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Actors, Visions and Developments in the History of Computer Communications

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1. The current status of technohistorical research

The history of technology has concerned itself so far to only a minor extent with the linking of computers, terminals and other teleconnections, or with the genesis of special data communications networks and information systems, despite the fact that these have been under development for over 40 years. While some interesting work has been produced on specific issues and network types, large areas of computer communications history have not been subjected to any major treatment as yet. There is a consequent lack of any comprehensive overview of the so-called "merger" of information and communications technology. The reasons for this abstinence seem to be a product firstly of the intermediate position that this technology occupies between telecommunications and computer technology. Secondly, however, the fixation on the part of historians on the early phases of computer technology and the relative lack of attention paid to systemic aspects of the origins and development of computer technology, or to more complex sociotechnical applications concepts such as time-sharing or distributed processing has also played a role here.[1] The history of computing is still the history of hardware and not data processing as such. In view of these gaps in research and the lack of specialization and controversy in this field, I should like in the following to outline the development of computer communications, whereby the central focus should be on questions relating to the explanatory power, the limits and the shortcomings of more recent technohistorical approaches such as the "genesis of technology", the analysis of technological visions [*Technikleitbilder*] [2] and especially "large system theory".

2. The principal development phases in computer communications technology

Subdividing the overall development of computer communications into various phases in a plausibly argued manner is a much more difficult undertaking than it is for computer technology or classical telecommunications. The typical distinction between computer generations on the basis of component technologies is of little value when applied to computer or data networks. Transistor and IC development is a central precondition in each case, and a decisive impulse for changes in the design and operation of networks, but this provides only a partial explanation of their changing architectures and the essential lines of computer communications development.

Greater relevance should be attached to the equipment level, in other words the gradation between mainframes, minicomputers and microcomputers, since each of the smaller computer types enabled new networking constellations: on the one hand, the creation of decentralized minicomputer and PC-networks, and, on the other, the more pronounced hierarchies and distribution of mainframe-oriented systems. Because these are not pure substitution processes, but much rather a diffuse mixing of old and new structures, analyzing the development of size categories does not produce clear distinctions between different epochs either. Qualitative "leaps" in development, for example on-line, time-sharing or client-server systems, is more important than the actual size of the computer hardware itself.

A meaningful approach must centre instead on the higher and more complex level of the networks themselves, if the distinction between different phases is to produce any useful results. Thomas P. Hughes has worked out an evolutionary model on the basis of the long-term development of electrical supply networks, according to which national and finally global systems develop out of what are initially local and regional systems[3]. In the course of this development, heterogeneous and discontinuous batch processes become progressively integrated into extensively networked real-time systems. Similar developmental stages, organized according to the extensiveness and degree of integration of a system, can be observed in the development of telephone networks, but cannot be directly applied to the networking of computers. The following short overview of the changing focus in the development of computer communications is provided as evidence of this, and at the same time as a rough outline of my own proposed periodization, including initial references to the forces that determine such development.

The first phase of computer communications extended from 1950 until the mid-60s, with precursors existing from 1940 onwards. This phase was determined above all by centrally controlled wide area networks designed for special requirements on the part of the air force, the major banks and corporations, which is in contrast to the system-historical model. The leading concepts during this period were provided by the famous SAGE system. Only later, with the development of time-sharing procedures in which a circulating clock permits consecutive CPU utilization by several on-line terminals, did a technology appear that could also be applied over short distances, the model here being Baudot's time slice method in telegraphy.

The introduction of time-sharing systems did not occur until the second phase, from the mid-60s to the second half of the 70s, in which a communications technology specifically created for data and computer communications crystallized through the invention and innovation of packet switching networks. Unlike traditional circuit switching systems, packet switching no longer reserved an entire channel for the duration of communication, but split up messages into standardized data packets using enroute storage, sending them in bursts via free sections of the link, together with address and control data (the store and forward principle). This data transfer technique was developed above all for the public long-distance data communications systems initially, but was quickly integrated into the in-company network architectures of computer manufacturers.

Not until the beginning of the third phase at the end of the 70s was there a genuine transformation of local computer communications, when Local Area Networks (LANs), a combination of broadcast and packet principles, of new topologies and access procedures, appeared on the market and heralded the introduction of specifically local network architectures. This period also saw a growing divergence between military packet switching systems and manufacturers' standards, on the one hand, and between the civil CCITT norms and the system structures and standards for "open systems" (the "OSI world")[¥].

Since the end of the 80s there have been indications that a new phase has started, in which heterogeneous network architectures are to be integrated and raised to higher speed levels on the basis of worldwide standards. Because LAN technology possesses much higher transfer capacity and transfer speed than previous public and private wide area networks, and these are constantly being raised still higher, this network type has undergone an extension of function and range in recent years. The creation of Metropolitan Area Networks (MANs) and ultimately of Global Area Networks (GANs) offer high-speed computer network infrastructures to corporations and institutions operating on a worldwide basis. Intensive efforts are being made to integrate voice communication at some point in the future as well, either on the basis of the "packet voice" technology that has been commercially available since 1986, or through the creation of hybrid networks that make use of existing telecommunications and satellite networks.

The complex sequence of main development foci in computer networking as outlined above is only matched to a certain extent in classical telecommunications if telegraphy as a wide area network and telephony as a local communications resource are notionally combined as an integrated telecommunica-tions system. The following pattern of development can then be identified: in both cases, wide area networks are established initially by military and state authorities, by transport companies, banks and commercial enterprises, and only then, with the greater need for local telecommunications systems, especially in offices and factories, do we find the creation of broader band local communications networks which subsequently expand to become regional, national and global systems. This development pattern and the shift in focus from local to wide area networks and systems is guided by the respective interests in each case, in other words it is determined by constellations of actors, be they manufacturers, network operators or large users, as well as by their interests and technological visions. Hughes' concept of stages should therefore be seen only as a descriptive model for actual processes, and not as a normative evolutionary model for technical systems per se [4]. In the following, the interaction of various constellations of actors and visions will be described using some central innovation processes and phase transitions in computer communications.

