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# The Art of Virtualization

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# XEN Virtual Machine Monitor

1. Introduction
2. Overview
3. Detailed Design
4. Evaluation
5. Conclusion

# XEN Virtual Machine Monitor

- University of Cambridge Computer Lab.
- High performance virtual machine monitor.
- Challenges:
  - Virtual machines have to be isolated from another.
  - Support a variaty of operating systems.
  - Small performance overhead.
- XenoLinux(2.4), Xenoserver

# XEN Virtual Machine Monitor

- Approaches:
  - Deploy hosts to running a standard OS.
  - Retrofit support for *performance isolation* to the OS.
    - Resource containers, Linux/RK, QLinux.
    - Problem of „QoS crosstalk“.
  - Multiplexing at low level.
    - Exokernel, Nemisis

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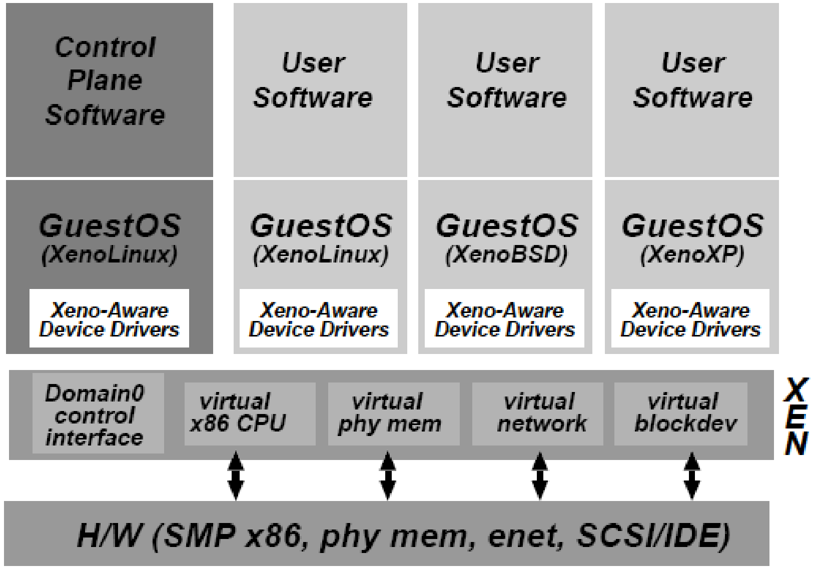
- **Xen:**
  - Multiplex physical resources at the granularity of an *entire* OS.
  - Performance isolation.
  - Very flexible.
  - 100 hosted OS instances.
  - Run unmodified binaries.
  - But: GuestOs has to be modified !



# XEN Virtual Machine Monitor

- Outline:
  - Design principles.
  - The virtual machine interface.
    - Memory Management.
    - CPU.
    - Device I/O.
  - The cost of porting an OS to Xen.
  - Control Management.

# XEN Virtual Machine Monitor

- Design Principles:
  - Full virtualization vs. Paravirtualization.
    - X86 Hardware problems.
    - ESX Server uses shadow page tables.
    - Real & Virtual resources are desireable.
      - GuestOS can improve performance using **superpages** or **colored pages**.
    - Support unmodified application binaries.
    - GuestOs has to be modified.

# XEN Virtual Machine Monitor

- Design Principles:
  - Multi-application OS, unlike DenaliOs.
  - GuestOs perform its own paging.
    - Self-paging (NemesisOs).
  - Physical resources directly visible to GuestOs.

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- The Virtual Machine Interface:
  - Memory Management(paging):
    - Most difficult part (mechanism and porting Guest).
    - Software managed TLB, tagged TLB.
    - X86: Hardware TLB
    - GuestOS is responsible for managing hardware page tables.
    - Xen at top of every address space, avoiding TLB flush .

# XEN Virtual Machine Monitor

- The Virtual Machine Interface:
  - Memory Management(paging):
    - Example:
      - Os requires a new page table.
      - Allocates page from own memory reservation.
      - Registers with Xen.
      - Os has to relinquish direct write privileges to PT memory.
      - Updates validated by Xen.
      - May update batch requests.

# XEN Virtual Machine Monitor

- The Virtual Machine Interface:
  - Memory Management(segmentation):
    - Like paging scheme.
    - Validating updates to segment descriptor tables.
      - Lower priviledged than Xen.
      - May not allowed to access to the Xen reserved portion of address space.

