Xen and the Art of Virtualization

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What I plan to address

- Motivations for Virtualization
- How Xen works
- Xen vs. Bare Hardware vs. Disco/VMWare
  - In this case it is sometimes easier to use VMWare to compare against because (Xen and VMware) they were both designed for the x86 architecture
- The future of Xen

Virtualization & the Challenges

- Speed & Performance
- Security
  - Resource Isolation
- Functionality

- Xen & its target
  - The authors came up with the design goal of being able to run 100 simultaneous virtual machine implementations with Binary Compatibility

Breaking it Down

- Virtualization (today) can be broken down into two main categories
  - Full Virtualization
    - This is the approach that Disco and VMWare uses
  - Paravirtualization
    - This is the approach that Xen uses

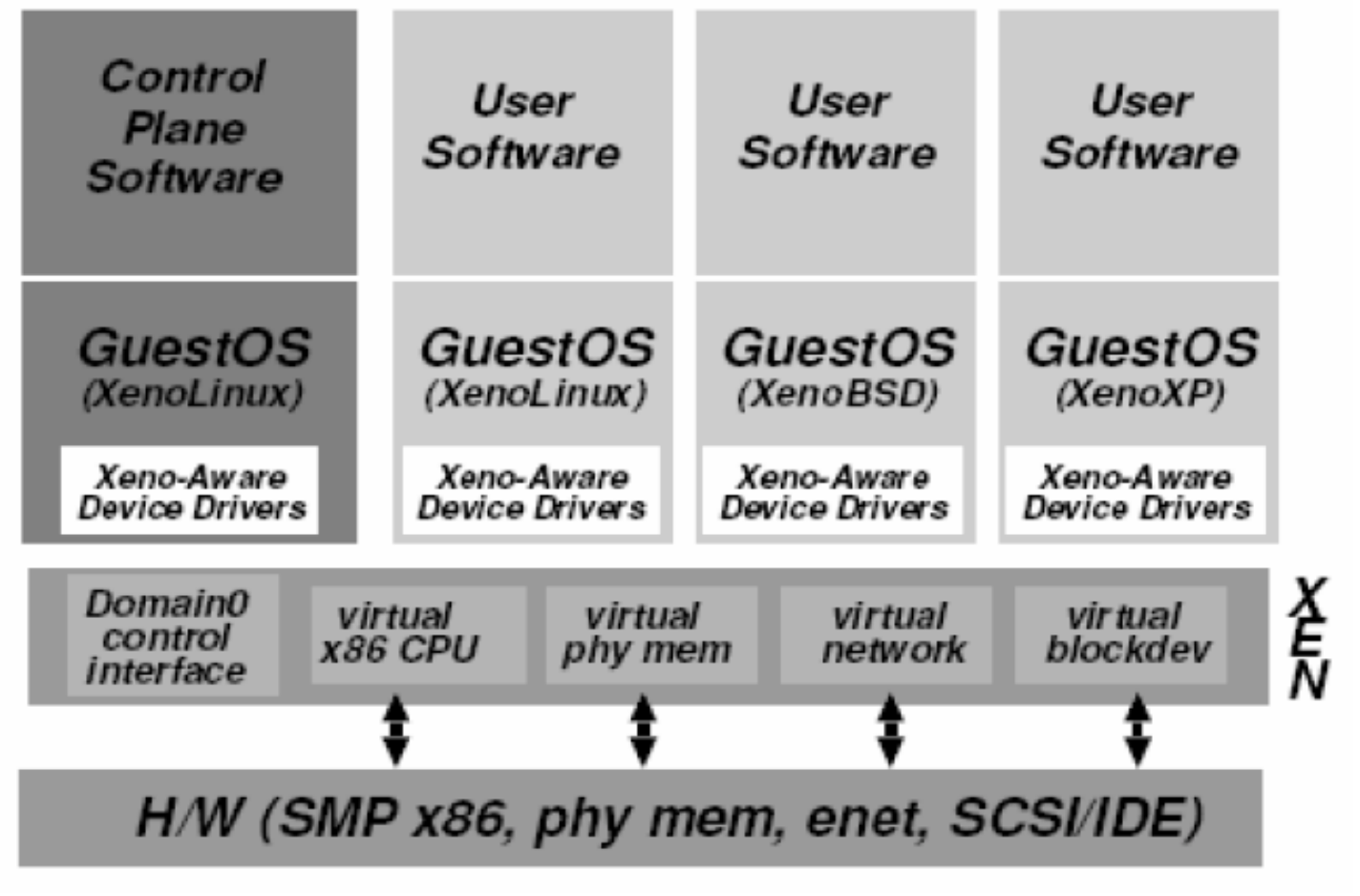
The Traditional Approach

- Traditional VMM (Virtual Machine Monitor) exposes its “hardware” as being functionally identical to the physical hardware
  - This approach can be difficult to implement (especially with x86 systems)
  - There are also situations where it is useful to provide real AND virtual resources (for example virtual and real timers)
    - Under this model, the “guest” machine would not have access to this information