3. The initial phase of computer communications - the crucial role of "Central Command and Control Systems"

Early computers were conceived of and developed as separate devices, but the idea of networking them to make them capable of communication also arose at an early stage. One of the first public demonstrations of a computer, namely the "complex number computer" developed by George Stibitz and Samuel B. Williams from Bell Laboratories in September 1940, involved data transfer via a data transmission link. Indeed they obtained the first computer communications patent for the data transmission equipment they used to transfer data between the host computer in New York and the American Mathematical Society's Congress in Hanover[5]. At about the same time, the "punched card tele-typewriting" project carried out within the machine reporting section of the German army ordnance department achieved its first implementation of data transmission, although this was still on the basis of the old Hollerith technology[6]. These wartime efforts at developing data transmission were all stopped when the war ended. The ideas for electronic banking systems, for statics calculations in the construction field and for "staff control" with the aid of data transmission, developed in an unpublished paper by Konrad Zuse as early as 1939, were not able to obtain any real function as guiding ideas. The same applied for Vannevar Bush's futurist vision of a "Memex" communication system, dating back to 1945, which envisaged a point-of-sale system, personnel information systems, "conferencing services" and personal data communication from storage medium to storage medium, things which were far ahead of the technical possibilities of the time[7].

Punched cards, punched paper tape and magnetic tape remained the most important transport media for data and program commands for a relatively long time, while tele-typewriters were the main devices used for local input and output. Only in the time-sensitive military field, especially the Air Force and in air defense, but also in civil aviation, did the batch-oriented form of data transport lead to such serious bottlenecks that the first attempts were made at installing "real-time teleprocessing systems". In 1952, the Teleregister Corporation created the first flight reservation data network, the "Magnetronic Reservisor", in which they linked all American Airlines offices in New York via telex lines to a central magnetic drum storage device at La Guardia airport[8]. This technology was still relatively simple, but it was completely inadequate for military requirements, which were highly complex and necessitated a global data communication system. For this reason, in 1950, the US Air Force initiated a project entitled SAGE (**S**emi-**A**utomatic **G**round **E**nvironment), a systematic development of a real-time "large-scale automated command and control system".

Sources and research on the SAGE system

The creation and development of the SAGE project between 1946/1947 and 1963 has been documented relatively comprehensively, firstly as early project descriptions in specialist journals and at the national computer conferences in the USA, the spring and fall meetings of the American Federation of Information Processing Systems (AFIPS). In the 60s, Harold Sackmann presented a series of psychological, ergonomical and work process studies on this large-scale project, which were then compiled in 1967 in a summary evaluation that arrived at many interesting conclusions[9]. In 1983, the end of the SAGE system and the twentieth anniversary of its completion offered the occasion for a retrospective view by the project's leading system developers and for a report by George Valley, the leader of the SAGE project, on the experience he had gained. Both of these appear in the "Annals of the History of Computing"[10].

Taken as a whole, however, this means that official statements and insider accounts tend to dominate, whereby all problematic aspects are left out for reasons of secrecy, as is the case with later, more or less heroic reports by SAGE engineers and members of the military-industrial complex on the successes they achieved. As a result, there is a lack of critical evaluation of the project in total that would allow in particular the many structural problems, or the internal contradictions and changes in conception to be identified. Similarly, very little is known about the parallel or competing projects that existed, but which were displaced by the 1953 Air Force decision in favour of SAGE. The debates and controversies within the SAGE project about the degree of automation and the problems of man-machine communication are also given insufficient consideration in the material that has been published, or these issues have been smoothed over after the event. Finally, the problems with practical deployment that are mentioned again and again, especially those involving system breakdowns, faulty functioning and deficits within the system, are documented and examined to an inadequate extent.

The competition of visions in the initial phase of real-time control systems

The preliminary ideas behind the SAGE system dates back to the very beginnings of the Cold War. As early as 1946/47, Perry Crawford from the Special Device Center of the US Navy, and Jay Forrester and Robert Everett from the famous Servomechanism Laboratory at MIT recognized that analog computer technology could no longer keep pace with the rapid advances being made in the technology of war, in particular with the speed of intercontinental missiles[11]. Crawford, especially, was the one who formulated the vision of a "combat information and control system" based on a digital computer. In contrast to Bush's Memex vision, this concept soon acquired a genuine vision function, one that bundled various R&D

activities at MIT, in the Air Force and for a while in the Navy as well, in the years 1947 - 49. Commencing with the higher order sociotechnological vision of a "digital computer for coordinating military combat information", the technological vision of an "information system of interconnected digital computers" and a centralist "real-time control system" took shape[12]. Defining the tasks to be performed in this way led to the reorientation and redesign of Forrester's Whirlwind I Project, and to its being linked to the efforts by the group centred around John Harrington to transmit radar data via telecommunications lines. All this development work was aimed at creating a large-scale data collection and processing centre for military purposes, with "central command and control system" becoming the standard label.

The decision in favour of a digital computer plunged the project for a computer-aided air surveillance system into the controversy raging at that time between analog and digital computer technologies[13]. It was by no means certain that the SAGE concept would prevail, despite the support it received from the powerful "Air Defense System Engineering Committee" headed by Valley, since the military and technical staffs in the Air Force, with their pronounced orientation towards analog computers, gave their full support to competing projects. These included, especially, an analog "man-machine system" for semi-automatic flight path tracking designed by John Ragazzini from the Electronic Research Laboratories at Columbia University, and the Air Defense Integrated System (ADIS) developed by the Willow Run Laboratory at the University of Michigan, which envisaged a decentralized analog tracking system and the central digital control of interceptor planes[14]. The divergent solutions being developed were a result not only of different assessments within the scientific community, but also of different scenarios for armed conflict. The representatives of the analog computer concept assumed, as the Air Force did, that bomber aircraft would become faster and faster and would fly at ever-higher altitudes, whereas the SAGE group expected an attack to come from very many low-flying bombers. Because tracking the latter would require a greater number of radar stations and a greater mass of computations, they believed that only digital computers would possess the requisite power. This worst case assumption and the fact that the MIT group had solved the problem of fast transmission of radar data provided the SAGE project with the better cards. In 1953, i.e. one year after the first successful demonstration of a prototype in the so-called Cape Cod System, the Air Force decided in favour of the SAGE concept[15]. This meant that only the team based around Forrester and Everett received the necessary funding to implement their vision of a central command and control system on a large scale.

Technical innovations resulting from the SAGE system

The Semi-Automated Ground Environment developed between 1953 and 1963 was the largest computer-aided real-time information system of its time. Numerous technological innovations were forced by the very scale of implementation, as well as by specifically military requirements, so that the project became a promotor for the radical transformation of data and computer communications. The compulsion towards higher and higher transmission capacities for the transfer of radar pictures led between 1949 and 1957 to the development of the first modem. With this device, 750 bits/s could be transmitted on telephone lines, increasing in 1959 to 1,300 and later to 2,100 bits/s[16].