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- The Virtual Machine Interface:
  - CPU:
    - Application- Level, OS- Level, Hypervisor- Level.
    - X86 supports 4 priviledge levels !
    - Requires modification of GuestOs.
    - Piviledged instructions → hypervisor call
      - Installing new page tables, yield(),...
      - Exceptions: memory faults and software traps

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- The Virtual Machine Interface:
  - CPU (Exception Handling):
    - Page Fault Handler:
      - Normally read faulting address from a privildged register.
      - Copy exception stack frame on the guestOs stack.
    - Register „fast“ exception handler.
    - What about safety ?
    - Double Faults.

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- The Virtual Machine Interface:
  - Device I/O:
    - Clean and simple device abstractions.
    - Data transfer:
      - shared memory.
      - asynchronous buffer desciption rings.
      - Lightweight event-delivery.

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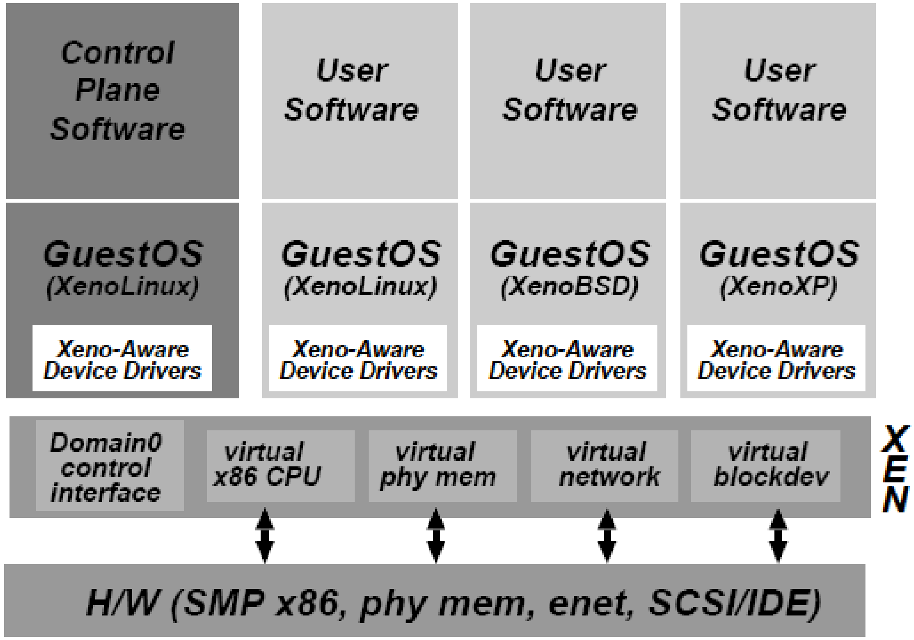
- The Cost of Porting an OS to Xen:
  - Linux 2.4:
    - Total: 2995 LOC.
    - Portion of total x86 code base: 1,36%.
  - Windows XP:
    - Total: 4620 LOC.
    - Portion of total x86 code base: 0.04%.
    - Not yet finished.

# XEN Virtual Machine Monitor

- **Control & Management:**
  - Create domains
  - Terminate domains
  - Scheduling parameters
  - Physical memory allocation
  - Access to devices



# XEN Virtual Machine Monitor

- Outline:
  - Control Transfer: hypercalls, events.
  - Data Transfer: I/O Rings.
  - Subsystem Virtualization
    - Domain scheduling.
    - Virtual address translation.
    - Physical memory.
    - Network.
    - Disk.

# XEN Virtual Machine Monitor

- Control Transfer:
  - – Synchronous calls: hypercalls.
    - Priviledged operations: page-table updates.
  - – Asynchronous calls: events.
    - Device interrupts, lightweight notification.
    - Event-callback handler defined by GuestOS.
    - Per domain bitmask for pending events.
    - Domain defers notofications → disabling interrupts.

