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Robert Fano, an Italian Computer Scientist from Project Mac to the Internet

Benedetta Campanile

Abstract

In 1938 Italian-American Robert Mario Fano emigrated to the United States following the issuing of the racial laws in Italy. Extrovert and determined, in the United States Robert found an adoptive homeland in which his young talent could be nurtured, a place in which science was fostered by democracy and freedom of choice. In the US he became a pioneer of the concept of "making the power of computers directly accessible to people." He believed that the tools of information processing could build a better society in which everyone would have the same opportunities to make their dreams come true. In fact, in the early 1960s, he led the launch of the Massachusetts Institute of Technology's Project MAC which "took the first step in the computer revolution that changed the world," as Professor Fano himself said, and brought the Internet into being.

> "Perhaps the best opportunity for personal use of computers will come about through "time-sharing," the technique which divides the use of a large central computer among several users ... Within a few years I would expect a number of time-sharing computer systems to be interconnected—capable of communicating with one another as well as with many remote subscribers." (Fano, 1968a, p. 6)

With this prophetic sentence in 1968, Italian-American Robert Mario Fano announced the dissemination of computer systems as tools for communication and connection. He pioneered the concept of "making the power of computers directly accessible to people." In fact he believed that the tools of information processing could build a better society in which everyone would have the same opportunities to make their dreams come true. In the early 1960s, he launched Massachusetts Institute of Technology (MIT)'s MAC project, which "took the first step in the computer revolution that changed the world," as Professor Fano himself said, and brought the Internet into being (Fano, 2014).

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Born in Turin in 1917, Fano was a twenty-one-year-old student of the School of Engineering at the Polytechnic of Turin when the Fascist government's racial laws hit his Jewish family. His father, Gino, from a wealthy Jewish family originally from Mantua, abandoned his career teaching mathematics at the University of Turin and fled to Switzerland, whereas his older brother, Ugo, a physicist from Enrico Fermi's Via Panisperna group, emigrated to the USA. Robert brought his studies in Italy to an end and joined his brother overseas. Here he was admitted to MIT in Boston, where he graduated with a BSc in Electrical Engineering in 1941 and an Sc. D. in Electrical Engineering in 1947. Before becoming Project MAC's director, Robert had a long career in MIT where he started as teaching assistant in the electrical engineering department, from 1941 to 1943, and then moved onto being instructor in 1943-44. Then he joined the Institute as a Radiation Laboratory staff member. In 1951 he was appointed Associate Professor of the Electrical Engineering Department at Lincoln Lab and in 1962 became Ford professor (Campanile, 2018; Wildes, 1986).

In the spring of 1963 Fano was granted the support of the Department of Defence's Command & Control Branch of the Advanced Research Projects Agency (ARPA), part of the Naval Research Contract Number Nonr-4102(01) office, for a program focusing on enquiring into the relationship between human users and computers. With people potentially able to work from remote locations, namely online, this system aimed to examine the ways in which direct links to on-line computers could aid people in their individual work. Fano grasped that the search for solutions to increase man-computer interaction would broaden computers' integration into human life for solutions to research, design and employment issues and in the knowledge-based services (management, education, banking, etc.) (Fano, 1972, pp. 1249-1250). The program was the brain child of experimental psychologist Joseph C. R. Licklider (1915-1990), the author of *Man-Computer Symbiosis* (1960) (Licklider, 1960, pp. 4-11), and director of ARPA's Information Processing Techniques Office (Fano, 1998). Licklider's was an ambitious goal, a "Galactic network," a universal network of computers connected to one another for online work (Licklider & Taylor, 1968) and he broached this issue in a memo to the "Members and Affiliates of the Intergalactic Computer Network" in April 1963 (Licklider, 1963).

Fano wrote the plan after discussing the potential feasibility of such ideas with his colleague Licklider on a return train trip from a conference in Virginia in November 1962. He brought Licklider's project to the MIT together with $2 million a year for five years and a new challenge for himself, because he was not MIT's greatest computer expert (Flamm, 1987). The MIT received a funding total of $25 million from 1963 to 1971 (Reed, Van

Atta, & Deitchman, 1990, p. 19 [14]). The contribution of academic research laboratories was fundamental to the history of computer science, but it has been overshadowed by the emphasis accorded by historians to the role of computer companies and military objectives (Garfinkel, 1999, p. viii).

