state-behavior and the internal logic of autonomous sequential networks. Relations such as these lie at the core of the coding problem, which is central to the development of synthesis procedures for sequential networks generally. Although achievement of this long-range objective may not be immediately imminent, it is hoped that the preliminary results established here will set a pattern for further exploration of this important subject.

References

1. THE SYNTHESIS AND ANALYSIS OF DIGITAL SYSTEMS BY BOOLEAN MATRICES, J. O. CAMPEAU.

System Evaluation and Instrumentation of a Special-Purpose Data Processing System Using Simulation Equipment

A. J. STRASSMAN L. H. KURKJIAN

TESTING and instrumentation are essential prerequisites for the completion and operation of any new system. A system can be defined as a number of components that are amalgamated or integrated together to perform a desired operation. Throughout this paper a "component" is considered to be a complete functional part of a data-processing system such as an arithmetic unit or a buffer. To ascertain if a component in the system is going to perform its specific function, it is sometimes necessary for the implementation of tests to be more complex than the component undergoing the testing. This becomes apparent when the component is a part of a large system and has many inputs and outputs.

To prove the system feasibility or operation of the components it is necessary to do either of two things: 1. duplicate and maintain an entire system and use it as one master-test fixture to evaluate each functional component; or, 2. provide individual test fixtures for the evaluation of each of the functional components. The second approach requires the design of simulation equipment to provide the necessary inputs (control signals and data) to check out completely the operation of each individual component. It is believed that this approach offers the greatest advantages for large special-purpose data processing systems.

It is necessary to provide the proper work organization for the evaluation of these computer systems. A differentiation can be made between small and large systems and the work organization can be adjusted accordingly. Although the basic philosophy of test remains the same, the details evolved for the testing or evaluation of a small system will be different from that evolved for a large system. For the purpose of this paper in which the evaluation and instrumentation of a large system will be described, a "large" system will be defined arbitrarily as one that contains more than 500 flip-flops. Since the flip-flop is a basic part of any digital computer, the number of flip-flops can be used as an indication of the size and complexity of the system.

The philosophies contained within this paper led to the basic planning considerations for the test and evaluation of a special-purpose data processing system; parts of which will be described in later paragraphs. This data processing system contains approximately 1,500 tubes, 2,500 transistors, 40,000 logical gating diodes and 3,500 flip-flops. Each flip-flop in the system has four transistors making a total of 16,500 transistors in the entire system. This qualifies the described system to be classified as a large system.

In the case of a small system, all the

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work can be handled by a small group which will perform the necessary tasks from system design to final evaluation. This work includes the logical design, circuit design, and testing. It is admitted that to be able to perform all the tasks included, the technical personnel associated with a small system must be those of broader background than those required for the evaluation of a large system. This becomes obvious when the personnel requirements are outlined for the large system. In this case, due to the actual limitations of time, complexity of large systems, and efficiency of utilization of personnel, specialists are needed in each specific area to perform all the necessary tasks to complete the system. Specialization is indicated by the fact that the system design is done by a group of systems engineers whose function is to define the necessary components needed to implement the system and their interrelationships. Logical design and circuit design are two functions that are performed in an analogous manner by logicians and circuit engineers who are specialists in their respective realms.

The test and evaluation of the system is also handled in a specialized manner. Each component is assigned to a circuit or unit engineer whose responsibility is to:

1. design the logical circuitry of the component from the Boolean equations,
2. design the test fixture,
3. write the necessary procedural, and
4. test the component when it is fabricated.

Types of Tests to Be Performed for Evaluation

The basic parts of any large system can be broken down into five categories which are listed in their order of complexity: 1. elements, 2. units, 3. components, 4. subsystems, and 5. systems. If these basic parts of the system are evaluated and tested in order of complexity, the sequential building of testing integrity yields the understandable advantage of solving small problems first before becoming involved with the intricacies and troubles inherent in any large system. The first type of tests to be performed therefore would be element tests.

