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RESEARCH ARTICLE

Could the SNA Complete the SCOT Model? Computer development in the USA between 1931-1950: a case study approach

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Abstract

Analyzing the literature of computing history we can establish that computing stories of different epochs are concerned with an array of problem areas, thus the authors of the accounts posed various questions – from the misunderstood inventions and forgotten genius to the community revaluation role of the Internet in the post-modern society.

J. V. Atanasoff, J. Mauchly, J. P. Eckert, H. Aiken, G. Stibitz and J. Neumann all played their parts in the history of computing between 1930 and 1950 in the USA. Bowing before their notability the authors of institute-specific accounts recognised all of them as founders of electrical-digital computing technology.

In this study I will argue that any discussion about claims to priority is an outworn conception because the first electrical-digital computer in the USA came into being in a network of "socio-technical ensembles".

The argument is based on a social construction approach (SCOT) of the history of technology combined with social network analysis as during our investigation the SCOT model proved inadequate for studying the history of computers. Following the improvement of key concepts and methods applied by SCOT-ists in different case studies I endeavour to choose the best suitable framework which can be applied to a description of a technological artefact more complex than the bicycle.

Keywords

history of computing · SCOT · SNA

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1 Historiographical review

Following the classification of Campbell-Kelly one can distinguish three different groups among the historians of computing in the last 50 years: the *internalists*, *professionalists* and *integralists* (see: [18]).

The *internalists* are the historians of the sixties, the so-called intuitive historians who, although specialists of their own scientific areas, are not sufficiently knowledgeable to deal with the history of science and technology. The works typical for this period usually comprise the chronological description of the happenings and different technological achievements (e.g. Sammet 1969 , Randell 1973 [38]). These papers were written only for a professional audience. And in general a typical internalist history was written by professionals for professionals.

The *professionalists* or *colonizers* appeared in the eighties. The members of this group are professionals who were encouraged by the internalists to develop a scientific background. One can mention such names as Martin Cambell-Kelly, W. Aspray (1990 [3], 2008 [18]), P. Ceruzzi (1998, [19] 2008 [2]). They are *colonizers* in that they have elevated the historiography of computing to the level of a genuine science by creating such status symbols as scientific journals, conferences, research institutes, museums, PhD programs, university courses – accompanied by academic recognition. Some publications substantiated by this scientific community as PhD dissertations are worth mentioning – such as Ceruzzi in 1998 [19] and Stern in 1981 [45].

By the nineties the history of computing became a part of the general history of science and technology.

It is noticeable that the communities belonging to the different schools created fields of publications in very diverse areas. Why? The answer to this question is that the notion of 'computer' has been redefined in the different developmental periods.

The computing accounts characterizing the different epochs addressed a variety of problem areas, thus the authors of these papers asked diverse questions.

When the computer appeared in the research institutes merely as an unusual mathematical tool the initial reactions reflected merely its scientific applicability. Books and publications greeted the birth of computers and the early computer-like innovations, and commemorated the achievements of such personalities as Babbage, Turing and Atanasoff [42], [17], [16], [22], [34]).

Then the computer started to mean predominantly business and the efforts of IBM to get on top of other computing firms came into prominence. The problems and possibilities of the commercial applicability of computers such as public databases and the seat reservation systems of aviation companies also came to the fore (e.g. [36]). Favourite topics of that period were biographical accounts of the creators of the computing business such as that of Hermann Hollerith or IBM's Thomas Watson (e.g. [23], [44]). Many stories were published also about the phenomena surrounding Microsoft or the "Silicon Valley" (e.g. [33]). Later on, naturally, the story of the Internet became trendy too and its impact on our economies and societies have been analysed by leading scholars. (e.g. [29], [2], [14], [41])

Nowadays the history of computing covers a broader research area – the scientists, the *integralists,* focusing not only on the computer itself but touching upon all areas affecting the development of computers. We can mention here, for example, the adaptation of information processing technology in life insurance firms. Also in the defence industry, the political and social interpenetration of computing are subjects widely analysed (e.g. [24], [20]).

The representatives of this school do not call themselves "historians of computing" but rather historians who are interested in following the developmental process of computing and information processing and their integration into science, technology and society.

Summarizing the historiographical review we can state that much of the literature of computing history has an episodic character and is competing in order to reveal the most precise architectural details of a given computer-technology and also the walk of life of their reputed constructors. This kind of computing history is typical in literatures dealing with the first computers designed in the USA, England and Germany.

In this paper my aim is to illustrate an alternative method to reconstruct the history of the first computers designed in the USA.

2 Technology in society

At the beginning of the eighties a new tendency appeared which aimed at applying the new ideas developed in sociology of science to the history of science and technology. This school came to be known as "*constructivism*". Founders of this school were Thomas P. Hughes historian of technology, Wiebe Bijker sociologist of technology and Trevor Pinch sociologist of science.[1]

The area cultivated by the representatives of this school belonged neither to the field of philosophy of science nor to that of the sociology of technology nor to the history of science and technology. It was rather a multidisciplinary area bordering on these fields of research. The key conception of constructivism is that the developments in science and technology are socially constructed which inevitably implies that they can be examined only as part of, embedded into, their historical, political and cultural context[2].

The SCOT-ists statement that *"technological artefacts are socially constructed*" is not revolutionary in computing history; it can be interpreted as an extension of the *integralists* approach mentioned above.

The SCOT model undertakes nothing less than to jointly describe both the technological changes and the technological development (e.g. [10]; [11], [9], [8]). For the description of the technological changes it borrows two procedures from Darwin: variation and selection. Variation is responsible for the technical variedness and the creation of different alternatives, and selection for picking from the alternatives. Key concepts within this approach are: *interpretative flexibility, closure* and *relevant social groups*[3]. [10, p 5]).

In the SCOT approach *relevant social groups* are the starting point for the analysis. Technological artefacts are described through the eyes of the members of relevant social groups. The *selection* process and *closure* are also interpreted as interactions within and among relevant social groups. They and their social-political and technical environment (denominated afterwards by Bijker as *socio-technical ensemble*s) play the key role in the stabilization process. As the development of complex technological artefacts such as computing devices cannot be credited to one person, we are convinced that a deeper analysis of these groups is inevitable.

Bijker developed the SCOT theory outlined in the case study of bicycle (e.g. [11], [9], [8]); he preserved some key ideas while generalizing others, but his reviewers found a number of details were left incomplete even so (e.g. [21]; [32], [35]).