Initially MIT named this strange project simply "FF"—short for "Fano's Folly"—because it seemed to be one of his crazy ideas. Fano's aim was to set up a new research lab, but administrative obstacles prevented people from other MIT labs joining it without resigning from their existing positions. Therefore, the lab had only one physical employee while the others worked online, a new virtual way of working which revolutionized the idea of the physical laboratory. The need to identify the research laboratory and its only employee obliged Fano to find a name for it (Campanile, 2018, p. 312). During a dinner party on the night of April 1, 1963, with Marvin Minsky and John McCarthy, Robert Fano coined the name MAC, an acronym with two meanings: Machine Aided Cognition, as the goal of the project, and Multiple-Access Computer as the tool, because it was based on a new technology, time-sharing (Garfinkel, 1999, pp. 6-7).

Project MAC's starting aim was to create the "illusion" for multiple users of having a private computer to themselves (Fano & Corbató, 1966, p. 128). In actual fact, time-sharing was based on rapid time division multiplexing of a central processor between several users. So each user operated a teletypewriter or other terminals online.

This new way of working with computers had been on trial at the MIT Computation Center since 1961, when John McCarthy had explained that a multiple-access computer system could improve user capabilities because it could connect up a large number of people simultaneously. He named this system "time sharing" (McCarthy, 1983, p. 2). In effect the term "time-sharing" had been in use in programming in SAGE (Semi-Automatic Ground Environment) Air Defense System for some time. McCarthy introduced the concept of time-sharing as a community utility to encourage a new type of processing to save time in preparing programs and waiting for computer results.

A copy of a Computation Center system, named "The Compatible Time Sharing System" (CTSS), was made for Project MAC to explore the potential of the online man-computer partnership (Corbató, Dagget, & Daley, 1962; Lee et al., 1992). The CTSS was the brainchild of the associate director of the Computation Center, theoretical physicist Fernando J. Corbató (1926–2019), "Corby," who implemented a multiple-access computer capable of both batch and time-share processing.

Indeed, time-sharing was an alternative to conventional batch processing which "had made programming a hard task" (Garfinkel, 1999, p. 3), because computer users spent long periods waiting for task queues to be processed. On the other hand, the project's goal was to show that continuous dialogue between users and machines was possible in which computers would act as man's intellectual assistant and the man-computer partnership would be non-hierarchical (Fano, 1965, p. 56). Project MAC was described by Fano in 1964 in his ARPA *Report*: "Project MAC was organized as an interdepartmental, interlaboratory 'project' to encourage widespread participation from the MIT community." There were thirteen participants from all sections of the Institute. "Such widespread participation is essential to the broad, long-term project goals for three reasons: exploring the usefulness of on-line use of computers in a variety of fields, providing a realistic community of users for evaluating the operation of the MAC computer system, and encouraging the development of new programming and other computer techniques in an effort to meet specific needs" (Fano, 1964, pp. I; X).

The "MAC Man"

Fano transformed himself into "Mac Man." Indeed, if Corbato was called "Mister Time-Sharing," it was Fano who shared his new belief in "time-sharing" with colleagues inside and outside MIT and within the Federal Government. In fact, at the start of the project, Fano organized a summer study school at MIT which was attended by 100 participants from the US and Europe. The meeting raised scientific awareness of the project's aims. With his empathy, likeableness, enthusiasm and determination, Fano built up a network of people—his academic colleagues—who were to test the new computer system. The same people would set up the network on which internet technology was to be based.

In May 1983, at MIT's Electrical Engineering Department Celebrations, Fano argued that time-sharing had been a revolution, because in the late 1950s it was mainframes which had been the computer market trend. These computers were big, expensive machines and users could not even conceive of owning one. The key companies, such as IBM, were mainly interested in large-scale commercial batch processing applications. This is why Robert Sproull, at that time director of ARPA, became convinced that the Federal Government should intervene to develop the new time-sharing technology (Reed, Van Atta, & Deitchman, 1990, p. 19).

