed and, in an attempt to leverage Univac's sales mission, Nygaard decided to introduce SIMULA to the Americans. As soon as the party arrived in New York, he contacted the Univac Europe representative, James W. Nickitas, and presented him with

* All US dollar figures in this article are based on US-Norwegian exchange rates listed in *Historical Statistics 1978*, p. 513.

SIMULA and another NCC software project on linear programming. Nickitas found Nygaard's ideas interesting and agreed to set up a meeting with a few influential representatives from Univac's software division. Present at this meeting was Univac's director of systems programming, Robert Bemer, who had previously been a key person at IBM. Bemer had been an Algol 60 fan and, at one point, while still at IBM, he had tried to replace Fortran with Algol 60. As he listened to Nygaard explaining his ideas for an Algol-based simulation language, he became more and more convinced that SIMULA's sophisticated simulation facilities would significantly benefit Algol 60 in its struggle with Fortran.[25]

By the end of the meeting, Nikitas announced that he was to chair a session at the IFIP 1962 World Congress in Munich, and that he very much wanted a presentation of SIMULA for this occasion. Nygaard immediately accepted this offer.[26] The presentation of SIMULA at the IFIP conference implied an important step toward consolidation of the language concepts. Furthermore, it offered a suitable setting for the introduction of SIMULA, and simultaneously provided Dahl and Nygaard with an important entry to the distinguished community of computer professionals.

Even though Nygaard had managed to draw professional attention to SIMULA, the vital question of financial support was still unsettled. At this point, however, Univac started to move. In connection with the marketing of the UNIVAC 1107, the company needed a demonstration site in Europe as soon as possible. Nygaard must have made quite an impression on the Univac people and really succeeded in convincing them of the NCC's professional qualities because, upon his return to Norway, Nickitas approached him with an informal proposal for Univac to establish a demonstration site at the NCC. The deal was that the site would serve promotional purposes for Univac, and NCC would get a 50 percent discount on an eventual purchase. In return for this generous offer, however, Univac wanted NCC to provide it with SIMULA and an implementation of the linear programming system developed by Sverre Spurkland.[18]

A new and powerful ally

When Univac made its appearance, the conditions for the SIMULA project changed considerably. Through its initiative, Univac had altered the terms by linking the development of SIMULA to NCC's computer acquisition. It is worth noting that Univac knew that NCC had already ordered a GIER computer from Denmark.[18] In this regard, their initiative must be understood as an attempt to circumvent the GIER order by offering NCC a better contract. However, their strategy was more subtle than this. In addition to favorable economic conditions, it also implied inside collaboration. By claiming implementations of SIMULA and the linear programming package in return for their computer offer, they clearly aimed at enlisting Nygaard as their ally and inside man in Norway.

From Nygaard's point of view, Univac's initiative must really have had an appealing sound: first of all, because the UNIVAC 1107 would provide a far better environment for the development of a SIMULA compiler than the GIER. Even today, high-precision Monte Carlo modeling and simulation are highly CPU intensive tasks where three-hour supercomputer runs are not uncommon.[27] Another aspect that must also have attracted Nygaard was Univac's conspicuous marketing position and worldwide distribution network. By being associated with a powerful computer like the 1107, SIMULA would be launched onto the world market as standard software on a scale that NCC would never have accomplished.[15] However, the most important aspect was probably the prospect of NCC taking on the development costs related to the SIMULA project.

As Bemer listened to Nygaard's ideas for an Algol-based simulation language, he became convinced that SIMULA's sophisticated simulation facilities would benefit Algol 60 in its struggle with Fortran.

In a broader context, a number of other elements might also have influenced Nygaard's reasoning. From the preceding description it should be apparent that Nygaard was quite an ambitious man, and that his professional aspirations were largely linked to NCC's position as a research center in informatics. In this respect he must have judged the possibilities of attaining a computer like the 1107 (among the ultimate solutions in high-tech computer technology in the 1960s) as a God-given opportunity to fortify Norwegian informatics, and undoubtedly his own professional prestige simultaneously. In any case, it was obvious that Univac would constitute a formidable stronghold for the SIMULA project, and that Nygaard and Univac had common interests in this case, even though they pursued different goals.