Single radar images were no longer evaluated in situ - track monitoring was activated remotely instead, and a whole series of pictures from different radar stations had to be gathered and integrated in the SAGE Direction Center to obtain a complete view. For this reason, monitors capable of displaying graphic images and which permitted interaction with the operator were needed. This was the context for the development in 1952 of the first Video Display Terminal within the Cape Cod Project. The light gun and the alphanumeric display unit that then followed enabled an interactive "man-machine dialogue", although this was still in an extremely reduced military code that was decidedly user-unfriendly[17]. The graphics interface and the man-machine interaction were designed to such an extent for people trained in military technology that any applicaiton of the SAGE monitor in the office or in industry was out of the question.

A precursor to the time-sharing process was developed in 1956 within the SAGE project, born of the need to organize fast access to the CPU by ninety and more processes. Two further MIT projects that were carried out between 1961 and 1969, MAC and MULTICS, then succeeded in developing this process into a user-friendly dialogue system. Availability requirements specified by the armed forces finally led to the introduction of error detecting codes into data transmission and to the construction of the first standby computer.

In the software field as well, SAGE was for years the largest project running. Because the large-scale programs comprising up to 100,000 commands were subdivided into several sub-programs and had to be developed by thousands of programmers working in parallel, the need arose to replace the individually operating systems that had dominated until then by a systematic organization of software production. Turning away from the traditional decentralized handling of programs, a group of programmers around Herbert D. Benington developed a nine-phase model for the development of "large centralized programs"[18]. The "Lincoln Utility Program System" was also an attempt to make do with "relatively inexperienced programmers". The result of these efforts at structuration and rationalization was a "modular, top-down system organization" in which the software was made up of "discrete structured program modules". The "big scale programming" efforts within the SAGE project thus involved a rudimentary form of "software engineering", a concept first designed in 1968 within a military context[19].

The unusual plethora of hardware and software innovations brought about by this large-scale military project, and the system inventions and new methods for development and testing resulted above all from the dramatic increase, compared to data transmission and processing systems in non-military fields, in the size and complexity of this continent-wide real-time information system. The chief designers of SAGE'S IBM AN/FSQ 7 mainframe computer, Astrahan and Jacobs, came to the conclusion that "the SAGE system provides a demonstration of the kind of innovation that can be achieved when cost is secondary to performance. This kind of environment is difficult to create in a commercially oriented company, but SAGE provided the environment."[20]. While the large-scale technology developed by the project had resulted in powerful stimulation and acceleration of development in large-scale EDP and computer communications in the civil sphere, the exaggerated scale and the extreme specifications defined by the military context led on the other hand to major problems in the SAGE system itself and in some of its civil imitations.

Problems and design deficiencies in the SAGE system

The North American air surveillance system evidenced the typical weaknesses and structural problems of large-scale military projects: protracted development times of almost 15 years, extreme cost intensiveness (figures quoted vary between 10 and 20 billion US$[21]), exaggerated complexity and thus considerable susceptance to failure. When implementation was finally completed in 1963, SAGE was already obsolete in terms of its intended application purpose, since the growth of intercontinental missiles meant that the war scenarios that had determined the design of the project now had to be thrown overboard. At the component level as well, the system was already outdated when installation was begun in 1958, and even more so when it was finally taken into service: the systems specifications for the computer had been drawn up as early as 1952/53 on the basis of valve technology, which at that time provided the only guarantee of adequate quality, and which could not be revised later on. The fact that two of the Direction Centers were still active, without major complications arising, until SAGE was finally closed down in 1983, would suggest that the 49,000 vacuum tubes in each of the 24 AN/FSQ 7 computers did not constitute the central problem of availability[22]. The major shortcoming, however, was related instead to the coordination of software for flight path tracking, system response times and the time-sharing cycle time. The detailed ergonomic tests conducted by Sackman in the Phoenix Direction Center in 1964 showed conclusively that the wrong timing of human and technical operations was leading to frequent truncation of the flight path tracking system[23]. The total lack of any feedback by the computer regarding the correctness of operator input rendered man-machine interaction a matter of pot luck. False alarms were often the result. In addition, a cumulation of flights appear to have over-taxed the system very quickly. The extent to which these software defects, which occured in everyday operation and in the detailed test series, or the problems with system operating could be removed at a later date has not yet been sufficiently documented.

Another bottleneck that was even more serious in the eyes of the military resulted from the inadequate topological and communication characteristics of the SAGE network: if the circuit switching network was heavily loaded, or if one of its central nodes failed, then the correct functioning of the entire network was no longer assured. This fundamental deficiency of the system, and its low availability in practice finally forced a parallel continuation of the old decentralized "manual system" for air surveillance. After attempts in 1959/60 to remedy the availability problems by increasing the degree of automation and intensifying the centralization strategy in the form of less "SAGE Super Combat Centers", the Air Force decided on a more strongly decentralized concept: a greater number of smaller and less sensitive systems, the so-called Backup Interceptor Control Systems (BUIC), were supposed to radically reduce the risk of failure of the USA's air surveillance systems[24]. Despite these major internal problems and the various construction defects, the SAGE system had a major influence on the entire further development of computer communications, and in the 50s and 60s became *the* guiding vision for large-scale information and automation systems.

SAGE as the starting point of vision chaining in early computer communication

The spectacular large-scale realization of a data collection, processing and distribution centre produced considerable resonance for the idea of a centralized information system operating over great distances in the non-military field as well. The generalization of the system architecture, which was based implicitly on military hierarchy and command structures, as a vision for the "central command and control system" produced, however, an involuntary import of military communications and control structures into civilian, market-oriented environments[25]. The least important problems in this transfer of vision still existed where structural conditions were relatively similar, in the logistics of branch and distribution networks and in *civil* air traffic surveillance. On the other hand, attempts to control the much more complex rail and road traffic networks centrally had to abandoned very early on. Introducing real-time process control modelled on SAGE into power stations and chemical plants did not succeed at first either. Not until a complex hierarchy of automation levels had been laboriously established was it possible to even think about central process control[26].

The Central Command and Control idea was totally unsuited to production monitoring and control. All of the first Management Information Systems, which were developed along the same lines as SAGE by IBM, Hughes Aircraft and other US corporations, met with failure[27]. This was partly because the technical preconditions did not exist, but also because an information system initially created for the collection, processing and evaluation of radar pictures and flight path data was totally inadequate as a model for the complex labour, communications and decision-making processes within companies.