Xen's Approach

- Instead of making the virtual machine 100% functionally identical to the bare hardware, Xen makes use of Paravirtualization
- Paravirtualization is a process where the guest operating system is modified to run in parallel with other modified systems, and is designed to execute on a virtual machine that has a 'similar' architecture to the underlying machine.
  - Pros:
    - Allows for improved performance
  - Cons:
    - The hosted operating system must undergo modification before it can be hosted by the Xen Hypervisor (this can be a bit of a challenge)

Xen's Design Approach



Xen: Notation

- Guest Operating System
  - The OS software that Xen hosts
- Domain
  - The virtual machine within which a guest operating system executes
- Guest OS'es and domains are analogous to a program and a process
- Hypervisor
  - This is the instance of Xen that handles all of the low level functionaly

Under the hood (how does Xen perform its magic?)

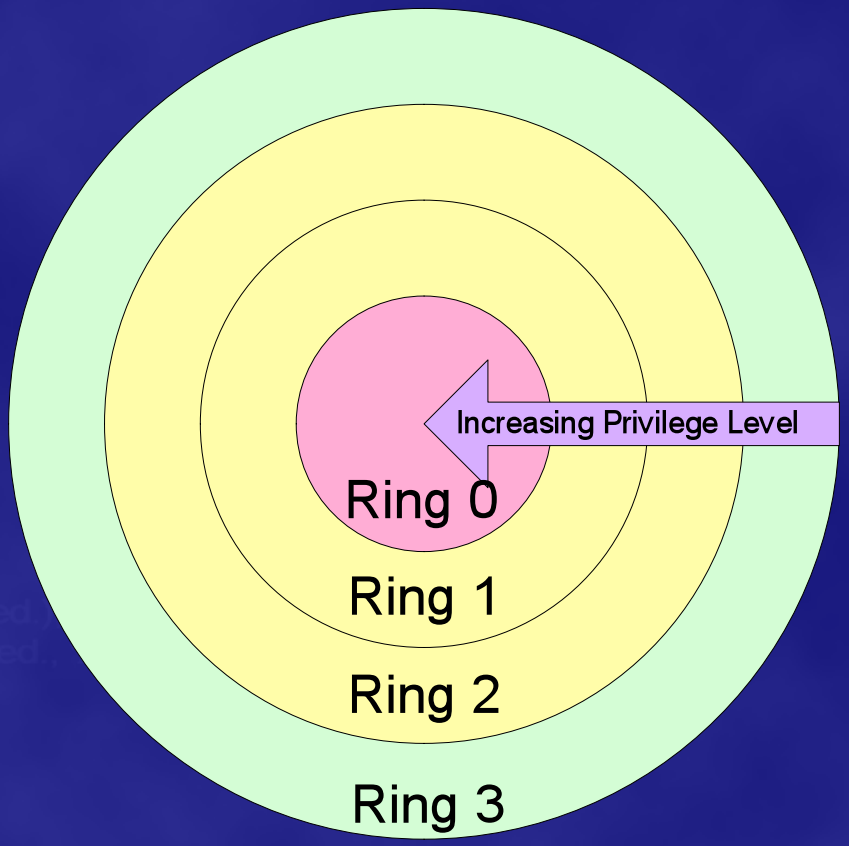
- The Xen paper discusses the following areas
  - CPU
    - Virtualization of the CPU
    - CPU Scheduling
    - Time & Timers
  - Memory Management
    - Virtual Address Translation
    - Physical Memory
  - Device I/O
    - Network
    - Disk
  - Control Transfer

