ENCYCLOPEDIA OF COMPUTER SCIENCE AND TECHNOLOGY

EXECUTIVE EDITORS

VOLUME 2
AN/FSQ to Bal

ENCYCLOPEDIA OF COMPUTER SCIENCE AND TECHNOLOGY

EXECUTIVE EDITORS

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PITTSBURGH, PENNSYLVANIA

VOLUME 2
AN/FSQ to Bal

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AN/FSQ-7 COMPUTER

INTRODUCTION

Systems Overview

The AN/FSQ-7 digital computer was the data processing heart of SAGE (Semi-Automatic Ground Environment), a system of electronic air defense developed by the Rand Corporation of Santa Monica, California, for the United States Air Force. The SAGE system began as Project Rand shortly after World War II when the project's researchers were commissioned to study the economics and technology involved in developing a man–machine air defense system utilizing the then state-of-the-art electronics available. The research and development work was accomplished at Lincoln Laboratories of the Massachusetts Institute of Technology. System hardware and software design and implementation was a multicontract cooperative effort. The basic ideas of the system resulted from the efforts of Drs. G. E. Valley and J. W. Forrester of M.I.T. Many organizations contributed to the development of SAGE. The International Business Machine Corporation designed, manufactured, and installed the AN/FSQ-7 combat direction center and AN/FSQ-8 combat control computer installations. The Western Electric Company, Inc. provided management services and the design and construction of the direction center and combat center buildings. A subcontractor, Bell Telephone Laboratories, assisted in the performance of the Western Electric Company services. The Burroughs Corporation manufactured, installed, and provided logistic support for the AN/FST-2 coordinate data transmitting sets. The Systems Development Corporation (SDC), formed from the System Development Division of the Rand Corporation, assisted Lincoln Laboratories in the preparation of the software program system for both the direction center and combat center complexes. The SDC assumed full responsibility for the software systems in the late 1950s, a responsibility that they retained for the duration of the SAGE system. SDC also assumed the responsibility of development of training programs for each air defense station that would both exercise the system and keep the Air Force manning staffs sharp and improve training methods.

The SAGE system became operational in 1957. Various considerations including changing technology and continuing reassessment of the strategic value of SAGE resulted in its obsolescence in the mid-1960s. The final complement of direction centers fell short of the originally planned 32 stations. Original estimates of the cost of each installation was $20 million. Undoubtedly the experience gained in computer technology by the participating contractors of SAGE has contributed significantly to the advancement of the state of the art of computer science.

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The SAGE System Complex

SAGE direction centers, each containing duplexed AN/FSQ-7 digital computers, were built, installed, and made operational at strategic sites around the perimeter of the United States. SAGE combat centers, each containing duplexed AN/FSQ-8 digital computers, were also installed. The combat centers were higher echelon divisional data gathering and summarization headquarters for two or more direction centers. Combat centers displayed, monitored, and condensed the air defense picture for their respective direction centers, transmitted tactical directives to these direction centers, and forwarded the divisional air defense status to the North American Air Defense Headquarters (NORAD) in Colorado Springs, Colorado.

The SAGE System Mission

At the end of World War II, United States defense planners assessed that the immediate defense threat would be air attacks by intercontinental bombers that could deliver thermonuclear weapons to the United States. They concluded that the existing manual air defense system, including radar systems, automatic fire control devices, and communication links for ground-to-ground or ground-to-air communication, navigational systems, and both missiles and manned aircraft were only necessary components for a successful air defense system. Intelligent utilization of these components, however good, must be coupled with a system of detection and tracking of enemy targets at long ranges. More important, the intelligent commitment of these resources requires up-to-date knowledge of the total enemy threat and the success and status of weapons already committed. The researchers concluded that the manual air defense system could not adequately coordinate the use of our improving components against a growing enemy threat. The problem was inadequate continental data handling capability and inadequate facilities for communication filtering, storage, control, and display of the air defense situation. A system was required that would (1) maintain a complete current picture of the air and ground situations throughout North America; (2) control modern weapons rapidly and accurately; and (3) present filtered pictures of the air and weapons situations to the Air Force personnel manning the defense system.

SAGE, therefore, was developed to satisfy these requirements. SAGE utilized digital computers which were then considered large to process continent-wide air defense data. It was a real-time control system, a real-time communication system, and a real-time management information system.

THE AN/FSQ-7 COMPUTER

General Characteristics

The SAGE AN/FSQ-7 duplexed computer occupied the entire second floor of a SAGE direction center. Seventy frames containing almost 60,000 vacuum tubes were required to handle all input–output data, perform air defense calculations, and store systems status data. The primary application of the AN/FSQ-7, air defense, required a reliability capability of a 24-hour operation. The duplex philosophy—that whenever individual equipment failure could cause a complete system failure that equipment would be duplicated—was adhered to; therefore the central computer, the drum system, and the magnetic tape units were duplexed.