The chaining of vision (*Leitbildkette*) suggested here shows that the pattern of the Central Command and Control system that had been implemented on a large-scale elsewhere was then transferred to more and more complex fields of application in the non-military sphere. The particular military purpose that the model was originally designed to serve was progressively lost from view, indeed it was generalized to such an extent that the term information system was generally taken to mean "vast computer systems under centralized control", or "networks consisting of the central computer function and its remote or slave functions". Computers appeared to be "the key to total systems control" in almost all fields of technology, business, politics and society, the main topic at the AFIPS Conference in December 1961[28]. Similarly, as David Noble has shown for the numerical control of machine tools and industrial automation, the military origins of computer communications led to the managerial emphasis on the control and domination aspects of computer communications becoming further strengthened by the technocratic and cybernetic thought patterns of developers and engineers of these systems[29]. This resulted in reductionist logistics concepts that were purely concerned with the efficient control of material, energy and information flows, and which therefore failed to recognize the specific complexity of these communications and data processing systems. This underestimation of the complexity of large information systems, resulting from the application of the SAGE model, the general orientation on the part of systems designers towards large-scale centralized host systems and instant, "total" solutions were perhaps the most problematic consequences of the technology transfer from the military to the civil spheres during the first phase of computer communications. In any case, SAGE was followed by a whole series of failures, problematic system designs and very protracted implementation phases in centralized information system networks. One example was the first version of the S.W.I.F.T. network for international banking, which was equipped with only two central nodes, another was ITS, the Integrated Transportation System of the German Railways, which was conceived of as a centralized network of interlocking computers. Even the concept behind the interactive videotex system, first developed in 1970 on the basis of central databases, can be traced back to the notion of "information center" as found in the SAGE project. In future, technohistory should therefore analyze systematically such inheritances of structural problems through the transfer of solutions to other technologies, as well as mistaken orientations implicit in specific problem-solving horizons on account of inadequate transfer of guiding ideas. It might then arrive at conclusions that enable prospective research into the genesis of technology.

4. The breakthrough phase of computer communications - the crucial role of "large central time-sharing systems" and "packet switching networks"

The enormous difficulties of computer networks and information systems based on the SAGE model had already shown up, in the early 1960s, the fundamental weaknesses of centralist and hierarchical structures for communications and decision-making within Central Command and Control systems, as well as the deficits in network architecture and in the interaction of data and communications technology in the basic concept for computer communications in the 50s, namely:

- The man-machine system developed within a military context viewed the user only as "humanly extended machines" and thus did not support any *in situ* interactive problem-solving processes.
- As a result of the short transfer bursts in asynchronous, interactive data traffic (burst transmission), only about 10% of the band width of the data channels was actually used.
- In local switching nodes, a longer data transfer could block much shorter and perhaps much more urgent or important messages.
- At higher load factors in switching nodes, this had to lead to self-blocking of the network.
- Due to the extremely centralist network topology, any failure or destruction of central components represented the risk of total network failure.
- Finally, the separate transfer of data, voice and picture messages in military applications could not be tolerated in the long term.

The immense conceptual problems experienced during the first phase of computer communications led to critical modernizers of the military-industrial complex themselves laying the technical foundations for the phase that ensued. In the aftermath of the Cuba Crisis, fear of a nuclear Pearl Harbor provided the critics of the established Central Command and Control philosophy not only with an audience, but also with financial resources. The crucial coordination unit became DARPA (Defense Advanced Research Projects Agency), which was initially established in 1958 under the name ARPA after the Sputnik shock under the leadership of John C.R. Licklider and Robert Taylor. It was in this circle as well that the new models for network architecture and computer communications were formulated, namely the so-called "survivable network" featuring the long-term integration of data, text, picture and voice communication, and the time-sharing system as a "thinking center"[30] which the user himself could access from user-friendly, interactive terminals. The breakthroughs in computer communications that ensued after 1960 then removed, in the decade that followed, the fundamental design faults and bottlenecks that characterized the basic concept as it existed in the 50s, with the following features being the main foci of development:

- the creation of genuine interactiveness with the aid of an on-line environment
- full digitalization to harmonize data and communications technologies
- more widely distributed network architecture on the basis of packet switching

Sources and research on the (D)ARPA Projects

The computer and data processing journals and the Proceedings of AFIPS, IEEE, IFIP, ICCC provide a wealth of material on the origins of interactive time-sharing within the MIT defense research projects MAC and MULTICS, material which has not yet been subjected to systematic analysis. An initial historical overview was produced on the occasion of the centenary of the MIT Department for Electrical Engineering[31]. Three comprehensive publications with chronologies, interviews and summary appraisals were presented on the occasion of the 25th anniversary of the MAC projects, all of them successful combinations of documentation and oral history[32]. By contrast, the parallel and subsequent time-sharing approaches, especially the development of commercial TS systems and the substantial problems in practical use that were frequently experienced with them have remained more or less unresearched.

There are many reports, conference papers and journal articles that deal with the early history of packet switching networks as well. Most of these refer to ARPANET, while the other American and European research networks are less well documented. The only descriptive studies that exist are the profound study by Campbell-Kelly on the early packet switching activities of the National Physical Laboratory in Britain[33], while one study by Arthur Norberg and Judy O'Neill on the contribution by the (D)ARPA projects to the development of computers ia awaiting publication. Perhaps the 25th anniversary of ARPANET's going on-line will provide the occasion for more extensive publications along the lines of the material on MAC. These should throw light on problem areas, mistakes in approach and on the political-military background, aspects that had to be left out or referred to only cryptically in earlier publications.

The origins of "Large Central Time-Sharing Systems"

Increases in computer performance and greater productivity in FORTRAN programming led to a rapid increase in the numbers of users and to corresponding problems with the organization of job processing. The transition to batch processing using punched cards or magnetic tapes, especially in the transition to night-time and shift operation, were able to solve these bottleneck problems temporarily, but not the chronic disparity between the timing of job queues by the computer and that of the individual work processes. This obvious incongruity between the performance of digital computers and the rigid organization of console or batch operation led Christopher Strachey in England and John McCarthy, Douglas T. Ross at MIT to think in the direction of interactive programming and debugging in multiple access operation on the host processor[34]. Around 1960 it was above all McCarthy and Licklider who then developed the general vision, based on the idea of an instrument for programmers and program testers, of an *interactive real-time on-line environment*, in which the central host computer was to function as a permanently available aid for decentralized information and query access. The time-sharing principle as a new organizational solution comprising a central computer, decentralized input and output systems, and a user conceived of for the first time as a design factor, was intended to supercede the incomplete system represented by the early computer center. This enormous task was taken over above all by two large-scale projects at MIT initiated by Licklider and financed mainly by DARPA and other military agencies: the MAC project of 1962-75 led by Robert Fano and Fernando Corbató, which developed the basic solution for the **M**ultiple **A**ccess **C**omputer, and the MULTICS project carried out between 1963 and 1972 in conjunction with Bell Lab, which designed the time-sharing system for software and communications[35].