Xen and the CPU

- This undoubtedly where the most change is required by the guest OS
- Xen challenges the assumption that the OS is the most privileged entity
- Privileged instructions
  - These are paravirtualized by requiring them to be validated/executed within Xen

Xen and the CPU

- The x86 is less difficult than most systems to virtualize
  - This is due to the built in security levels build within the x86 (known as rings)
  - Most systems have the OS running on ring 0 (the most privileged)
  - Most user software runs on ring 3
  - Ring 1 & 2 generally are not used
- Xen uses this fact to modify the OS to execute on ring 1



Xen, Scheduling, and Timers

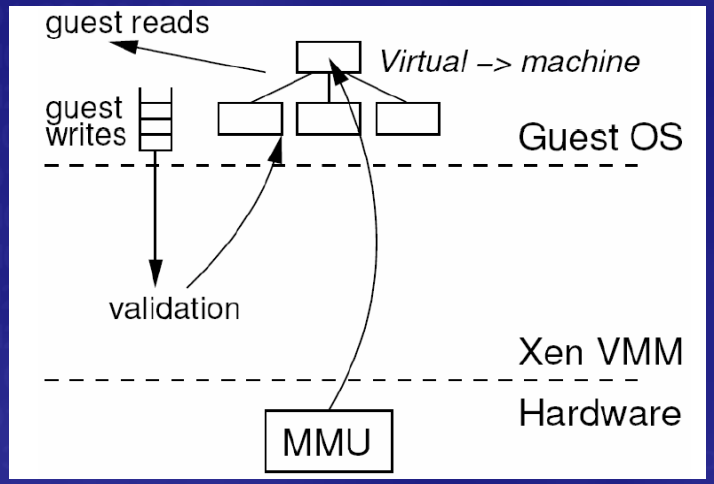
- Xen currently uses an algorithm called the Borrowed Virtual Time algorithm to schedule domains
- This is important to mitigate the problem of one domain executing code that can adversely affect another domain.
- Xen also provides several different types of timers
  - Real Time (time that always advances regardless of the executing domain)
  - Virtual Time (time that only advances within the context of the domain)
  - Wall Clock Time (time that takes in to account local offsets for time zone and DST)

Control transfer & Eventing

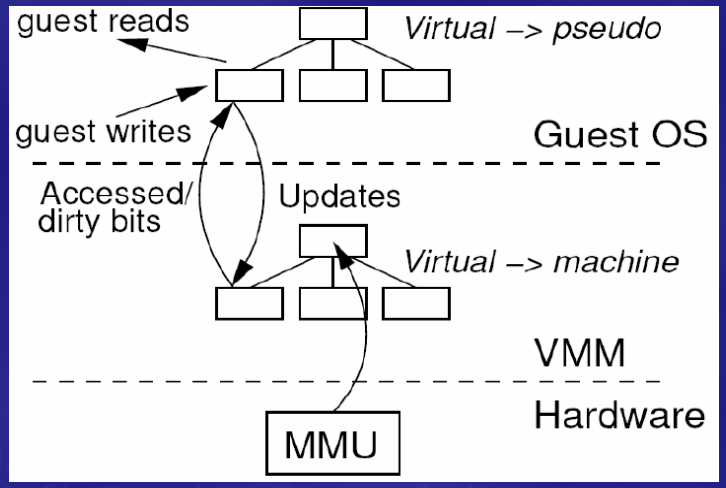
- Exceptions and Eventing
  - These include memory faults and software traps
  - These are generally virtualized through Xen's event handler
  - Typically the two most frequent exceptions that occur (enough to effect performance)
    - System Calls
    - Page Faults
  - These are two examples of a 'fast' handler (one in which bypasses the hypervisor)

