System/370 integrated emulation under OS and DOS

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INTRODUCTION

The purpose of this paper is to discuss the design and development of integrated emulators for the IBM System/370. Specifically, emulation of IBM 1400 and 7000 series systems on the IBM System/370 Models 145, 155 and 165, integrated under an Operating System. While the author acknowledges the development and presence of emulation outside of IBM, it is not the intent of this article to conduct a comparative survey of all emulator products. Rather, the discussion will be restricted to the design and development considerations involved in producing the System/370 integrated emulators.

EMULATOR HISTORY

The System/370 integrated emulators are evolutionary products of earlier IBM emulators on System/360. Before discussing the design and functional characteristics of the System/370 emulators, a review of emulation as it existed prior to System/370 is presented in order to form a base of comparison for the new system.

Three methods are employed by the emulators to effect the execution of prior systems programs on the new system and are referred to throughout this article:

1. Interpretation/execution via hardware (referred to as *emulation*).
2. Interpretation/execution via software routine (referred to as *simulation*).
3. A combination of the above (referred to as emulation).

In System/360, emulation was composed of three distinct design types:

1. Hardware: Some emulators, such as the IBM 1401 emulator on System/360 Model 30, were exclusively implemented by hardware. The Model 30 became, in effect, a 1401, with the appropriate registers, addressing, I and E-time execution, etc., handled by the hardware. While performance and operating characteristics were quite good, the system was dedicated to a specific mode of operation, i.e., either emulation or "native" mode. The resultant loading and reloading necessary to attain the desired mode of operation imposed unproductive overhead on the user.
2. Hardware/Software: Other emulators, such as the IBM 7000 series emulators on System/360 Model 65, were comprised of both hardware and software. By adding software, the emulator offered more flexibility in device support and operational characteristics, while at the same time retained the desirable performance attributes of hardware execution. (Pure software implementation would become total simulation, with the obvious degradation of performance.) These emulators required a total dedication to the system of a specific operating mode—emulation or native, with the unproductive overhead of loading and reloading. This overhead was more noticeable when the native mode operation involved an operating system. Additionally, terminal applications were not possible because of the necessity to "shut down" the operating system for emulator loading.
3. Hardware/Software/Operating System: Two programs, Compatibility Operating System (COS)/30 and COS/40 were developed by IBM which integrated the 1401 emulator on System/360 Models 30 and 40 under DOS. At first considered to be interim programs, these programs, because of their wide acceptance and usage, were subsequently upgraded through hardware and software refinements and renamed Compati-

bility System (CS)/30 and CS/40. For the first time, 1401 jobs and System/360 native-mode jobs could be run concurrently in a limited multiprogramming environment. (Limited multiprogramming in the sense that there were certain restrictions on the Foreground/Background allocation of jobs under DOS.) Single job stream input was also possible. Overall system thruput was significantly improved by eliminating the need to reload the system between emulator and System/360 jobs.

In addition to the CS emulators, there were other applications such as Hypervisors and "hook loaders," which, to a lesser degree, provided a single operating environment by eliminating the need to re-IPL between emulator and System/360 jobs. Hypervisors enabled two emulators to run concurrently or, an emulator to run with a System/360 job.

The Hypervisor concept was relatively simple. It consisted of an addendum to the emulator program and a hardware modification on a Model 65 having a compatibility feature. The hardware modification divided the Model 65 into two partitions, each addressable from 0-n. The program addendum, having overlaid the system Program Status Words (PSW) with its own, became the interrupt handler for the entire system. After determining which partition had initiated the event causing the interrupt, control was transferred accordingly. The Hypervisor required dedicated I/O devices for each partition and, because of this, the I/O configurations were usually quite large, and, therefore, prohibitive to the majority of users.

Hook loaders, developed by individual installations, effected a "roll-in/roll-out" of the emulator or System/360 job. The decision to swap operating modes could be interrupt driven or initiated by the operator. The basic attribute of this application was to eliminate the need for IPL when changing operating modes.

DESIGN CONSIDERATIONS AND OBJECTIVES

At the time they were initially released, the System/360 emulators were considered to be short term programs. They were intended to provide the user with the facility to grow from a second generation system to the improved facilities of System/360 with little or no reprogramming. To this end, they served their purpose very well. Their predicted demise however, did not take place as expected. Emulation usage continued at a high rate, with installation resources directed at new applications rather than conversion of existing applications.