In 1963 the CTSS had 30 on-line users and, surprisingly, some of the same core principles described for the first version are still relevant in today's cloud computing systems (Hu, 2015, pp. 53-54). Very soon, 200 users in 10 different academic departments were connecting to MAC computers via the MIT telephone system. Fano observed that people were communicating with one another through computer commands as if MAC was a communication system. For Fano and his assistants this was an important social phenomenon because it was computer users working together which shaped the first net community (Fano, 2014). After three years of experience, "the system and its users have developed like a growing organism" (Fano & Corbató, 1966, p. 136). Through the system's features, and "message central" storage and "permit" commands in particular, users could communicate that they had stored private files in a public memory location and authorize others to use these files. Therefore, once people had been authorized to use files owned by somebody else, they could "link" to these files and use them as if they were their own (Fano, 1967, p. 31). Thus time-sharing allowed users to move files, data and programs (Lee et al., 1992, pp. 14-35). This "ease of exchange had encouraged investigators to design their programs with an eye to possible use by other people" (Fano & Corbató, 1966, p. 138). Moreover, a memory protection mechanism with password access prevented theft or accidental deletion of information.

The availability of a physical area on which to collect data and programs was one of the system's most significant features as it concretely configured electronic media as a support for immaterial goods, "information," just as the paper in the place of papyrus had done for commercial calculations in Europe at the end of the seventeenth century, marking the abandonment of the abacus in favor of so-called Arabic numbers. In fact, the availability of a "core memory" acting as buffer allowed all devices—mass memories, core memories, central processors and input-output channels—to communicate with one another. The search for an efficient means to replace paper as a support for the recording and transfer of knowledge had begun with MIT scientist Vannevar Bush (1890-1974) in 1945 (Bush, 1945, p. 102). The latter hypothesized that his Memex could work with magnetic tapes, but the period's still rudimentary mechanical technology had blocked his initiative (Campanile, 2016, p. 212). Twenty years later, new magnetic media, magnetic drums and new digital computers guaranteed optimal performance, even if the costs were still too high as compared to paper:

> A page of single-spaced text stored in the disk file of the current MAC computer system costs approximately 10 cents per month. We see no reason why recording in the mass memory of a computer system should not become competitive with other recording media (David, Jr. & Fano, 1965, p. 245).

The innovation was time-sharing's ability to virtually duplicate memory and processors for individual users. This was based on the concept of a functional subdivision of hardware into shared equipment serving the same function.

The duplication of each element was designed to respond to average user demands as a group rather than as "typical users." This hardware management mechanism oriented scientific research toward memory-centered as opposed to processor-centered systems (Fano, 1965, p. 64).

The path chosen was the right one and Fano pushed Project MAC's research in the direction of the best possible knowledge representation through the use of high level program language to improve computer utility and user dialogue. The system's services were organized into commands, also called instructions, that system users could make to the system to implement programs. Users could use the system's various languages for several applications: FAP, MAD, COMIT, LISP, SNOBOL, a limited version of ALGOL, and two problem-oriented languages named COGO and STRESS, for engineering applications (Fano, 1965, p. 59). This was to lead to the reuse of programs or parts of programs by the largest number of users. For example, to edit text, users could use the Michigan Algorithmic Decoder language (MAD) to make simple alterations, corrections or otherwise change the program's text (Fano, Corbató, 1966, p. 132).

High level language was thus an interface between natural user language and the computer's machine language. This simplification of access to information stored on mass devices would extend the use of computers to a larger number of unskilled users, a choice which would generate real change in knowledge sharing and transmission and in the establishment of large economic organizations (Damascelli, 1998, p. 108). Hence, it would make information exchanged on the web the "digital gold" of the twenty-first century (Floridi, 1997, pp. 49-52).

The network as a new social model

Networks and knowledge sharing were the MIT scientific community's new social model. As historian Patrice Flichy has written, it was through time-sharing that MIT's scientists modeled the new computer environment "in terms of their own practices and representations of modes of sociability" (Flichy, 2008, p. 28). Interaction and joint working was standard behavior between MIT's scientists, as Fano well knew. In fact, Robert had accepted the challenge to work on computers for DARPA precisely because he was counting on the help of his friends and colleagues at MIT's Computation Center. With Project MAC this cooperation was widened to distant colleagues (Campanile, 2014) and Licklider called this social organization a community "of *common interest*" (Licklider & Taylor, 1968, p. 38). In fact, unlike other universities MIT was made up of *a community of equals* in which each member's status was based essentially on merit

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(Flichy, 2008, p. 29). Joint working was more intense when the aim was to network computers deliberately designed to differ, as time-sharing did. Differences—gender, nationality, competence, religion—were a value at MIT. The joint working principle allowed complex software to be created as an aggregation of programs drawn up by different people. MIT served as a model for other institutions (Kaiser, 2012, p. 5) and thus a new computer service dimension had taken shape: communication between users mediated by computers.