Negotiating for the Univac-SIMULA deal

Back in Norway, Nygaard's mission was to canvass opinion for the Univac proposal at NCC and within NTNF. Since the Research Council had already ordered the GIER computer from Denmark, efforts had to be aimed at converting their interests in this case. Toward midsummer of 1962, Luthar Harr, director of Univac Europe; Stig Wallstam, director of Univac Scandinavia; and James Nickitas came to Norway to announce their formal proposal. In connection with this, members of the board of NCC together with a few influential people within the Research Council were invited to a meeting with the Univac representatives. At this meeting, Univac came up with an offer which meant that NCC could acquire an 1107 at a 50 percent discount, or approximately 7.1 million NKr ($991,400).[28,29]

During the discussions, however, the Univac representatives got the notion that the computer configuration in question was seen as too large and thus too expensive. So in an attempt to make it more appealing to the Norwegians, they decided to extend their offer. In the subsequent discussions, they revealed that they would be willing to offer NCC a software contract on SIMULA and the linear programming package. This unexpected offer, seemingly an improvised attempt to entice NCC and Nygaard in particular, was actually an ace that they had been hiding all along in an attempt to get SIMULA for free. At the time, the head of Univac Systems Programming, Robert Bemer, had a yearly budget of about $8 million, 5 percent of which was discretionary money that he could spend on whatever projects he found worth doing. Since the SIMULA project, in his opinion, was very much worth doing, he had already authorized the necessary funding for the project.[25,30] Evidence of Univac's sustained interest in SIMULA is found in a letter from Univac to Nygaard dated October 23, 1964:

> A major reason for our interest in SIMULA is that we wish to establish a strong systems simulation capability for our own use here in St. Paul. We have been evaluating alternative approaches and your material (progress reports and specifications on SIMULA) is being studied with considerable interest.[31]

The new initiative implied a closer link between SIMULA's destiny and the outcome of Univac's sales mission, and for Nygaard this must undoubtedly have been a vital spur for further engagement.

The American offer had a strict time limit attached to it, and the deadline for acceptance was August 1, 1962. Later, this deadline was postponed until October 1, and delivery stipulated for March 1963. In July, NTNF's working committee decided to take the 1107 question under deliberation, and Nygaard was given the task of drawing up a report on the subject. In this report, Nygaard, not surprisingly, concluded that an eventual purchase of a UNIVAC 1107 could be justified. He argued that the needs for computing power in research, public agencies, private commerce, and various industries were rapidly increasing, and that a computer like the 1107 would indeed cater to present as well as future needs. Another asset was the fact that Univac's offer was approximately 2.5 million NKr ($350,140) less than the competitors' (IBM's and English Electric's) quotations.[23]

NTNF's working committee handled the Univac case at meetings held on August 21 and September 12, 1963. The committee members were generally in favor of the conclusions in Nygaard's report, that is, with the minor exception of NDRE's director, Finn Lied. Lied pointed out that it would be an unfortunate development if NCC were to expand its staff by recruiting expertise from other similar institutions. He was also concerned that the acquisition of a large and expensive computer like the UNIVAC 1107 would jeopardize NDRE's chances of getting a similar computer in the near future. However, despite his concern, he did not choose to dissent in this case. As for the canceling of the GIER order, this proved to be rather more difficult than at first assumed. However, after a few rounds of negotiations during the spring of 1963, the problem was eventually solved, and NTNF's total losses amounted to a mere 8,000 NKr ($1,117).[32]

When the contract between NTNF and Univac was signed on October 24, 1962, the software systems to accompany the computer were not yet ready. However, Univac assured NTNF, through a penal clause in the contract, that these systems would be available by the time the 1107 was delivered. The original delivery date was set for March 1963, but for various reasons was later postponed. When the computer eventually arrived, in August 1963, it became apparent that the software systems provided did not meet the standards promised by Univac. This situation did not improve and, by March 1964, the NCC had accumulated a claim on Univac amounting to approximately 1.8 million NKr ($250,000). However, progress was being made and, in June 1964, NCC finally considered the software situation satisfactory. By then NCC's standing claim on Univac was substantial and, to maintain friendly terms with Univac, the NCC agreed to accept an upgrade of the hardware configuration instead of a cash payment. In short, this meant that NCC got a very powerful computer configuration on exceedingly favorable terms.[6,33]

The Department for Special Projects

The SIMULA project now finally seemed to be under way. The vital financial question was at last settled, and the technical premises fairly well clarified. However, despite these promising conditions, it would still take close to a year before the development of SIMULA really took off. The reason for this seemingly unexpected delay is partly technical and partly political — and clearly shows how science and research are largely dependent on external premises.