Element Tests

The basic computing elements are usually flip-flops, logical followers, drivers, shift registers, diode cards, and pulse regenerators, etc. These items are referred to as "standard elements." The functional requirements of each of these standard elements determine the design of the test fixture necessary for evaluation. The test fixture for a flip-flop contains the necessary steering circuitry which makes the flip-flop a modulo-2 counter. When more than one flip-flop is built on a standard card, the fixture can be expanded to make the flip-flops count in any prescribed manner. Shift registers, followers, and drivers are most commonly evaluated by inserting specific computer word patterns at the input and observing the appropriate outputs. Simple sequential relay circuits are used to step through the forward and reverse characteristics of diodes on standard diode cards. Typical standard elements of a digital computer system along with a standard-element test fixture are shown in Fig. 1.

The electronic implementation of the digital computer logic that is represented in Boolean notation is formed from the standard diode card and specific resistor networks on the matrix card assembly. The wiring of the resistors to the diodes on each individual matrix card determines its logical function. The logical function of each card can be statically evaluated by a "matrix card tester" which simulates each input term to the card. The output of each gate is monitored as logical true and false levels are placed at the inputs to the gate. A meter is used to indicate to the operator the result of the simulation of any of the logical terms under test. Fig. 2 is a photograph of a matrix assembly and a matrix card tester.

Unit Tests

Each module of the system under discussion is called a unit and contains up to 21 element cards. A unit module is shown in Fig. 3. The combinations of, and connections between the elements in the unit provide a portion of an over-all computing function that is to be performed by the system. Evaluation of units are difficult because units are incompletely functional items and therefore the amount of simulation becomes large and complex. However, it is considered that this step in the system evaluation is critical. It is therefore necessary to ascertain that each unit has been tested to the maximum. This obligates one to perform the most exhaustive tests possible on the unit level within the framework of the computer. Provisions to accomplish this can only be done by generating ideal simulated signals that the unit would expect in system operation. This type of simulation has been achieved by the design of equipment referred to as the "unit tester." The unit tester provides combinations of static and dynamic signals to the unit under evaluation. All system timing signals, synchronizing signals, and data inputs are generated in the unit tester. Each connection in and out of the unit under test is available on a patch panel on the unit tester. The choice of four signals is available at each point. The point may be:

1. connected to a logical true signal,
2. to a logical false signal,
3. to a special function (synchronization, timing, data, etc.), or
4. it may be left unconnected if it is an output of the unit that is to be observed.

The unit test insures that the interelement wiring and the input-output wiring of the unit is correct and at the same time provides a semidynamic test to the various element.
configurations. Many of the logical functions can be completely evaluated during this phase of test. The unit test can be easily modified for production testing of each module by simple automation techniques. In Fig. 4, a unit is shown under test in the unit tester.

**Component Tests**

A system component is a unit or group of units that has been defined in the system to perform a particular computing or data processing function. Examples of typical components are the arithmetic unit, the various buffers, the computer controls, and the buffer controls. It is at this level that the simulation of external signals is very important, as the completeness of testing at the component level determines the ease with which it is possible to system test and evaluate the entire system. The component test provides for the testing of all of the logic contained within the integrated units by means of the external simulated signals. These external signals are developed by a special test fixture that is unique for each component. A component consisting of eight units mounted on its test fixture is illustrated in Fig. 5. The test fixture is designed to simulate the complete system to the component. This test is basically dynamic, and as a consequence, logical errors can be discovered during this phase of evaluation. The simulation equipment consists of the appropriate switches, function generators, and timing and synchronizing signals that the component would operate from if it were in the system. Procedurals are written which outline the detailed steps necessary to cause the component function as specified by the system's design. This test actually provides or disproves the component logic with the test fixture as the system simulator. Both the test fixture and the procedurals are designed and written by the cognizant circuit or unit engineer who is charged with the responsibility of this component and has by necessity a complete grasp of the functional operation of this component. Typical examples of system components and an idea of their complexity follow.

