Virtualization

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Outline

- Introduction
- Xen
- Denali
- Comparison
- Conclusion

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Introduction

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Virtualization

- Creating a simulated computer environment called virtual machine (VM)
- Enabling running of guest software
  - Users applications
  - Operating systems
- Providing the ability of creating several VMs on one physical machine
  - VMs share physical resources of the host machine

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Common Terminology

- "Host" is the physical machine that hosts one or more VMs
- "Host OS" is the OS of the host
- "Domain" or "Guest" is a virtual machine
- "Guest OS" is the OS that is running in one domain

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Why we need virtualization?(1)

- Installing several instances of different OSs on one single machine
  - Developing & running applications for different OSs
- Having the ability to copy VM from one physical machine to another
  - Balance load
  - Improve reliability & availability
  - Recover from failure

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Why we need virtualization?(2)

- Replacing physical servers by one powerful physical server
  - Increasing the utilization of hardware resources
  - Reducing costs (hardware & energy)
  - Reducing time needed for provisioning new servers
- Using for disaster recovery scenarios
- Faults remain contained within the domain where they occurred

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Virtualization Techniques

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Guest Operating System Virtualization

- Host physical machine runs unmodified operating system
- Virtualization application runs on the host OS
  - Starting, stopping and managing each virtual machine
    - Guest OS runs in VM
  - Controlling access to physical hardware resources
- No change required for OSs
- Example:
  - VMware Server & VirtualBox

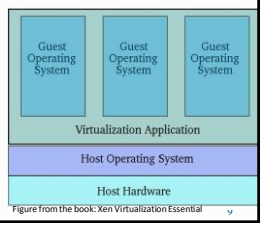

Figure from the book: Xen Virtualization Essential

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Shared Kernel Virtualization

- Each Guest OS has its own root file system
- All OSs share the same kernel of the host OS
- Example:
  - Linux Vserver
  - FreeVPS

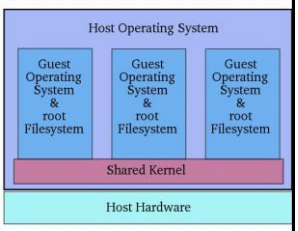

Figure from the book: Xen Virtualization Essential

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Kernel Level Virtualization

- The host OS has modified kernel that is
  - Designed to manage and control multiple virtual machine
- Each VM owns guest OS
- Each guest OS has its kernel
- Guest OS tightly coupled to the underlying hardware
- Example:
  - User Mode Linux (UML)
  - Kernel-based Virtual Machine (KVM)

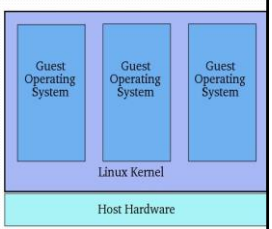

Figure from the book: Xen Virtualization Essential

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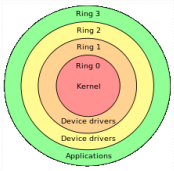
Hypervisor Virtualization (1)

- Privilege levels for X86 CPU are described in rings
  - Ring 0, most privileged level, used by the kernel
  - Ring 1, least privileged level, used by the users applications



- Hypervisor virtualization
  - Program that is running in ring 0
  - Called type 1 Virtual Machine Monitor (VMM)

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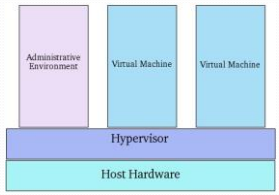
Hypervisor Virtualization(2)

- Handling resource and memory allocation for VMs
- Providing interfaces for higher level administration and monitoring tools
- Guest OSs must run in less privileged ring



- Problem: OSs designed to run in ring 0

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Hypervisor: Paravirtualization

- Modifying the kernel of guest OS to run on the hypervisor
- Replacing privileged instructions that run in ring 0 with calls to hypervisor
- Performing sensitive guest OS instructions by hypervisor

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Hypervisor: Full Virtualization

- Supporting running of unmodified guest OSs on hypervisor
- OSs perform privileged operations as they were running in ring 0
- CPU emulation provided by hypervisor is used
  - To handle and modify privileged operations issued by OS kernels
- Emulation process requires time and resources
  - Increases performance overhead

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Hypervisor: Hardware Virtualization

- Guest OSs can perform privileged operations in ring 0
- Hypervisor is embedded in the circuits of a hardware component
  - Existing in latest generations of CPUs from both Intel and AMD
- Hypervisor higher privileges levels than OSs

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Overview

- Xen is a paravirtualisation software
- Providing interface to create and manage VMs on single physical machine
- VMs are similar but not identical
- Installing direct on hardware
  - Does not use of host OS
- Targeting to host up to 100 VMs on one physical machine
- Minimum performance overhead

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Xen VM Interface

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Memory management

x86 limitations

- x86 does not have a software-managed TLB
  - Missing addresses in TLB requires looking up the page table
- TLB is not tagged
  - Address space switches require complete TLB flush

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Memory management

Solution

- Guest OSs allocate and manage their own hardware page tables under Xen's control
  - Each OS can only map to its own reserved memory
  - Xen validates write operations
- Xen exists at the top 64MB of every VM's address space
  - Not accessible by domain
  - Avoid to flush TLB when guest OS enters and leaves Xen

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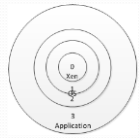
CPU

Problem

- X86 provides 4 different privileged levels
  - The highest level is assigned to OS kernel

Solution



- Xen runs at level zero
- OSs can run at level 1 or 2
- Privileged instructions are passed to Xen
- Exceptions are registered with Xen for validation