The growth of time-sharing systems that finally took hold in the later 60s thanks to MIT's systematic development work led to a radical transformation in data processing technology. Only now was it possible to remove the serious problems that had been developing in the computer centers through the uncontrolled linking of more and more new teletypewriters, teleprinters and other terminal equipment to the CPU. Just as the SAGE model contributed to a temporary removal of the *transport-logistical* bottlenecks in the import and export of data across wide area communications networks, the time-sharing concept solved the problems associated with *processing logistics* in host computers, and thus contributed to greater system utilization and thus the more efficient deployment of capital-intensive central resources. With the help of data transmission and remote processing, the immanent obstacles to the further expansion and larger scale of isolated hosts were now eliminated as well. But this situation was also short-lived, since time-sharing only shifted the bottleneck problem to a different part of the system, namely the network. In conjunction with the immanent contradictions within the computer communications systems advanced in the 50s and early 60s, time-sharing operation forced the creation of a fundamentally new basic concept for data transfer, one that no longer depended on traditional telecommunications structures, but which was specially designed for the demands of digital computer technology. Theoretically, these processes can be understood very well in terms of Nathan Rosernberg's "imbalance" concept, or with Hughes' notion of "reverse salient"[36]. What is astonishing is that these theoretical approaches have not yet been applied to the systematic longitudinal analysis of computer technology and computer networks.

The development of DP-specific computer networking technologies and architectures

Two basic technologies were soon selected and promoted for eliminating system bottlenecks in early computer communications: PCM and packet switching technology. *Pulse Code Modulation (PCM)* technology, which was already available at that time, involves the sampling, quantization and digital coding of voice, data and picture signals for transfer across a data transmission line. The transition to PCM technology was thought to remove the previous disharmony between digital data processing, on the one hand, and analog transmission and switching technology, on the other. PCM technology had been developed by Alex H. Reeves in ITT's Paris laboratories on the basis of precursors dating back to the 20s and 30s, with an eye to future applications in the military radio communications field[37]. The invention had little practical significance at first, however, due to the lack of high-performance components, with the result that for quite some time only the military could afford the expensive pilot systems.

The invention between 1961 and 1967 of *packet switching technology*, which no longer establishes fixed or switched connections, but dynamically assigns parts of the band width using data packets of fixed length, was to create a more decentralized or distributed network architecture and thus remove the risk of failure and self-blocking of centrally switching networks in traditional telecommunications systems. It is based, firstly, on the transfer of the time-sharing principle to data transmission technology, and secondly on the so-called message switching method introduced in the USA during the 30s, with which telegrams could be transmitted across free segments of the total network using intermediate storage on punched tape. As early as 1961, research work was started in the US Air Force's own RAND Corporation on "the use of redundancy as one means of building communicaions to withstand heavy attacks". In 1962, Paul Baran, a member of the RAND project team, was the first to develop *packet switching technology* following detailed studies on network topologies[38]. He replaced the central switching unit and the circuit switching network by a distributed stored program control system (the "hot potato principle"). Here, each message is assigned an address and transferred from one network node to the next. To increase throughput, Baran divided the entire message into "standard message blocks", or "packets", as they were later to be called, hoping that voice messages could also be transmitted on this principle, thus arriving at an "all-digital distributed system". A combination of cable, point-to-point radio links, mobile radio links and satellite channels was expected to grant transmission that was absolutely guaranteed at last. The highly redundant system design was considered as proof "that highly survivable system structures can be built, even in the thermonuclear era"[39]. This worst-case design, however, was hypertrophic for the civil telecommunications networks of the time, and indeed exceeded the technical and economic resources of the Department of Defense. Baran's astonishingly early concept of an integrated services, narrow-band digital network (ISDN) based on packet switching failed, however, on account of the bad voice transmission quality. Not until 1983 and the development of Fast Packet Switching were the problems associated with asynchronous digital voice transmission finally overcome. Since then, broadband services integration on a packet switching basis has once more become a central R&D objective in the military sphere. Until the mid-80s, however, packet switching networks and ISDN technology were developed separately.

Baran's notion of message packets was taken up by MIT in 1965, following considerable resistance from military quarters and from civilian telecommunications technicians, and implemented on a large scale for the first time in the ARPANET project. ARPANET was a large-scale research and military research network linking university, military and civil research institutes, in addition to NASA. It was conceived of in 1967 and commenced operations in 1969[40]. The importance of its role in the history of computer and data communication cannot be underestimated - it epitomized this whole period. The guiding idea behind the host computer network architecture with decentralized control, designed primarily by Lawrence G. Roberts, was *resource sharing*. This resource sharing principle involved the distribution of load, data and functions and was intended as a means to overcome not only the problem of failure in centralized networks or isolated computer centers, but also a crucial dilemma in military data processing - the lack of networking of military bases necessitated a "duplication of resources" and for cost reasons permitted only an intermediate level for hardware and software technology. A computer network covering as wide an area as possible was expected to enable a division of labour between larger and more heavily specialized systems, and thus the application of high-tech and high-performance equipment[41]. ARPANET was conceived of from the outset, therefore, as a solution for institutions and enterprises operating over wide areas. However, the way in which the military research network was actually utilized in practice came as a surprise to the ARPANET engineers and operators, because the central service turned out to be the mailbox service, developed by Roberts in 1970 as an additional feature, and not the anticipated wide area sharing of resources and loads.

Regionally and organizationally specific technology styles in packet switching networks

The scale envisaged for a worldwide network of innumerable host computers, combined with generous financing by the Pentagon, provided the opportunity here to solve very many fundamental problems of a technical and theoretical nature associated with fully-digitalized, software-controlled networking of hosts, such as queuing theory, routing, and the correction of transmission errors. Many of these research and development efforts were also made at the same time or shortly afterwards in the experimental packet switching network of the National Physical Laboratory in Teddington, England. But the latter's approach was much more tradional, oriented heavily towards engineering and construction aspects. Although it was developed in isolation from the PTT environment, the NPL network design was guided by the PTT model[42]. The objective of the most important systems engineers, Donald Davies and P.T. Wilkinson, was the creation of a new public wide area network for data communication - for this reason they used switching nodes instead of the host (IMP) architecture of the ARPANET system - and they were fixated on this objective to such an extent that they overlooked the fact that they were actually the first, with their NPL research network, to have created a functioning Local Area Network.

