Red Hat Summit, Boston, 2010

KVM@IBM: Virtualization, Consolidation and Maximizing Server Utilization

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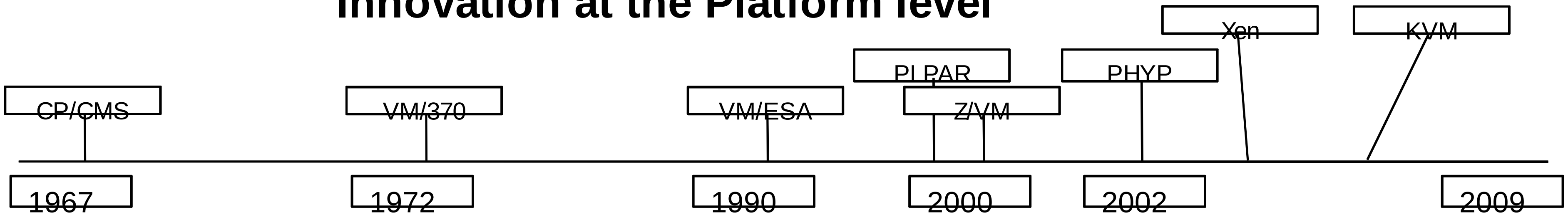
Gerrit Huizenga

Agenda

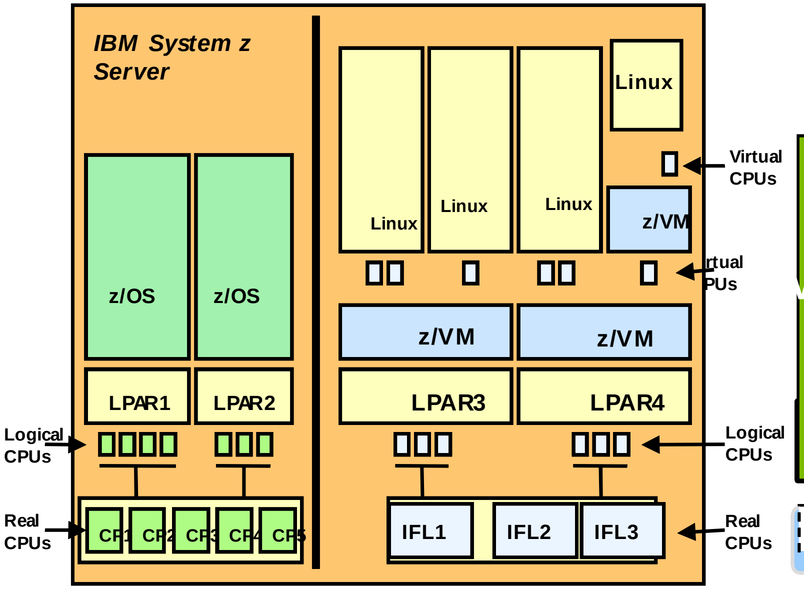
- **Background / History and Red Hat Partnership**
- KVM and Cloud Requirements
- IO in Virtualized Environment
- Memory Resources
- EX5 Systems : Designed with Virtualization in mind

The Evolution of Virtualization

Innovation at the Platform level



CP/CMS
1967
VM/370
1972
VM/ESA
1990
PLPAR
Z/VM
2000
PHYP
2002
Xen
KVM
2009



IBM System z Server
z/OS
z/OS
LPAR1
LPAR2
Logical CPUs
Real CPUs
CP1
CP2
CP3
CP4
CP5
Linux
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Linux
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z/VM
Virtual CPUs
rtual PUs
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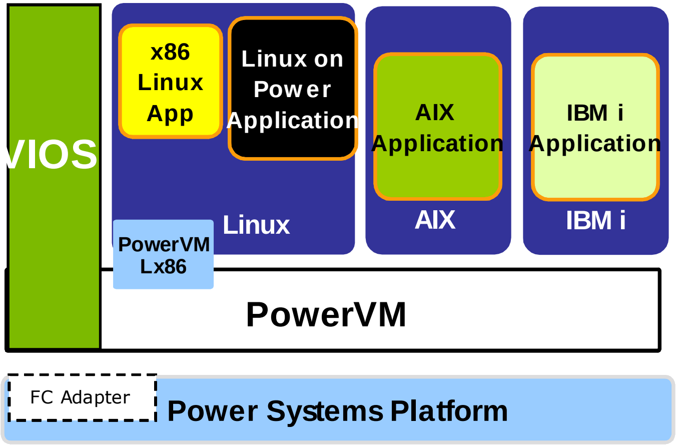
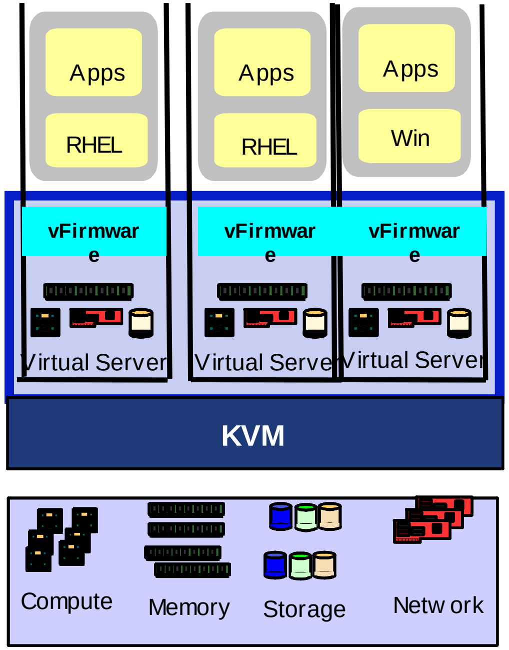
LPAR3
LPAR4
Logical CPUs
IFL1
IFL2
IFL3
Real CPUs

System z



VIOS
x86 Linux App
Linux on Power Application
AIX Application
IBM i Application
PowerVM Lx86
Linux
AIX
IBM i
PowerVM
FC Adapter
Power Systems Platform