In the case study of the fluorescent lamp Bijker throws light on the fact that 20th century society cannot be examined in the same way as the society existing in the history of the bicycle. In the history of the bicycle the *technological artefacts* and their interactions with *relevant social groups* are the objects of the examination (see: [10, pp. 17-51]) while in the case of the fluorescent lamp they are replaced by *socio-technical ensembles* (see: [11, pp. 124-129]).

During our previous research related to the applicability of mentioned models to the history of computers from the 1930's to 1950 we have revealed that following the SCOT steps in our historical research we can identify the different variations of computing devices, resulting from different interpretations of current technological possibilities by diverse groups [13]. At the analyzed period of time as relevant social groups we identified

[1] Their first case study collection appeared in 1987. See: BIJKER, W.E.-HUGHES, T.P. -PINCH, T. (eds.) 1987 [10]

[2] This thought was already earlier conceived, see: BERGER-LUCKMANN 1966 [4]

[3] These concepts are developed in the case study of bicycle: [10]: 17-51.

first of all the costumers group the executioners, and scientists who were interested in the automation of difficult mathematical calculations. Although we were able to show the traceability of "artefact –> technological frame –> relevant social group –> new artefact –> new technological frame –> new relevant social group –> etc" cyclical movements proposed by the SCOT approach (see: [7, 681-707], we found it difficult to analyze in practice the interactions among social groups (or socio-technical ensembles) within the confines of the SCOT model.

The main difficulty is that these concepts remained just on the theoretical level because Bijker doesn't put forward an exact methodology which is suitable for a profound analysis of these socio-technical ensembles. However in his case study of the fluorescent lamp the focus is on the examination of the intergroup and intragroup interactions, and he also makes an attempt to discuss the role of the "power" in technological development. (BIJKER 1997 [9]:199-264)

However, we have to mention that all of these separate aspects of *sociotechnical ensembles* are integrated in the social network analysis (SNA). All round, using the methods of SNA (see e.g. [30]) one will be able to discuss all of the mentioned queries in the framework of only one study.

In the following I am going to expound my conception in a case study based on the history of computer development in the USA between 1930 and 1950.

3 About social network analysis

In order to find and analyse the interactions among the relevant social groups (intergroup and intra-group interactions) and the group-dynamics I will apply the methods of SNA.

A data-network consists of a square array of measurements. The rows of the array are the cases, or subjects, or observations. The columns of the array are the same set of cases, subjects, or observations; each cell of the array describes a relationship between the actors.

Network data are defined by actors (or *"nodes"*) and by relations (or "*edges*").

A social network is a set of actors (or nodes, or agents) that may have relationships (or edges, or ties) with one another. For the manipulation of network data, and the calculation of indexes describing networks, it is most useful to record information as matrices. For visualizing patterns, graphs are the most useful.

There is no single "right way" to represent a network of data with graphs. Different ways of drawing pictures of networks of data can expose different features of the social structure. It is usually a good idea to play with visualizing a network, to experiment and to be creative. There are a number of software tools that are available for drawing graphs and each has certain strengths and limitations. For visualizing graphs we will use NetDraw[4] which is distributed along with UCINET software.

A graph, representing the information about the relations among nodes can be a very efficient way of describing a social structure. A good drawing of a graph can immediately suggest some of the most important features of overall network structures, like: Are all the nodes connected? Are there many or few ties among the actors? Are there sub-groups or local "clusters" of actors that are tied to one another, but not to other groups? Are there some actors with many ties, and some with few?

A good drawing can also help us to better understand how a particular node is connected to its "neighbourhood" and to the larger graph. By looking at "ego" and the "ego network" (i.e. "neighbourhood"), we can get a sense of the structural constraints and opportunities that an actor faces; we may be better able to understand the role that an actor plays in a social structure.

3.1 Collection of data for drawing the network of relevant social groups

The identification of the relevant social groups, as well as the tracking of the group dynamics in the different phases of the development of technological objects is one of the key problems of the SCOT theory. The researcher has an easy task as long as the analysis does not concern historical events but only those of the recent past, because in this case the actors can be easily identified. So it is when the persons constitute a relatively small group determined by well definable interests, and also the hidden connections can be explored by means of a series of interviews.

In most of the historical investigations, however, the actors can not be contacted, so the researcher has to identify them with reference to other sources – and also the criteria of "belonging to the group" need to be indirectly determined.

In order to identify the actors and their social network[5] I have analysed primary and secondary sources as well. First of all I have focused on the computing pioneers' work (e.g. [1], [28], and the memoirs of Bigelow, Burks, Eckert, Everett, Mauchly, Rajchman, Ulam collected in Metropolis N., J. Howlett and Rota, G. C. 1980. [6, 15, 25, 26, 37, 46]) but as primary sources I can mention here the oral history database of the Charles Babbage Institute Collections.[6]

In order to achieve an overview of the relevant events in the mentioned period of time I have studied as secondary sources the works that other historians have written about the early computer development in the USA (e.g. [40, 91-195], [23], [22], [31], [38] etc.).

I have attempted to search for source materials very thoroughly, however I cannot state that this study is based on all relevant sources. Since it is impossible to know whether relevant information can be found in sources that have not been consulted, the quantitative results of SNA summarized in Table 1 are merely influential. As the numerical results of SNA are based on the links between the actors they can be further

[4] Free available from the website: http://www.analytictech.com.

[5] Here we are interested just in actors' work on different computer design, and our aim is to explore the collaboration among actors from different groups.

[6] http://www.cbi.umn.edu/oh/index.phtml

refined by adding new actors and links to the network after supplementary research.

On the basis of the analysed sources the following institutes can be considered as relevant social groups in this period: Bell Laboratories, Harvard University, IBM, Moore School, Ballistic Research Laboratory, MIT (Massachusetts Institute of Technology), IAS (Institute for Advanced Study, Princeton), Iowa State College.

In our case the actors are researchers and other individuals interested in computer science and development. They are employed in the above mentioned institutes. The basic idea of our actor-by-actor matrix representation is that the rows and the columns of the array are the name of the actors, in each cell of the array we put in a "1" if an actor collaborates (or has direct relation) with another, and a "0" if they don't. As "key actors" we identified 61 persons from eight institutes.

To visualize the matrix (Fig. 1) we used the NetDraw software.

In the followings I will explore and analyse the connection network of the institutes mentioned above, and that of their workers.

3.1.1 Bell Laboratories

Bell Laboratories is one of the modules of the network active in the field of building computers. The nodes represent well known personalities such as George R Stibitz, Nelson Sowers, Samuel B. Williams, T.C. Fry and Ernest G. Andrew.

