CYBERNETICS AND CONTROL THEORY

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MICROCONTROL AND FAULT DIAGNOSIS IN DIGITAL COMPUTERS

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In program methods of diagnosis, the procedure for locating a fault is based on the fact that each instruction consists of a definite set of elementary control signals—micro-operations. If the execution of one instruction with some set of micro-operations gives the correct result, while the execution of another instruction with additional micro-operations leads to an error, then the error is considered to be associated with the execution of these additional micro-operations.

If it were possible, for any machine failure, to use program methods, then automation of the search for the location of the fault would be ensured. However, there exist such errors in a digital computer— "major errors" —which in principle do not allow diagnostic programs to be used. The occurrence of major errors leads to a violation of the proper sequence of instruction execution, as a result of which the results of diagnostic tests may be completely arbitrary.

Let us call the operability region of a diagnostic test that part of the digital-computer equipment in which failures are detected by program means. A quantitative measure of the operability region of diagnostic tests may be the coefficient of their effectiveness K_{eff}, defined by the expression

$$K_{\text{eff}} = n_2/(n_1 + n_2),$$

where n_1 is the number of possible major errors, and n_2 is the number of possible secondary errors, i.e., errors that do not affect the correctness of the execution of diagnostic tests ([1]).

The effectiveness of program methods of diagnostic checking increases considerably when computers with macrocontrol use microcontrol apparatus. The use of the principles of microcontrol for locating a fault in a macroprogram-type digital computer is achieved through such an organization of the control equipment that allows the computer to operate in one of two possible modes—macrocontrol or microcontrol. Computing machines capable of operating both

Fig. 1. Block diagram of the control unit of a macroprogrammed-type digital computer; Fig. 2. Block diagram of the control unit of a microprogrammed-type digital computer

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in the macrocontrol mode and in the microcontrol mode will be called digital computers with combined control.

The improvement in the quality of diagnostic checking in a digital computer with combined control is due to a number of positive properties of such a digital-computer structure. It is known that localization of faults with high resolving power requires that such sets of input quantities be applied to the input of the device being monitored, and in such a sequence, as are determined by the structure of the device and by the list of its faults. However, in a digital computer with macrocontrol there are rigid restrictions on the order in which input signals are generated, imposed by the selected instruction system and by the algorithm for executing each operation. The possibility for a digital computer to function both in the macrocontrol mode and in the microcontrol mode makes it possible to eliminate these shortcomings, since in this case the execution of any sequence is ensured.

micro-operations. In addition, in doing so it is easy to introduce a number of additional micro-operations, which is equivalent to adding inputs to the devices being monitored. This also makes it possible to increase the resolution of diagnostic checking.

On the other hand, in a digital computer with combined control it is possible to reduce the amount of equipment whose failures lead to principal errors. The possibility of this reduction is explained by the fact that the correct passage of diagnostic tests in the microcontrol mode is realized when the equipment is in proper working order; the volume

Fig. 1. Block diagram of the control unit of a macroprogrammed-type digital computer
Fig. 2. Block diagram of the control unit of a microprogrammed-type digital computer

of which is substantially smaller than the volume of equipment used for analogous purposes in the macrocontrol mode.

The implementation of the microcontrol mode in each particular digital computer will have its own features, determined by the structure and composition of that particular digital computer, as well as by the required characteristics of the microcontrol mode.

In the present work, the fundamental aspects of organizing microcontrol modes

Fig. 3. Block diagram of a CU of a digital computer with combined control

Figure 2: Fig. 3. Block diagram of a CU of a digital computer with combined control

in a macroprogrammed-type digital computer are noted. Figure 1 presents a simplified block diagram of the control unit (CU) of a macroprogrammed-type digital computer. The program is stored in the instruction memory (IM), from which information, at the address in the instruction counter (IC), is transmitted to the instruction register (IR). The generation of a sequence of elementary control signals corresponding to the instruction being executed is performed by the operation decoder (OD), the central and local control units (CCU and LCU), and the control-signal generators (CSG).

The block diagram of the control unit of a microprogrammed-type digital computer is presented in Fig. 2. In this case, the codes of the elementary control signals—the microinstructions—are stored in the instruction memory (IM). Microinstructions are selected from memory according to the address written in the microinstruction address register (MAR). The functions of the CCU are mainly reduced to carrying out conditional transfers and ensuring the temporal coordination of the operation of the IM with the other devices of the machine. In this case there is a strict correspondence between each bit position of the control code and the corresponding micro-operation generated by the control-signal generator.