Power

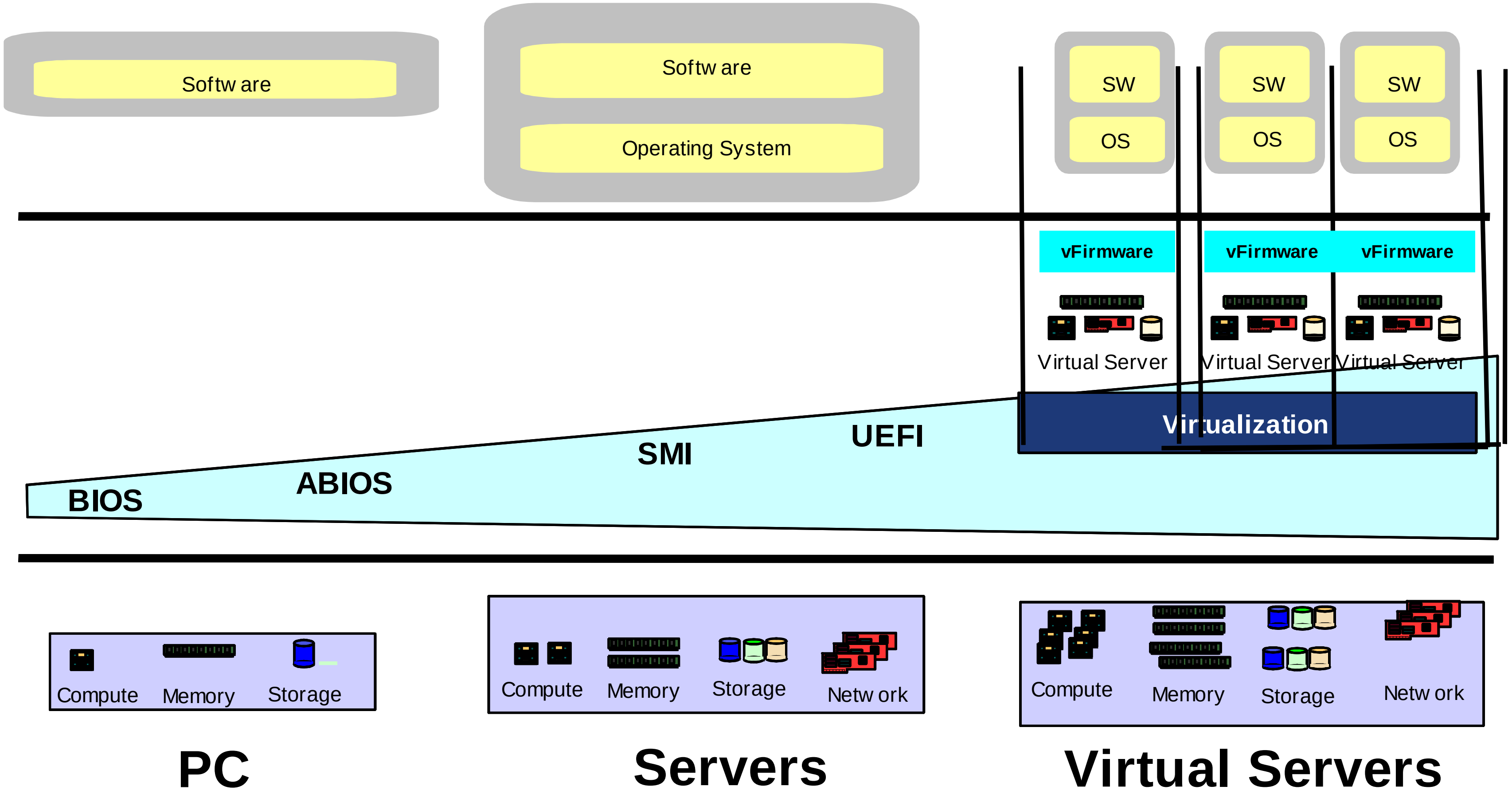


Apps
RHEL
Apps
RHEL
Apps
Win
vFirmwar e
vFirmwar e
vFirmwar e
Virtual Server
Virtual Serve
Virtual Server
KVM
Compute
Memory
Storage
Netw ork

System x

The Evolution of the x86 “Platform”

Processors , firmware, operating systems, and applications all continue to evolve



KVM (Kernel-base Virtual Machine): Overview

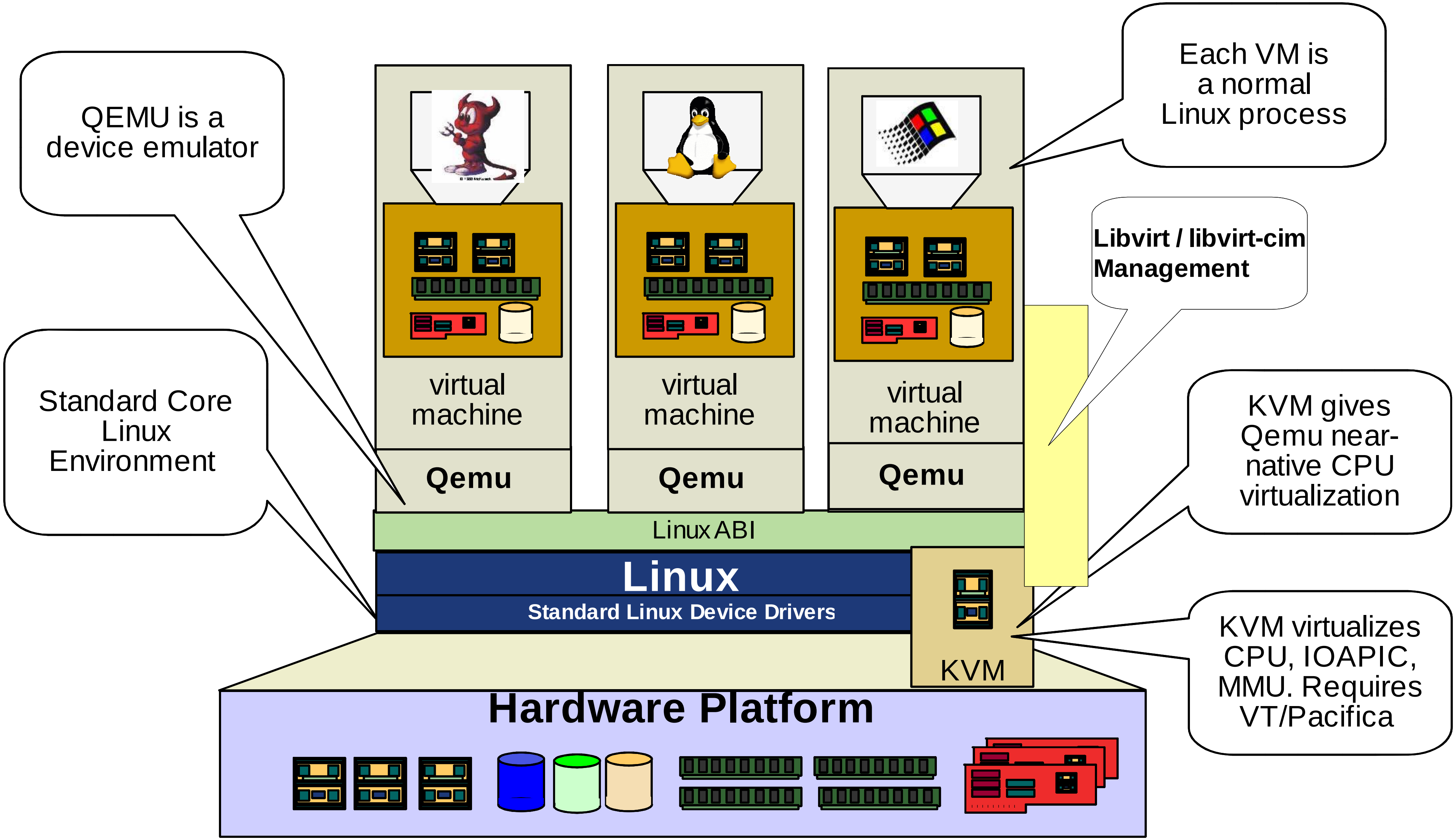
http://www.linux-kvm.org

- Integrated Hypervisor for Linux
  - **Converts Linux into a Type-1 Hypervisor**
- Runs Windows, Linux and other guests
- Allows for Hybrid-mode operation
  - **Run regular Linux applications along side VM guests**
- Upstream since Linux 2.6.20 (2007)
- Control over future evolution is held by linux development community
- Supported in RHEL since v5.4 (Sept. 2009)
- Elegant, simple design reuses Linux and builds upon CPU virtualization assistance