Time-sharing was a change in direction in computer production. IBM agreed to modify MIT's computer, IBM 7090, for time-sharing use and Bolt Beranek & Newman and DEC created time-sharing systems. DEC made the first minicomputer, PDP-1, for use in time-sharing.

The quality of knowledge-based services

In 1968, in his paper *On Increasing the Availability and Quality of Knowledge-Based Services*, Fano clarified that decision-making quality was directly proportional to the amount of information available. This is why the time-sharing system, which again allowed several sources of information to be brought together, consequently improved the quality of knowledge-based services.

In fact, the time-sharing system was to increase the quality of the information industry in the same way that the industrial process had improved handicraft work. Increasing the number of computers connected in time-sharing meant more users could share specialized knowledge. The network could create a shared mass of knowledge and science and society's more challenging problems could be solved. For example, this system could generate significant improvements in the management of the large volumes of information needed in knowledge-based services such as education, health and banking (Fano, 1974, pp. 6-8).

Fano was thus concerned with two issues: knowledge production and fruition. He suggested a solution: good symbolic representation of knowledge recorded in a computer's memory for knowledge reuse. This involved building good software interfaces with which to access information, which were to compensate for the physical limits of the technology. For this reason he pushed the development of research funded by Project MAC in the direction of the creation of advanced interfaces capable of interacting with the users via innovative tools. An example was a multiple-display system developed by the MIT Electronic System Laboratory for computer-aided design which included two oscilloscope displays with a character generator and a light pen (Fano, 1965, p. 57).

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Thus Fano highlighted the following issue: is mass production of knowledge-based services possible? His answer was that increasing quality was a feature of mass production and four conditions were required:

1 dividing tasks up into specialized activities connected by strict logic;
2 creating a flexible network infrastructure for transporting and distributing information;
3 creating an interface including all subjects which produce, require, distribute, and consume information;
4 finding investment capital to create an information industry (Fano, 1967, p. 36).

In this problem solution strategy Fano demonstrated a more concrete vision than Vannevar Bush, whose prophecies on information technology's future were more utopian.

Computer Utility Service

Fano foresaw that computers would have a profound impact on social functioning—in laws, regulations and business operating procedures—and would also potentially create a new form of society. In placing computer at the service of individuals, by means of information processing, such services would provide "thinking tools" to individuals to aid them in their everyday intellectual labor. Fano believed computers increased human skills and empowered minds by providing a high volume of information on which to base accurate decisions. Information overload was a real danger and people to acquire, record, search and use this information were needed. A similar need inspired Bush's Memex, but the technology was not yet ready for a suitable solution to be found at the time. Now Fano and his group could handle data with digital computer for better effectiveness in searching and using information.

Fano and Corbatò popularized the public utility metaphor for time shared computer services, introducing the notion of "customer" which changed computation's meaning. This meant that computer utility or information utility were general and measurable services. Supplying computer power to individual "customers" would mean that users could access services "where, when and in the amount needed" (Fano, 1967, p. 36). This was the new computer utility model that McCarthy had proclaimed in 1961, Martin Greenberger had theorized in *The Computers of Tomorrow* (1965) and Fano promoted as the computer of the future (Greenberger, 1962, p. 8). Furthermore, new technologies could measure and accurately price the amount of information transferred and exchanged. This measurement then completed the process by which intangible 'information' resources

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were commodified and made it comparable to other products, but with a substantial difference linked to the "clear separation between sale and transfer of the product" (Floridi, 1997, p. 50). In fact this different property exchange mode modified agricultural and industrial society's product purchase concept according to which producers handed over their goods in the act of transfer to the buyer. As Fano and Corbatò explained, the new information utility was a loss-free service supplied to an "entire community" of knowledge resembling a "powerful library." Fano "was among the first to tell businessmen that 'time-sharing' is part of a growing trend to market the computer's abilities much as a utility sells light or gas" (Hu, 2015, pp. 53-54). Associate professor at MIT's School of Industrial Management, Martin Greenberger, also compared the change from batch to time-sharing to the gradual electrification of cities (Greenberger, 1964; 1965) and to the distribution of telephone services (Parkhill, 1966, p. 52).