After an initial "tinkering" phase, the development of ARPANET, by contrast, was oriented much more towards theory and pure research. This is shown, for example, by books such as Leonhard Kleinrock's "Queuing Theory", but also by the efforts made at solving network design problems using systems theory methods. Howard Frank and Ivan Frisch developed a general systems theory analysis of networks related to ARPANET and based on graph theory, information theory and operations research; in this analysis, they worked on the basis of military-logistical calculation for secure data transmission, and arrived at a general mathematical model for information, energy and transport networks[43].

The result of this more systematic procedure at ARPANET was also a fundamental structuring of the extensive software tasks in the handling of communication processes between data terminals, and in the control and management of sub-networks. Taking up and applying structuring approaches developed within the fields of structured programming and software engineering that came into being during the later 60s, a layer model was developed that structured the entire communication process into lower-order protocols more heavily oriented towards transport and connection factors, and a higher-oder protocol related more to software applications[44]. This concept of layers was developed further in NPL (the Mark II network), in the French research network named "Cyclades", and later perfected by IBM in their well-known Systems Networks Architecture (1973/74). Finally, in 1977-1983, the concept led to the reference model standardized by the ISO for Open Systems Interconnection (the OSI model), which has now become the basis for all standardization in non-voice services[45].

In the layer approach as well, one can observe the transfer of ideas revolving around reuseable modules and hierarchic division of labour in software structures, as described by Mahoney[46]. As in Ford's conveyor belt model, each layer performs a certain group of tasks and forwards the message to the next layer together with additional control and protocol information. Unlike software engineering, which structures and organizes the work procedures of software developers in a specific manner, the conveyor belt and the structure of exchange in the layer model have only a metaphorical existence, one that is of little relevance to the actual user of a transparent data transmission system. Even the higher complexity of OSI protocols, which is often experienced as disturbing even by simple applications (a consequence of the model's previous design for host communication) is disappearing in the course of its general implementation into chip solutions. We see, therefore, at least for information and communications technologies, that the inheritance of a specific pattern does not necessarily imply that its influence remains the same in other contexts.

The packet switching principle and the layer model for digital communication first developed out of large-scale military research projects. But the development activities conducted parallel to or immediately after ARPANET at civil research institutions in Britain and France show that they most probably arose as well through purely civil requirements as well, albeit with a certain delay. The origins in the military-industrial complex of the USA led from the very beginning, however, to special features in the style of development and in systems design. The stronger emphasis on military-strategic aspects was reflected in the more systematic approach and pure research orientation in the DARPA projects. This also influenced the specific *design* of network architecture: the American packet switching networks based on ARPANET corresponded, with their connection-less datagram principle for lower layers, much more to the military specifications for a "survivable network", in which priority was assigned to robustness, data protection and availability under extreme conditions. AT&T and the European Telecom corporations were more interested in their packet switching networks making efficient use of expensive telecommunications lines and keeping operating costs as low as possible, and were therefore looking for a switching principle that combined the benefits of connection-less packet switching technology, on the one hand, with connection-oriented circuit switching, on the other. They took up the virtual circuitry principle soon after it was developed by Alexander G. Fraser at Bell Laboratories, a principle which avoided the high overheads of datagram networks (where each packet must be assigned a full address) by establishing a *logical* connection between terminals, thus reducing the amount of routing effort involved[47]. In the public packet data networks, a compromise was engineered between the circuit switching philosophy of traditional telecommunications systems and the new packet switching principle, but this solution was no longer compatible with the connection-less military and large-scale research networks. This redesign for civilian purposes thus meant, much to the regret of the US military, that computer communications became split up into different protocol worlds, namely the PTT, the IBM and the DoD worlds[48]. These actor-related differences were reflected within the engineering community by what were sometimes heated controversies between advocates of the various systems. But there was no major central conflict, as Hughes has shown for the controversy in the electrical supply industry over direct current, alternating current and three-phase current, but instead a cascade of larger or smaller conflicts over the pros and cons of each system.

The rapid success achieved by the ARPANET concept resulted very soon in its being extended to other transmission media, to satellite channels, mobile radio and broadband coaxial cable systems for military, state and commercial applications. The ARPANET protocols had to be adapted, however, to the various transmission specifications. The competition between different manufacturers and network operators intensified this trend toward heterogeneous, non-compatible or only partially compatible network systems. The very success of ARPANET thus led to a situation that critics aptly labelled "a new version of the Tower of Babel"[49]. Because this inherent dynamic ran counter to the military strategy of using or controlling all networks in the case of political tension or war, DARPA started the *Internetting* program as early as 1973, with the aim of developing technologies and protocols "for a flexible and robust packet network interconnection". In this context, the first "*gateway*" was created at the end of 1973, an interface for protocol translation between heterogeneous networks that very soon found extensive application in the office communication field, as well as the Internetwork and TCP/IP protocol family, which guarantees the transport of datagrams between networks of different manufacturers using additional addresses[50]. The enormous efforts made at establishing the ARPANET network architecture as an industrial standard meant that the DARPA network planners were working in opposition to IBM's efforts at raising SNA to a worldwide industrial standard just as much as they were to European standardization efforts aimed at genuinely open communication. The strategic network and protocol policies of the Pentagon or of DARPA thus led to three different standards, thus creating a dilemma in which they had to decide between specific military specifications and design criteria for data and computer networks, on the one hand, and the military vision of a "supernetwork" accessible worldwide, on the other. In 1987 the Pentagon finally decided to migrate to OSI architecture, whereby the heavy marketing for TCP/IP products meant that its continued existence on the basis of standard translations was guaranteed.

The genesis of packet switching technology as outlined above suggests, in contrast to David Noble's analysis of the origins of numerically controlled machine tools in US Air Force and MIT contexts, that there existed a multiphased and partially contradictory process that markedly influenced development. Within this process, as a consequence of the different interests of the actors involved, adaptations to civil application concepts and to new patterns and distinctions were implemented which in turn compelled military developers to modify and extend their own initial system and network architectures. Given the typical variety within information and communications technologies, the notion of a unique "technical choice" or a "trajectory", which is by all means appropriate for some energy and production technologies, must be replaced by other concepts such as branching or cascading metaphors, or perhaps even by recursive models for system genesis. The concept of a "regional style" or an "organizational style of technology" are particularly suitable for describing and explaining the formation of different network architectures.[51]

Innovations and limits of the Large Central Time-Sharing Systems and Packet Switching Networks

Taken as a whole, the intensive R&D efforts on the part of the military during the breakthrough phase in computer communications made a decisive contribution to the elimination of many defects in centralized information and control networks. The decentralization of switching and control processes made it possible for the first time to have full control over large computer networks, and in this way enabled the development of an efficient network of interlocked computers. The use of digital packet switching for data transmission produced improvements in data communication and data processing, especially for large and medium-sized users. The more user-friendly approach applied to the design of time-sharing systems also facilitated access by single, small-scale users via teletypewriter terminals to central mainframes and computer centers. In general however this phase was characterized by the fundamental orientation towards mainframes and computer centres: all efforts were essentially geared towards the optimization of large system availablility, the elimination of logistical difficulties with data transport and processing, and of fluctuations in the utilization of mainframes, using a network of hosts modelled on the "National Grid". As in the power supply network, the network of interlocked computers was supposed to stimulate the previously inhibited growth in mainframe size and expansion of the computer centers[52].

