Paravirtualization

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Full virtualization

- Unmodified OS
- It doesn’t know about hypervisor
- Back and forth between hypervisor and MMU-visible shadow page table: inefficient
- Unprivileged instructions which are sensitive: difficult to handle (binary translation VMware ESX)
- Cannot access hardware in privileged mode
- If guest OS wants real resource information? (Timer, superpages)

Paravirtualization

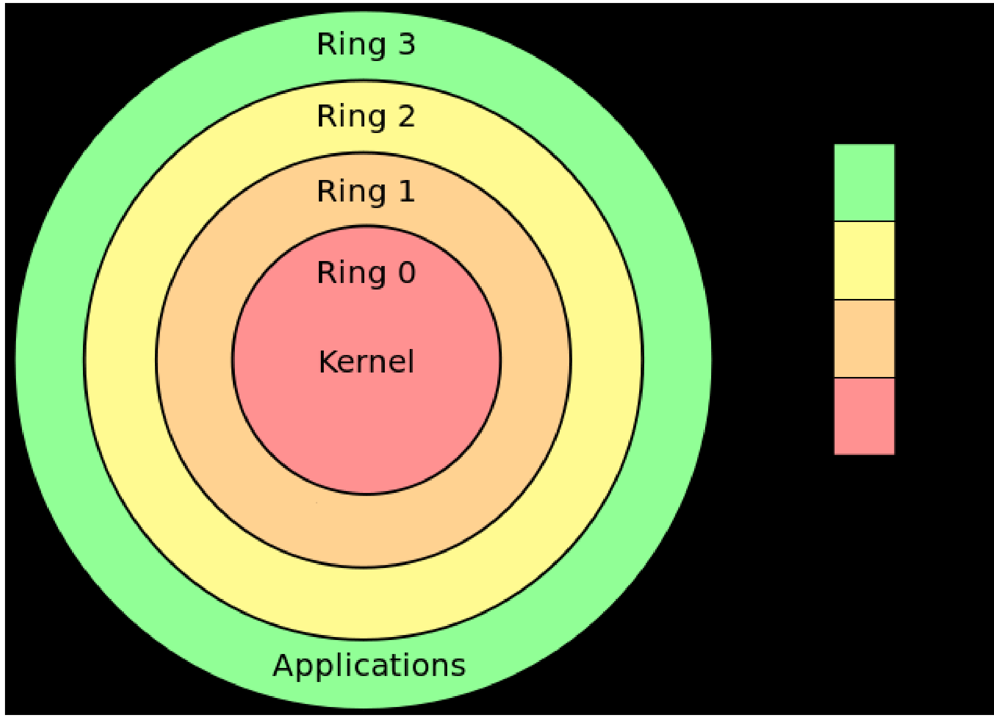
- Modify Guest OS
- It knows about hypervisor
- Applications not modified
- Some exposure to hardware and real resources like time
- Improved performance (reduce redirections, allowing guest OS to use real hardware resources in a secure manner)
- It can allow us to do virtualization without hardware support

Discussion – Xen

- Memory Management
- CPU
    - Protection
    - Exception
    - System call
    - Interrupt
    - Time
- Device I/O

Protection

- Privilege of OS must be less than Xen:
- In x86, 4 levels of privilege
- 3 for applications, Zero for OS - generally
- Downgrade guest OS to level 1 or 2
- Xen will be at 0



Wikipedia

Exceptions

- System calls, Page Faults

- Register with Xen: descriptor table for exception handlers
- No back and forth between Xen and Guest OS like in full Virtualization

- Fast handlers for system call:
- When Applications execute system call, it directly goes to Guest OS handler in ring 1 – not to Xen (But not page fault handler it has to go through Xen)
- Handlers validated before installing in hardware exception table

Time

- Guest OS can see: both real and virtual time
- Real time
- Virtual time
- Wall clock time
- Why do you want to see time? e.g., need it for TCP: TCP timeouts, RTT estimates

Memory Management

- TLB flush on context switch (Guest OS – Guest OS) – Undesirable
- Software TLB – can virtualize without flushing between switches
- Hardware TLB – tag it with address space identifier.
- Want to Avoid flushing between switches (Guest OS - Xen)

- What about x86?
- Not software TLB. Hardware, but no tags
- What can we do?

Memory Management

x86 architecture perspective

- Guest OS allocate and manage own hardware page tables
- Minimal involvement of Xen
- More safety and isolation
- Avoid flush on switch (Guest OS - Xen) : Xen in top 64MB of VM address space.
- Guest OS shouldn’t access top 64MB.
- Xen never paged out

Paging

- Guest OS has its own memory reservation.
- When it needs new page table, allocate from what it has
- Registers with Xen
- Xen gives up write-privileges
- Guest OS can read directly
- Guest OS must validate with Xen for writes / updates
- No back and forth like in Full virtualization.
- No shadow table here. Life is easier.