Paravirtualization of the MMU

Paravirtualization



Full Virtualization



Diagrams provided by a presentation from the Universität Karlsruhe

Xen and Virtual Memory

- When the guest OS requires a new page table, it allocates it from its own memory reservoir
  - After this it is registered with Xen
  - The OS then gives up all direct write privleges to the memory
  - All subsequent updates must be validated by Xen
  - Guest OS's generally batch these update requests to spread the cost of calling the hypervisor
- Segmentation is virtualized in a similar way

Xen and Virtual Memory

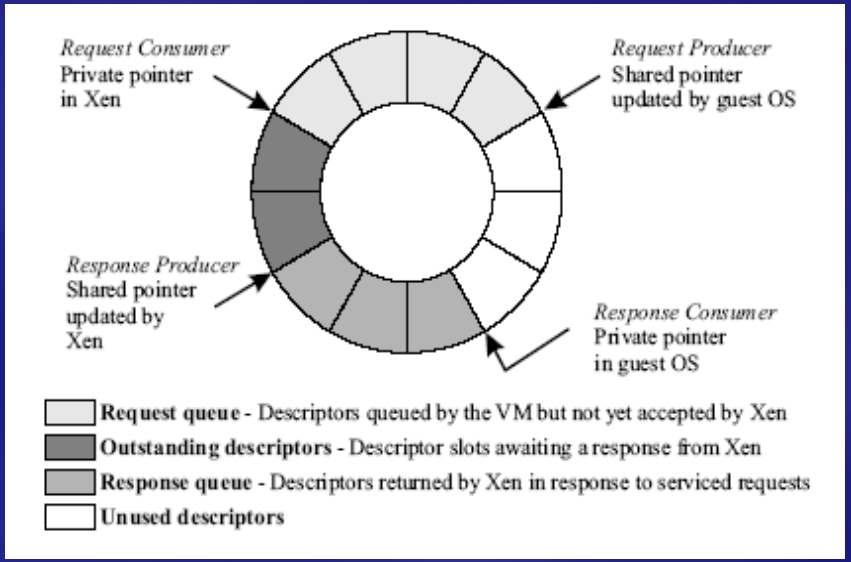
- Xen uses a design where
  - Guest OS's are responsible for allocation and managing hardware pages
  - Xen exists in a generally unused section at the top of every address space. This is to ensure that the Xen is never paged out
- This differs from the approach that Disco takes where the Disco VMM keeps a second level of indirection.
  - Essentially VMM within VMM

Memory Management

- As discussed in an earlier class Memory Management can be quite challenging
- Some key challenge points
  - x86 does not have a software managed TLB
    - Its TLB is not tagged, which means that the TLB must be flushed on a context switch

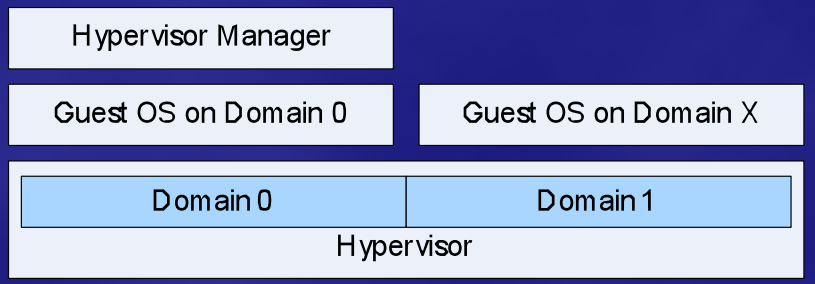
Xen and Device I/O/ Management

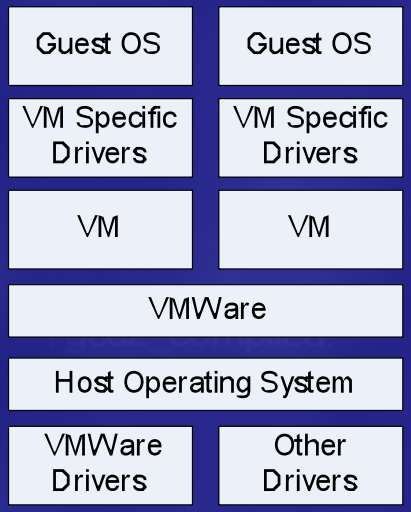
- Data I/O is transferred to and from domains via Xen through the use of a buffer descriptor ring
  - This is a system that is based around a pair of producer consumer pointers, one set used within the guest OS, the other within the Hypervisor
  - This allows for the decoupling of when data arrives/is accessed and the event notification



Control of the Hypervisor

- Domain0 is given greater access to the hardware (and hypervisor). It has a guest OS running on top of it as well, but also has additional “supervisor” software to manage elements of the other existing domains.
- This is different than VMWare which has the notion of a Host OS acting underneath it.