The first plans for computers were elaborated in 1937 aiming to computerize the tasks of calculations with complex numbers. According to the main profile of the company the plans were based on the technology used for the production of telephone sets.

By 1940 the Model 2 was ready, financed by NDRC[7]; by 1944 Model 3 followed, which was ordered by Antiaircraft Board, (Camp Davis, North Carolina). Model 5 also was financed by the defence industry, with two specimens (for NACA Langley Field and Aberdeen Proving Ground).

All machines mentioned were made to serve the defence industry except the first one which was built for the laboratory's own purposes.

The central actor of the group was Stibitz and so he can be represented by the central node of the module, since he had most of the contacts in the leading position. As a consequence of his contact system he served as a technical fellow-worker at NDRC during World War II where his main task was to design digital computers using relays (see: [23, pp 30-64], [28, pp. 105-116])

3.1.2 MIT

MIT represents another module of the network composed of elements in strong connections with each other and maintaining less (so called weak) connections with other modules of the network; thus it was a representative of the "conservatism" similar to Bell Laboratories. The key notions inside the module were prestige and analogue technology which was represented by Vannevar Bush[8] lengthy decades from 1927 to 1942. As the developments based on the analogue technology were successful MIT devoted itself to this developmental path excluding the digital line from the set of possibilities.

The prestige of Bush was augmented not only by the widespread propagation of the successful analysers bearing his name in the thirties but also by his contact system which he built up by holding different positions.

He was the leader of NDRC from its establishment (1939) until 1946 and later that of OSRD[9]. During the development of the integrator his direct co-worker was Harold Hansen, chair of the department of electrical engineering at MIT; from 1940 he was the leader of NDRC committee.

From 1940, as a result of a change in the network (generation change) a new generation gathered around Jay. W. Forrester who succeeded in breaking away from the traditions and so MIT could cross over to the world of electronic digital calculators. The change in the network was accomplished in the framework of the Whirlwind project[10]. The prerequisite for it was that the sub-network representing the analogue technology was structurally transformed and J.W Forrester displaced V. Bush in the centre. Thus the contact system of the module to the whole network also changed and it had weaker and weaker connections to other modules in the network.

J. W. Forrester together with Gordon Brown founded in 1940 the MIT Servomechanisms Laboratory and continued the research and development work according to the traditions of the institute. The Whirlwind designs were also based on the analogue technology. Forrester was the one who as a kind of *bridge-person* connected the MIT research group to the other sub-networks of the network representing already the digital electronic technology. He got to know the plans for ENIAC and EDVAC at the Moore School, and possessing the information he broke away from the traditions.

In the framework of the Whirlwind project between 1945 and 1952 the developments continued on the digital electronic basis involving such personalities as Robert R. Everett, Julius Stratton, Norman Taylor, Gus O'Brien, Jack Gilmore, Joe Thomson, Steve Dodd and Ken Olsen.

3.1.3 Moore School

The Moore School of the University of Pennsylvania was founded in 1923. By the 1930s it had formed an arrange-

[7] NDRC: National Defence Research Committee

[8] For more details about V. Bush's role in differential analyzer developments in the USA see:[43, pp. 40-49], and Owens, L. "Vannevar Bush and the Differential Analyzer: The Text and Context of an Early Computer". *Technology and Culture*, Vol. 27, No. 1, January 1986, pp. 63-95.

[9] OSRD: Office of Scientific Research and Development

[10] The Whirlwind project was treated by R. Everett (1980) [26] and by K. C. Redmond - Smith, T. M. (2000) [39]