Hypercalls and Events: Control Transfer

- So guest OS validates with Xen for every update.
- Minimize these calls: Batch these updates together. “Hypercalls” to Xen
- **Hypercalls:** think of them as synchronous calls TO Xen
- In xen/include/public/xen.h: ~40 hypercalls. E.g. set trap table, mmu update, etc.
- Another term: Events
- **Events:** async notifications FROM Xen. Like device interrupts

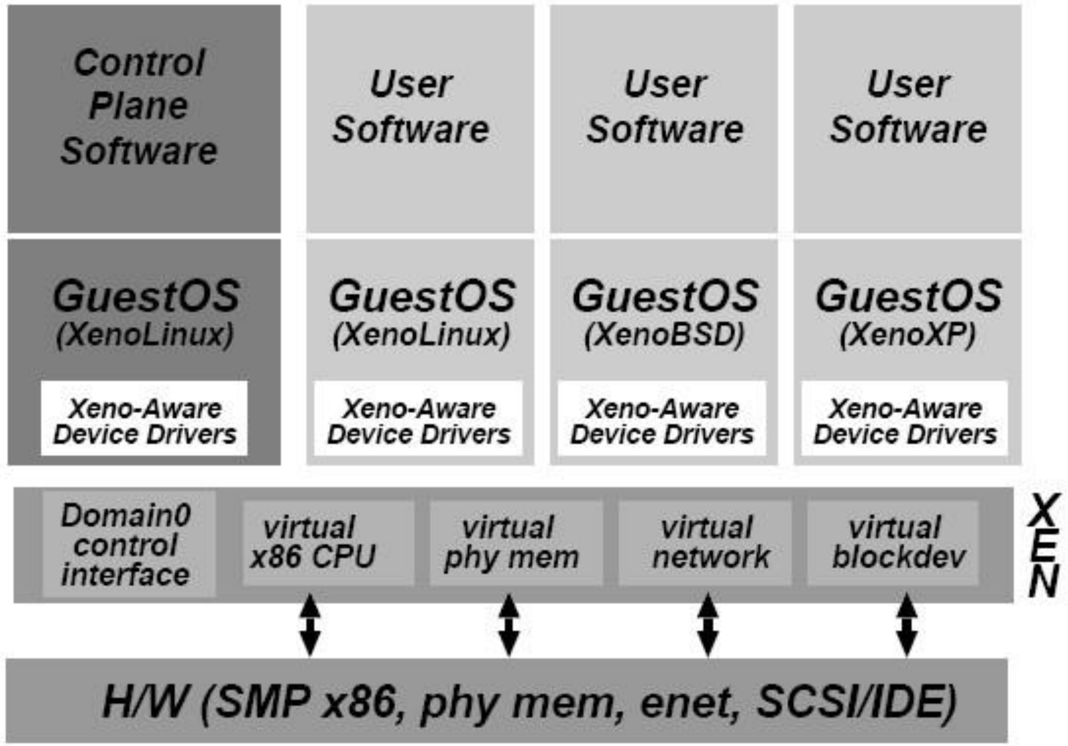


Figure 1: The structure of a machine running the Xen hypervisor, hosting a number of different guest operating systems, including *Domain0* running control software in a XenoLinux environment.

Xen and the Art Of Virtualization. Paul Barham, Boris Dragovic, Keir Fraser, Steven Hand, Tim Harris, Alex Ho, Rolf Neugebauer, Ian Pratt, Andrew Warfield

- Guest OS: Xen hosts this OS
- Domain: VM, inside which Guest OS executes
- Guest OS- program, Domain- process
- **Domain0 :** separate Guest OS. Privileged. Control management
- Domain0- more access to hardware & hypervisor
- Like a “supervisor” who manages others
- It creates new domains. Work delegated to it.
- Reduces hypervisor complexity
- Memory reservation for new domains done statically. Non contiguous phys mem.