... So KVM Developers can focus on Virtualization

- **While Linux ecosystem continues to provide essential core services**
  - Hardware support
  - Bootstrap
  - Memory Management
  - Process Management and Scheduling
  - Access control
  - IPC and Sharing infrastructure
  - Scaling
  - RAS
  - Power Management

KVM + QEMU Architecture


QEMU is a device emulator
Standard Core Linux Environment
virtual machine
virtual machine
virtual machine
Qemu
Qemu
Qemu
Linux ABI
Linux
Standard Linux Device Drivers
KVM
Hardware Platform
Each VM is a normal Linux process
Libvirt / libvirt-cim Management
KVM gives Qemu near-native CPU virtualization
KVM virtualizes CPU, IOAPIC, MMU. Requires VT/Pacifica

KVM is a Virtualization Driver

- KVM is a small kernel driver that adds virtualization support on multiple architectures
  - AMD, Intel (included in 2.6.20)
  - KVM-lite: PV Linux guest on non-VTx / non-SVM host
  - IA64 (included in 2.6.26)
  - S390 (included in 2.6.26)
  - Embedded PowerPC (power.org, included in 2.6.26)
- About 30k LOCS
- Compared to ~250k LOCS for Xen
- Uses QEMU in userspace as a device model
- Safe to use by unprivileged userspace processes
- Can leverage almost all Linux features

KVM Development Communities - 2009

- KVM-devel
  - 18,303 messages
  - 884 unique participants
  - 382 unique address domains

9471	redhat.com
1382	ibm.com
929	intel.com
949	novell.com

- Qemu
  - 23,562 messages
  - 757 unique participants
  - 349 unique address domains

8751	redhat.com
2643	ibm.com
819	aurel32.net
712	codesourcery.com

- Libvirt
  - 8,835 messages
  - 370 unique participants
  - 194 unique address domains

5791	redhat.com
415	meyering.net
260	ibm.com
230	sun.com

2010 LTC KVM Focus Areas

Core KVM

- Cooperative Memory Management
- Balloon driver
- Qemu maintainership
- KVM function/feature
- VirtFS
- Energy management - CPU folding

Networking, I/O

- Virtio, vhost-net enhancements
- PCI device assignments to Vms
- SRIOV support
- Efficient interrupt handling/routing
- Vswitch
- Advanced ACLs, SNMP MIBs
- Automatic profile migrat

Performance

- Cooperative Memory Management
- Memory overcommit study
- SPECvirt
- Micro-benchmarks
- Network I/O
- Storage & FileSystem

Systems Management

- Libvirt-cim function/feature
- Libvirt storage & network pools
- libvirt-cim maintainership
- Director integration
- Cloud management integration

Security

- Flexible policy support in sVirt
- Common criteria certification
- Blueprints: Cloud security

Hygiene

- RAS – tracepoints, dump, serviceability
- ID
- Support
- Test

Early Deployment Team

- Compute Cloud
- Private Clouds
- Systems Management Integration
- PoC, Partner Engagements

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- Memory Resources
- EX5 Systems : Designed with Virtualization in mind

Cloud Computing and Hypervisors

- **Cloud Computing is primarily about Economics**
  - Driving down the cost of all aspects of Data Center Operations
  - Sharing Data Center Resources for increased Flexibility
- **For KVM, this translates to:**
  - Upward pressure on VM Density
  - KVM must get more out of less hardware
  - Downward pressure on Energy Consumption
  - Increased Security and Auditing needs
  - Creative use of storage resources

KVM Performance Activities

- **Six separate focus areas of performance analysis**
- Memory Usage and Over-commitment
- Storage (local, SAN, and NAS)
- Network (10G, SR-IOV, paravirtual)
- Windows VM performance
- SPECVirt and complex workload analysis
- Micro benchmarks and regression analysis

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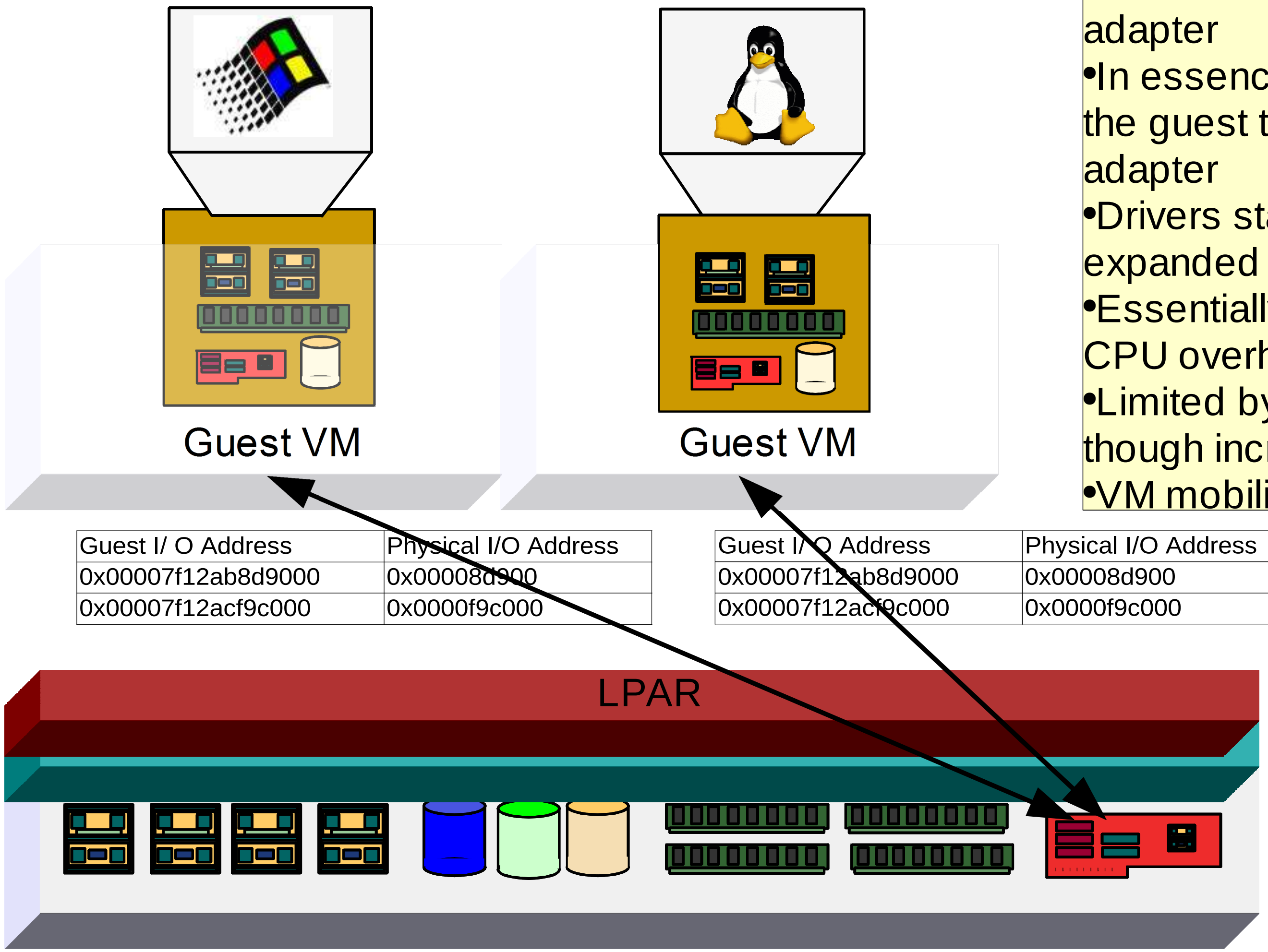
I/O Virtualization – The Current Bottleneck