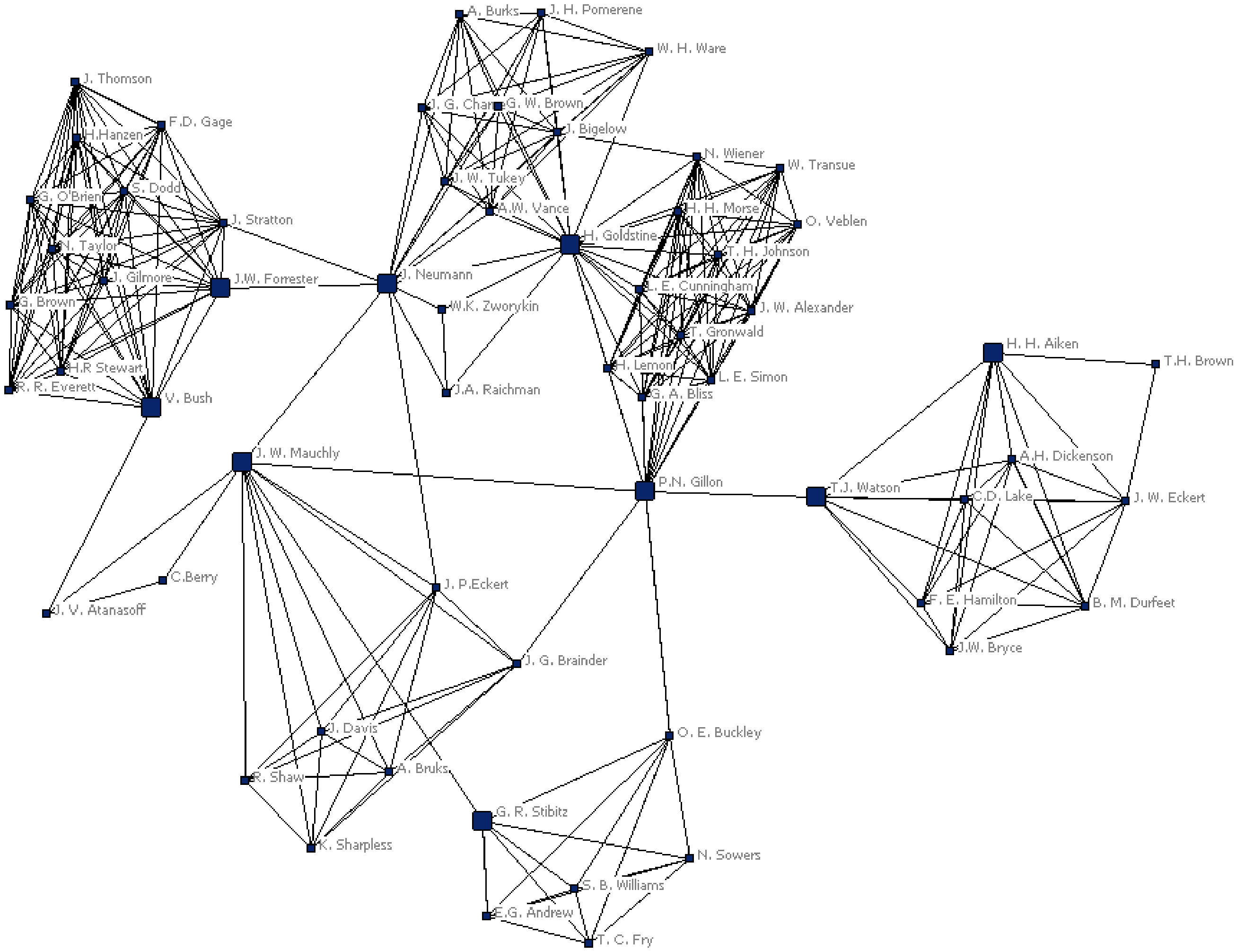

Fig. 1. Social network of relevant social groups

ment with the U.S. Army's Ballistic Research Laboratory at Aberdeen. A major result of this collaboration was the construction of two differential analyzers, one at the Moore School, and one at Aberdeen.

By the 1940s, the faculty at the Moore School was involved in radar and other electronics research. John Mauchly, was a professor of physics at Ursinus College and because of the war, he enrolled in a wartime electronics course at the Moore School; John Presper Eckert, Jr., was a graduate student overseeing the laboratory for that course. When the Moore School needed to replace members of the faculty who were drafted into military service, Mauchly agreed to join the Moore School Faculty.

In August 1942, Mauchly condensed his ideas into a short paper, "The use of high-speed vacuum tube devices for calculating," in which he compared the advantages of electronic techniques to those of mechanical technology.[11] Mauchly estimated that calculations for ballistic trajectories would be in the 100-second range, compared to the 15 to 30 minutes required using mechanical technology.

The draft plans of the Electronic Numerical Integrator and Computer (ENIAC[12]) started in 1942; it firstly tested the possibilities inherent in the digital electronic technology by way of many compromises, taking giant risks, sharing and involving the existing technologies. Lots of uncertainty factors affected the construction, the often mentioned problems: the great number of the unreliable and short-lived vacuum-tubes was only one of them. The given task was to build a piece of calculating equipment to largely accelerate the calculations made at the Ballistic Research Laboratory.

In order to reach the goal an agreement was concluded between the Ordinance Department and Moore School regarding a development program aimed at developing a digital electronic computer for the Ballistic Research Laboratory. The decision to use digital electronic technology was supported by the analyses of two excellent colleagues of Moore School; they perceived the possibilities inherent in the digital electronics. These key actors were John W. Mauchly and J. Presper Eckert, who proved to be irreplaceable in preparing the plans for ENIAC and in the early

[11] First printed in RANDELL (1973) [38], pp 355–358, from original typescript.

[12] The identification of key actors from ENIAC project are based on the following literature: [15], [28], [37]

phase of the development.

The objections to be overcome in order to reach the success of the "research plan", having estimated costs of 150 000$, were in the form of view-points antagonistic to the intentions of the designers, but their representatives had great influence. Stibitz and his team put forward the argument that digital but electromechanical devices were to be preferred rather than electronic ones. The group of S.H. Caldwell suggested analogue but partly electronic equipment.

The debates around the applied digital electronic technology regarding the reliable operation of the machine were not unreasonable. The machine contained in the end more than 17,000 pieces of vacuum-tubes representing as much as 16 different types, with an unacceptably short life span.

Besides the discovery and application of the available technical innovations the key to the successful accomplishment of the experiment was that a team of excellent people worked together representing different institutes and technologies. Fig. 2 shows the institutes and the name of the connecting people taking part in building ENIAC; the arrows show the direction of information flow (providing or request).

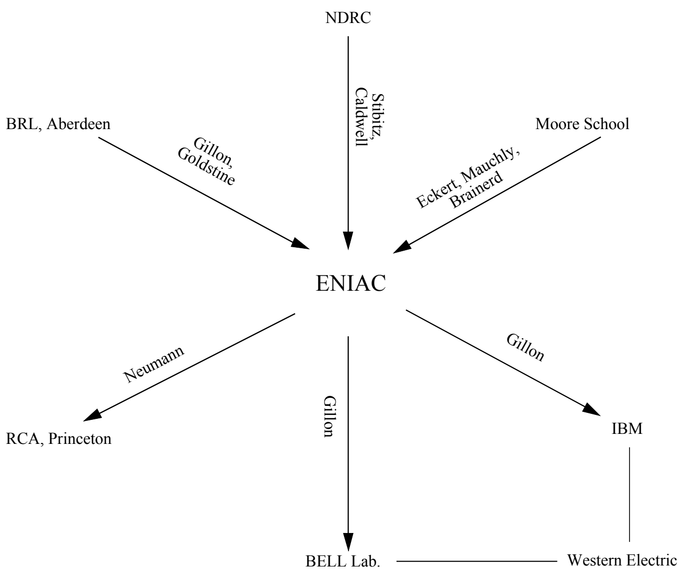

Fig. 2.

Neumann became interested in electronic devices to speed up the computations of problems he faced for projects in Los Alamos during World War II. Von Neumann learned about ENIAC in 1944 and became a consultant to its design team. His primary interest in this project was the logical structure and mathematical description of the new technology. This interest was in some contrast to the engineering view of Eckert and Mauchly whose goal was to establish a strong commercial base for the electronic computer.

The Development of EDVAC, a follow-up project to ENIAC, began during the time that Neumann, Eckert, and Mauchly were actively collaborating. At this time, substantial differences in viewpoints began to emerge. In 1945, von Neumann wrote the paper "First Draft of a Report on the EDVAC," which was the first written description of what has come to be called the von Neumann stored-program computer concept [13]. The EDVAC, as designed by the University of Pennsylvania Moore School staff, differed substantially from this design, evidencing the diverging viewpoints.[14] As a result, von Neumann engaged in the design of a machine of his own at the Institute for Advanced Study at Princeton University, referred to as the IAS computer (see e.g. [3], [27]).

3.1.4 Harvard

Harvard's interest in computers can be connected to the work of Howard Aiken. He elaborated the necessary modifications which made it possible to convert the punched card data processor / accounting machines of IBM into special machines serving scientific purposes. He determined four requirements to be fulfilled by the further developed machine to become a calculation tool for scientific purposes (Randell 1982:195-202).