Ever since Univac's offer was first known to NTNF in June 1962, it had emphasized the fact that an engagement involving such a heavy investment would necessarily imply that the bulk of NCC's available resources had to be directed strictly toward the business side of the institute's activities.[34] Since NCC operated largely on a reimbursement basis, this meant that activities constituting sources of income had to be given top priority. In this respect it can be asserted that the UNIVAC 1107 came to represent a double-edged sword, at least as far as basic research activities were concerned. It is somewhat difficult to establish exactly how this situation might have affected the development of SIMULA, since the SIMULA project was financed by Univac. It is evident, however, that one result of the 1107 procurement was an attitude that basic research was less desirable, since it did not bring in funding. This attitude, at least to a certain extent, resembled the situation at NCC before 1960. For Nygaard who, in December 1962, was appointed NCC's director of research, this outlook must have been most disquieting, and he obviously found it difficult to accept research being pushed into "a small corner."[35]

In an attempt to compromise between these diverging interests and at the same time establish a more suitable, efficient, and dynamic organization, the board decided to restructure the entire institute by dividing it into a number of independent departments. According to the board's resolution of December 11, 1962, these new departments were meant to engage in practical commissions as well as applied research on specific target areas within NCC's mandate.[21,36] The SIMULA project, however, represented a slight problem with regard to this new organizational structure. Since software development had not previously been an integrated part of NCC's activity and required highly specific professional expertise, it must have been somewhat difficult to ascertain under which department it actually belonged. It was, so to speak, a disturbing element inflicted on NCC as a result of Nygaard's entrepreneurial activity in connection with the Univac deal.

Conflicts of interests must also have been important with regard to another of the board's reasons for reorganizing the institute. When NTNF decided to go for the UNIVAC 1107, this implied that one had to attach greater importance to economics. This responsibility rested first and foremost with NCC's director, Bjørn Ørjansen, but it also applied to the rest of the staff. As mentioned previously, Nygaard did not quite share this opinion, and accordingly he did what he could to prevent basic research from being curtailed by scarce resources. Nygaard's activity in this regard created a most difficult administrative situation for Ørjansen, and for various reasons untenable social conditions within NCC developed.*

It might therefore have been a matter of necessity that the board subsequently decided to establish a Department for Special Projects and put Nygaard in charge as director of research. In this way they could keep him occupied and prevent him from interfering with administrative matters, and simultaneously provide a suitable forum for software development.[6,21,36-38]

The Algol connection and the development of SIMULA I

When Nygaard and Dahl started out, during the spring of 1962, they had a rather vague set of ideas for a programming language that should meet a broad set of specifications. If we compare these initial ideas with the actual outcome of their scientific endeavor, the SIMULA I compiler, we find that there is a rather distinct difference between these two positions. In what follows, I will point out a few reasons for this change of goals.

The early approach to SIMULA was based on an idea of a mathematically formulated network concept associated with Algol 60.** In general, Dahl and Nygaard's idea was to implement SIMULA as a simulation procedure package along with a preprocessor to Algol 60.[39] The preprocessor idea implied that a given SIMULA program first had to be translated to Algol, and then in turn, compiled into an executable program. In other words, this meant that a SIMULA program had to operate strictly within the framework of Algol 60.

NCC operated largely on a reimbursement basis, so sources of income had to be given top priority. Hence, the UNIVAC 1107 came to represent a double-edged sword as far as basic research was concerned.

This proved to be a serious obstacle when simulation was involved. However, at this early stage they were mainly preoccupied with the idea that customers in a simulation model could be depicted as Algol blocks and characterized by using local variables. At that time, this idea looked rather promising, since Algol's recursive block mechanism allowed multiple occurrences of user-defined data structures.[18]

By the spring of 1963, however, Dahl's work on the storage management scheme made it quite evident that Algol's block structure and strict, dynamic, single-stack regime were incompatible with an adequate implementation of SIMULA's sophisticated simulation facilities. In short, the problem facing Dahl and Nygaard at this stage was that Algol 60's procedure calls and storage allocation mechanisms operated strictly according to a stack principle, whereas objects (customers) in a simulation model tended to behave according to the queue principle. In light of this, they subsequently realized that they would not achieve their design objectives unless they found a way to get around Algol's rigorous stack regime.