A comparative analysis of the control structure of macro- and microprogrammed-type digital computers shows that a macroprogrammed-type digital computer has a large part of the equipment needed for its operation in the microcontrol mode. Figure 3 shows the block diagram of the control unit of a digital computer with combined control, where dashed lines indicate the additional connections and equipment (in comparison with a macroprogrammed-type digital computer) that ensure operation of the digital computer in two modes (2). The central control unit of microprogrammed type (CCUM) ensures the joint functioning of the main devices of the digital computer in the microcontrol mode. The micro-operation decoder (MOD) is necessary because the word length of the instruction code of a macroprogrammed-type digital computer is less

of the number of all micro-operations with which the given machine operates. This fact does not make it possible to establish a one-to-one correspondence between the state of each bit of a microinstruction and the micro-operation corresponding to it. The presence of the decoder DM ensures that several micro-operations correspond to each bit of the microinstruction. For this purpose, each read amplifier of the ZUK is connected to the first inputs of a group of gates (two-input coincidence circuits), the number of which in the group coincides with the number of outputs of the DM. Different outputs of the DM are connected to the second inputs of this group of gates. Each of these gates provides the initiation of one micro-operation.

Fig. 3. Block diagram of a CU of a digital computer with combined control

The required number (m) of DM outputs is determined by the relation

$$m \geq N/n,$$

where N is the total number of micro-operations in the digital computer, and n is the word length of the digital computer.

The automatic program transition from one mode to another is provided by special control indicators in the instruction code. Switching the digital computer from macro-mode to micro-mode and back can be carried out in two principal ways. In the first case, the digital computer necessarily returns to macro-mode after the execution of one microinstruction. If in this case, in the next macroinstruction at address N, the value of the mode indicator corresponds to the microcontrol mode, then the microinstruction is executed according to the value of the address part A of the current macroinstruction. Then the next macroinstruction is fetched from memory at address $N + 1$, and so on.

The second method differs from the first in that the return from the microcontrol mode to the macrocontrol mode is carried out according to a special control indicator in the microinstruction code. In this case it becomes possible to execute sequences of microinstructions without the expenditure of service macroinstructions for each microinstruction. However, the first method is more economical when working with single microinstructions.

Analysis of the solution of diagnostic tests in a digital computer with combined control in micro-mode shows that, for successful diagnosis of the digital computer, the following units must be in good condition: ZUK, SK, PUUM, DM. Thus, the region in which major errors exist is substantially reduced, and the overwhelming majority of faults of a digital computer with macrocontrol are, with such a structure, easily localized.

The sequence of input actions on a given element being tested is determined by the program for checking this element, compiled to detect possible faults of the element.

Programs for checking individual devices of the machine (for example, a register, a counter, etc.) constitute a certain set of elementary checking subprograms, the composition and sequence of execution of which are unambiguously determined by the types of elements included in the device being tested, by the interconnections of these elements, and by the logic of operation of the device as a whole.

The greatest effect in organizing automatic diagnostic control in a digital computer with combined control (macro- and micro-

—with microprogram control) is achieved in the case where the machine provides for two autonomous modes of microprogram control (organized, for example, on any two autonomous storage devices), since in this case almost any malfunction can be regarded as a secondary error with respect to some operating mode of the digital computer. In fact, when a digital computer has one mode of microprogram control, $K_{\text{eff}} \approx 0.9$, whereas with two autonomous modes of microprogram control $K_{\text{eff}} \approx 0.95 \div 0.97$. (Let us note that for ordinary digital computers $K_{\text{eff}} = 0.5 \div 0.7$.) The hardware costs for organizing, in a digital computer of the macroprogram type, a diagnostic-control system based on one or two modes of microprogram control amount to $5 \div 10\%$ (the smaller values correspond to more complex digital computers), while this ensures localization of the malfunction with accuracy down to the replaceable functional module of the machine.

The advantages of digital computers with combined control, as compared with digital computers of the macroprogram type, are not limited only to a high level of automation and degree of malfunction localization when program methods of diagnostic control are used. A digital computer with combined control has greater computational capabilities, since it is possible to program new machine operations directly without rebuilding the machine ([3]).

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Note: Figure translations are in progress. See original paper for figures.