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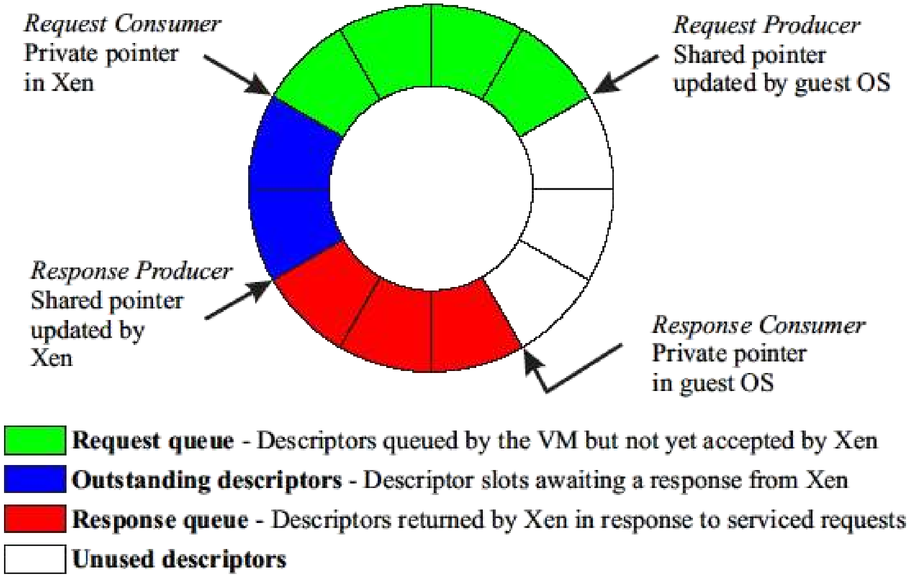
- **Data Transfer: I/O Rings.**
  - Goal: little overhead.
  - I/O descriptor ring.
  - Allocated by GuestOS
  - Accessible within Xen.
  - Not directly contain data.
  - Have not to be ordered.



🟩 **Request queue** - Descriptors queued by the VM but not yet accepted by Xen

🟦 **Outstanding descriptors** - Descriptor slots awaiting a response from Xen

🟥 **Response queue** - Descriptors returned by Xen in response to serviced requests

□ **Unused descriptors**

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- Domain Scheduling:
  - – Borrowed Virtual Time (BVT) algorithm
    - Universal Scheduler.
    - Thread execution is monitored.
    - Latency-sensitive thread is allowed to „warp“ back in virtual time, for earlier dispatch.
  - – Fast dispatch: minimize the effect of virtualization.
  - – Low latency dispatch.

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- Virtual address translation:
  - VMWare: virtual page tables, costly.
  - Xen: only involved by updates.
  - Hypercall Validation:
    - Type per machine page frame.
      - PD = Page Directory.
      - PT = Page Table.
      - LDT = Local Descriptor Table.
      - GDT = Global Descriptor Table.
      - RW = writeable.

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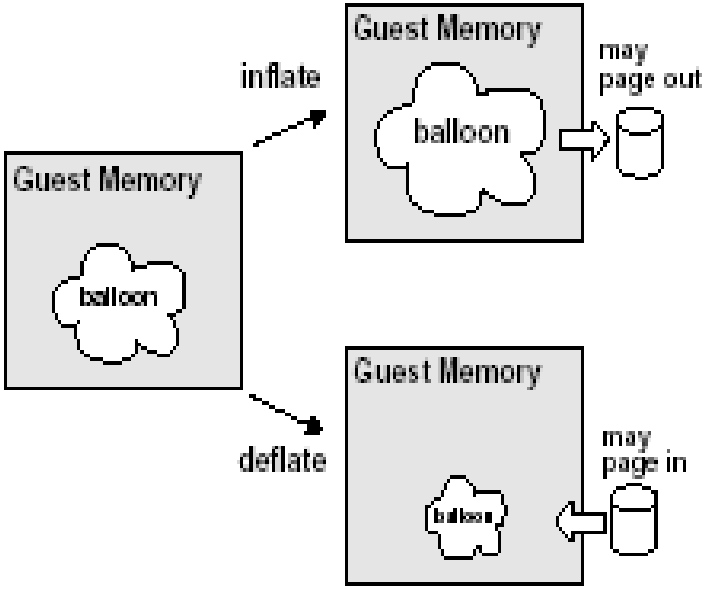
- Physical memory:
  - Statically partitioned due to initial memory reservation.
  - Reservation Limit.
  - XenoLinux implements a balloon driver.
  - Illusion of continous memory by GuestOS.
  - Shared translation array.



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- Network:
  - Virtual network interface (VIF):
    - I/O descriptor buffer rings (receive, transmit).
    - Transmit:
      - Scatter-gather DMA: only packet-header is copied.
      - Round-Robin scheme.
    - Receive:
      - Exchange an unused page frame for each packet.
      - Page-aligned receive buffers.