During the summer and autumn of 1963, while Nygaard was preoccupied with political problems, Dahl commenced work on a new storage allocation scheme based on a two-dimensional free area list.[12,40] With this new scheme at hand, they found that they were no longer tied by the restrictions imposed by Algol 60, and thus they eventually decided to drop the preprocessor idea completely. Instead, they decided to implement SIMULA through a modification and extension of Univac's Algol 60 compiler. This change of strategy opened a whole new set of perspectives on SIMULA, and they were compelled to start over again. This time they derived the basic concepts from a variety of thorough case studies, including studies of job shops and airport departure systems, and epidemiological studies.

With regard to the original network concept, they eventually discovered that this could just as well be regarded the other way around — that is, active customers making use of passive stations. This in turn led to the realization that an in-between or dual point of view could profitably be adopted. From this perspective, the customers were regarded as active

* The conflict reached a climax in March 1963 when three employees were fired for, among other things, conspiracy against Ørjansen and Nygaard. Since the politics surrounding these events were rather complex, I will not engage in further discussions here. As a result of this crisis however, Bjørn Ørjansen decided to resign from his position as director of NCC and was released by Leif K. Olaussen in December 1963. For Kristen Nygaard the heavy strain caused by the working conditions in the wake of the crisis led to a sick leave during autumn of 1963. This difficult situation must also have contributed to slowdown in the development of SIMULA.

** It should be added that even though Dahl and Nygaard at this stage asserted that SIMULA should be Algol-based, they did not rule out a later version based on Fortran, using the same basic concepts.

in moving from station to station, but passive in their interaction with the service parts of the various stations. As a result of this vital construct, the joint activity within the system itself now became the one general principle applying to wide classes of systems. In light of this new understanding, they found that the simple network concept seemed too narrow and subsequently abandoned it. Instead, Dahl and Nygaard introduced the far more powerful process concept which came to constitute the basic, unifying feature of the SIMULA I language. A process can be understood as a generalized Algol procedure with quasiparallel properties.[12,13,15] This decisive breakthrough in February 1964 implied that the simple notion of a system being described by a general mathematical structure had been replaced by a much more powerful concept. The system was now understood as consisting of a series of interacting quasiparallel processes, operating as Algol stacks within the main program.

By March 1964, the design phase had finally come to an end. It was now time to translate the paper version of SIMULA into an operating compiler. The implementation effort was conducted solely by Dahl. On specific Algol-related items he had, however, some assistance from two American software engineers, Ken Jones and Joseph Speroni; the latter was responsible for the Case Western Reserve 1107 Algol.[41] The implementation effort proceeded throughout the year, and in December 1964, the first prototype of the SIMULA I compiler was ready for acceptance by Univac. From the end of 1963, it is evident that they now strove toward general, unifying concepts to realize a true high-level programming language. In this respect, SIMULA I must be perceived as an intermediate position en route to what was later to become SIMULA 67.

The SIMULA 67 common base language

During 1965 and 1966, Dahl and Nygaard spent a lot of time introducing and teaching SIMULA, and the use of the language rapidly spread to Sweden, Germany, the Soviet Union, and a number of other countries. Apart from the Univac version, SIMULA also became available on Burroughs B5500 computers during 1968, and later on the Russian URAL-16 computer. However, Dahl and Nygaard's ambitions were greater than this. They knew that they now had a powerful and generalized language that would make an excellent platform for a general-purpose programming language. Furthermore, through using the language, they realized that a number of shortcomings existed. Among other things, they had become aware of an obvious lack of serviceable tools for expressing common properties among interrelated processes in the system. Moreover, it was obvious that the sophisticated simulation facilities embedded in SIMULA I were too heavy a burden for a programming language with general-purpose ambitions, and finally they had become aware of certain serious deficiencies in the UNIVAC Algol 60 compiler itself.[18]

In the autumn of 1965, the Norwegian Institute of Technology in Trondheim contacted NCC and expressed its interest in implementing a new and improved Algol compiler for the 1107. Their idea was to design this compiler especially with SIMULA in mind. From Dahl and Nygaard's point of view, this sounded like a promising suggestion, and for some time during 1966, relations with a team headed by Knut Skog in Trondheim were maintained.