System Organization

The SAGE computer system consisted of the duplexed AN/FSQ-7 central computer, system status data stored on auxiliary magnetic drums, and the air defense computer programs consisting of approximately 100,000 computer instructions. Figure 1 shows a system organization chart. The central computer was buffered from all sector and console in–out equipment by magnetic drums. An exception was console keyboard inputs which used a 4096-bit core memory buffer. A real-time clock and four IBM 728 magnetic tape units used for input simulation and output summary recording compiled the basic computer configuration.

System Components

The AN/FSQ-7 Central Processing Unit

The AN/FSQ-7 was a large-scale vacuum-tube general-purpose binary, parallel, single-address computer with a 32-bit word length and a memory cycle time of 6 μsec. Its magnetic core memory contained 8192 words or 270,336 bits of storage arranged in two banks of 33 planes, each plane consisting of a 64 × 64 core matrix. The 33rd plane was used for parity checking. The programs were written in a machine language instruction code with each instruction using one 32-bit word. The effective operating rate was about 75,000 instructions per second. Four index registers were available for address modification as was a 17-register test memory that could be used for system modifications at the operator console.

Magnetic Drums

Twelve magnetic drums, each with a capacity of 12,288 32-bit words, were available. They were used to store system control programs, system status data, and to buffer input and output data from external sources and the internal display system.

System Display Consoles

The major air defense functions required the use of over 100 display console stations, most of which included a keyboard input, a situation display, and a digital display

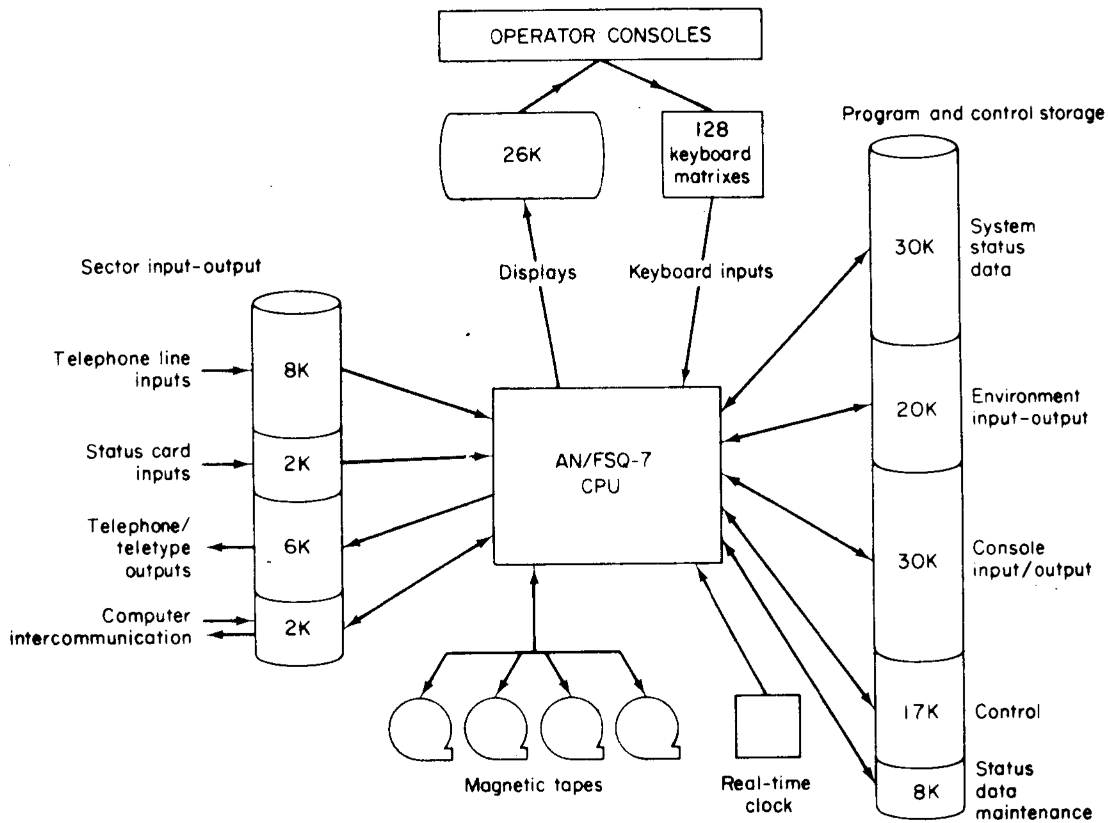

Fig. 1. AN/FSQ-7 logical organization.

scope. Each operator at a console had input and display facilities tailored to his responsibilities. Input information was inserted via the keyboard. Each console was provided with an input capacity to the computer of 25 to 100 bits of information at one time; the total keyboard input capacity for all consoles was over 4000 bits which were processed by the computer every 5 to 15 sec. A 19-in. Charactron cathode-ray tube displayed geographically oriented data covering the whole or part of the sector. On this air situation display scope the operator viewed different categories of tracks or radar data, geographical boundaries, predicted intercept points, or special displays generated by the computer. A light gun was available to the operator to notify the computer of data selection. Every 2.5 sec the computer would display up to 200 different types of displays requiring up to 20,000 characters, 18,000 points, and 5000 lines. Some of these displays were always present on the situation display scope. Others could be requested by the operator. Displays requiring the operator's attention or action would be forced to the operator's console display.

