Introduction to Virtualization: z/VM Basic Concepts and Terminology
Session 9102

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Credits

People who contributed ideas and charts:

- Alan Altmark
- Bill Bitner
- John Franciscovich
- Reed Mullen
- Brian Wade
- Romney White

Thanks to everyone who contributed!
Introduction

We'll explain basic concepts of zSeries:
  • Terminology
  • Processors
  • Memory
  • I/O
  • Networking

We'll see that z/VM *virtualizes* a zSeries machine:
  • Virtual processors
  • Virtual memory
  • ... and so on

Where appropriate, we'll compare or contrast:
  • PR/SM or LPAR
  • z/OS
  • Linux
Why z/VM?

Infrastructure Simplification

- Consolidate distributed, discrete servers and their networks
- IBM Mainframe qualities of service
- Exploit built-in z/VM system management

Speed to Market

- Deploy servers, networks, and solutions fast
- React quickly to challenges and opportunities
- Allocate server capacity when needed

Technology Exploitation

- Linux with z/VM offers more function than Linux alone
- Linux exploits unique z/VM technology features
- Build innovative on demand solutions
Terminology & Background
System z Architecture

Every computer system has an architecture.
- Formal definition of how the hardware operates
- It's the hardware's functional specification
- What the software can expect from the hardware
- *What it does*, not how it does it

IBM's book *z/Architecture Principles of Operation* defines System z architecture
- Instruction set
- Processor features (registers, timers, interruption management)
- Arrangement of memory
- How I/O is to be done

Different *models* implement the architecture in different ways.
- How many processors are there
- How do the processors connect to the memory bus
- How is the cache arranged
- How much physical memory is there
- How much I/O capability is there

*z800, z900, z890, z990, z9, and z10* are all *models* implementing z/Architecture.
The virtual machine concept is not new for IBM®…

* Investments made in hardware, architecture, microcode, software
## System z Parts Nomenclature

<table>
<thead>
<tr>
<th>Intel, pSeries, etc.</th>
<th>zSeries</th>
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<tbody>
<tr>
<td>Memory</td>
<td>Storage (though we are moving toward &quot;memory&quot;)</td>
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<tr>
<td>Disk, storage</td>
<td>DASD- Direct Access Storage Device</td>
</tr>
<tr>
<td>Processor</td>
<td>Processor, CPU (central processing unit), engine, IFL (Integrated Facility for Linux), IOP (I/O processor), SAP (system assist processor), CP (central processor), PU (processing unit), zAAP (zSeries Application Assist Processor), zIIP (zSeries Integrated Information Processor)</td>
</tr>
<tr>
<td>Computer</td>
<td>CEC (central electronics complex) Server</td>
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Virtual Machines
What: Virtual Machines

A virtual machine is an execution context that obeys the architecture.

The purpose of z/VM is to virtualize the real hardware:
- Faithfully replicate the z/Architecture Principles of Operation
- Permit any virtual configuration that could legitimately exist in real hardware
- Let many virtual machines operate simultaneously
- Allow overcommitment of the real hardware (processors, for example)
- Your limits will depend on the size of your physical zSeries computer

Virtual machine aka VM user ID, VM logon, VM Guest, Virtual Server
### What: Virtual Machines in Practice

<table>
<thead>
<tr>
<th></th>
<th>z/OS</th>
<th>CMS</th>
<th>VSE</th>
<th>Linux 32-bit</th>
<th>Linux 64-bit</th>
<th>TPF</th>
<th>Others</th>
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<tbody>
<tr>
<td>z/VM's Control Program (CP)</td>
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- Control Program Component - manages virtual machines that adhere to 390- and z-architecture
- Extensions available through CP system services and features
- CMS is special single user system and part of z/VM
- Control Program interaction via console device
Phrases associated with Virtual Machines

In VM...
- **Guest**: a system that is operating in a virtual machine, also known as user or userid.
- **Running under VM**: running a system as a guest of VM
- **Running on VM**: running a system as a guest of VM
- **Running second level**: running a system as a guest of VM which is itself a guest of another VM
- A virtual machine may have multiple *virtual processors*
- Sharing is very important.

In relationship to LPAR (partitioning)...
- **Logical Partition**: LPAR equivalent of a virtual machine
- **Logical Processor**: LPAR equivalent of a virtual processor
- **Running native**: running without LPAR
- **Running in BASIC mode**: running without LPAR
- Isolation is very important.
Phrases Associated with Virtual Machines

- z/VM
- z/OS
- Linux
- vCPU
- LPAR
- LPU
What: A Virtual Machine

Virtual machine

- z/Architecture
- 512 MB of memory
- 2 processors
- Basic I/O devices:
  - A console
  - A card reader
  - A card punch
  - A printer
- Some read-only disks
- Some read-write disks
- Some networking devices

We permit any configuration that a real zSeries machine could have.

In other words, we completely implement the z/Architecture Principles of Operation.