Actually, the partitioning of computer services offered by time-sharing more closely resembled TV program broadcasting. In fact, the customers would be served round the clock and a single broadcasting station, the CTSS, allocates programs and resources to a plurality of users. However, unlike broadcasting, time-sharing computation was a product with dynamic features that needed to be actioned by users as it took place via two-way dialogue with input and information as feedback, such as in the system login service which needed direct interaction between system and user.

Demands for a round-the-clock service became evident when Fano's scientist colleague Joseph Weizenbaum (1923-2008), the author of the *Eliza* program, waited in Fano's office to complain that the system did not work at night (Garfinkel, 1999, p. 9). This was a personal satisfaction and goal for Fano's team. The conditions for the birth of an information age were thus created: service supply and public utility demand.

"Freedom of choice"

Fano described computers as a mental aid, a much needed tool with which to manage society's new complexity (Lee, David, Jr., & Fano, 1992, p. 36; David, Jr. & Fano, 1965, p. 244). Fano (1968, pp. 259-260) wrote:

> It is also important to note that a human society equipped with much more effective means of gathering and using data will allow much more individual freedom and more inequality among its members, without running the risk of becoming chaotic and losing control of itself.[1]

1 Translations are the author's own.

In fact, a mass of information needed to be acquired, recorded, sought out and used if many problems were to be solved, such as those of an educational, technical, managerial, economic, political, social, legal, ethical and philosophical nature.

Fano believed it necessary to adapt computers to people's desires and needs, rather than vice versa. Good interface design could impact on user efficiency as it limits its usability. Thus, designing a computer system can limit and shape the way a community of people interacts. Consequently, it was software designers' responsibility to develop easy-to-learn interaction methods. He also stressed that a community's characteristics influence a computer system's evolution in feedback.

Fano believed that the use of computers in any tasks involving people could enhance "freedom of choice:"

> In today's society we force a certain amount of conformity simply because if there weren't such conformity we wouldn't be able to manage the situation ... Now all this can be changed substantially by better means of information processing. In other words, in an information-rich society, the individual will have much more freedom of choice because society will be able to stand much more diversity among its members without the results being chaotic (Fano, 1968a, p. 5).

Fano wrote that information was the new society's cement and computers were a tool with which to satisfy knowledge transfer, management and production needs: "The state of equilibrium that society will assume with respect to the new boundary conditions will depend largely on how each individual, in his roles as worker and citizen, will decide to exploit the new tools available" (Fano, 1967, p. 262). With the new digital technologies even the marginalized social categories, such as black minorities, could exercise their "freedom of choice," which was the possibility to shape their own future and the recognition of their existence through new job opportunities. In fact, the optimistic view of the report of the Joint Committee on the Economic Report to the US Congress denied the pessimistic one proposed by Norbert Wiener, who reflected on negative incidence of automation on employment (*Cybernetics; The human use of human beings*). The Committee, instead, highlighted the benefits of technology, automation, and economic progress in the Automation and Technological Change Report (Douglas, 1955, p. 11). The aforesaid report spoke of new jobs promoted by new government policies regarding the use of automation technologies. However, the creation of different jobs compared to the past was seen as an element of uncertainty and fear with respect to tradition (Caffè, 1967, pp. 431-444).

Fano firmly believed in the new digital paradigm of computation based on the "jump" function. This new paradigm exceeded the old model of the continuous circuit where it was not possible to identify the discontinuity between the values of the magnitude examined. This digital paradigm was also fitting the need to describe the wealth of the new society in which each individual, although belonging to minority social groups of race, gender and religion, could be represented in its singularity and, therefore, in its "freedom of choice."

The digital paradigm was a metaphor in the struggle for civil rights, in the name of Martin Luther King, his prominent supporter, and J. F. Kennedy, his most sensitive interlocutor, which was making its mark on the US. In his manifesto *A Nation of Immigrants* the latter had introduced the concept that it was diversity that had made America great. The nation's strength was therefore its "composite" character and its ability to give a voice to every difference. Digital computers were the technology best suited to rapidly evolving societies that had to handle large amounts of information to master the complexity of their times (Kennedy, 2009, p. 1). The idea of adapting technology to human beings was a consequence of the cybernetic concept introduced by Fano's friend, colleague and neighbor at MIT, Norbert Wiener (1894-1964) (Pogliano, 2007, p. 91).

The time-sharing computer system was creating a community in which diversity was a value because computer helped to manage differences without causing confusion. "Information" was becoming the mirror of the community that the computer system served since it was the archive of that community's knowledge (Fano, 1974, p. 4).