1 The computer built for scientific purposes must be able to handle both positive and negative numbers.

2 Its operation must be fully automatic.

3 It should use different mathematical functions.

4 The calculations should be done according to the natural sequence of the mathematical operations.

Howard H. Aiken established at Harvard a computational laboratory in which a series of computers was developed for the US Navy and Air Force with the collaboration of IBM[15]. The first machine got fame as Mark I; it was the result of the common developmental work of Aiken and a group of IBM engineers led by Clair D. Lake and it was launched in 1944 under the name Automatic Sequence Controlled Calculator.

A proof for the success of the collaboration with IBM was that the fulfilment of the four requirements determined by Aiken was enough to convert the existing and manufactured punched card computers of IBM into special machines serving scientific purposes.

The series contained further machines as Mark II, III, and IV.

Mark IV was planned and built by Aiken at Harvard between 1950 and 1952. Finally Aiken perceived the advantages of the electronic equipment over the electromechanical machines and

[13] Harry Reed points out that there has been, and still is, controversy over the degree to which von Neumann was responsible for the development of shared memory machines. H. Goldstine credits von Neumann with the seminal role. Another school of thought credits Eckert, who claims to have had the idea for internal programming long before von Neumann ([5, p 34]).

[14] Differences between the EDVAC described by von Neumann and the EDVAC constructed at the Moore School are revealed by Godfrey. M. D. – Hendry D.F in: "The Computer as von Neumann Planned It" *IEEE Annals of the History of Computing*, Vol.15 No. 1. 1993. [27]

[15] For detailed description of cooperation among Harvard and IBM see: RANDELL 1973, 1982 [38]; COHEN 2000 [22], ROSENBERG 1969 [42], PUGH 1995 [36] p.67-77

the eminent importance of his work was perhaps that he established a laboratory at Harvard where young researchers could take part in university level education in the field of the design of circuits and parts of digital electronic computers.

3.1.5 IBM

IBM got in touch with computers in connection with the developments of the 1930s at Harvard. Its main intention was to get into the groves of academe. It was shown among others by the gesture by which Thomas J. Watson in the name of IBM donated the Automatic Sequence Controlled Calculator to Harvard University on the 7 August 1944 "as another sign of the interest of IBM in science".

1944 was a memorable year when IBM, again flexibly responding to the new ideas, helped to design and to develop the input and output devices and the units for printing out the results (in a readable form) for ENIAC[16].

Recognizing the possibilities inherent in the new scientific area, IBM presented in 1946 the Electronic Multiplier as an independent development, in 1945 IBM announced the plans for a "supercomputer" and in January 1948 SSEC (Selective Sequence Electronic Calculator) was introduced.

IBM Corporation flexibly responded to the scientific and economical needs of the given period and learned how the technologies being mostly able to adjust themselves to the needs can remain capable of staying in the competition. In 1950 when the Korean war broke out IBM, using for itself radically new ideas, undertook a key role in the war endeavours, in 1952 its Defence Calculator came into action. It was a general purpose piece of equipment already finding its way onto the commercial market in 1953 – IBM wrote its name into the good book of the world of the production and commerce of electronic computers.

3.1.6 Institute for Advanced Study, Princeton

From 1946 a fundamental change can be observed in the network. A new site appears with the Institute for Advanced Study but one can hardly find among its players new ones not seen on one of the other sites analysed above. Neumann collects a team from members who are men of light and leading in their scientific area: mathematicians, electric engineers, statisticians, and meteorologists can be found among the employees (e.g. the meteorologist Jule G. Charney). Known from the ENIAC project were e.g. A. Bruks, H. H. Goldstine and his wife Julian Bigelow came from MIT on the recommendation of Norbert Weiner. Also in connection with ENIAC were the well-known V. K. Zworykin and J.A. Rajchman from RCA, two colleagues, the statistician G. W. Brown and the electric engineer A.W. Vance followed them. Upon the invitation of Neumann and Goldstine the electric engineers of Hazeltine Corporation (New York) having experience in radar technology, James H. Pomerene and Willis Ware joined the project. Further members of the team worth noting were: Jule Charney, Hewitt D. Crane, John Davis, Gerald Estrin and Ralph Slutz. The best people gathered here together to create the prototype of „computer".

The Institute for Advanced Study, Princeton ensured the facilities for Neumann to build the computer known as IAS from 1946 to 1952[17]. This machine was mainly characterized by parallel data processing and modular structure, thus it had a memory, arithmetic and logical units, control unit, and input and output units. Further a totally new and perfect instruction system was designed to control and program the computer, an instruction counter register was built in for this purpose. The computing activities – all logical, technical and engineering aspects of the research work – were well documented; based on these the IAS machine is considered a milestone in the history of the computer.

With the advent of the IAS machine a whole period, the period of the machines built to facilitate and accelerate scientific calculations terminated, because IAS outgrew this narrow application area and showed, as a general purpose universal computer, new ways to apply the computers to almost every field of life (e.g. [6], [3]).

3.1.7 Ballistic Research Laboratory, Aberdeen

The Ballistic Research Laboratory of the Ordnance Department, established in 1938 from the Research Division of Aberdeen Proving Ground, was charged to produce firing tables for the Army[18]. For artillery, for example, these tables showed the soldier what angle of elevation was required for a specific projectile to impact a target at a specified range with a given propellant charge. The tables also indicated corrections to apply for variations in atmospheric temperature, air density, wind, angle of sight, weight of projectile, muzzle velocity, and compensation for drift. Especially in wartime, firing tables had to be prepared and sent to the field as rapidly as possible, because without the information, artillery became less effective.

The seriousness of the calculation tasks accomplished in the institute required high level work which presented the challenge to the management to ensure the team of scientists a proper structure, and the human and technical resources. Therefore the institute watched the advent of the computing equipment capable for their calculations. In 1935 they already possessed a Bush differential analyser and from the 1940 years BRL was equipped with standard punched card equipment as a result of the collaboration with IBM. Beyond that in 1944 IBM built two multiplying machines for the institute according to its special needs. The war period required the scientific team of Ballistic Research Laboratory to be reorganized according to the highest scientific norms. The personnel was increased by a lot of university scientists being acknowledged in their own scientific area.