I/O and Virtualization

- Hardware assisted Virtualization
  - Support for advanced hardware features for both KVM and Xen
    - **VT-d** for secure PCI Pass-thru on Intel platforms
    - **IOMMU** for secure PCI Pass-thru on AMD platforms
    - PCI Single-Root I/O Virtualization (**SR-IOV**)
  - Delivers native I/O performance for network and block devices
- Emulated I/O
- Paravirtualized Drivers for KVM/Linux
  - virtio was chosen to be the main platform for IO virtualization in KVM
  - The idea behind it is to have a common framework for hypervisors for IO virtualization (same in XEN)
  - network/block/balloon/PCI passthrough devices are supported for KVM
  - The host implementation is in userspace - qemu, so no driver is needed in the host (but still has some performance issues)
- Support for Microsoft Windows Servers guests
  - Paravirtualized drivers for network and disk (WHQL certified -> Enterprise Distros)
  - Microsoft SVVP Certification (-> Enterprise Distros)

Single-root I/O Virtualization (SRIOV)

“Root” in “Single-root” refers to PCI bus and device tree



Guest I/ O Address	Physical I/O Address
0x00007f12ab8d9000	0x00008d900
0x00007f12acf9c000	0x0000f9c000

Guest I/ O Address	Physical I/O Address
0x00007f12ab8d9000	0x00008d900
0x00007f12acf9c000	0x0000f9c000

- An SRIOV PCI Device has multiple PCI functions
- Each function behaves like a distinct physical adapter
- In essence, the PCI device virtualizes itself, but the guest thinks it is controlling a dedicated I/O adapter
- Drivers started to appear with RHEL 5.4, expanded with 5.5, and growing...
- Essentially native performance with minimal CPU overhead
- Limited by number of Virtual Functions (Vfs) – though increasing in latest gen adapters
- VM mobility still needs to be addressed

I/O Paravirtualization

- KVM Community in general prefers paravirtualized I/O
  - Performance can be comparable to direct pass-through
  - More flexible
    - Live Guest Migration
    - Integrated virtual switching
  - Hypervisor can optimize I/O scheduling to meet different performance or resource goals
  - SR and MR -IOV hardware can be paravirtualized in creative ways

Virtio

- First proposed by Rusty Russell
  - Based on our experiences with Xen frontend/backend architecture

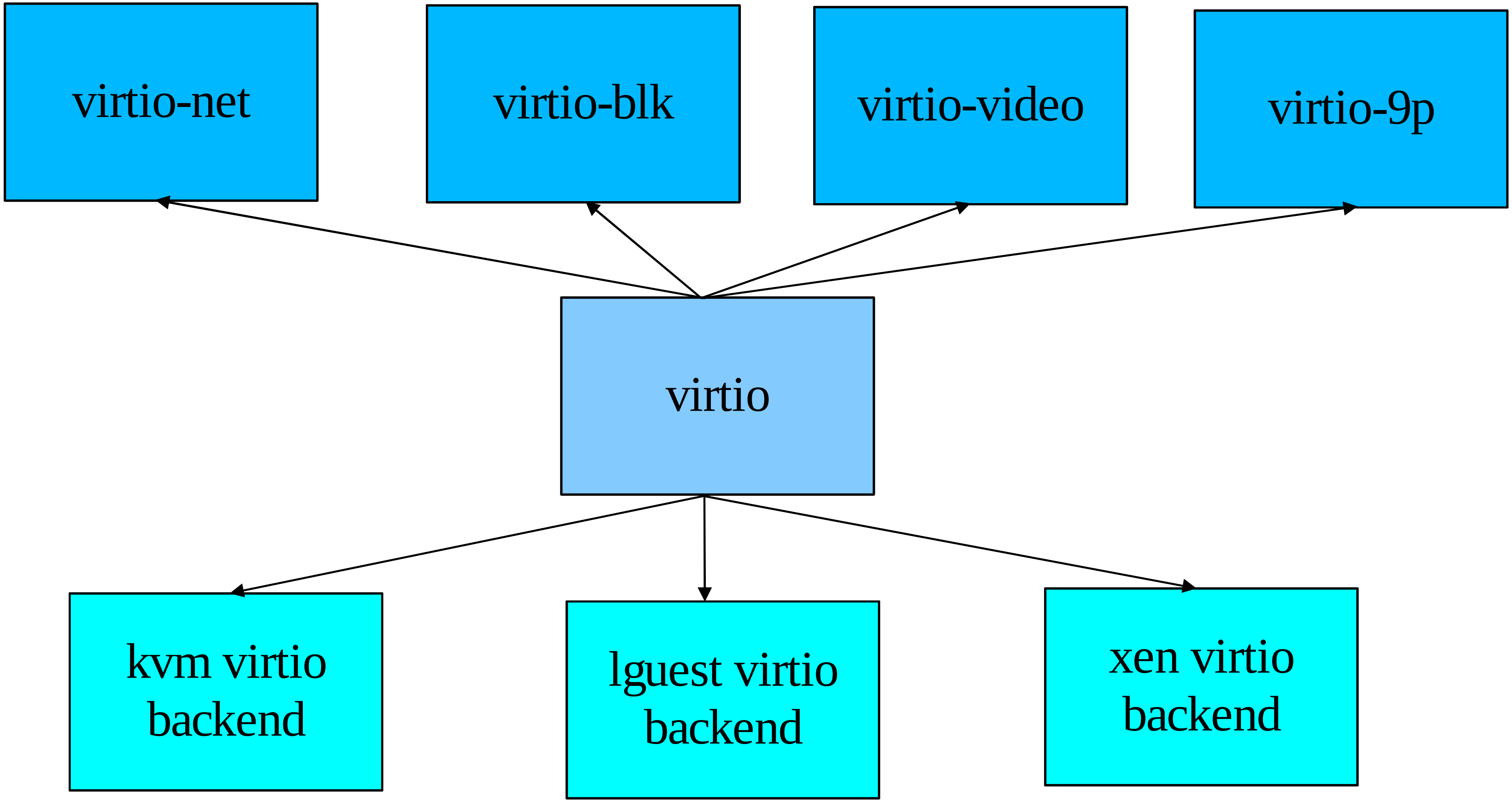
- virtio is an abstraction of the common mechanism of VMMs
  - A single driver could, with little modification, run on many different VMMs