Clearly, as system and customer applications became more complex, the need for expanded emulator support became more evident. Early in the planning cycle of System/370, IBM began a design study to determine the most efficient architecture for emulators on System/370. Based on an analysis of existing and projected future operating environments, feedback from user groups, and the experience gained to date with emulation, the following key design points were established as objectives for System/370 emulators:

1. Emulators must be fully integrated with the operating system and run as a problem program.
2. Complete multiprogramming facilities must be available including multiprogramming of emulators.
3. Device independence, with all device allocation performed by the operating system.
4. Data compatibility with the operating system.
5. A single jobstream environment.
6. A common, modular architecture for improved maintenance and portability.
7. An improved hardware feature design with emulator mode restrictions eliminated and all feature operations interruptible.

MODELING

While the COS/CS emulators had proved the basic feasibility of integrating an emulator as a problem program under an operating system, in this case DOS, extending this feasibility to include a large scale, complex system with the full multiprogramming facilities of OS/360 remained to be proven. Therefore, it was decided that a model should be built which would integrate a large scale system into OS/360.

The system selected was the 7094 Emulator on System/360 Model 65. The 7094 and the 7094 Operating System (IBSYS) represented the most complex and sophisticated second generation system available. If this system could be successfully integrated with OS/360, the design and technology could certainly be applied to smaller, less complex systems.

The OS/360 option selected was MFT II. This system, with its fixed partition requirement, could be more easily adapted to the 7094 Emulator design which also included fixed locations and addressing.

This particular feasibility study proved to be an excellent subject for modeling. The goals were well defined, the emulator itself was relatively self contained, and the design alternatives were varied enough to make

multiple design evaluations necessary. Modeling was primarily concerned with the assessment of four major areas: input/output techniques, operation under an operating system, hardware design/requirements, and operating system interfaces. There were a number of key recommendations and resolutions achieved in these areas as the result of modeling.

Input/output techniques

- To provide the most efficient means of I/O Simulation, an emulator access method with standard interfaces to the operating system was developed. OS/360 Basic Sequential Access Method (BSAM) was used for tape operations and Queued Sequential Access Method (QSAM) for support of Unit Record devices. Basic Direct Access Method (BDAM) support was later added for those systems that support disk. This access method was subsequently expanded to be usable by any System/370 emulator, regardless of the emulated system. This access method is currently used by the 1400 and 7000 series emulators on System/370.
- To solve the problem of prohibitively long tape records (32K maximum), and some file formats which were unacceptable to OS/360, a tape preprocessor program was developed to format second-generation tapes into a spanned variable length record format. A post-processor was also developed to convert these tapes back to their original format, if desired.
- To enable selective processing for Operating System error recovery procedures, parity switching and density switching modifications were made to the data management facilities of OS/360.

Operation under an operating system

- Whereas the stand alone emulators had used privileged instructions at will, this could not be done if the emulator was to run as a problem program under the operating system. Those routines requiring privileged Op-Codes were either replaced by operating system routines or redesigned to use only standard Op-Codes.
  To achieve a common, portable architecture, emulator routines were standardized as emulator dependent and operating system dependent modules.

Hardware design/requirements

The need to operate in emulator mode should be eliminated. The emulator program should be transparent to the operating system.

- There should be no fixed addresses and the emulator including the target memory, should be relocatable.
- Emulator Op-Codes should be standardized.
- Emulator Op-Codes should be interruptible and capable of retry. (In emulation, it is possible to remain in E-time simulation for an unusually long period of time, relative to normal System/370 E-time. Therefore, the hardware feature, must be fully interruptible if functions requiring the immediate dispatch of asynchronous interrupts are to be supported.)
- Hardware/Software communication should be done via General Purpose Registers and Floating Point Registers rather than through special hardware registers and/or fixed tables. This is required if emulators are to be multiprogrammed.

Operating system interfaces

- Three standard interfaces were defined. These interfaces are emulator and operating system dependent.
  1. An interface was established between the compatibility feature and the emulator modules which performed CPU simulation, I/O simulation and Operator Services.
  2. A second interface was established between the CPU, I/O and Operator Service modules and the emulator access method.
  3. A third interface was established between the emulator access method and the operating system
- By implementing the emulator to these standard defined interfaces, the goal of a common, modular design with the inherent facility of portability was realized.