1. The co-ordinate extrapolator updates co-ordinates on the basis of velocity stored in the memory. This component requires 12 flip-flops, 8 logical followers, and 180 diodes. The logic written in Boolean notation consisted of 3 typewritten pages and the test procedural was 9 pages long. The control and addition logic in this component were evaluated by means of a component test fixture which simulated the system input co-ordinate data, velocity, and time by means of variable word generators and counters.

2. The computer's control are in the form of a special-purpose wired program computer that controls information from and to three arithmetic units. Its outputs include control signals and generation of appropriate constants needed during the various steps in the wired program. The component was implemented with 15 units which contained 148 flip-flops, 384 logical followers, and 6,350 gating diodes. The logical equations in Boolean notation comprised 26 typewritten pages and the test procedural was 114 pages long. The control signals and the terms of the constant generators checked by a test fixture simulated the essential control signals required to cause the computer to perform each program step.

**Subsystem Tests**

After the component has been completely evaluated, the next step for system completion is to integrate the components together into the various subsystems as determined by a logical sequential build-up. Fig. 6 demonstrates a simple integration of one subsystem consisting of four components. There is less simulation equipment needed in this phase than for the component test. The example shown shows control and decoder components that have the facility for entering data into a special-purpose computer which steps through a wired program cycle and stores information on a magnetic drum. Parts of this information are used in the control component during system operation. This makes the subsystem a small closed loop within the system. Logical tie-in and timing errors can be found and solved during this part of system completion. Simulation equipment for subsystem tests usually consists of inhibiting signals that effect the closed loop operation and generating all those other signals which are necessary to make the loop operate. In the example shown, X and Y co-ordinate data in Gray Code, simple operator control buttons and radar-antenna position signals were the only signals needed to be simulated. Parts of existing component test fixtures can be used during subsystem tests as they contain the necessary simulation equipment.

**System Test and Evaluation**

This phase is the culmination of all the test and evaluation effort that has been
as magnetic-ink character readers and converters, which the bank ultimately expect to have, approximately 7,000 square feet in total for the equipment was actually allocated.

Since this electronic data-processing system contains its own air-conditioning equipment and, in fact, air conditions the converters, which the bank ultimately expects to make for air conditioning. This would be provided for controlling the temperature and humidity in the magnetic file room, which was approximately 1/6th of the total area. There was also provided at the site, the equivalent of approximately 90 gallons of water per minute, at a temperature not higher than 75 degrees, for the compressors included in the system and, of course, the necessary power supplies. Both supplies, that is water and power, were made independent of other requirements within the building, so that any failures resulting from the use of equipment in other areas would not have any effect on the system. The question, which is frequently raised, of whether or not an independent power supply for emergency use was needed was considered and it was resolved that this would be uneconomical in the long run. After all, if the bank should lose power throughout the main office today, it would be “off the air,” so to speak, until it were restored. When recalling the multitude of profit machines, bookkeeping machines, tabulating equipment, and other electrical devices upon which the bank relies from day to day, it can be realized that it is not practical to install an emergency supply system of sufficient size to operate them in the event of a main line power supply failure. Hence, it is reasonable to say that exposure with an electronic data-processing system is really no greater, in the event of such a power failure, than it is today with conventional equipment.

Delivery of the equipment began shortly after the middle of April 1958, and on June 2, the engineers had completed assembly of all of the various units involved, and engineering tests and check-outs were commenced.

The contract provided for a minimum of 3 weeks of acceptance tests and these were started later that month. Acceptance tests were run for the required period under the general supervision of the computer expert, who had been retained originally as a consultant. The tests included not only the operation of various routines developed for regular daily use, but also specific programs written for the purpose of testing all of the various components of the system, and each of the mechanical and electromechanical pieces of equipment associated with it. By the middle of July, the bank was convinced that the equipment was satisfactory in all respects, with the exception of one unit, the high-speed printer, which at that time needed some further engineering work. Therefore, the system was placed on a rental basis, with the exception of the printer, on July 17, 1958. The printer and converter, as initially delivered, was essentially a prototype, and after rather extensive field testing a production model, incorporating many improvements in design, is being substituted for it.