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- Disk:
  - Virtual Block Devices:
    - Domain0 has unchecked access.
    - Accessed via I/O Ring mechanism.
    - Ownership, access-control.
    - Translation table managed by Domain0.
    - Reorder requests.
    - Round-Robin.
    - Reorder barriers: write ahead logs.

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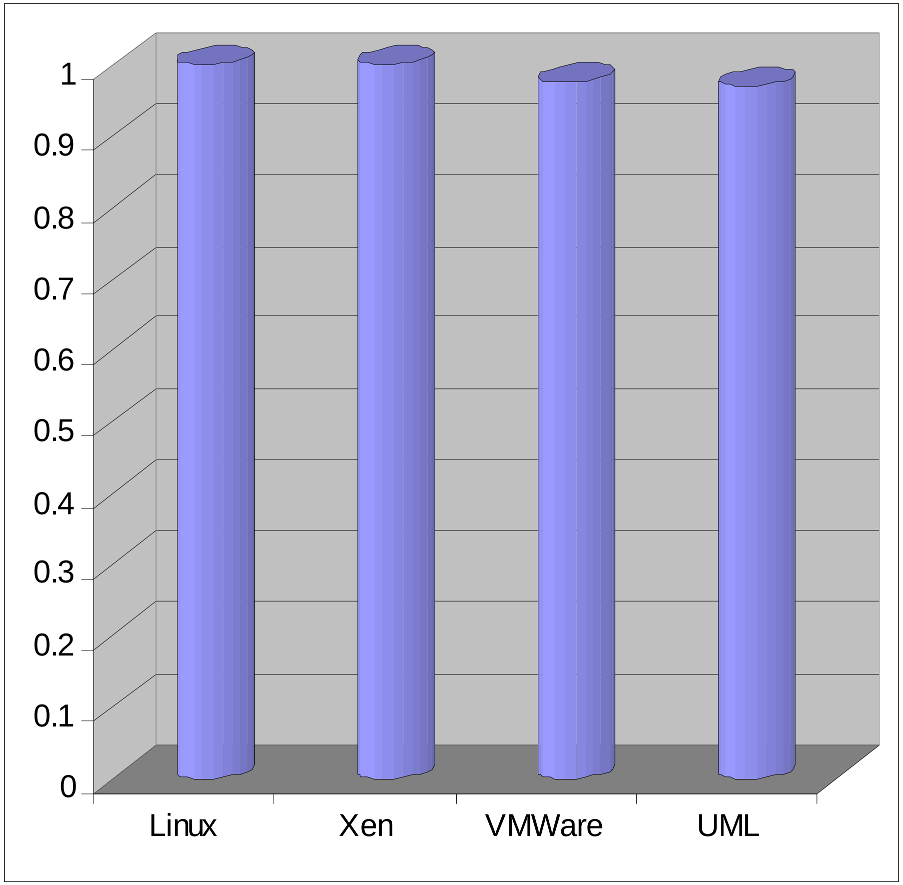
- Outline:
  - Relative performance.
  - Concurrent Virtual Machines.
  - Scalability.