There is no "standard virtual machine configuration".
How: VM User Directory

Definitions of:

- memory
  USER LINUX01 MYPASS 512M 1024M G
  MACHINE ESA 2
  IPL 190 PARM AUTOCR

- architecture
  CONSOLE 01F 3270 A
  SPOOL 00C 2540 READER *
  SPOOL 00D 2540 PUNCH A
  SPOOL 00E 1403 A

- spool devices
  SPECIAL 500 QDIO 3 SYSTEM MYLAN

- network device
  LINK MAINT 190 190 RR
  LINK MAINT 19D 19D RR

- disk devices
  LINK MAINT 19E 19E RR

- other attributes
  MDISK 191 3390 012 001 ONEBIT MW
  MDISK 200 3390 050 100 TWOBIT MR
How: CP Commands

CP DEFINE
- Adds to the virtual configuration somehow
- CP DEFINE STORAGE
- CP DEFINE PROC
- CP DEFINE \{device\} \{device\_specific\_attributes\}

CP ATTACH
- Gives an entire real device to a virtual machine

CP DETACH
- Removes a device from the virtual configuration

CP LINK
- Lets one machine's disk device also belong to another's configuration

CP SET
- Change various characteristics of virtual machine

Changing the virtual configuration after logon is considered normal. Usually the guest operating system detects and responds to the change.
Getting Started

IML

- Initial Machine Load or Initial Microcode Load
- Power on and configure processor complex
- VM equivalents are:
  - LOGON uses the MACHINE statement in the CP directory entry
  - The CP SET MACHINE command
- Analogous to LPAR image activation

IPL

- Initial Program Load
- Like booting a Linux system
- zSeries hardware allows you to IPL a system
- z/VM allows you to IPL a system in a virtual machine via the CP IPL command
- Linux kernel is like VM nucleus
- Analogous to the LPAR LOAD function
Processors
What: Processors

Configuration

• Virtual 1- to 64-way
  – Defined in user directory, or
  – Defined by CP command
  – Specialty or General Purpose
• A real processor can be dedicated to a virtual machine

Control and Limits

• Scheduler selects virtual processors according to apparent CPU need
• "Share" setting - prioritizes real CPU consumption
  – Absolute or relative
  – Target minimum and maximum values
  – Maximum values (limit shares) either hard or soft
• "Share" for virtual machine is divided among its virtual processors
How: Start Interpretive Execution (SIE)

- SIE = "Start Interpretive Execution", an instruction

- z/VM (like the LPAR hypervisor) uses the SIE instruction to "run" virtual processors for a given virtual machine.

- SIE has access to:
  - A control block that describes the virtual processor state (registers, etc.)
  - The Dynamic Address Translation (DAT) tables for the virtual machine

- z/VM gets control back from SIE for various reasons:
  - Page faults
  - I/O channel program translation
  - Privileged instructions (including CP system service calls)
  - CPU timer expiration (dispatch slice)
  - Other, including CP asking to get control for special cases

- CP can also shoulder tap SIE from another processor to remove virtual processor from SIE (perhaps to reflect an interrupt)
How: Scheduling and Dispatching

VM
- *Scheduler* determines priorities based on *share* setting and other factors
- *Dispatcher* runs a virtual processor on a real processor
- Virtual processor runs for (up to) a *minor time slice*
- Virtual processor keeps competing for (up to) an *elapsed time slice*

LPAR hypervisor
- Uses *weight* settings for partitions, similar to share settings for virtual machines
- Dispatches logical processors on real engines

Linux
- *Scheduler* handles prioritization and dispatching processes for a time slice or *quantum*
Memory
What: Virtual Memory

Configuration

- Defined in CP directory entry or via CP command
- Can define storage with gaps (useful for testing)
- Can attach expanded storage to virtual machine

Control and Limits

- Scheduler selects virtual machines according to apparent need for storage and paging capacity
- Virtual machines that do not fit criteria are placed in the eligible list
- Can reserve an amount of real storage for a guest's pages
- Can lock certain specific guest pages into real storage
What: Shared Memory

Key Points:
Sharing:
- Read-only
- Read-write
- Security knobs

Uses:
- Common kernel
- Shared programs
How: Memory Management

VM
- Demand paging between central and expanded
- Block paging with DASD (disk)
- Steal from central based on LRU with reference bits
- Steal from expanded based on LRU with timestamps
- Paging activity is traditionally considered normal

LPAR
- Dedicated storage, no paging

Linux
- Paging on per-page basis to swap disks
- No longer swaps entire processes
- Traditionally considered bad
VM Memory Virtualization

Guest Virtual

Guest Real

VM

Host Real

Guest

Paging

Swapping
I/O Resources
What: Device Management Concepts

- **Dedicated** or **Attached**
  - The guest has exclusive use of the entire real device.