Since late 1963 or early 1964, Dahl and Nygaard had invested an increasing amount of time trying to come up with as many general and unifying concepts as possible. As this pursuit proceeded throughout the summer and autumn of 1966, they became more and more preoccupied with the opportunities embedded in Tony Hoare's record class construct from 1965. After having carefully examined Hoare's record proposal, they eventually came to the conclusion that, even though it obviously had a number of very useful properties, it failed to fully meet their requirements. What they were really looking for was some kind of generalized process concept with record class properties.[13]

The answer to their problem suddenly appeared in December 1966, when the idea of prefixing was introduced. A process, later called an object, could now be regarded as consisting of two layers: a prefix layer containing references to its predecessor and successor along with a number of other properties, and a main layer containing the attributes of the object in question. In addition to this important new feature, they also introduced the class concept, which can roughly be described as a highly refined version of SIMULA I's activity concept. This powerful new concept made it possible to establish class and subclass hierarchies of concatenated objects. As an example, we can imagine the class *vehicle*, which can be understood as a generalization of the subclasses *car, bus,* and *truck.* The basic concept of speaking both in general and more specific terms had been adopted as a way of expressing reality in the context of a programming language. Having these unifying tools at hand, Dahl and Nygaard immediately decided to commence designing a new, general, high-level programming language in terms of which an improved SIMULA I could be expressed.[18]

Their motivation for embarking on yet another extensive programming language project can roughly be regarded as a combination of high ambitions and a certain degree of dissatisfaction with their existing software product, the SIMULA I compiler. In addition, there may have been yet another reason which, at least from the autumn of 1965, contributed to their efforts to develop new concepts. As a result of a proposal made by Dahl, at the time the Norwegian representative to IFIP Technical Committee 2 (on programming languages), in the autumn of 1965, it was decided that an IFIP working conference on simulation languages should be held in Oslo in May 1967. Acknowledgment from a professional forum like IFIP TC-2 would undoubtedly constitute a professional stronghold of major importance, and thus when the conceptual breakthrough finally came, they were determined to present a new and revised version of SIMULA at this IFIP working conference.[42]

Before the conference, Dahl and Nygaard had been working around the clock to finish their "Class and Subclass Declarations" paper.[42] Despite the short time available to them, they managed to incorporate all the important new aspects, and thus this paper became, in a sense, the first formal definition of the new language. The conference's response to SIMULA 67 was positive, and the project now finally seemed to be on the right track.

Two weeks later, in June 1967, another important conference was held. The purpose of this was twofold: first to define a standard for the exchange of SIMULA programs between various implementations, called the *Common Base Standard*, and second to initiate implementation projects for the Control Data 3000 (upper and lower) series and the UNIVAC 1100 series. Once again, Dahl and Nygaard came up with a number of new proposals. One of the things that they wanted to incorporate was a unification of the related notions of *type* and *class*. The new proposal underwent serious discussions, but after having considered the implications and difficulties involved, the pragmatic approach prevailed and the implementers subsequently rejected it. This, however, did not signify that the idea, as such, was dead — like Sleeping Beauty, it would eventually come to life again.

Items related to string handling and I/O had not been discussed in any of Dahl's and Nygaard's many proposals to the conference. However, the implementers unanimously stressed the need to have these things incorporated and defined as part of the Common Base Definition. To secure high standardization and portability, it was therefore decided to furnish SIMULA with these facilities. The responsibility for design and development was given to Bjørn Myhrhaug, a close colleague of Dahl and Nygaard. The results of his work were accepted at the first meeting of the SIMULA Standards Group (SSG) in February 1968, after which SIMULA was formally frozen.[43]

Dahl and Nygaard wanted SIMULA 67 to be a "living" programming language, but so far their ideas existed only on paper. At the beginning of 1968, Dahl and Nygaard felt that SIMULA was "a statue with one leg missing."[18] They envisioned, at the time, that only a few of the many programming languages developed in the 1960s would still be in use by 1980, and that if SIMULA was to become one of these, it was essential that implementations of the language were available on the important mainframes. Around 1970, this basically meant the UNIVAC 1100 series and the IBM 360/370 series of computers.[18]