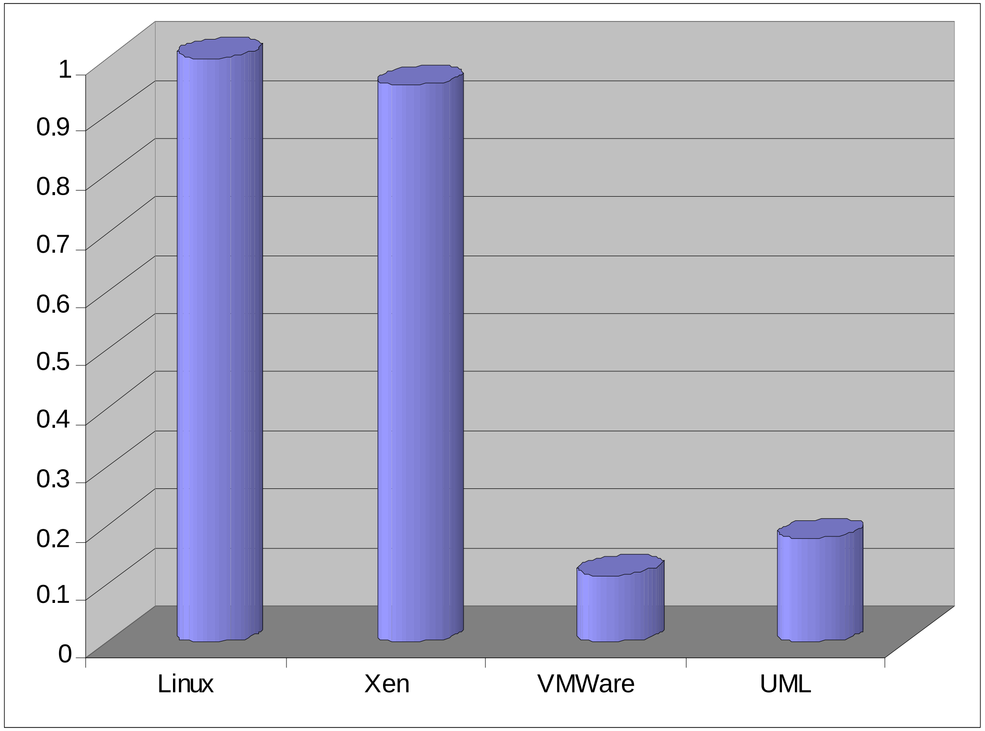
# XEN Virtual Machine Monitor

- SPEC INT2000:
  - Long running computationally-intensive applications.
  - Almost time spent in user- space code.