[16] See: e.g.SOBEL 2000 [44], and PUGH [36] 1995:89-109

[17] For the developmental process of IAS computer see: [46], [6], [27], [28]

[18] For a detailed discussion of U.S. Army role in the inauguration of the modern computer age see: [5], [31]

Parallel to this the Scientific Advisory Committee was established having the members John von Neumann, Theodore von Karman, Hugh L. Dryden (man of light and leading in aerodynamics), Albert W. Hull (inventor, his speciality was the vacuum-tube), Bernard Lewis (his speciality was the field of combustion processes and bursting), the astronomer Henry N. Russell, the Nobel laureate physicist and scientist-politician Isidor I. Rabi, and the Nobel laureate chemist Harold C. Urey ([28, p 123]).

By 1941, the production of firing tables was far behind. The officers of BRL were searching for any opportunity to improve processing. Herman Goldstine, an assistant professor of mathematics at the University of Michigan before the war, was assigned to oversee the production of firing tables, including the supervision of the women computers at the Moore School. Hearing of Mauchly's ideas, he approached his former supervisor, Colonel Paul Gillon, about pursuing the construction of an advanced machine. Colonel Gillon, who worked at this time in the office of the Chief of Ordnance, recognized the potential for success and convinced the Army to fund the project.

Accordingly, on June 5, 1943, the Army Ordnance Corps and the University of Pennsylvania signed a contract for "research and development of an electronic numerical integrator and computer and delivery of a report thereon"([31, p 22]).

Beginning in the fall of 1944, the ENIAC team, working with von Neumann, designed EDVAC (Electronic Discrete Variable Computer). The new device, a collaborative effort by BRL, the Moore School, the Institute for Advanced Studies (IAS), and the National Bureau of Standards (NBS), was the first computer to be designed with an internally stored program. EDVAC was installed at BRL in 1949, but design problems delayed acceptance and practical operation until 1952. BRL was already at work on a new system. ORDVAC (Ordnance Variable Automatic Computer) belonged to the group of computers whose basic logic was developed by the IAS. It was built by the University of Illinois and brought to Aberdeen in 1952. Thus, for a brief time in 1952, with ENIAC, EDVAC, and ORDVAC, BRL was the world's largest computer center.

3.2 Centrality and Power in the Network

All sociologists would agree that power is a fundamental property of social structures. The network approach emphasizes that power is inherently relational.

The network perspective suggests that the power of individual actors is not an individual attribute, but arises from their relations with others. Power arises from occupying advantageous, "central" positions in networks of relations.

In order to identify the most important actors of the network I consider four measures of centrality: degree centrality, closeness centrality, betweenness centrality and the eigenvector centrality (see: [47]).

3.2.1 Degree centrality

Degree centrality measures an actor's centrality according to the number of connections to others.

Actors who have more ties to other actors may have favourable positions. Because they have many ties, they may have alternative ways to satisfy needs, and hence they are less dependent on other individuals. They may also have access to, and be able to call on, more of the resources of the whole network. In this case H. Goldstine has the highest degree centrality and it is not surprising because he is the "bridge man" between three groups with high density (with more ties between the actors) namely: the BRL, Moore School and IAS group (Fig. 3).

3.2.2 Closeness centrality

Degree centrality measures could be criticized because they only take into account the immediate ties that an actor has, or the ties of the actor's neighbours, rather than indirect ties to all others. An actor might be tied to a large number of others, but those others might be rather disconnected from the network. In a case like this, the actor could be quite central, but only in a local neighbourhood.

Closeness centrality is a more sophisticated measure of centrality, it is defined as the mean geodesic distance (i.e. the shortest path) between a node and all other nodes reachable from it.

Actors with high closeness are in an excellent position to monitor the information flow in the network – they have the best insight into what is happening in the network.

3.2.3 Betweenness centrality

Betweenness centrality indicates the extent to which a node lies on the shortest path between every other pair of nodes. The person with the highest betweenness centrality is the person that others in the network most commonly must go through in order to reach each other.

Generally a node with high betweenness has a great influence over what can flow – or not – in the network (Fig. 4).

With this index we can answer the question of: *who are the actors with the biggest power in this period in the analyzed network, concerning the whole network* (not only concentrating on the number of connections within the groups)?

The members with the greatest *power* in the network are, Gillon, Neumann, Mauchly, Goldstine, and Watson. Gillon and Goldstine (two officers of Ordnance Department[19]) are interested in getting hold of the most suitable machine for the purposes of the defence industry; this is their inner motivation. At the same time as the defence industry endeavours to possess all the types of calculating equipment developed by different groups, Gillon as the representative of this power has the highest betweenness centrality, and is able to control the resources flowing along the network.

Neumann, from his position on the network, had an insight into the material and intellectual resources of the network, and

[19] Detailed description of their role in ENIAC project can be found in[5]