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Device I/O

- Set of simple device abstractions are provided
  - To support protection & isolation
- Xen transfers I/O data to and from domain
  - Using shared memory
- Privileged instructions are passed to Xen
- Event mechanism is used to notify domains about hardware interrupts

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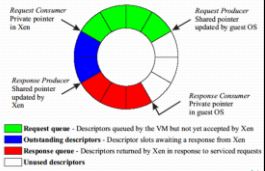
Device I/O Data Transfer(1)

- I/O ring (zero-copy mechanism) is used as shared buffer to exchange data between guest OS & I/O devices through Xen
- The ring is allocated by domain
- The ring buffer does not contain data, but descriptors
- Descriptors reference to data buffer allocated by guest OS



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Device I/O Data Transfer(2)

- Two pairs of producer & consumer pointers are used to access the ring
- Requests do not need to be processed in order
  - Each request has unique ID
  - Each request reproduced in the associated response
- Each domain can trade-off between latency & throughput
  - By deferring delivery of notifications by specifying minimal number of responses.
  - By invoking a hypercall only after placing number of entries in the ring

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The Cost of Porting an OS to Xen

The cost is defined as the number of code lines that need to be added or modified to port OS to Xen

- Linux, XenoLinux, is completely portable
- Window XP, XenoXP, is still in progress
- NetBSD, XenoBSD, is in early stage
-

OS subsection	# lines	
	Linux	XP
Architecture-independent	78	1299
Virtual network driver	484	–
Virtual block-device driver	1070	–
Xen-specific (non-driver)	1363	3321
Total	**2995**	**4620**
(Portion of total x86 code base	1.36%	0.04%)

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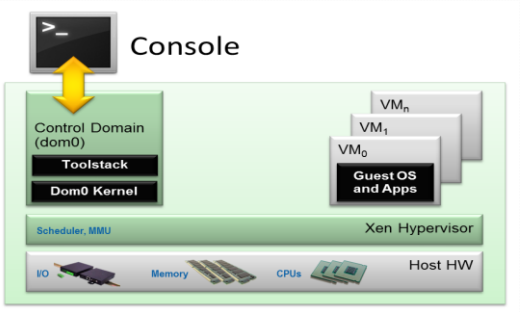
Xen Architecture



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Control Transfer

Hypercalls

- Synchronous calls from a domain to Xen
- Equivalent to system calls

Events

- Asynchronous event mechanism is used to deliver notifications from Xen to domain
- Virtualizing of device interrupts

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Scheduling OF VMs

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Challenges

Virtual machines in a single physical machine

- Host applications with very different timing requirements
  - Sometimes conflicting
- Must safely coexist
- Must work independently and cooperatively

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VM Scheduler

- Virtual machine monitor that manages VMs switches between their applications
  - Switching between VMs is switching between process
- VM can schedule its own processes
  - But only relative to its own assigned time

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VM Scheduler Requirements

- Deterministic mapping between real time and virtual time.
  - For time driven processes
  - Time should be known in advance
- Dynamic reallocation of spare computing time
  - To improve resource utilization
- Since each VM could have real & none-real time processes
  - VM is a good place to use dynamic reallocation strategy
- Distinguish between virtual and real time
  - For time sensitive tasks

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VM Scheduling in Xen (1)

Borrowed virtual time scheduling

- Proportional share scheduler
- Allowing of borrowing processor allocation for future use
- Allowing the assignment of weights to each individual VM
- According to weights processing capacity is relatively partitioned to VMs

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VM Scheduling in Xen (2)

Borrowed virtual time scheduling

- Used to balance load
- Reduces scheduling latencies
- Temporarily violates fair sharing to favor recently-woken domains.
  - They can borrow time that they have to pay later

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Time & Timer

- Xen provides each guest OS with
  - Real time (since machine boot)
  - Virtual time (time spent for execution)
  - Wall-clock time
- Each guest OS can program a pair of alarm timers
  - Real time
  - Virtual time

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Evaluation

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Experiments Setup

All experiments are performed using

- Dell 2650 dual processor 2.4GHz Xen server
- 2GB RAM
- Broadcom Tigon 3 Gigabit Ethernet NIC
- Single Hitachi DK32EJ 146GB 10k RPM SCSI disk
- Linux 2.4.21 (native)

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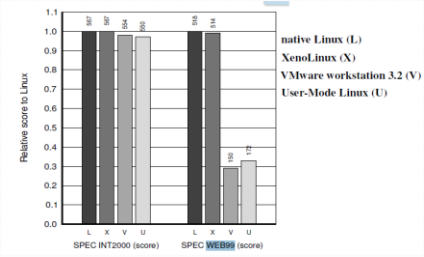
Relative Performance

- Evaluation of overhead of the various virtualization techniques relative to running on the `bare metal'.



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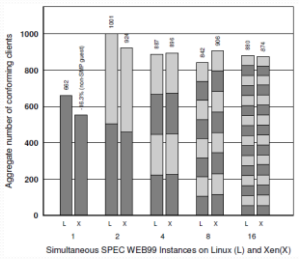
Concurrent Virtual Machines

Results of running 1, 2, 4, 8 and 16 copies of SPEC WEB99 benchmark in parallel on native linux and Xen



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Performance Isolation

- 4 domains configured with equal resource allocations
- 2 running benchmarks(PostgreSQL/OSDB, SEP WEB99)
- 1 running disk bandwidth
- 1 running “fork bomb”

- **Result**
- 2 benchmark domains showed only 4% & 2% performance degradation

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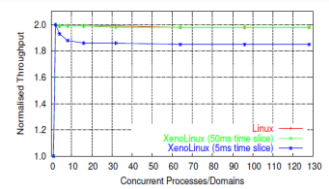
Scalability



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