- Addressed a number of concerns:
  - Clear separation between protocol and transport to allow multiple hypervisors to utilize
  - Each component uses well defined interface and is replaceable
  - Minimum driver implementation required
  - Fits on top of existing hardware abstraction well (PCI)

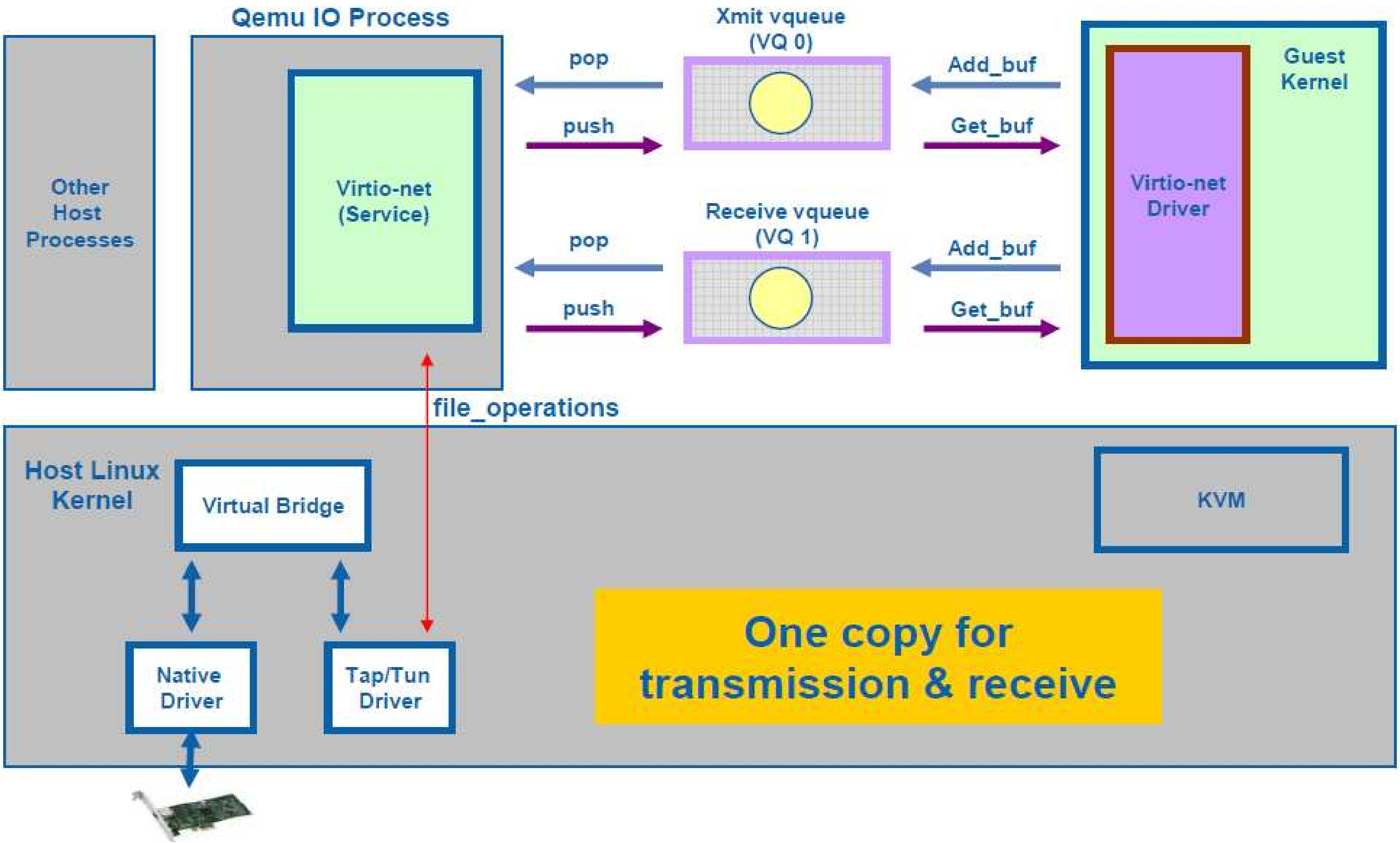
- Linux will support lguest, KVM, Xen, KVM-lite, PHYP, VMware, Viridian, and possibly more
  - If each has 4-5 PV drivers, that's 35 new drivers!
  - All drivers would be doing the same thing

- Especially important for “small” drivers (entropy driver, CPU hotplug, ballooning, etc.)

Virtio Architecture



Virtio-net



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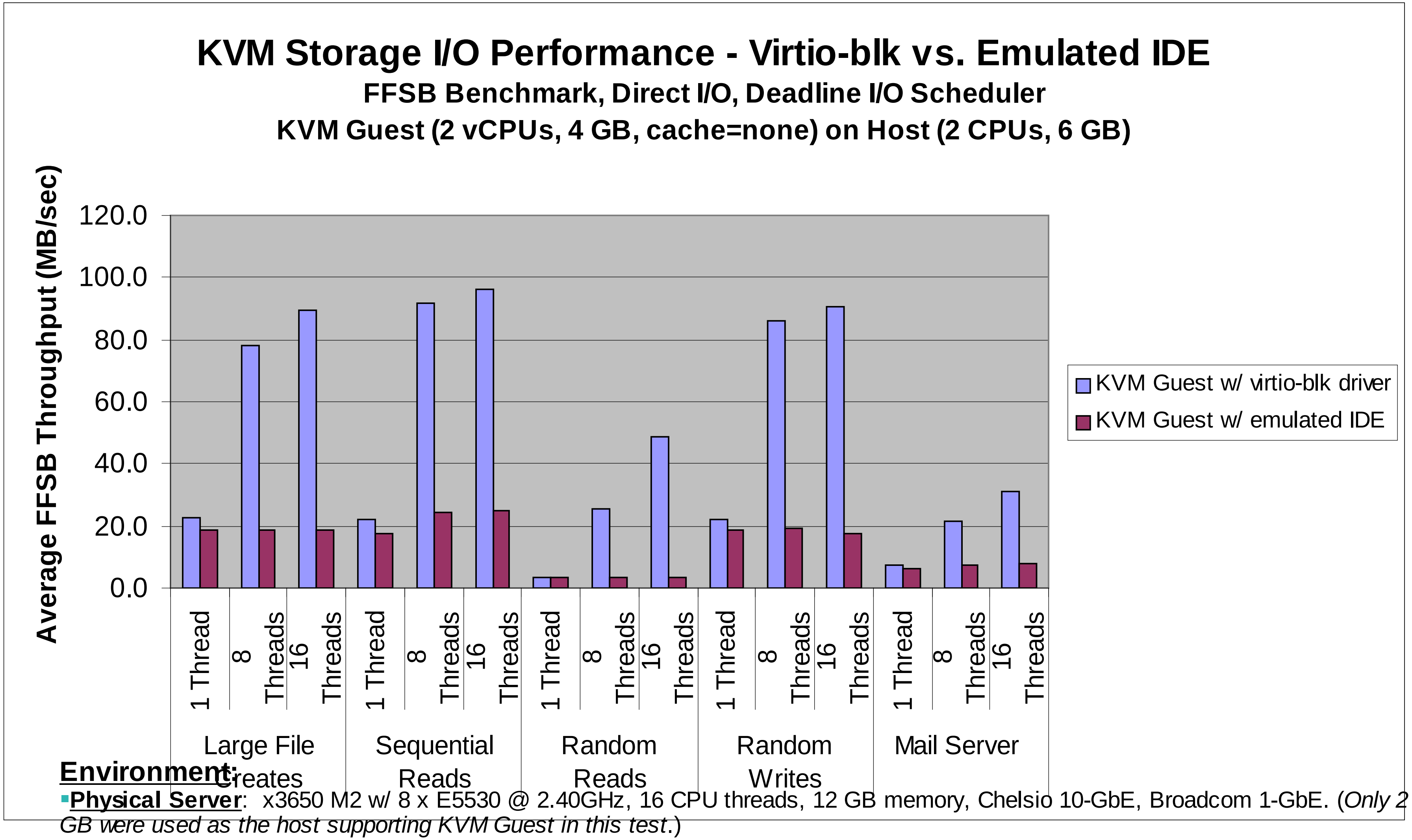
Virtio-block vs Emulated IDE