In summary, the modeling effort successfully demonstrated the feasibility of large scale integrated emulation, while at the same time meeting all of the design and performance objectives. The architecture which evolved from the model was used by the OS/M85/7094 emulator and was released in early 1970. This architecture, with further refinements, is used by all of the System/370 emulators:

Models 145 and 155	Model 165
DOS/1401–1440–1460	OS/7074
DOS/1410–7010	OS/7080
OS/1401–1440–1460	OS/7094
OS/1410–7010	

These systems represent the most advanced emulators ever offered in the IBM product line, combining the powerful new System/370, its high performance I/O devices, the multiprogramming facilities of Operating System (OS)/360 and Disk Operating System (DOS)/360, and an improved technology in emulator design.

SYSTEM REQUIREMENTS AND FEATURES

On the Model 155 there are four emulator combinations available. The 1401/1440/1460 Emulator under both DOS and OS and the 1410/7010 Emulators under DOS and OS. These are four separate programs, each with an individual program number. The compatibility feature on System/370 Model 155 is an integrated feature which provides the facility to emulate the 1401/1440/1460/ and 1410/7010. These emulators can be multiprogrammed in any combination.

On the model 165—7074, 7080 and 7094 emulators are provided. These emulators run under OS/360 and can be multiprogrammed. Each emulator consists of a compatibility feature and a corresponding emulator program that has a unique feature and program number. Only one feature can be installed in the system at one time.

The System/370 emulators have a number of requirements, considerations and support functions in common:

Minimum Requirements

- Compatibility Feature
- A sufficient number of System/370 I/O devices to correspond to the devices on the system being emulated, plus the devices required by the Operating System.
- Sufficient System/370 processor storage for: (1) the version of the operating system being used (MFT, MVT or DOS), (2) emulator functions needed for the system being emulated, and (3) the program being executed.

Additional Features

- Two tape formatting programs are provided: (1) to convert 1400/7000 series tape files to Operating System (spanned variable length) format for more efficient data handling by the emulator, and, (2) to convert output records in spanned variable length format to original 1400/7000 series format.
- A disk formatting program is provided to assist in converting 1400/7010 disk files to the standard Operating System format.

Data File Restrictions:

- 1400/7000 series tape files must be converted if record lengths exceed 32,755 bytes or, if data is in mixed densities.
- All 1400/7010 disk files must be converted.

COMPATIBILITY FEATURES

The Compatibility Features on System/370 Models 155 and 165 are under microprogram control. The feature on the Model 155 is an installed resident feature, whereas on the Model 165 it is loaded into "Writable Control Storage" via the console file.

The compatibility feature is, in effect, a number of special instructions added to the base System/370. These special instructions are used by the emulator program to emulate target machine operations. The selection of operations to be performed by the special instructions is based on an analysis of the target machine operations relative to complexity and frequency of use.

The most significant special instruction (since it is used once for each target machine instruction executed) is called DO INTERPRETIVE LOOP or simply, DIL (Figure 1). The DIL instruction replaces with a single instruction the subroutine that a pure software sub-

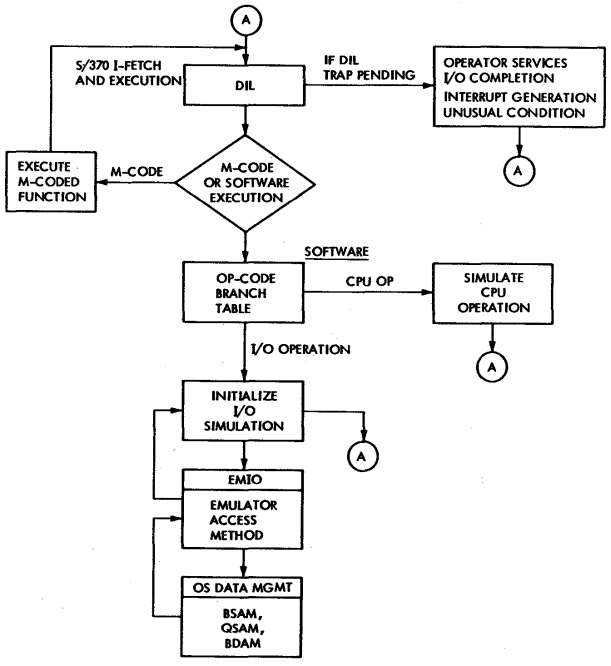

Figure 1—Overview of emulator instruction execution

routine would use to:

1. Access the simulated instruction counter (IC).
2. Convert the IC to a System/370 address in the simulated target machine storage which contains the instruction to be interpreted.
3. Fetch the instruction.
4. Update and restore the simulated IC.
5. Perform any indexing required for the subject instruction.
6. Convert the effective address obtained to the System/370 address in the simulated target machine storage which contains the subject operand.
7. Interpret the instruction Op-Code and branch to the appropriate simulator routine which will simulate the instruction.