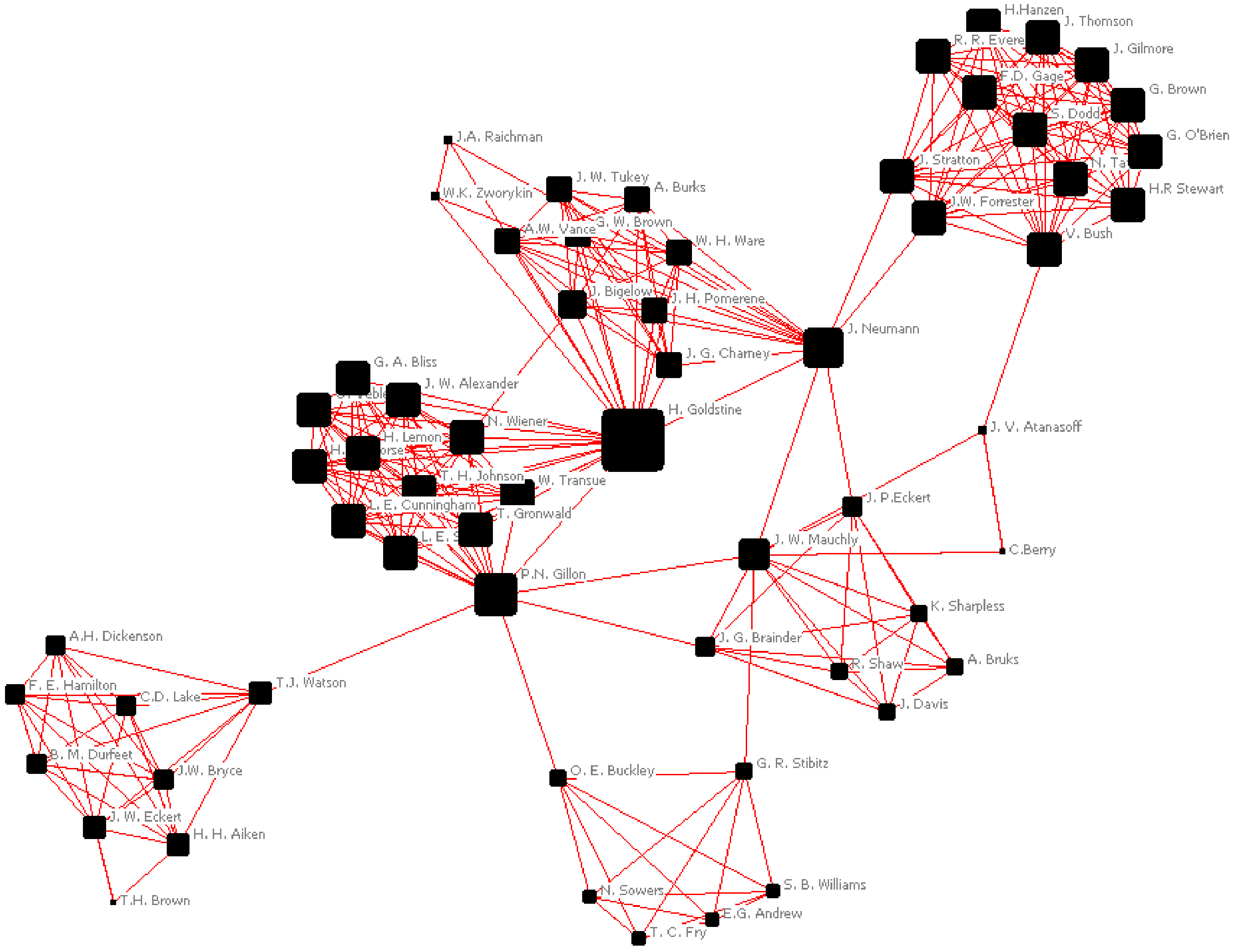

Fig. 3. Degree centrality

beyond the harmonization of the requirements and possibilities, advanced special purpose calculating equipment to the level of the "Computer" by the Neumann architecture.

Although J. W. Mauchly was mentioned by Goldstine [28], (2004: 146), as only a "sprinter" in the ENIAC program he was the one who knew the design details of the contemporary electromechanical IBM machines, hence he could counsel the engineers in handling the different design problems. It is worth mentioning that Mauchly also knew, besides the IBM machines, the plans for the digital electronic computer suitable for solving systems of equations made by Atanasoff. He is the intermediary for the engineering knowledge in the network.

3.2.4 Eigenvector centrality

Eigenvector centrality is a measure of the importance of a node in a network.

The *eigenvector* approach is an effort to find the most central actors (i.e. those with the smallest distance from others) in terms of the "global" or "overall" structure of the network, and to pay less attention to patterns that are more "local".

It assigns relative scores to all nodes in the network based on the principle that connections to high-scoring nodes contribute more to the score of the node in question than equal connections to low-scoring nodes.

Applying the Ucinet *Network – Centrality – Multiple measures* algorithm for our database we will get the results summarised in Table 1.

4 Summary

Within the framework of this study I first of all intended to point out that the metaphor of "*social-technical ensembles"* introduced by Bijker as objects for historians of technology can be put into practice and examined by the methods of SNA.

However, it must be pointed out that the matrix behind the network serves as a basis for visualisation, as the results are derived from the graph. Difficulties in the application of SNA can appear when we cannot determine the personal connections among different groups representing different technologies or key actors are missing from the graph, because in this case the numerical results of SNA can be misleading.

Nevertheless, after a prudent source analysis and collection of data the graph theory approach is suitable for visualization of the network and for identifying the most important actors in the network. We have found them in the strategic nodes (es-