- **Virtualized**
  - Present a slice of a real device to multiple virtual machines
  - Slice in time or slice in space
  - E.g., DASD, crypto devices

- **Simulated**
  - Provide a device to a virtual machine without the help of real hardware
  - Virtual CTCAs, virtual disks, guest LANs, spool devices

- **Emulated**
  - Provide a device of one type on top of a device of a different type
  - FBA emulated on FCP SCSI
What: Device Management Concepts

• Terminology
  - RDEV is Real Device
    • can refer to the device address or the control block
  - VDEV is Virtual Device
    • can refer to the device address or the control block
  - UCB is Unit Control Block
    • used in hardware definitions
  - RDEV=UCB=subchannel=device=adapter

• Control and Limits
  - Indirect control through "share" setting
  - Real devices can be "throttled" at device level
  - Channel priority can be set for virtual machine
  - MDC fair share limits (can be overridden)
What: Virtualization of Disks

Minidisk Cache
(High-speed, in-memory disk cache)

Virtual Disk in Storage
(memory)

Excellent swap device if not storage-constrained

Linux 1

Linux 2

Linux 3

Linux

1

2

3

Virtual Disk in Storage
(memory)

TDISK: on-the-fly disk allocation pool

Minidisk: z/VM disk allocation technology

Notes:
R/W = Read/Write
R/O = Read Only
z/VM Disk Technology - SCSI

Enterprise Storage Server™ (Shark)

SCSI Disks attached to z/VM. Appear to guests and rest of VM as emulated FBA.

FBA = Fixed Block Architecture

Minidisk Cache
(High-speed, in-memory disk cache)

TDISK: on-the-fly disk allocation pool
What: Data-in-Memory

Minidisk Cache
- Write-through cache for non-dedicated disks
- Cached in central or expanded storage
- Pseudo-track cache
- Great performance - exploits access registers
- Lots of tuning knobs

Virtual Disk in Storage
- Like a RAM disk that is pageable
- Volatile
- Appears like an FBA disk
- Can be shared with other virtual machines
- Plenty of knobs here too
Networking
What: Virtual Networks

Connecting virtual machines to one another

- Guest LAN
  - QDIO or HiperSockets
- Virtual Switch Guest LAN
  - Layer 2 or Layer 3

Connecting virtual machines to another LPAR

- HiperSockets
- Shared OSA

Connecting virtual machines to the physical network

- Dedicated OSA device
- Virtual Switch
  - IP or MAC oriented
What: Virtual Switch Guest LAN

Linux Guest One  Linux Guest Two  ...  Linux Guest N

VM Control Program

Network

Linux Guest One  Linux Guest Two  Linux Guest N

Switch  Network
Beyond Virtualization
What: Other Control Program (CP) Interfaces

Commands
- Query or change virtual machine configuration
- Debug and tracing
- Commands fall into different privilege classes
- Some commands affect entire system

Inter-virtual-machine communication
- Connectionless or connection-oriented protocols
- Most pre-date TCP/IP

System Services
- Enduring connection to hypervisor via a connection-oriented program-to-program API
- Various services: Monitor (performance data), Accounting, Security

Diagnose Instructions
- These are really programming APIs (semantically, procedure calls)
- Operands communicate with hardware (or in this case the virtual hardware) in various ways
What: Debugging a Virtual Machine

Tracing of virtual machine
- CP TRACE command has >40 pages of documentation on tracing of:
  - instructions
  - storage references
  - some specific opcodes or privileged instructions
  - branches
  - various address space usage
  - registers
  - etc
- Step through execution or run and collect information to spool
- Trace points can trigger other commands

Display or store into virtual memory
- Helpful, especially when used with tracing
- Valid for various virtual address spaces
- Options for translation as EBCDIC, ASCII, or 390 opcode
- Locate strings in storage
- Store into virtual memory (code, data, etc.)
What: Programmable Operator

1. Send all Linux console output to a single CMS virtual machine.

2. Use PROP and REXX to interrogate console messages.

3. Initiate hypervisor commands on behalf of Linux servers.
What: Performance and Accounting Data

- Linux
- z/OS
- CMS
- VSE
- TPF

CP

- performance monitoring
- accounting data

Collection

Raw data

Performance Toolkit

Realtime Displays

Reports, Historical Data

TCP/IP

Web browser

Data sources:
- Guests
- CP itself
References

- **VM web site:** www.vm.ibm.com
  - www.vm.ibm.com/events/ for various conferences
  - www.vm.ibm.com/education/ for classes
  - www.vm.ibm.com/techinfo/ for good stuff, plus links to listservs

- **Publications on VM Web Site**
  - Follow the links to the latest z/VM library
  - Of particular interest:
    - z/VM CP Command and Utility Reference
    - z/VM CP Planning and Administration
    - z/VM CP Programming Services
    - z/VM Performance

- **z/Journal article based on this presentation**

- **IBM Systems Journal Vol. 30, No. 1, 1991**
  - Good article on SIE
End of Presentation

*Question and Answer Time*