When the equipment was delivered in June, the programming for the bank’s deposit accounting operation was completed. This program is a comprehensive one intended to eventually handle more than 108,000 checking accounts. Since approximately 32,000 of these accounts are in the nature of special checking accounts where the checks themselves are in the form of punched cards and provide a ready means of input, these accounts were selected for the initial operation. Early in June they were transferred to magnetic tapes and processing on a day-to-day basis behind the old operation was begun. This procedure not only assisted evaluation of the equipment during the test period, but also enabled final polishing of the program itself.

In the middle of July, an attempt was made to operate the new system on a parallel with the old. This attempt eventually led to one conclusion: that it is not possible, as a practical matter, to operate an accounting function designed to make the most effective use of electronic equipment on a parallel basis with manual or automatic systems. The use of a computer system in data processing enables one to approach problems in a considerably different manner than it is otherwise possible to do in other systems. This difference in philosophy, combined with the greater speed and the high degree of accuracy, makes it extremely difficult to draw comparisons in any intermediate stages of handling data. The adjustments that were necessary to balance one system to the other were extremely cumbersome to handle on a day-to-day basis. These tests, however, did serve to convince many employees who were unfamiliar with this new method of data processing of the reliability and accuracy that could be expected of the new accounting procedures, and of the equipment itself. Early in September, procedures were altered so that regular processing was done electronically and the old system followed a day behind, in order that one final check of our cycled statements could be made. At the end of that month, the old system was abandoned entirely and, since that date this work has been done very satisfactorily on the new equipment. It might be of interest to note here, that a normal day’s operating time on the computer to edit, sort, and post between 20,000 and 22,000 items to approximately 33,000 accounts, including the preparation of tapes for the printing of statements, lists of overdrafts, and numerous other special reports is in the order of 28 to 32 minutes, figures which compare favorably with the original estimates of the research group as to the time required for this operation.

As indicated earlier, other applications were being programmed and program fixing has continued. In the past few weeks checking out the routines for the Corporate Trust operation have been completed and the records, with respect to all of the bank’s stockholders, are on magnetic tape files. These are being processed regularly on the new system. When the conversion of data in old files to tapes is complete, the bank will increase this operation to include in excess of 765,000 accounts. This conversion will take some time, since the practical problem of manually punching the equivalent of more than 5½ million cards in order to translate the data in the old files into machine language must be faced.

There are one or two points that are unique about this particular application. First, it is believed that this is the first bank to apply fully automatic techniques, and second, the routine, itself, puts upon the computer the burden of calculating and assigning to each item, a key in lieu of an account number, which when sorted results in arranging the files in alphabetical sequence. In a file of the size with which this bank is concerned, the cost of looking up and assigning numbers to each item in the file, and to each transaction affecting the file, in order to preserve its alphabetical sequence is very high. Some banks have felt that this cost is sufficiently great to wipe out any gains that might otherwise be realized from other semiautomatic or automatic accounting systems requiring the numbering of accounts and have, therefore, stayed with manual systems. While the bank has not as yet had an opportunity to fully check out the application, it is believed that solving this problem of account numbering has been successful. Experiments under actual operating conditions with a file of approximately 25,000 stockholders have led to this conclusion.

It is frequently asked, "If you can
performed previously. All the elements, units, and components have been proved to perform within the framework of the several subsystems. It is now necessary to prove that the integration is complete by operational use of the entire system. Obviously a minimum of simulation equipment is required during the system evaluation. Fig. 7 shows system test fixtures with the components mounted. Since large systems are complex, it is considered good design to incorporate self-test features into the system. This involves the design of simulation equipment to be incorporated within the actual system hardware. This equipment is useful during the initial evaluation as well as during normal system operation.