Because this "mainframe and high-speed mentality" was so strongly developed, however, militarily oriented computer communications also acted as an obstacle to the general trend towards the decentralization of resouces and applications. The security and reliability requirements imposed by the military on data communications systems, exemplified by the concept of a network that could survive under the most extreme conditions, did indeed provide the stimulus within large-scale research for the development of more strongly decentralized network architectures. At the same time, however, the structural restriction of perspective in the R&D apparatus of the military and large-scale industrial research complex prevented or obstructed any targetted development of solutions and products that could also be suitable for simpler fields of application in offices and factories. A change in direction therefore occured in several areas of computer and computer communications development at the end of the 60s. Parallel to the dominant efforts of that decade, which were aimed at bringing the large centralized systems under control through structuring, hierarchies and partial decentralization - e.g. through structured programming, software engineering, time-sharing, packet switching networks, and hierarchical concepts for process control and automation, and with the aid of layer models for large computer, database nad network architectures - sociotechnical approaches were now developed which were completely independent of such centralist, hierarchically distributed systems. Personal computers, local area networks and stored program control systems are the most visible representatives of these local "opposition technologies", which were based mainly on microprocessors. The conflicts and interactions between these two orientations gave rise to the specific characteristics of the following, third phase of computer communications.

5. The social construction of new network architectures for local computer communications

LANs fill the gap between microprocessor systems and public or private wide area networks. Before this area of computer communications could be opened up and developed after being neglected for so long by developers, manufacturers and network operators, a series of new network topology types, such as buses and rings, first had to be created, as had new access processes for workstations on a simultaneously used transfer medium. Despite the deficits and acute defects of large-scale time-sharing systems (overloading during peak periods) and the weaknesses shown by digital PABXs in connection with data transmission, the impulses for the creation of these new network architectures did not emanate from the demand side. Bottlenecks and problems experienced by network operators and by the manufacturers of mainframe, minicomputers and microcomputers were what actually led to the interest in alternatives for local data communication at the end of the 60s. The initial stimuli resulted from the adaptation problems in the local sections of civilian wide area packet switching networks and from the military's striving towards less vulnerable network architectures. Other factors which stimulated research activity were the deficiencies in operating economics when using time division multiplex technology for the allocation of network capacities in combination with burst techniques for data transmission, a bottleneck that affected the major operators of public networks. The factors which moved the computer manufacturers to direct their development activities in the direction of local networks were the enormous problems encountered in the technical organisation of access by more and more terminals and periphery devices to host computers, on the one hand, and the need for shared utilization of printers, servers and other hardware and software resources by minicomputers and microcomputers, on the other.

Early LAN approaches within traditional wide area data networks

The first operational LAN was installed, as already mentioned, by the National Physical Laboratory in Teddington in 1967/68. A combination of time-sharing and store-and-forward principles was designed to optimize the internal and external transmission of messages and access to central resources. Fixation on solutions developed in the large-scale time-sharing world and WAN packet switching networks was still so marked that the possibilities that could be opened up by local networks were still not recognized[53]. Another early precursor of LAN networks was the ALOHANET system developed between 1968 and 1973 at the University of Hawaii with the support of DARPA and NASA. Because of the special geographical conditions, it was designed as a packet radio network, in which all workstations (minicomputers) were linked to a central node[54]. This intermediate stage between wide area and local area networking became the pioneer of broadcasting LANs with random access features. The systems designers and the research institutions and companies involved did not, however, recognize the opportunity for a new local data and computer communications system based on the ALOHANET system, since they were too fixated on radio transmission and the time-sharing model for central computers.

A second strand in the development of LANs involved the early experiments with ring topologies at AT&T and Bell Lab. While looking for a substitute for the unsuitable TDM method in data communications, the US and later the Canadian university research team headed by Farmer and Newhall had already developed the concept of a ring network as early as 1968/69, in which the right to send was allocated to workstations by a central computer in the form of a bit pattern called a "token"[55]. This preliminary form of Token Ring architecture still fluctuated between a local perspective ("conversation" between workstations) and the WAN perspective (replacement of the classical telecommunications network architecture). Because Bell had no special interest in the local components, this system was quickly dropped. Another ring network developed by Bell Lab, the Pierce Ring of 1970/71, retained the supraregional components of the Farmer-Newhall loop, but used the more traditional slot ring access method[56] instead. The Pierce Ring was thus a typical network operator development: the guiding idea was a more efficient hierarchical data transfer network on a large scale that would solve the problems of network economics experienced by a large telecommunications company, but which could not provide the technical infrastructure for a local cooperation network. The Pierce Ring became important for other ring net designs in Europe, however, for example the Hasler Loop, which itself became the starting point for the Cambridge Ring and other European ring systems.

Early LAN developments in the IBM mainframe world

IBM, surprisingly enough, was also involved at a very early stage in experiments wih this new network typology. Steward and Hippert from IBM's Systems Development Division developed a centrally controlled Token Ring. This contained elements of the star-ring architecture (wiring center) that was later favored by IBM[57]. This method of connecting several terminals to a central system was designed to avoid the expensive mass of cables that in larger computer installations was barely controllable. This development, which arose from acute bottlenecks in existing systems, was further developed for use in computer centers and was integrated in 1973/74 into the standard IBM protocols for SNA networks (SDLC loop), but was not pursued any further as a possible LAN architecture. Parallel to this, another LAN precursor, the first "Zurich Ring", was developed in 1970/71 by Konheim and Meister at IBM. The declared objective of this US Air Force supported ring network was similarly the replacement of the star-type linkages between terminals and CPU[58]. The selected architecture, a Slot Ring featuring a central supervisor, was highly problematic, however, since the susceptance to failure in the ring topology was compounded by the central control feature. IBM therefore stopped pursuing the idea, and did not take up the ring structure again until Saltzer, Clark and Pogran had developed, in 1979-1981, a network architecture less susceptible to failure and disturbance, namely the Star-Ring architecture, which was actually a further development of an access technology invented as early as 1972.[59] What is noteworthy here is the fact that it was not IBM's development laboratories in America that rediscovered ring topologies, but their Zurich laboratory instead. Ring topologies had been considered a typically European network architecture by the computer networking community since the late 1970s, even though the first steps in this direction had been made in the USA. The evolution of LAN types thus comprise an interesting research object for examining the explanatory power of the "regional style of technology approach".