Disk I/O (The Differences)

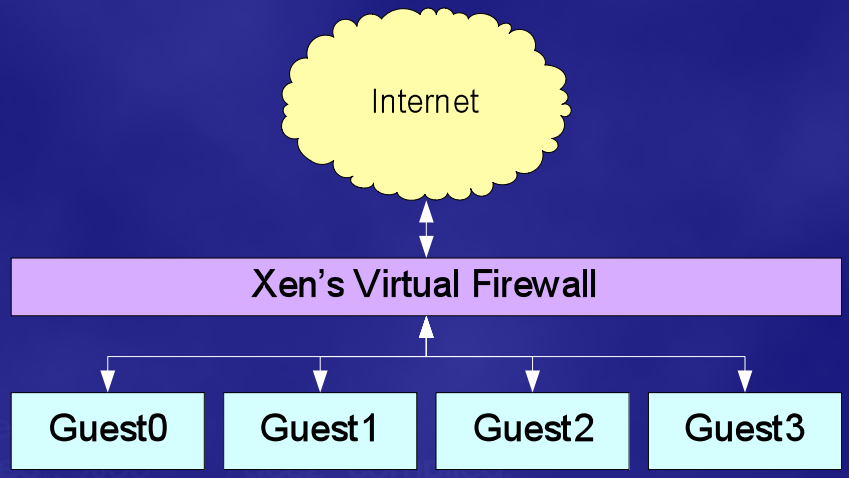
- Disco acts as the go between for Disk I/O
- Xen allows Domain0 to have direct access to the disk.
  - Domain0 houses virtual block device (VBD) management software
  - The VBD makes use of the ring mechanism
  - Subsequent domains confine their disk access through the VBD management software
  - This allows Xen to maintain a tighter control over disk access, and to allow “batching” of disk requests
- VMWare (from experience) allows for several options for Disk I/O.
  - To allow the guest OS unfettered access to the raw device--basically as a “pass through”
  - Allow VMWare to create a “virtual disk” that is a binary file that is contained within the file system of the host OS, and is controlled by the VM Virtual Machine
- These are also different from running an OS on top of bare hardware, where Disk I/O is managed by the OS

Building a new Domain on Xen

- Domain0 is a privileged domain
- New domain creation is delegated to Domain0
  - This offers the advantage of reducing the complexity of the hypervisor
  - Additionally building new domains that originate from Domain0 allow for a better debug environment

Networking

- Networking and Computers go hand in hand today
- Because of this, Xen also provides a “Virtual Firewall”
  - Domain0 is responsible for creating the firewall rules (can we see a common theme emerging?)
  - Data is transmitted (and received) using two buffer rings (one for outgoing, the other for incoming data)
  - Incoming data packets are analyzed by Xen against the Virtual Firewall rules, and if any are broken, the packet is dropped



Other Hardware

- What was observable from the block diagram for Xen was that you still have the notion of Xen enabled hardware drivers
- This is similar to how VMWare operates.
  - For instance if you have a sound card on your machine, the hosting guest machine will detect that you have a Sound Blaster enabled sound card.
  - Another example (from VMWare) is the video driver that can be installed on the guest OS to improve video performance.
- This is another hidden challenge of virtualization
  - Not only do you have to virtualize the memory and CPU, but also any other devices that the guest OS can access!