UNIVAC 1100 SIMULA

Since late 1966 or early 1967, research scientists from NCC had been working with Knut Skog's team in Trondheim to develop a new Algol compiler (NUALGOL) for the UNIVAC. The intention had been that this should be both an Algol and a SIMULA compiler, but it soon became apparent that the differences between these languages and their respective implementation techniques made such a unification impractical.[44] Partly because of these technical problems, and partly because NCC felt a certain obligation toward SIMULA I and its user community, it was decided, during 1968, that NCC should withdraw from the NUALGOL project and that a SIMULA 67 implementation for the 1107 be developed instead.[45]

The UNIVAC SIMULA team, consisting of Ron Kerr and Sigurd Kubosch, with some assistance from Myhrhaug, did not start from scratch. The code of the Algol implementation served as a guide throughout the entire effort, and wherever they could, they cannibalized and reused this code. This way, the only areas that needed

Dahl and Nygaard's motivation for embarking on yet another extensive programming language project was roughly a combination of high ambitions and dissatisfaction with the SIMULA I compiler.

fresh design and implementation were related to SIMULA-specific items. Working so close to the Algol code, Kerr and Kubosch took great pains to ensure that, wherever possible, SIMULA's code-generation and runtime performance was competitive with that of Algol. This painstaking work contributed largely to the fact that the UNIVAC SIMULA compiler became one of the fastest SIMULA systems ever made. A competitive element introduced by the IBM compiler development also had positive effects on this effort.

For various reasons, the Research Council decided in September 1969 to sell the 1107 and hand over the profitable computing commissions, which that year alone amounted to approximately 1.2 million NKr ($167,832),[46] to Computas, a company owned by the large and influential ship classification society Det Norske Veritas. Despite the abandonment of the old 1107, the UNIVAC SIMULA project continued, and the new target machine became the UNIVAC 1108.

In terms of progress, this represented an immediate and significant setback, because of all the recoding it necessitated. However, the UNIVAC 1108 and its new operating system (EXEC 8), in many ways state of the art around 1970, provided the implementers with a much more powerful and efficient environment, which in the long run would actually prove to have quite a positive effect on the overall performance of the compiler. Another problem was that the new 1108 host was not located in-house, as had been the case with the 1107. At a time when batch processing was the order of the day, this undoubtedly slowed the project. In any event, progress was being made, and in March 1971 the first commercial version of UNIVAC 1100 series SIMULA was released.[44,47,48]

Univac was not unanimous in its reactions to the new SIMULA compiler. First of all, SIMULA I had been a useful but not very important part of their software repertoire, and they felt no market demand for a new and improved version. Second, they had spent a substantial amount of money on the SIMULA I project, and saw no reason why they should share SIMULA with other manufacturers. Nevertheless, in 1968, a long series of discussions between NCC and Univac concerning a possible transfer of rights to the compiler took place, but no contracts were ever signed.[45,49]

IBM 360/370 SIMULA

In the case of the IBM 360/370 compilers, the situation was somewhat different. When Nygaard and his team expressed their interest in developing SIMULA 67 compilers for IBM and Univac, the conditions for doing so were stated very clearly. First, such projects could be undertaken only if sufficient external financing was at hand, and second, that in the course of five years, they would be able to cover the total expenses by selling the compilers on a strictly commercial basis.[18] According to these preconditions, Nygaard and the private consultant Harald Omdahl started the tedious and difficult task of putting together a consortium of firms that would be interested in investing money in these compiler development projects. The hunt for investors went on with little or no success until Nygaard eventually met with representatives from the Swedish Research Institute for National Defense (Swedish abbreviation: FOA) in the summer of 1969. FOA had, for many years, been wanting to make use of SIMULA in connection with its research activities, and as it had recently purchased an IBM/360 computer, it was naturally very interested in Nygaard's proposals regarding the development of a SIMULA 67 compiler for this particular system.[50,51] FOA subsequently agreed to support the IBM 360/370 project by funding the participation of two Swedish software engineers, Lars Enderin and Stefan Arnborg. IBM also made an important contribution, by giving NCC a total of 240 hours of computing time to be used in connection with the development and testing of the compiler.[18]