Eugene Fubini (1913-1997), who emigrated to the U. S., like Fano, in response to Nazi persecution (Fubini, Brown, 2015, pp. 61-64), was a supporter of Project MAC when he was undersecretary to the American Ministry of Defense, also expressed the need to manage social complexity with technologies that had: "the ability to extend a process that is uniquely human: the mental process that uses information" (Fubini, 1968, p. 397)

In Italy distrust of new technologies was fueled by some politicians' fear of American technological invasion. In this regard, Fubini argued that:

> It seems to me that the opinion of those who argue that for Europe the best way forward is to minimize the interdependence of the two continents is illogical. European technological capabilities will develop much faster if the "old continent" continues to use the flow of information and knowledge coming from America, instead of concentrating its efforts on national or local self-sufficiency criteria. By this I do not mean to defend myself in the Americanization of Europe, but rather in the Europeanization of certain technological procedures

> and certain commercial methods which have proved to be very profitable in America (Fubini, 1968, p. 396).

Fano believed that the employment of computers in any task involving people had many social consequences and, in some instances, that these consequences could be adverse. For example, job destruction (David, Jr., & Fano, 1965, p. 246), the subtraction of data and code and individual control.

Related to this issue, in the US a commission was set up to assess the impact of automation on employment levels that made statistical projections over the next ten years: *Automation and Economic Progress* (US Congress, 1964, p. 7). The report was reassuring, but it was not discussed because military commitments abroad called politicians' attention to other priorities (Caffè, 1967, p. 438).

Privacy was considered a fundamental American freedom and an unquestioned constitutional right. The menace of bureaucratic control of individuality and citizens' privacy was a real Federal Government concern because there were plans to set up a National Data Center or Data Bank "to reduce the costs of duplication of files and to provide more rapidly available information to those with legitimate need" (Paul Baran, computer expert with the RAND corporation, US Congress, 1966, p. 121). The Hon. Frank Horton said: "The Subcommittee believes it is important that we consider this question before the establishment of a National Data Center or bank becomes a fact" (US Congress, 1966, pp. 1-4). A data bank was the trend for "increasing demand for a centralized facility [...] into which would be poured information collected from various Government Agencies and from which computers could draw selected facts. It is our contention that if safeguards are not built into such a facility, it could lead to the creation of what I call 'The Computerized Man,' [who] would be stripped of his individuality and privacy" (Hon. Cornelius E. Gallagher, chairman of the subcommittee on Invasion of Privacy of the Committee on Government Operations, US Congress, 1966, p. 2). A climate of concern was kept alive by Congress because of the increasing rate at which computers were changing the lives of citizens and society. Jerome B. Wiesner (1915-1994), dean of science at MIT and former science adviser to President Kennedy said:

> The computer, with its promise of a million fold increase in man's capacity to handle information, will undoubtedly have the most far-reaching social consequences of any contemporary technical development. The potential for good in the computer, and the danger inherent in its misuse, exceed our ability to imagine [...] Our only hope is to understand the forces at work and to take advantage of the knowledge we find to guide the evolutionary process (US Congress, 1966, p. 5).

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Fano tackled the ethical issues around computers' potentially negative impact on individuality and privacy (Chartrand, 2013, p. 182): from hacker attacks to bureaucratic controls. The community expected system designers to protect the integrity and privacy of their data against malicious action.

The general-purpose time-sharing system

From 1963 to 1969, the Project MAC policy for the creation of the Multiplexed Information and Computing Service (MULTICS), the successor to the CTSS, was headed by the representatives of the three institutions involved: Robert Fano for MIT, Edward E. David for the Bell Labs and John Weil for General Electric. This so called "Trinity" was supported by the "triumvirate," the technical committee that included Fernando Corbató for MIT, Ed Vance for General Electric and Vic Vyssotsky for the Bell Labs. In this period many were attracted by time-sharing systems and adopted computers as working tools. In fact, ARPA contributed to the sponsorship of the other six time-sharing systems, in 1964 in particular: the Carnegie Institute of Technology, Dartmouth, Stanford, and UCLA which led to commercial time-sharing operations. This work was the basis for commercial time-sharing MARK I and MARK II. (Reed, Van Atta, & Deitchman, 1990, p. 19).