Successful and unsuccessful visions in the origins of LAN technology

Neither technological nor economic factors can explain IBM's lack of success, or greatly delayed success on the LAN market. The essential elements of the Token Ring already existed in the IBM's development department as early as 1970, but was not translated into products. IBM, the largest computer manufacturer by far, did not manage to present a marketable Token Ring system until 1985/86. There was also definite demand and finance for local data communications, as can be seen from the rapid growth in the LAN segment. Obsession on the part of managers and developers with the traditional sociotechnical architecture of the IBM world, in which the local dimension resembles a monarchy with the central processing unit and the computer center at the top, was what prevented IBM from assuming a pioneering role, and which caused an unusually serious delay in IBM's second-best strategy in this case.[60]

Even in the case of the largest telecommunications manufacturer and operating company in the world, the creation of a marketable LAN architecture was blocked by the dominant visions for computer communications technology. The large-scale network orientation was so dominant, indeed, that the local possibilities offered by ring networks were not even seen. This topology was so vulnerable and unsuitable for wide area networks, however, that it was quickly dropped. AT&T switched over after the experiments with ring architectures to the even more traditional star-type, but failed to achieve a significant share of LAN-market with this topology. The field was left to outsiders such as XEROX, smaller companies like Hasler in Switzerland, or to some company founders with backgrounds in university research on military projects, to finally develop marketable products from the initial steps taken in the direction of new local networks.

A movement away from the military-industrial complex by critical developers was required for small systems like the Personal Computer (PC) and the local network (LAN) as an alternative to the world of large-scale host computers. Xerox's Palo Alto Research Center (PARC), established in 1970, was a technologically avant-garde institution and an outsider to the computer industry. It became a collection point for the dissatisfied and the innovatives, and finally became the counterpole to the military technology centers of ARPA and MIT[61]. At PARC, Robert M. Metcalfe, an ex-member of the MAC team, succeeded in the period 1972 - 1976 in creating the first packet-oriented local network, Ethernet, as a supplement to the first PC, the "Alto". Metcalfe transferred the spontaneous access method (carrier sense multiple access) of the ALOHANET to a 50 Ohm coaxial cable with a initial transfer rate of 3 Mbit/sec (increasing later to 10 MBit/sec), improved the CSMA process by adding "collision detecting", and selected the more flexible bus topology for the network instead of the more complex ring architecture. [62] The technical concept behind Ethernet was geared in all its parameters towards achieving the simplest possible network for individual office buildings and office complexes, an inexpensive, strong and simple technology at a price level matching that for PCs. On the basis of this product philosophy, Ethernet became the most successful LAN architecture and has been able to hold on to this largest of market segments. And this despite IBM's intensive promotion of their Token Ring systems - a fruitless attempt at repeating the success achieved when they joined the PC market after the race had already started.Metcalfe's success was based on a total redesign of the previous "large central time-sharing systems" through concentration on downsizing, simplification and cost-efficiency. Instead of large-scale host and subhost networks for mass data transport, implicitly oriented towards nationally and internationally operations in the armed forces, the state and in business, Ethernet was inspired by the vision of "personal distributed computing" and by new types of local topology and network architectures. Finally, it was the fundamentally different social model - local work contexts and cooperation - which overcame the limits of the previous phase of computer communications, dominated as they were by purely military considerations. Approaches for decentralized network architectures had been studied initially within the military-industrial complex, but had not been developed and exploited there. On the contrary, the large-scale network community, comprised of the Armed Forces and large industrial corporations, responded to the new decentralized approaches with considerable resistance, and did not attempt to integrate them into their own large system strategies, until they had already become independent developments.

6. Conclusion: Usefulness and deficiencies of more recent technohistorical approaches to the study of computer communications

More recent technosociological and technohistorical approaches can make a decisive contribution towards overcoming the prevailing lack of theory that has characterised the writing of computer history to date. The "large system history approach", in particular, can promote the requisite change of perspective from the early history of hardware featuring inventor biographies and controversies over who was first, to a complex, systemic view dealing with the entire technological life-cycle. But other social-constructivist approaches, such as Noble's analysis of pattern-formation, or the *Leitbild-Assessment* propagated by Dierkes et. al., are of particular value for the technogenetic study of computer networks. The following theoretical statements and generalizations play a special role in this connection:

- The "reverse salient" or "imbalance" concept offers an explanation for many developmental impulses in the field of computer communications. This is especially the case if the concept is related not only to the internal perspective of computer network technology, but also to the dynamics of its development in interaction with bottlenecks in hosts and computer centers, and in data processing in larger, medium-sized and small companies and organizations. However, the historian should not just assume the role of a retrospective system manager who merely identifies obstacles to the expansion of systems, but should also inquire specifically into the effects of bottlenecks and inadequate system designs for the users in question.

- Equally productive for the analysis of computer communications and information systems is the observation made by the system-historical approach, namely that there is a high degree of convergence between technical and sociotechnical system architectures, on the one hand, and the social and management structures of manufacturers and other enterprises or organizations who purchase their products, on the other. The influence exercised by the military or large industrial context in which such technology is developed is less determining, however, than in the fields of energy or production technologies. Adaptation to other application fields is not only possible in the field of computer communications, but indeed a common occurence. The idea of a multi-stage pattern-formation process is therefore more appropriate than the assumption of a primary "technical" or "social choice".

- Studying the debates between advocates of different directions in the design of computer communications systems using "large system history" also reveals a whole series of controversies. However, this does not generally involve a singular central conflict between systems in a manner analogous to the direct current / alternating current battle in the electrical supply field, but instead a whole cascade of larger or smaller disputes involving the entire technology life-cycle.

- Guiding vision research, which has seen considerable growth over the last decade, may be able to contribute in a similar way to an explanation of genesis, especially the success or failure of system designs in computer communications. But the somewhat unelaborated "*Leitbild-Assessment*" approach needs to be sharpened up analytically and operationalized. The study of guiding vision transfers into other areas of society, a phenomenon which is only briefly outlined in this paper, or the formation of genuine vision chains following outstanding system developments, could become an important instrument of analysis with which prospective technology assessments are made possible.

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