Conclusions

It is apparent that any complex system can be tested and evaluated by a step-by-step instrumentation. Providing the necessary special purpose instrumentation has proved to be more rapid and economical than the accumulation of general-purpose testing devices. There are many instances in the testing of special-purpose computer components within a system that general-purpose instrumentation devices would not suffice no matter how much and how varied the instruments could be interconnected. In each of the stages of the system integration, particular classes of errors and failures can be uncovered. During element tests, electronic part failures and mechanical errors are discovered and corrected. After element testing, each element is considered operative and the troubles found in unit tests cannot be attributed to the elements. During unit testing, logical and timing design errors can be uncovered and intra-unit connections are ascertained to be correct. At the completion of the unit test, each unit is considered to be completely operative. Therefore, during the component test phase, any difficulties discovered cannot be attributed to the unit, but rather to logical tie-in errors between units and interunit wiring. Similarly, the problems within the subsystem test are only related to those difficulties encountered in integrating more than one component because of the completeness of the component evaluation. System testing is merely an extension of the previous statements, but now referring to problems encountered in integrating subsystems. The sequential building of test complexity offers the advantage of solving small problems first before becoming involved with the intricacies and troubles inherent in any large system integration. Finally, the experience of the personnel involved in the test build-up enables a better understanding of the system operation thereby decreasing the time required to integrate a large system made up of many discrete and special components.

Discussion

Howard W. Childs (Sylvania Electronic Systems): I gained the impression that the test equipment was largely manual in operation. Is this true?

Glenn W. Bills (North American Aviation): Why wasn’t tape-programmer automatic checkout equipment used in preference to manual checkout by technicians?

Mr. Strassman: These first two questions can be replied to with the same answer. In essence, this was a developmental model and therefore it did not behoove us to spend time and money to design special automatic checkout equipment to do the job. However, we could say that we had automatic technicians because they were provided with special instructions as to exact procedures to be followed for the checkout and what to do when a particular readout was not what it was supposed to be. However, the fact of economics primarily prohibited the design and use of automatic checkout equipment.

G. W. Smith, Jr. (Bell Telephone Laboratories): What provision is made for “in-operation” testing to indicate failures during service?

Mr. Strassman: I did not describe that particular portion of the system, but within the system there is built-in simulation equipment to provide external signals that provide facilities for in-operation testing. For instance, since this particular data processing machine is used for radar data processing, we have actually built into the system a radar target simulator which allows us to provide in-operation testing without an external radar.

W. A. Farrand (Autonetics Division, North American Aviation): To what degree do you find that the dynamic tests of elements provide workability criteria?

Mr. Strassman: Well, I could say it is 100% because the ones that do not work are not used. After testing the elements, it is ascertained completely whether or not they are working, and those that are not working are then repaired, tested again, and then put back into the system. So that we have proven workability of the items before they were actually installed in the system.

APAR, Automatic Programming and Recording

G. R. BACHAND J. L. ROGERS T. F. MARKER

THE AUTOMATED Integrated Data Systems (AIDS) program objectives are to: 1. automate weapon data activities reliably, economically and with realistic accuracies, 2. provide these facilities rapidly with a degree of flexibility for maximum utilization, 3. standardize a systems approach which takes into account technological advances.

One major development area is the automation of information acquisition, and germain to this paper is the problem of automatic acquisition of variables information in testing operations.

The systems needs are based primarily on acquiring data from quasi-static phenomenon at relatively low digitalizing rates and modest accuracies. In addition, building blocks should be made available having higher order capabilities commensurate with other application requirements.

In fulfilling the needs for an economical automated acquisition system, the development of functional modules has been completed which in various combinations, dictated by the application, make up an Automatic Programmer and Recorder (APAR). APAR, when equipped with the proper transducers or test heads, can be used to replace test equipment, the test equipment operator, the recording notebook or inspection sheets, the process of controlling equipment under test, and the process of recording the test data. This acquired information is converted to a machine language and recorded on punched paper tape. The people in the System Studies Department who have generated the concept of APAR and fostered its development were: G. R. Bachand, J. L. Rogers, and T. F. Marker.