Evaluation

- Relative performance
  - Compared performance of three virtualization techniques with Native Linux
- Concurrent virtual machines
  - Compared performance of Xen with Native Linux
  - Compared performance of Xen by increasing number of OS instances

Relative Performance

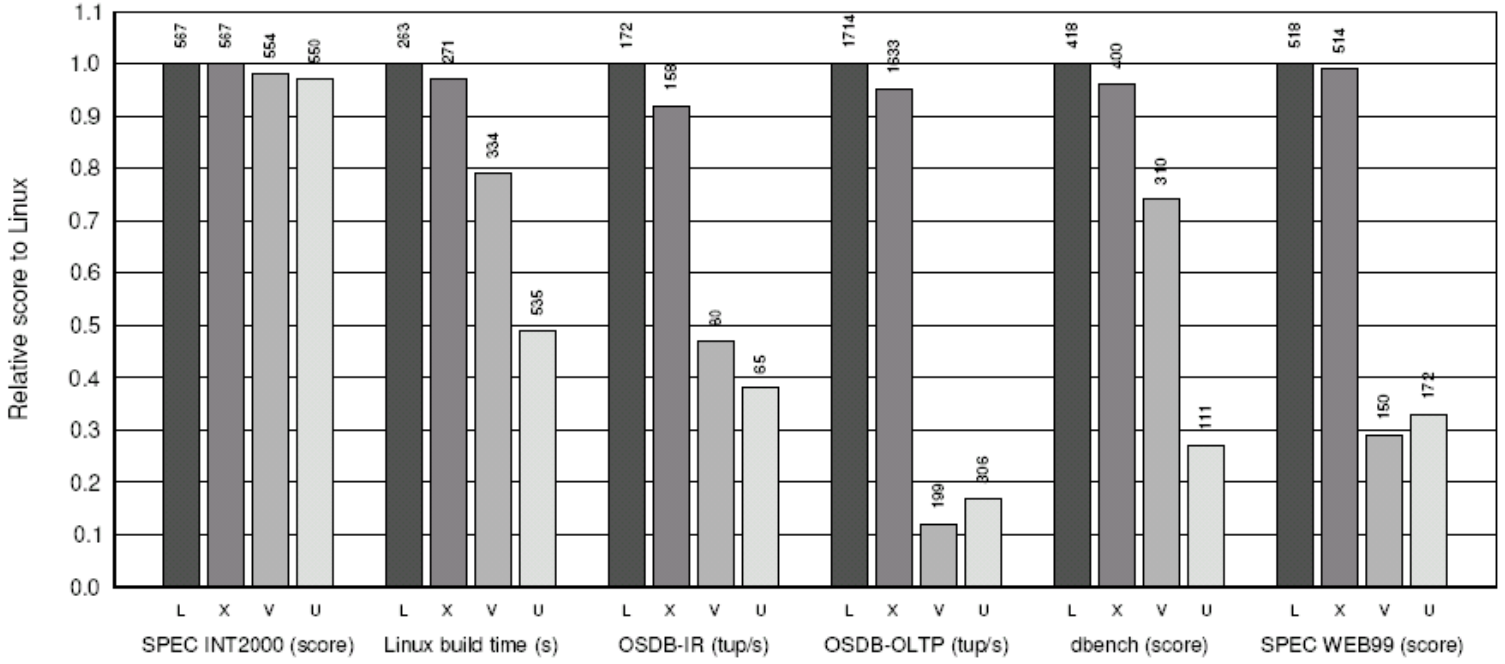
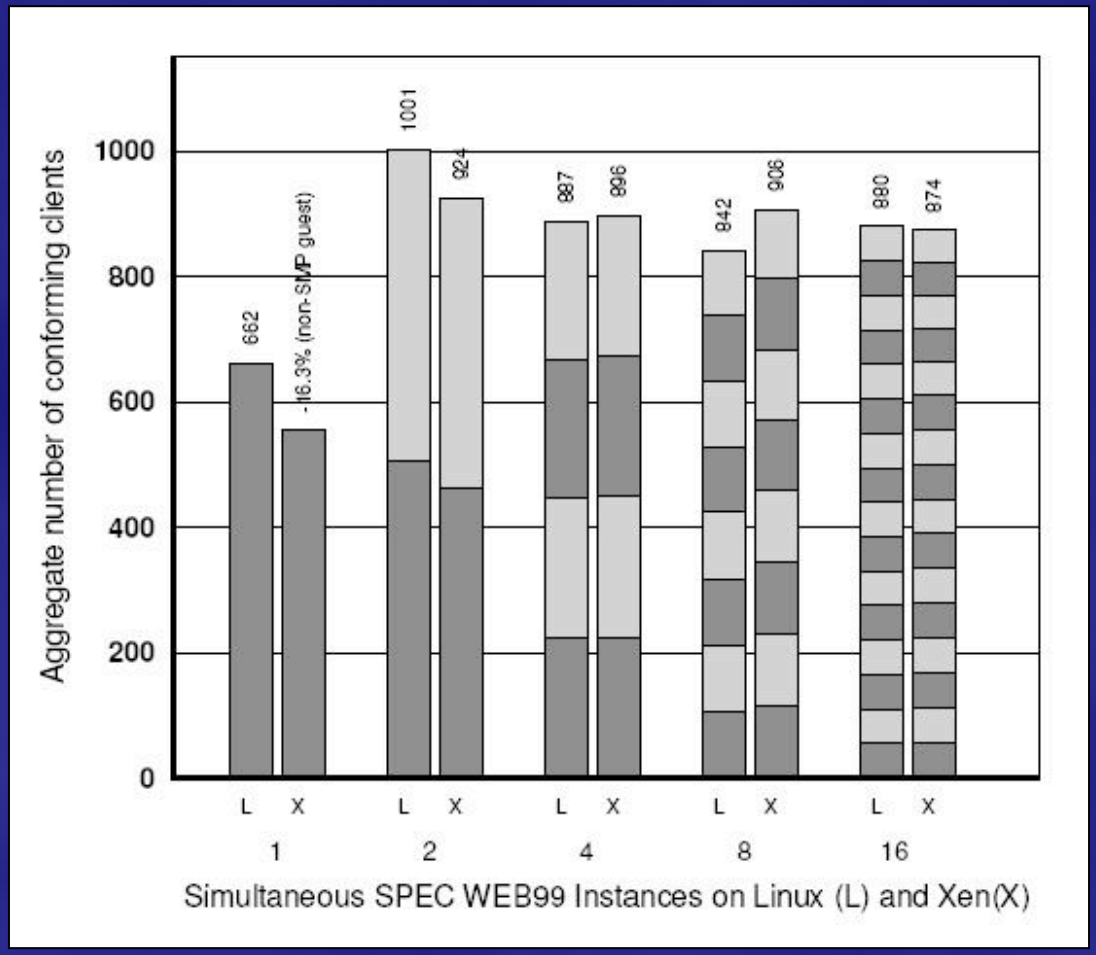