Environment:

- **Physical Server**: x3650 M2 w/ 8 x E5530 @ 2.40GHz, 16 CPU threads, 12 GB memory, Chelsio 10-GbE, Broadcom 1-GbE. (*Only 2 cores and 6 GB were used as the host supporting KVM Guest in this test*.)
- **Storage**: 8 x 24-disk RAID10 arrays; 4 x DS3400 controllers w/ 4-gbps host fiber links; *a single LVM volume was created across all disk arrays, then formatted with ext3 filesystem, and passed to KVM guest as a block device (/dev/vda).*
- **Host OS**: RHEL 5.5 GA
- **KVM Guest OS**: RHEL5.5 GA

virtio-9p

- A lot of work has focused on block devices, virtio-9p provides a paravirtual file system interface for guests
- Use 9p over virtio and v9fs within the guest
- Able to boot a RHEL5 guest from a v9fs root file system
- virtio-9p transport is in mainline Linux since 2.6.27
- Without any optimization, already able to beat NFS over virtio-net
- A great deal of additional optimizations are possible

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Cloud is Driving KVM Development...

- Physical Resource Over-provisioning
  - As long as guests don't experience peak load concurrently, we can “borrow” compute, I/O, and memory resources from one guest and “loan” them to another guest
  - Transparent memory sharing
  - Memory “Ballooning” (memory borrowing)
  - Host memory swapping
  - VCPU over-provisioning
    - Virtual CPUs > physical CPUs
- In best cases, resources can be highly leveraged

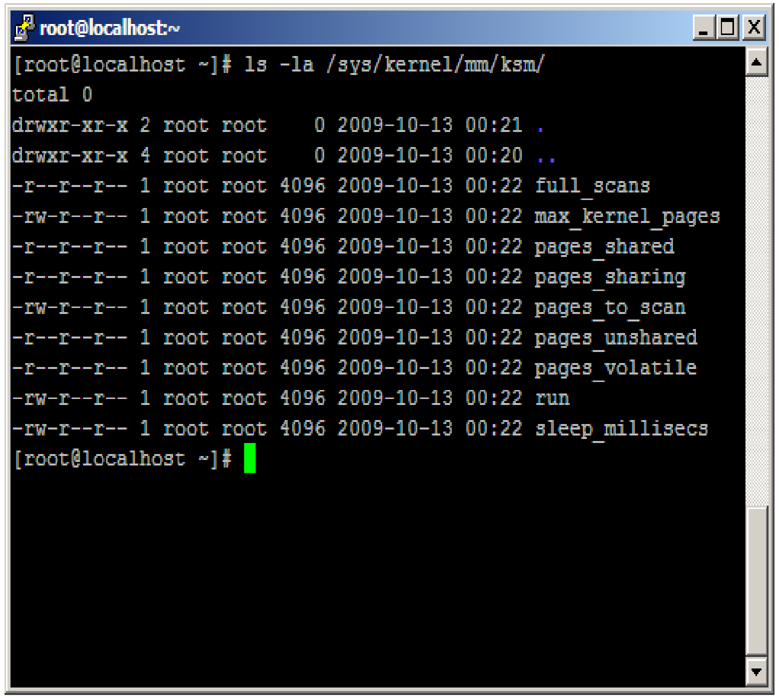
KSM - Memory Page Sharing

- Implemented as loadable kernel module
  - Kernel SamePage Merging (KSM) included in Linux Kernel 2.6.32 (Izik Eidus)

- Kernel scans memory of virtual machines
  - Looks for identical pages
  - Merges identical pages
  - Only stores one copy (read only) of shared memory
  - If a guest changes the page it gets it's own private copy

- qemu-kvm KSM-patch added to kvm development tree after kvm-88 release

- Significant hardware savings
  - Better consolidation ratio
  - Allows more virtual machines to run per host
- Memory Overcommit (avoiding Linux Swapping)



```
[root@localhost ~]# ls -la /sys/kernel/mm/ksm/
total 0
drwxr-xr-x 2 root root    0 2009-10-13 00:21 .
drwxr-xr-x 4 root root    0 2009-10-13 00:20 ..
-r--r--r-- 1 root root 4096 2009-10-13 00:22 full_scans
-rw-r--r-- 1 root root 4096 2009-10-13 00:22 max_kernel_pages
-r--r--r-- 1 root root 4096 2009-10-13 00:22 pages_shared
-r--r--r-- 1 root root 4096 2009-10-13 00:22 pages_sharing
-rw-r--r-- 1 root root 4096 2009-10-13 00:22 pages_to_scan
-r--r--r-- 1 root root 4096 2009-10-13 00:22 pages_unshared
-r--r--r-- 1 root root 4096 2009-10-13 00:22 pages_volatile
-rw-r--r-- 1 root root 4096 2009-10-13 00:22 run
-rw-r--r-- 1 root root 4096 2009-10-13 00:22 sleep_millisecs
[root@localhost ~]#
```

http://www.linux-kvm.com/content/using-ksm-kernel-samepage-merging-kvm

Other Memory overprovisioning...