In 1968 Licklider succeeded Fano as Project MAC's director, while Robert continued his work promoting computers. He participated in many conferences in Europe and the US. In so doing, his aim was to give an example of how information circulation and knowledge sharing could stimulate new research. Furthermore, his intention was to demonstrate the working strength of the new generation of time-sharing systems, the Multiplexed Information and Computing Service (MULTICS). Indeed, in October 1969 MULTICS became operational as a general-purpose system for multiple access designed for General Electric 645 in conjunction with Bell Telephone Laboratories. A new partner of MIT's, the Honeywell Information System, replaced the Bell Labs. The system was imperfect but it improved time sharing's management efficiency with a new technique, "program segmentation." Program segmentation used a new algorithm in use at MIT, named "paging," to manage the concurrency of programs into memory (Corbató, 1969). This algorithm could transfer pages of information between the main and secondary memories. When the size of a program exceeded the available memory, the program was divided up into pages, each made up of 1024 words, which corresponded to the size of logical blocks into which core memory was divided up. Pages were transferred into core memory only when needed, if at all. When a page was needed, the "supervisor," the system's main program, loaded it into the memory. If

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there was insufficient space, the supervisor removed another page from the memory. Then, "paging" answered the question: "Which page should be removed from core memory?" The MULTICS strategy was *Least-Recently-Used* (LRU), since it exploited the high correlation that linked the less frequently used pages to the less necessary pages in a running program (F. J. Corbató, 1969, pp. 217; 219).

With the LRU, individual tasks could be achieved with minimal use of precious memory space and "without having to waste too much core memory to store entire programs waiting to be executed" (*Ibidem*). In paging segmentation, segment information included a page table address for each segment. Individual segments had an associated set of permissions for authorized processes. In this way segmentation was also a method of implementing memory protection.

A further innovation in second-generation time-sharing systems was the data protection technique. The security system consisted in "protective rings," a series of levels which users could access with a personal password only. The levels created a limited area that safeguarded against both programming errors that could unintentionally open access to the whole system and deliberate attacks by criminals wanting to get their hands on space, data or other users' codes (Fano, 1967, p. 257).

Fano therefore envisaged the research undertaken bringing time-sharing systems to all production environments. These systems could change future work organization because they would allow the dominance of hierarchical structures to be overcome (Fano, 1967, p. 249). He also forecast a loss in meaning in concepts of centralization and decentralization for social organizations, since individual users would be able to directly coordinate their activities with their network of colleagues via time-sharing system tools (Fano, 1967, p. 259). In 1973, Honeywell issued a market product using the Honeywell 6180 hardware and MULTICS was installed at over 80 sites, but it was not very successful. Much more important was the influence that its design and many of its features had on modern commercial operating systems through the dissemination of a further operating system, UNIX. The latter inherited many of MULTICS's features because it was developed by two MULTICS programmers, Ken Thompson and Dennis Ritchie, from the Bell Labs. The latter wanted to create a simpler and more effective system for hardware with fewer resources (Van Vleck, 1995). Their success in this quest brought a large market share to UNIX which expanded in two directions: 1) into universities: a) Berkeley Software Distribution (BSD) from Berkeley University, from which NextStep and MacOS X originated; b) SunOs and Solaris from Stanford University; 2) the System III & V family. UNIX emphasized cooperative remote computer usage as Fano wished and BSD UNIX 4.2 was the first release to provide the tools with which to create a local network (LAN) (Frankston, 1996, p. 72). The effects of the computer utility concept were a split between computer systems' role as an object of research and development of theoretical research and their role as working tools. The former led to the UNIX operating system and the latter to mini computers and applications. The early 1970s pointed to the development of a billion dollars market in the computing utility industry, just as Fano had foreseen (Mahoney, 2008, p. 1).

As Corbató has stated, a continuity was established between MULTICS and UNIX because the first choices of the MULTICS Trinity influenced Thompson and Ritchie in their work on improving UNIX's functioning (Corbató, October 30, 2000).

Advanced Research Projects Agency NETwork (ARPANET)

Meanwhile, the interoperability introduced by time-sharing had incorporated computer use into interpersonal communications and entertainment and a new network project, ARPANET, was emerging in the public domain. In July 1968, during the MIT-Technical University of Berlin Computer Conference, the setup demonstrated how remote connection between the terminals in Berlin and a time-sharing computer at MIT worked. In 1969, the University of California in Los Angeles delivered the first Interface Message Processor (IMP), which would serve as the Network Measurement Center for the developing ARPA Network. In fact, in 1971-72, the MIT Project MAC MULTICS machine was connected to the ARPANET. In 1972 the first ARPANET hardware interface at Project MAC was set up between a Digital Equipment Corporation PDP-10 model KA (known as MIT-DM) and a Honeywell DDP-516 operating as an ARPANET Interface Message Processor. CTSS was turned off (Garfinkel, 1999, pp. 24-26).