Figure 3: Relative performance of native Linux (L), XenoLinux (X), VMware workstation 3.2 (V) and User-Mode Linux (U).

Concurrent Virtual Machines
Linux vs XenoLinux



Conclusion

- Architectures such as x86 does not support full virtualization
- Xen is a high performance virtual machine monitor which uses Para virtualization
- Modification to the kernel code of guest OS is required
- Performance achievement near to that of Native Linux

Xen and the Future

- This paper was presented October 2003. Since then, the popularity of Xen has increased to include support from vendors such as
  - Sun Microsystems
  - Hewlett-Packard
  - Novell
  - Red Hat
  - Intel
  - Advanced Micro Devices
  - Voltaire
  - IBM

Xen and the Future

- To quote the news.com article (see my works cited list for the complete article)

  "The requirement for a modified operating system will loosen with Intel's coming Vanderpool Technology"

  (Vanderpool is a hardware virtualization project)

- Additionally, AMD announced they are working on bring Xen to their 64 bit platform
- Intel has experimental support on its Itanium chipset
- IBM is also working on a varient of the Hypervisor (a "Secure Hypervisor") that adds more protections against attacks.

Works Cited

- I used several diagrams from the following paper for this presentation
  - http://i30www.ira.uka.de/teaching/coursedocuments/90/Xen.pdf
- This link provided some up to date info on Xen
  - http://news.com.com/Xen+lures+big-name+endorsements/2100-7344_3-5581484.html
- Information about Vanderpool can be found here
  - http://www.intel.com/technology/computing/vptech/
- Some Slides are taken from previous Class
  - http://web.cecs.pdx.edu/~walpole/teaching.html