After nearly three years of extensive work, the IBM compiler was released in May 1972. Myhrhaug had been in charge of the project and, in addition to Enderin and Arnborg, the team also consisted of Graham Birtwistle, who was responsible for the syntax analysis; Francis Stevenson, who took care of the code generation; Paul Wynn on the CMS modification; and last but not least Karel Babcicky, who was responsible for semantics processing, and who, during the second part of the 1970s, was responsible for the entire SIMULA activity at the Norwegian Computing Centre.[52]

Even though the costs related to the two implementation projects had been estimated at approximately 15 person-years each[18] and both were conducted at NCC under the auspices of Myhrhaug, they were very different. The IBM team worked within a well-supported and carefully planned project, whereas the Univac team was much more loosely organized and worked with less external support over a longer period of time. However, both projects produced high-quality compilers that have been used for more than 20 years.[52]

Control Data SIMULA

In the previous sections, I have tried to give a general outline of NCC's own compiler development projects. These two compilers, however, were not the first SIMULA compilers available. Prior to the Common Base Conference, Nygaard had managed to get Control Data Corporation (through important Norwegian customers) interested in SIMULA implementations for their 3000 (upper and lower) and 6000 series of computers.[53] In May 1967 contracts were signed, and in Paris a team directed by Jacques Newey commenced work on a SIMULA 67 implementation for the CDC 6000. This compiler was later refined by the SHAPE (Supreme Headquarters Allied Powers Europe) Technical Center in the Netherlands, and a new version for the CDC Cyber 70 series was developed in 1973 and 1974 by NDRE. In Norway, a team from the University of Oslo, headed by Per Ofstad, carried out the CDC 3300 implementation, while another Norwegian team from NDRE and the University of Oslo's Joint Computer Installation at Kjeller (KCIN), headed by Svein A. Øvergaard, handled the CDC 3600 implementation. The two projects were organized as a joint enterprise under the auspices of Per Martin Kjeldsaas from KCIN, and both were completed during the spring of 1969. Some financial support was provided by Control Data Europe, which in turn obtained marketing and distribution rights, whereas the maintenance responsibility for the respective compilers remained with the university and KCIN.[18]

In addition to these projects, compilers for the CII 10070 and IRIS 80 were implemented by the French company Compagnie Internationale pour l'Informatique (CII). The two identical systems were released in 1972, and were provided free of charge to CII's customers.[54]

DEC System-10 SIMULA

Another important SIMULA development took place in Sweden in the first half of the 1970s; this time the target machine was Digital Equipment's PDP-10.[50] Around 1970, the FOA in Stockholm had decided to establish a laboratory for advanced military studies in operations research. In connection with this, they intended to purchase a new computer, and Jacob Palme, the most prominent member of the SIMULA community in Sweden at the time, was appointed chairman of a committee whose purpose was to draw up an evaluation report on the subject. After having carefully examined four different computers, they eventually decided on the DEC PDP-10. Since this computer did not have a SIMULA compiler in its software library, such an implementation was immediately ordered from the Swedish software house ENEA Data. The first test version of the compiler was available to programmers at the QZ data center in Stockholm, and via communication networks, by September 1974. The first public release took place in January 1975.

The DEC System-10 SIMULA was in many ways more comprehensive than its predecessors. It contained, among other things, on-line debugging facilities that allowed setting and resetting of breakpoints during program execution.[55] The compiler was especially designed for interactive use and would soon set a new standard for the development of SIMULA compilers.

Apart from FOA, DEC also contributed to the project under the condition that the compiler should be distributed free of charge. This condition was accepted, with the result that the DEC System-10 compiler came to have a major impact on the dissemination of SIMULA, especially in the United

States. In August 1975, eight months after it was released, the compiler had been distributed to 28 sites, 22 of which were located in North America.[56]

A note on NCC's SIMULA project in the 1970s

In the 1960s, the promotion and marketing of SIMULA were mainly done by the developers themselves, whenever they attended a conference or gave introductory courses to other research scientists, either at NCC or abroad. However, as the language rapidly spread to larger groups of users and the amounts of money invested in the project steadily grew, this "selling" of SIMULA had to be approached in a more professional manner.