I/O

- Event notifications instead of Interrupts
- Simple abstraction:
- Asynchronous I/O rings
- Data transfer to guest from Xen and vice versa
- Using these shared memory buffers

I/O rings

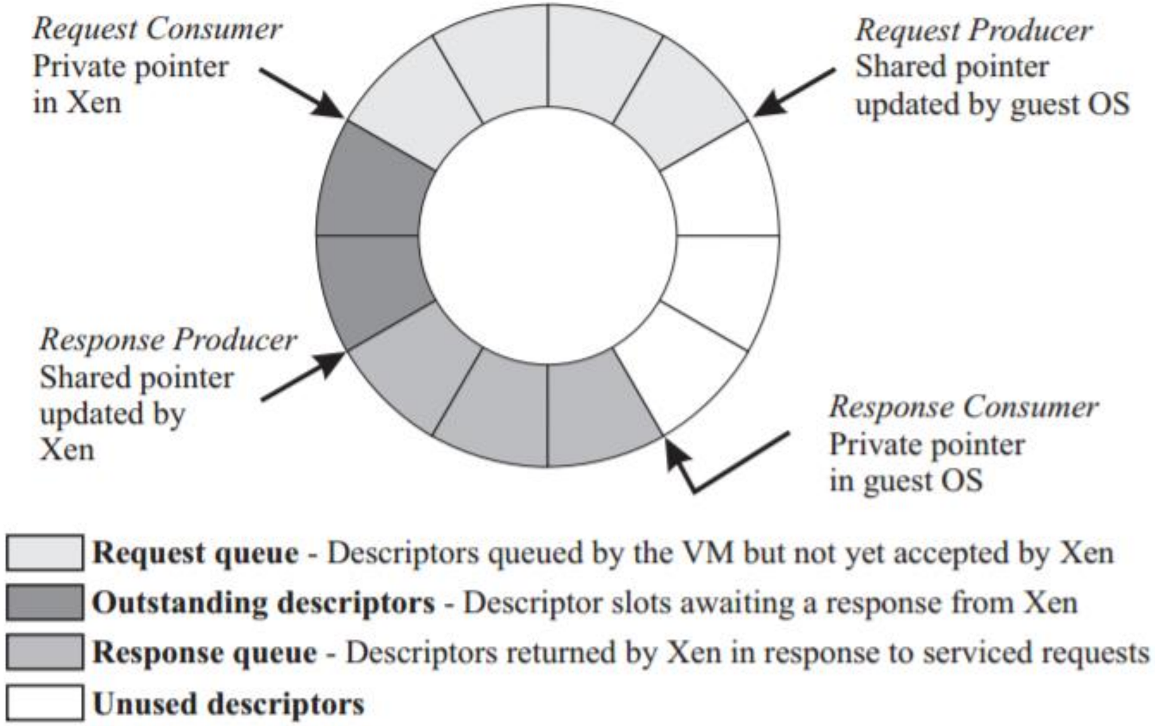


Figure 2: The structure of asynchronous I/O rings, which are used for data transfer between Xen and guest OSes.

Xen and the Art Of Virtualization. Paul Barham, Boris Dragovic, Keir Fraser, Steven Hand, Tim Harris, Alex Ho, Rolf Neugebauer, Ian Pratt, Andrew Warfield

- Ring is circular queue of descriptors
- Descriptors allocated by domains
- Descriptors don't directly contain I/O data
- Two pairs of producer/consumer pointers
- Domains place request
- Domain Advances request producer pointer
- Xen removes and handles them
- Xen advances request consumer pointer
- Zero copy transfer

Disk

- Domain0, the privileged one, can access disk directly
- Other domains can not. They use Virtual Block Drivers. VBD
- VBD: contains ownership and access control information
- Translation table: Map VBD request -> physical device, sector address
- VBD, for others, is created and configured at Domain0
- Other domains access via I/O rings
- Reorder, Batch disk requests

Network

- Each domain has:
  - 1 Send I/O ring,
  - 1 receive I/O ring
- Send packet: domains place in I/O ring.
- Receive packet: Xen does pattern matching to find destination domain
- Go through Virtual Firewall. Match patterns.
- Domain0 created the rules. Pattern -> Action

Questions ?

Memory Management	
Segmentation	Cannot install fully-privileged segment descriptors and cannot overlap with the top end of the linear address space.
Paging	Guest OS has direct read access to hardware page tables, but updates are batched and validated by the hypervisor. A domain may be allocated discontiguous machine pages.
CPU	
Protection	Guest OS must run at a lower privilege level than Xen.
Exceptions	Guest OS must register a descriptor table for exception handlers with Xen. Aside from page faults, the handlers remain the same.
System Calls	Guest OS may install a 'fast' handler for system calls, allowing direct calls from an application into its guest OS and avoiding indirecting through Xen on every call.
Interrupts	Hardware interrupts are replaced with a lightweight event system.
Time	Each guest OS has a timer interface and is aware of both 'real' and 'virtual' time.
Device I/O	
Network, Disk, etc.	Virtual devices are elegant and simple to access. Data is transferred using asynchronous I/O rings. An event mechanism replaces hardware interrupts for notifications.

Table 1: The paravirtualized x86 interface.