The operator's console usually was equipped with a 5-in. Typotron digital display tube which was used to present status or attention data such as weather conditions at an airbase, aircraft operational status, or "reason" data why the computer rejected an operator's actions. Sixty-three different characters were available on the Typotron scope. The computer display system displayed characters at the rate of 10,000 characters per 5-sec period to all the digital display scopes in the system.

System Operation

Data Transfer

With only an 8192-word core memory it is obvious that extensive data and program I/O transfer was required for the AN/FSQ-7 to operate a large-scale air defense program system. Under control of the central computer, data were transferred in variable length blocks between the magnetic drum and core memory. The CPU could transfer from 20 to 5000 word blocks of data per second. Maximum utilization of the computer was obtained by use of an in–out break feature. The in–out break feature allowed calculations in the CPU to continue during I/O operations; calculations were interrupted only for the one core memory cycle required to transfer a word between the core memory and the terminal device. More than 50% of real time was required for input–output searching, waiting, and transferring. The input–output buffering drums processed data independently of the CPU and thereby freed the CPU for more complex air defense processing. Separate READ-WRITE heads were provided for the buffering equipment and the CPU. The magnetic drums could therefore receive and transmit data while the CPU performed some other function of air defense. An example of this feature is in the method of receiving input data from voice bandwidth phone lines. A serial 1300 pulse/sec message was demodulated and stored in a shift register of appropriate length. When the complete message had been received, the message was shifted at a higher rate into a second shift register whose length was a multiple of 32 bits. This freed the first register to receive another message. When the first empty register was located on the input buffer drum, parallel writing stored the word in 10μsec. A relative timing indicator was also stored with the message, since the computer could not process the message for several seconds and time of receipt was critical. The CPU read this randomly stored message by periodically requesting block transfers of occupied drum slots only. Output messages were processed conversely. Another example of buffered processing is in the display system. The SAGE programs maintained ordered tables on the buffer display drum. This table was read and displayed by special-purpose equipment every 2.5 sec at the appropriate display console. The programs could change any part of the display at any time by rewriting only the appropriate words on the drum.

Real-Time Operation

The real-time SAGE system programs operated in time periods of fixed length termed "frames." Each frame was several seconds in duration and was subdivided into subframes and semi-subframes. Component programs were operated at least once per frame and some operated by subframe. The buffer storage, system status data, and the computer programs were organized into blocks, each block consisting of from 25 to 4000 computer words. A sequence control program stored in core memory transferred appropriate program and data blocks into core memory, transferred control to the appropriate program, and then resumed control from the program to transfer appropriate data blocks (but not program blocks) back to the buffer drums. In order to fully utilize the in–out break feature, the operation of each program was closely coordinated with the sequence control program so that the proper programs and their respective operating environments were transferred at the proper times. This real-time synchronization resulted in program operation at regular intervals. During periods of light load, the sequence control program would buffer time until the real-time clock would indicate that the next frame or program cycle should begin. This feature simplified many of the timing problems associated with the control and input–output functions without system degradation.

System Reliability

The primary application of the AN/FSQ-7, air defense, required a high reliability capability for 24-hour interrupted operation. For this reason, the system was duplexed. One AN/FSQ-7, the active computer, performed air defense, while the other was in "standby" status. The standby computer may have been in several modes, i.e., down for repairs, undergoing scheduled maintenance, or it may have been in use for program or system testing of special air defense programs. The reversal of active and standby AN/FSQ-7 computers was termed "switchover." Simplexed devices which had been connected to the active computer were automatically transferred to the standby computer. Periodic transfer of critical system data was effected during each frame of real-time operation via an intercommunication drum between the duplexed computers. Because of the independent drum buffering system, this was possible even if the standby computer was down for maintenance. Therefore the air defense data critical to system operation was made available to the standby computer in the event of an emergency failure of the active computer.

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Edward Wenzel

ANALOG-DIGITAL CONVERSION

ANALOG–DIGITAL CONVERSION

The mechanisms for converting between a discrete (digital) number (such as that held in a register of a digital computer) and a continuous analog signal (such as a voltage or current) is here described.

Conversion to analog is required in many applications such as process control and natural and physical sciences. For example, in medicine, an electrocardiogram is a graph of electrical potential voltage as a function of time as measured across various parts of the body. Similarly, a cathode-ray tube requires a voltage input whose value is proportional to the location of the point to be displayed.

DIGITAL-TO-ANALOG CONVERSION

To convert a digital (discrete) number to a continuous analog voltage (or current), a resistive divider network is connected to a flip-flop register which holds the digital

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