As mentioned in connection with the two NCC compiler development projects (the Univac and IBM implementations), the Computing Centre felt no immediate funding responsibility. As reported by Nygaard, this reluctance was especially articulated in the case of the IBM project.[15,57] The general opinion was that the lifetime for a programming language like SIMULA would not exceed five years. Furthermore, if one took into consideration the costs of developing a compiler, not to mention the great commercial risks involved, NCC was naturally very reserved. Nevertheless, when NCC eventually agreed to take responsibility for the two compiler development projects, their conditions for doing this were that sufficient external financing was secured, and that the center, as such, would not incur expenses. Based on this mutual understanding, the two projects were started (Univac in 1967-1968 and IBM in 1969), and Nygaard began his hunt for investors. As we know, however, his efforts proved unsuccessful, and when this eventually became clear to the parties involved, both projects had developed beyond a point of no return, and NCC had to carry the financial burden alone.

NCC has often been criticized for its pricing policy regarding its two SIMULA compilers. This critique has in some cases been justifiable — for example, when Donald Knuth was prevented from introducing SIMULA at Stanford University in 1973, partly because of NCC's unwillingness to reduce prices and give it away free of charge to universities.[15,57] When discussing these matters, however, one should bear in mind the fact that NCC was neither a conventional software house nor a fully financed governmental institution. In addition to the SIMULA operations, NCC was also committed to a number of other research activities that deserved equal attention and financial support. Nevertheless, by 1973 the use of SIMULA had spread to such an extent that NCC had lost track of it, and despite the fact that this dissemination could have gained even more momentum if NCC had lowered its prices, the language was estimated to be in regular use at more than 250 sites that year.[54]

The Association of SIMULA Users

When talking about NCC's SIMULA commitment in the 1970s, one must also mention the center's instrumental role in the establishment of the Association of SIMULA Users (ASU). The construction of an organizational framework that could facilitate the exchange of ideas among SIMULA users was actually an old idea, first proposed by Dahl and Nygaard back in 1967. However, at that time other more pressing needs were given priority, but in 1972 or 1973 the idea surfaced again, and in September 1973 the Association of SIMULA Users was formally founded.

The DEC System-10 SIMULA was in many ways more comprehensive than its predecessors. It came to have a major impact on the dissemination of SIMULA, especially in the United States.

Through annual conferences, workshops, and newsletters, ASU came to constitute an international forum for discussion and exchange of ideas in the SIMULA community. In this capacity, the organization also represented an important channel for exchange of information and ideas between the SIMULA standards group (consisting of members from the various SIMULA implementation teams) and the wider user community.*

At the first ASU conference in Oslo, there were 43 founding members; one year later, in August 1974, the number of attendees increased to 172. The SIMULA community now extended to more than 23 different countries around the world.[55]

This article has been an attempt to display and discuss aspects of what I have called the construction of SIMULA. Using a contextual or sociotechnical perspective on history, the basic aim has been to explore the heterogeneity of technological genesis and change, as demonstrated in the case of the development of a programming language.

When reading traditional internalist accounts in the history of technology, one often gets the mistaken impression that technologies, as it were, evolve in a technical or scientific vacuum. This flawed notion of the nature of technological change stems, as many writers have repeatedly said,[58,59] to a large extent from the absence of a wider context to which one can relate the technical narrative. As this article has shown, the construction of SIMULA was by no means a self-contained technical and scientific enterprise, and the outcome of Dahl and Nygaard's efforts was largely dependent on what are usually considered external or contextual factors.

* When talking about the ASU, it would be wrong not to mention the "Simulady" herself, Mrs. Eileen Schreiner. As secretary of the ASU from 1973 to 1989, and treasurer and newsletter editor to the present (1993), Mrs. Schreiner has been a thread of continuity in the SIMULA community and in many respects SIMULA's staunchest champion.

Another significant aspect of the problem is the myth that technologies, like Athena from Zeus' head, spring to life fully grown in a sudden flash of insight by genius minds. However, as should be fairly evident from the preceding, such was not the case with SIMULA.

From a simple simulation procedure package associated with Algol 60, the language was painstakingly constructed, shaped, and transformed, via SIMULA I, into the SIMULA 67 high-level programming language we know today. This genesis involved, as has been stressed, a high degree of heterogeneous engineering on the part of Dahl and Nygaard. Apart from their constant striving toward ultimate technical solutions, their activities also had ramifications in areas not normally deemed technical or scientific. Nygaard's entrepreneurial role in the Univac/SIMULA deal and Dahl's persistent work on language design and implementation, as well as his instrumental role within IFIP TC-2, are representative examples of the kind of heterogeneous engineering I have been trying to illuminate in this article. ■

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