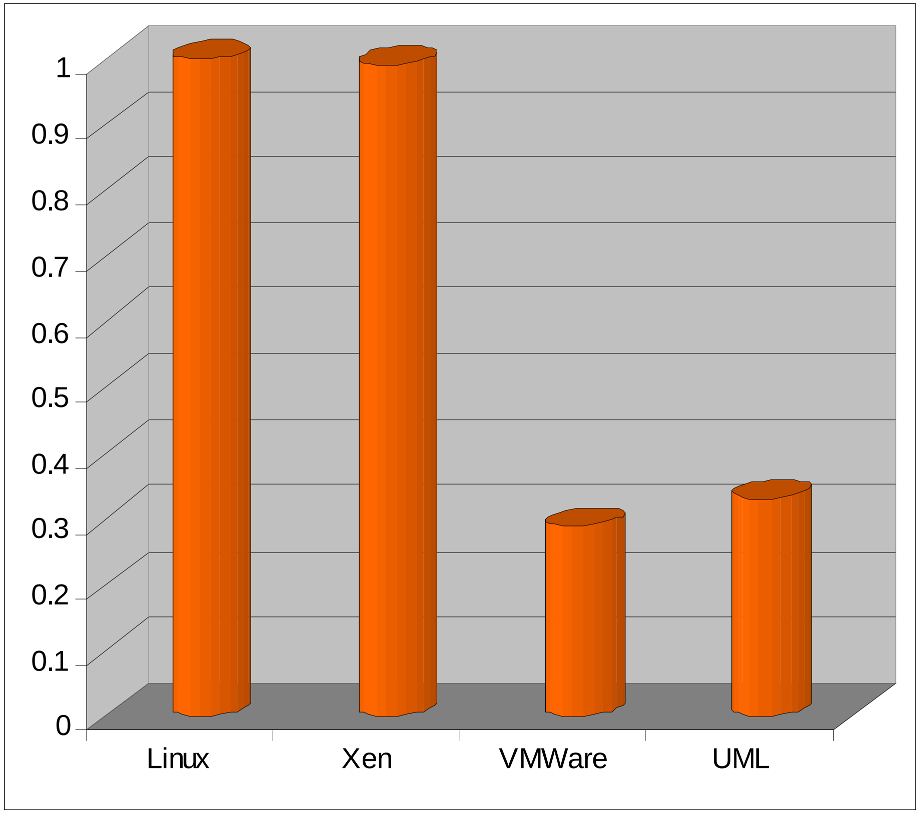
# XEN Virtual Machine Monitor

- OSDB- OLTP(tup/ s):
  - PostgreSQL 7.1.3
  - Online transaction processing



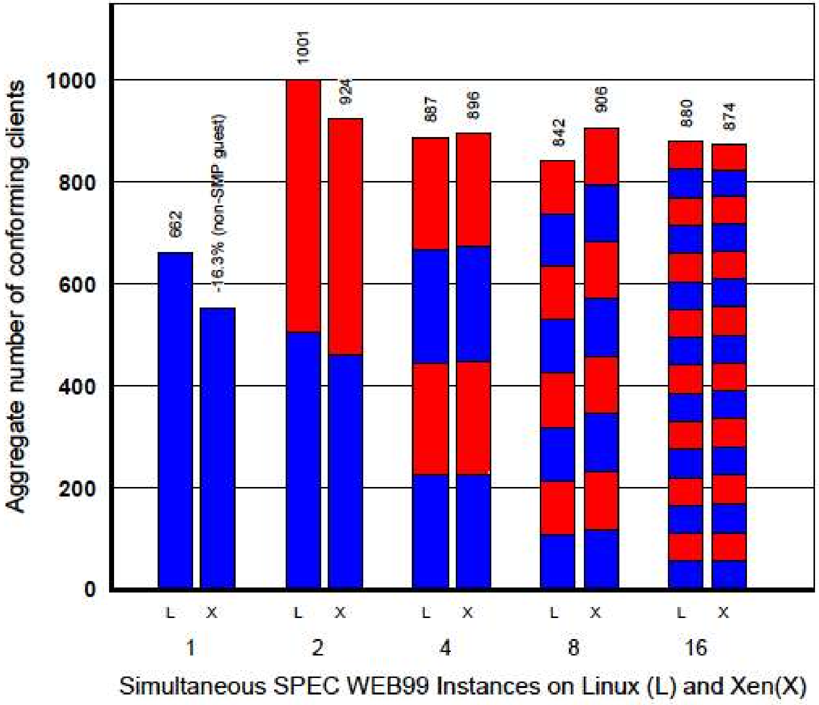
# XEN Virtual Machine Monitor

- SPEC WEB99:
  - Complex application-level benchmark for evaluating webservers and systems that host them.
  - Determine max. users.
  - Apache 1.3
  - CPU-bound
  - Most time spent in GuestOS.



# XEN Virtual Machine Monitor

- Concurrent Virtual Machines:
  - SPEC WEB99.
  - Multiple applications running in GuestOS.
  - 2 CPU machine.
  - Native Linux with SMP.
  - XenoLinux on uniprocessor.



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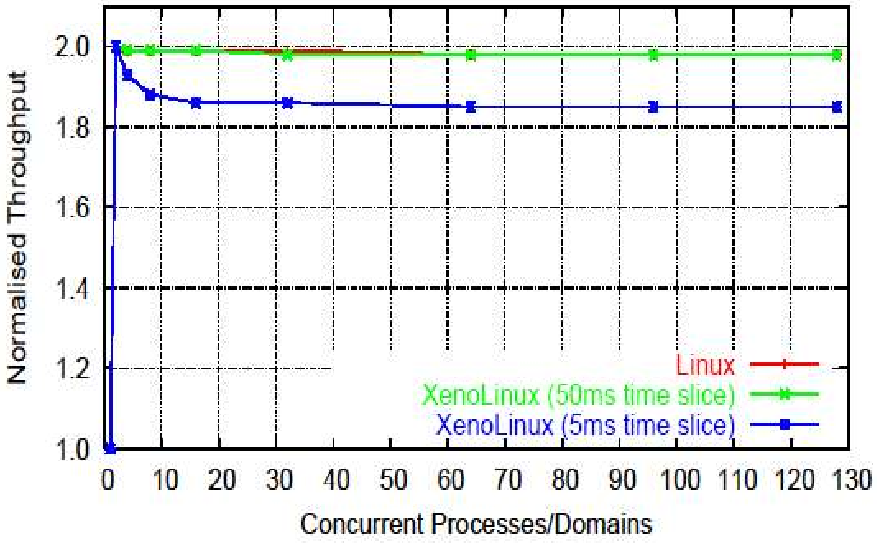
- Scalability:
  - SPEC CINT2000:
  - Linux 50ms timeslice.
  - XenoLinux, 5 and 50 ms.



**Normalized aggregate performance of a subset of SPEC CINT2000 running concurrently on 1-128 domains**

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- Summary:
  - Virtual machine monitor.
  - Paravirtualization.
  - 100% binary compatibility.
  - GuestOS has to be modified.
  - Support for general purpose OSes (Linux,XP,BSD).
  - Scales up to 100 instances.
  - Very efficient.
  - Easy configuration.
  - Transient servers for short periods of time and with low instantiation costs.
  - http://www.cl.cam.ac.uk/Research/SRG/netos/xen/

# XEN Virtual Machine Monitor

Thanks for your attention !