The Tech Square, Project MAC's home, hosted the nodes of the MIT network, ARPANET's East Coast hub (MIT, 2004). It was the original Network 18, known today as mit.edu. The continuity between the Project MAC technologies and the Internet must be sought in the search for a symbolic representation of knowledge in order for this to be reusable. In fact, "from the opening of the Project MAC to the invention of the Web, unlike many other technologies, the network components and at last Internet were developed almost entirely in the academic world, based essentially on computer programs, that is, intellectual work" (Flichy, 2008, p. 28). This was just what Licklider and Fano had hoped for when they launched the computer access improvement program.

In 1973, Fano was appointed to the National Academy of Engineering for pioneering work in the development of the first interactive time-sharing computer system and his contribution to communication theory (Garfinkel, 1999, pp. 30-31). In 1975 Project MAC was renamed Laboratory for Computer Science. Fano's 1960s vision for MIT, which accorded computers a future in education, was therefore achieved, because a broad range of new disciplines was born to shape the new MIT original curriculum in Computer Science. In 1978 Fano was elected to the National Academy of Science.

In the early 1990s, the father of the Web, Tim Berners Lee, set up the World Wide Web Consortium's global headquarters on the third floor of Tech Square. The Computer Science Lab became a global reference point for theoretical formalizations and the exploration of new technological environments to keep young engineers up-to-date with society's needs. This had originally been MIT's mission, according to its founder William Barton Rogers (1804-1882), and the vision of Vannevar Bush as MIT vice president (Campanile, 2016, p. 32).

In 2003, the Computer Science Lab was merged with the Artificial Intelligence Lab to form CSAIL. From Building NE43, known simply as Tech Square, the Computer Science and Artificial Intelligence Laboratory moved its home to the Ray and Maria Stata Center. Fano loved this building because it represented freedom and creativity for the community (Fano, 2013).

Conclusion

Fano's research naturally poses a question: Could the interaction of users in time-sharing, namely mediated by computers, bring a positive impact on the wider society? Fano's answer was more robust than Bush's analysis since the former had already accepted the digital paradigm and foreseen computers' use as a medium of transmission. Fano was the first to recognize time-sharing's capacity to give humans control over computers to the extent of their being able to use them in a creative way and share ideas with them, beyond their mere capacity to compute information (Lee, Rosin et al., 1992, p. 35).

Fano's vision of technological progress was a positive one, in line with his determined and optimistic character and a historic period in which he affirmed "scientism," or rather a belief in science's ability to solve social problems. He thought that scientists, especially software designers, played an important role in society because they were guarantors of people's most valuable asset, privacy. It was the duty of scientists to build software capable of protecting individuals' information. In fact, the risk of an attack on individuality through the improper use of new technologies required the scientific community to act as one of time-sharing system's "rings of protection," that is, as a level of protection. It was scientists' duty to ensure that electronic automation was an advantage and not a danger to democracy and humanity.

This vision was obviously based on unconditional trust in two elements: the superiority of democracy over despotism and science's ability to overcome religious, racial, gender and cultural barriers. Science and democracy together led to a common goal, human good. These beliefs stemmed from the personal experience of successful emigrants and Project MAC's positive results.

Certainly, Fano could not foresee all the aberrations of communication through the "social media," which would have undermined Internet's democratic nature.

Through his personal social ties Fano directly demonstrated that a social network is formed when more people identify with common interests. His social network thus preceded the global physical network that was to connect up the world, the Internet. Fano himself loved to say: "I came during the electric engineering age and being here I created the Computer Science Age at the MIT" (Fano, 2013).

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Benedetta Campanile

PhD in History of Science, is head of the Multimedia Lab of Scientific Museology and of the Lab of Computer Epistemology at the Interuniversity research center "History of Science Seminar", University of Bari "Aldo Moro". Campanile's research deals with IT applications for cultural heritage. She has published scientific papers and books on the history of scientific institutions, the history of information technology, and on communication and dissemination of science.