- Memory “Ballooning”
  - allows the hypervisor to borrow memory pages from one guest and lend those pages to another guest.
  - guest kernel decides which pages it should release for use by another guests
  - implemented in many hypervisors including VMware ESX, z/VM, Xen, and KVM
  - device driver acts like a "balloon" which can be inflated or deflated.
  - guest responds to the "inflation" by freeing memory and giving that memory to the balloon device driver
  - balloon driver hands those memory pages over to KVM, which allows another guest to borrow the memory.
- Host memory swapping
  - Evicting any type of page to a block device extracts a huge performance penalty, to be paid both when the page is evicted, and again when it must be faulted back into memory.
  - Compcache
    - virtual memory manager first evicts a page by compressing it and writing the compressed contents to the compcache device (which is a RAM disk)
    - When the compcache device is full, it de-compresses the oldest pages and writes them to the swap file on secondary storage.

Some simple handwave calculations...

- 2-4 GB / VM
- 2 socket * 8 core * 2 HW threads = 32 ʟCPUs
- Observed average System utilization 10-20%
  - So let's say 5x CPU overprovisioning possible
- 5 Guests/ʟCPU * 32 ʟCPUs * 2-4GB/Guest = 320-640GB
- 320-640GB / 8 GB/DIMM = 40-80 DIMMs
- And many Server workloads utilizing even more memory...

We've covered some software approaches for addressing capacity, but of course one can also use a platform with greater Memory / CPU ratio...

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- **EX5 Systems : Designed with Virtualization in mind**

IBM System x3850 X5 and Red Hat

Flagship System x platform for leadership scalable performance and capacity

Versatile 4-socket, 4U rack-optimized scalable enterprise server provides a flexible platform for maximum utilization, reliability and performance of compute- and memory-intensive workloads.

Maximize Memory

- 64 threads and 1TB capacity for 3.3x database and 3.6x the virtualization performance over industry 2-socket x86 (Intel Xeon 5500 Series) systems
- MAX5 memory expansion for 50% more virtual machines and leadership database performance
- Run more VMs and larger VMs with RHEV-H

Minimize Cost

- Lower cost, high performance configurations reaching desired memory capacity using less expensive DIMMs
- eXFlash 480k internal IOPs for 40x local database performance and $1.3M savings in equal IOPs storage
- Red Hat Enterprise Virtualization for Servers offers industry-leading performance, scalability, and lower total cost of ownership compared to other virtualization solutions.

Simplify Deployment

- FlexNode Partitioning and Automatic Node failover for maximum flexibility and application uptime
- Pre-defined database and virtualization workload models for faster deployment and faster time to value

System Specifications

- ✓ 4x next-generation Intel Xeon (Nehalem EX) CPUs
- ✓ 64 to 96 DDR3 DIMMs
- ✓ 6 open PCIe slots (+ 2 additional)
- ✓ Up to 8x 2.5” HDDs or 16x 1.8” SSDs
- ✓ RAID 0/1 Std, Optional RAID 5/6
- ✓ 2x 1GB Ethernet LOM
- ✓ 2x 10GB Ethernet SFP+ Virtual Fabric / FCoEE
- ✓ Scalable to 8S, 192 DIMM
- ✓ Internal USB for embedded hypervisor
- ✓ IMM, uEFI & IBM Systems Director

IBM System x3690 X5 and Red Hat

Industry's first high end scalable 2-socket for maximum memory and performance

High-end 2-socket, 2U scalable server offers up to four times the memory capacity of today's 2-socket servers with double the processing cores for unmatched performance and memory capacity.

Maximize Memory

- 33% more cores and 5x more memory capacity for 1.7x more transactions per minute and 2x more RHEV-H virtual machines than 2-socket x86 (Intel Xeon 5500 Series) systems
- MAX5 memory expansion for additional 46% more virtual machines and leadership database performance
- Run more VMs and larger VMs with RHEV-H

Minimize Cost

- Achieve 4-socket memory capacity with 2-socket software license costs and cheaper "2-socket only" processors
- eXFlash 720k internal IOPs for 40x local database performance and $2M savings in equal IOPs storage
- Red Hat Enterprise Virtualization for Servers offers industry-leading performance, scalability, and lower total cost of ownership compared to other virtualization solutions.

Simplify Deployment

- FlexNode Partitioning and Automatic Node failover for maximum flexibility and application uptime
- Pre-defined database and virtualization workload models for faster deployment and faster time to value

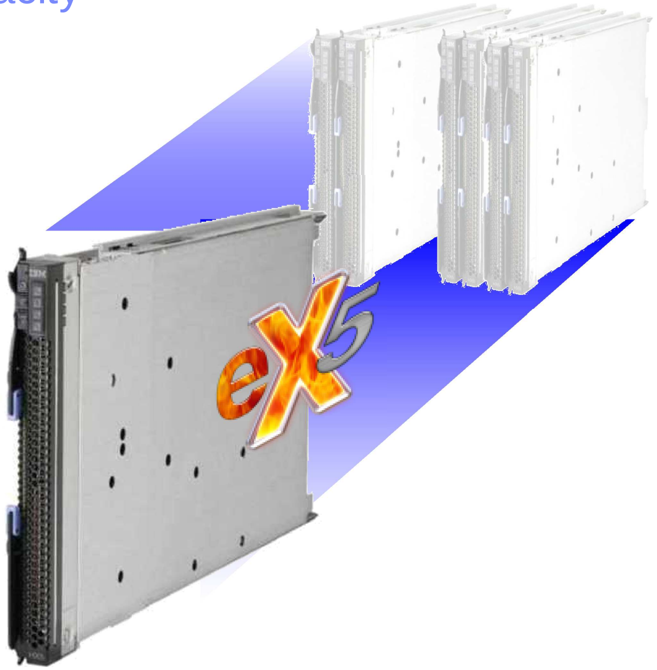
System Specifications

- ✓ 2x next-generation Intel Xeon (Nehalem EX) CPUs
- ✓ 32 to 64 DDR3 DIMMs
- ✓ 2 x8 PCIe slots, 2 x8 Low Profile slots
- ✓ Up to 16x 2.5" HDDs or 32x 1.8" SSDs
- ✓ RAID 0/1 Std, Opt RAID 5
- ✓ 2x 1GB Ethernet
- ✓ Optional 2x 10GB SFP+ Virtual Fabric / FCoEE
- ✓ Scalable to 4S, 64 DIMM or 128 DIMM
- ✓ Internal USB for embedded hypervisor
- ✓ IMM, uEFI, and IBM Systems Director

IBM BladeCenter HX5 and Red Hat

Scalable high end blade for high density compute and memory capacity

Scalable blade server enables standardization on same platform for 2- and 4-socket server needs for faster time to value, while delivering peak performance and productivity in high-density environments.