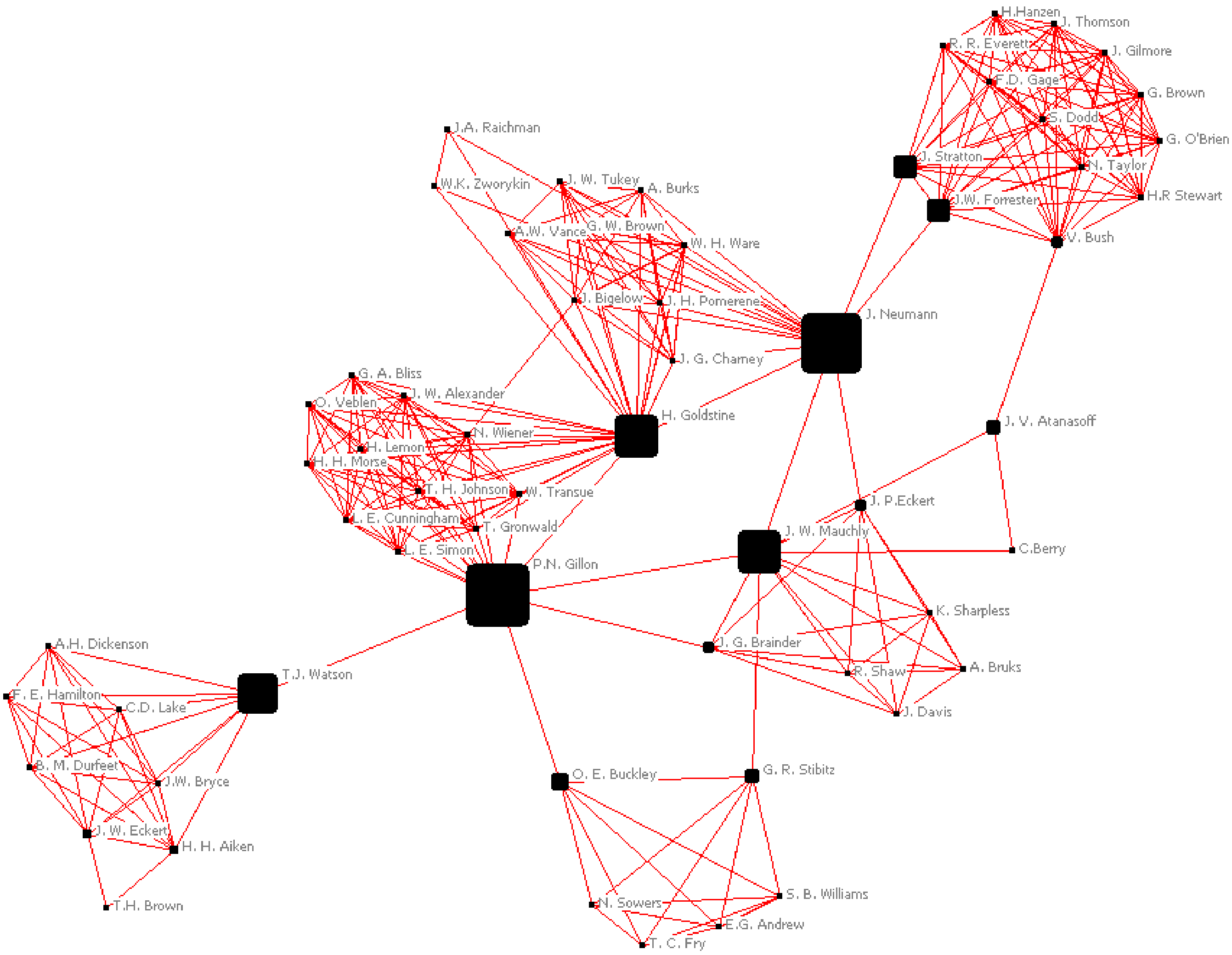

Fig. 4. Betweenness

pecially when they are bridges among different groups) of the social network, but their importance can be defined in different ways depending on what we consider as the basis of importance. That person can be considered as central who shows the highest activity and has connections to many others, or who has many tightly-knit connections with others – or who may be an actor in a position able to disconnect the network.

The degree centrality focuses on the activity of the actors but only those of a particular area of the network (i.e. not the whole network). From this point of view the most active members of our network are Goldstine, Gillon, Neumann and Bush.

Neumann, Gillon, Goldstine and Mauchly have the highest value of closeness centrality. From their central position they can reach every member relatively easily and quickly and do not need to involve any other actor, for instance to gather information – which is of primary importance as generally the more actors there are in the information chain the more deformations of the information are liable to occur.

The central position of Gillon and Neumann regarding the betweenness centrality is possibly due to their strong connections to leading military and scientific groups.

Also it is not surprising that N. Weiner has a high eigenvector value, because through cybernetics the knowledge leading to the advent of computing rested solely on the strength of his intellectual ability.

Last but not least, complementing the SCOT model with SNA we are able to put the information batches obtainable from different literature into a unified framework. Furthermore, going beyond the question, who were the key actors and from what point of view in given history? This approach, aligned with the episodic accounts, can show us an alternative way to study the history of computing.

Tab. 1. Normalized Centrality Measures

	Name	Degree	Closeness	Betweenness	Eigenvector
1	J. Bigelow	16,667	38,462	0,602	14,499
2	J. Neumann	25,000	46,875	36,166	14,291
3	A. Burks	15,000	38,217	0,000	11,709
4	H. Goldstine	38,333	46,875	24,928	45,164
5	J. H. Pomerene	15,000	38,217	0,000	11,709
6	W. H. Ware	15,000	38,217	0,000	11,709
7	J. G. Charney	15,000	38,217	0,000	11,709
8	J. W. Tukey	15,000	38,217	0,000	11,709
9	G. W. Brown	15,000	38,217	0,000	11,709
10	A. W. Vance	15,000	38,217	0,000	11,709
11	J. G. Brainder	11,667	37,736	3,008	4,052
12	J. P. Eckert	11,667	37,975	2,924	2,328
13	J. W. Mauchly	18,333	46,875	25,454	5,306
14	A. Bruks	10,000	32,967	0,000	1,254
15	K. Sharpless	10,000	32,967	0,000	1,254
16	J. Davis	10,000	32,967	0,000	1,254
17	R. Shaw	10,000	32,967	0,000	1,254
18	O. E. Buckley	10,000	33,898	6,864	3,235
19	G. R. Stibitz	10,000	33,898	6,653	0,835
20	N. Sowers	8,333	28,571	0,000	0,437
21	T. C. Fry	8,333	28,571	0,000	0,437
22	S. B. Williams	8,333	28,571	0,000	0,437
23	E. G. Andrew	8,333	28,571	0,000	0,437
24	V. Bush	21,667	32,432	4,266	7,123
25	F.D. Gage	20,000	28,708	0,000	7,044
26	H.R. Stewart	20,000	28,708	0,000	7,044
27	H. Hanzen	20,000	28,708	0,000	7,044
28	J. W. Forrester	21,667	36,810	12,080	8,118
29	G. Brown	20,000	28,708	0,000	7,044
30	R. R. Everett	20,000	28,708	0,000	7,044
31	J. Stratton	21,667	36,810	12,080	8,118
32	N. Taylor	20,000	28,708	0,000	7,044
33	G. O'Brien	20,000	28,708	0,000	7,044
34	J. Gilmore	20,000	28,708	0,000	7,044
35	J. Thomson	20,000	28,708	0,000	7,044
36	S. Dodd	20,000	28,708	0,000	7,044
37	H. H. Aiken	13,333	27,027	1,638	0,535
38	T. H. Brown	3,333	21,429	0,000	0,087
39	J. W. Eckert	13,333	27,027	1,638	0,535
40	T. J. Watson	13,333	35,088	23,503	3,326
41	J. W. Bryce	11,667	26,906	0,000	0,529
42	C. D. Lake	11,667	26,906	0,000	0,529
43	F. E. Hamilton	11,667	26,906	0,000	0,529
44	B. M. Durfeet	11,667	26,906	0,000	0,529
45	A. H. Dickenson	11,667	26,906	0,000	0,529
46	W. K. Zworykin	5,000	36,810	0,000	5,254
47	J. A. Raichman	5,000	36,810	0,000	5,254
48	P. N. Gillon	26,667	46,875	38,679	37,253
49	H. H. Morse	20,000	39,216	0,000	36,058
50	W. Transue	20,000	39,216	0,000	36,058
51	L. E. Simon	20,000	39,216	0,000	36,058
52	O.Veblen	20,000	39,216	0,000	36,058
53	J. W. Alexander	20,000	39,216	0,000	36,058
54	G. A. Bliss	20,000	39,216	0,000	36,058
55	T. Gronwald	20,000	39,216	0,000	36,058
56	N. Wiener	21,667	39,474	0,683	37,147
57	H. Lemon	20,000	39,216	0,000	36,058
58	T. H. Johnson	20,000	39,216	0,000	36,058
59	L. E. Cunningham	20,000	39,216	0,000	36,058
60	J. V. Atanasoff	5,000	37,037	5,105	1,051
61	C. Berry	3,333	34,286	0,000	0,516

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