INPUT/OUTPUT DEVICE CORRESPONDENCE

Expanded support of I/O devices is provided with the System/370 integrated emulators. The OS Emulators employ the QSAM, BSAM and BDAM facilities of OS/360 Data Management, and offer device independence within the support capabilities of these access methods. The DOS emulators provide device independence only for Unit Record devices.

DISTRIBUTION

DOS

The DOS emulators for 1400/7010 are distributed as components of DOS. Standard DOS system generation procedures are followed in generating an emulator system.

OS

The OS emulators for System/370 Models 155 and 165 are distributed independently of OS/360. Independent distribution was chosen inasmuch as the emulator modules would be superfluous to System/360 users and take up unnecessary space on the distributed system libraries.

SUPPLEMENTAL PROGRAMS

Tape formatting programs

Two tape formatting programs are distributed with the emulator program. The Preprocessor program converts tapes in original 1400/7000 series format to spanned variable-length record format. Any 1400/7000 series tape containing records longer than 32,755 characters must be preprocessed. Preprocessing of other tapes is optional, although greater buffering efficiency can be obtained because the emulator is intended to normally operate with a spanned variable-length format.

The post-processor program converts tape data sets from spanned variable-length format to 1400/7000 series format. The programs support tapes at 200, 556, 800 and 1600 BPI density and handle mixed density tapes. The programs support even, odd and mixed parity tapes.

Disk formatting program

A disk formatting program is provided to assist in converting 1400 disk files to a format acceptable to the emulator program. The disk formatting program runs as a problem program under the operating system. The program creates a data set composed of control information and of blank records whose size and number are determined by the device being emulated.

COMMUNICATING WITH THE EMULATOR PROGRAM

A full range of operator services are provided for operator communication with the emulator program. 1400/7000 series console operations are simulated through commands entered by the operator.

In an integrated, multiprogramming environment, the operating characteristics are expected to initially be more difficult for the operator. However, every effort has been made to ease the transition from stand-alone to integrated operation. Messages from the emulator program are identified by a unique message ID, including a sequentially-incremented message number and the job name of the program being emulated. The user has the option of including multiple console support and directing emulation messages to the second console.

SUMMARY

The System/370 integrated emulators have significantly extended the technology of emulation. They bring to the user an improved, more efficient operating environment for emulator and native mode System/370 jobs, while at the same time providing a nondisruptive growth path for today's System/360 user.

REFERENCE MATERIAL

System/370 Emulators—SRL Publications

Emulating the IBM 1401, 1440, 1460 on the IBM System/370 Models 145 and 155 Using DOS/360- #*GC33-2004*

Emulating the IBM 1410 and 7010 on the IBM System/370 Models 145 and 155 Using DOS/360- #*GC33-2005.*

Emulating the IBM 1401, 1440, 1460 on the IBM System/370 Models 145 and 155 Using OS/360- #*GC27-6945.*

Emulating the IBM 1410 and 7010 on the IBM System/370 Models 145 and 155 Using OS/360- #*GC27-6946*

Emulating the IBM 7070/7074 on the IBM System/370 Model 165 Using OS/360- #*GC27-6948*

Emulating the IBM 7080 on the IBM System/370 Model 165 Using OS/360- #*GC27-6952*

Emulating the IBM 709, 7090, 7094, 7094II on the IBM System/370 Model 165 Using OS/360- #*GC27-6951*

Hypervisor Documentation

Hypervisor for Running 7074 Emulation as an OS/360 Task- #*360D-05.2.005*

Double 7074 Emulation on a System/360 Model 65- #*360D-05.2.008*

Hypervisor RPQ's

Shared Storage RPQ for a System/360 Model 65- #*E 880801*

Shared Storage RPQ for a System/360 Model 50- #*E 56222*