Maximize Memory

- 1.7x greater performance over 2-socket x86 (Intel Xeon 5500 Series) systems while using same two processor SW license
- MAX5 memory expansion to 320GB in 60mm for over 25% more VMs per processor compared to competition
- Run more VMs and larger VMs with RHEV-H

Minimize Cost

- Upgrade to 80 DIMM for max memory performance or to save over $4K by using smaller, less expensive DIMMs
- Memory bound RHEV-H customers can consolidate more workloads on each blade with memory rich 2-socket configurations

Simplify Deployment

- FlexNode Get up and running up to 2x faster by qualifying a single platform for 2- and 4-socket server needs
- Partitioning of 4-socket to two 2-sockets without any physical system reconfiguration, and automatically fail over for maximum uptime

System Specifications

- ✓ 2x next-generation Intel Xeon (Nehalem EX) CPUs
- ✓ 16x DDR3 VLP DIMMs
- ✓ MAX5 memory expansion to 2S, 40 DIMM
- ✓ Scalable to 4S, 32 DIMM or 4S, 80 DIMM
- ✓ UP to 8 I/O ports and to 2x SSDs per node
- ✓ Optional RAID 5 with battery backed cache
- ✓ Optional 10GB Virtual Fabric Adapter / FCoEE
- ✓ Internal USB for embedded hypervisor
- ✓ IMM, uEFI, and IBM Systems Director

MAX5: Memory Access for eX5

Greater productivity and utilization through memory expansion and flexibility

Take your system to the MAX with ***MAX5***

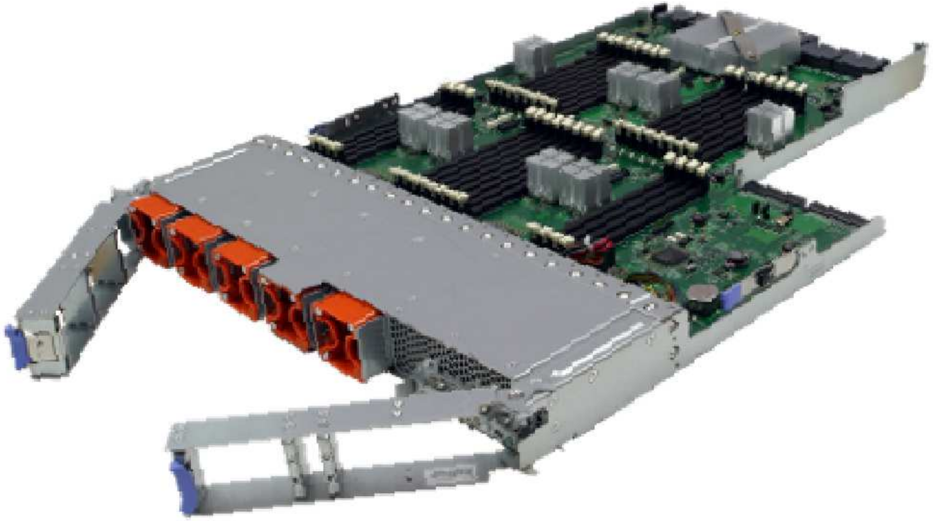
MAX memory capacity

-An additional 32 DIMM slots for x3850 X5 and x3690 X5

-An additional 24 DIMM slots for HX5

MAX virtual density

- Increase the size and number of VMs



MAX flexibility

- Expand memory capacity, scale servers, or both

MAX productivity

- Increase server utilization and performance

MAX license optimization

- Get more done with fewer systems

eX5 Rack System Configurations

Leadership high end x86 performance and flexibility

x3690 X5
(4S 64 DIMM)

Memory Enhanced

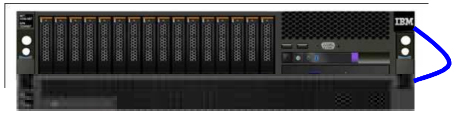
x3690 X5 w/ MAX5
(4S 128 DIMM)

x3850 X5
(8S 128 DIMM)

Memory Enhanced

x3850 X5 w/ MAX5
(8S 192 DIMM)

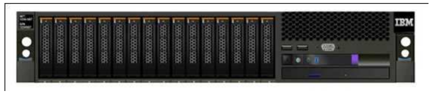
Memory Enhanced



x3690 X5 w/ MAX5
(2S 64 DIMM)

x3850 X5 w/ MAX5
(4S 96 DIMM)

Base Systems



x3690 X5
(2S 32 DIMM)

x3850 X5
(4S 64 DIMM)

IBM BladeCenter Scalable Blades

Maximum performance and flexibility for database and virtualization in a a

HX5 Blade

Never before seen levels of scaling…

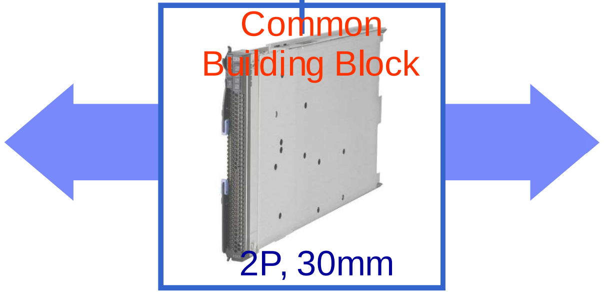
- 2-socket, 30mm building block
- 2-socket → 4-socket w/ logical partitioning

2-socket,
16DIMM
8 I/O ports
30mm

4-socket,
32DIMM
16 I/O
60mm

Max compute density!

- Up to 32 cores in a 1¼ U equivalent space
- Modular scalability in 2-socket increments to get to 4-socket
- *Targeted for database*, and compute intensive simulations



HX5 Blade with MAX5

Bringing the goodness of eX5 to blades…

- Snaps onto base blade (sold as a bundle w/ base HX5)
- Enables more memory than any other blades

2-socket,
40DIMM
8 I/O
60mm

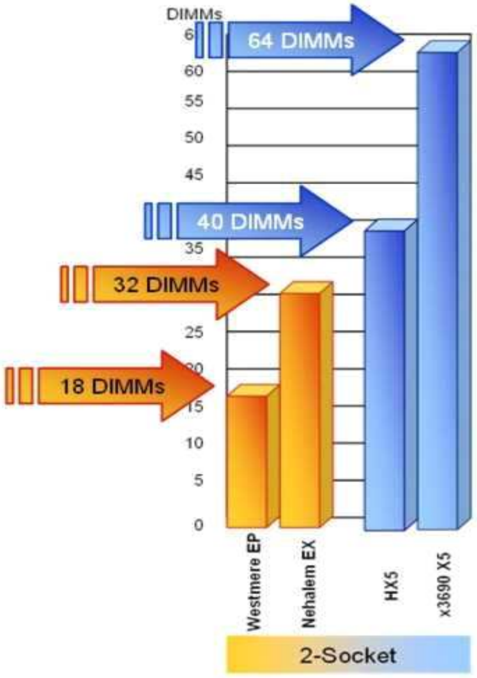
4-socket,
80DIMM
16 I/O
120mm

Blade leadership!

- Up to 30% more VMs than max competition blade
- Flexible configurations & unmatched memory capacity, scaling from 1-socket, 32D → 4-socket, 80D
- Uses processors that cost up to 30% less than the competition for scaling
- *Targeted for Virtualization* & DB for customers that need a blade form factor

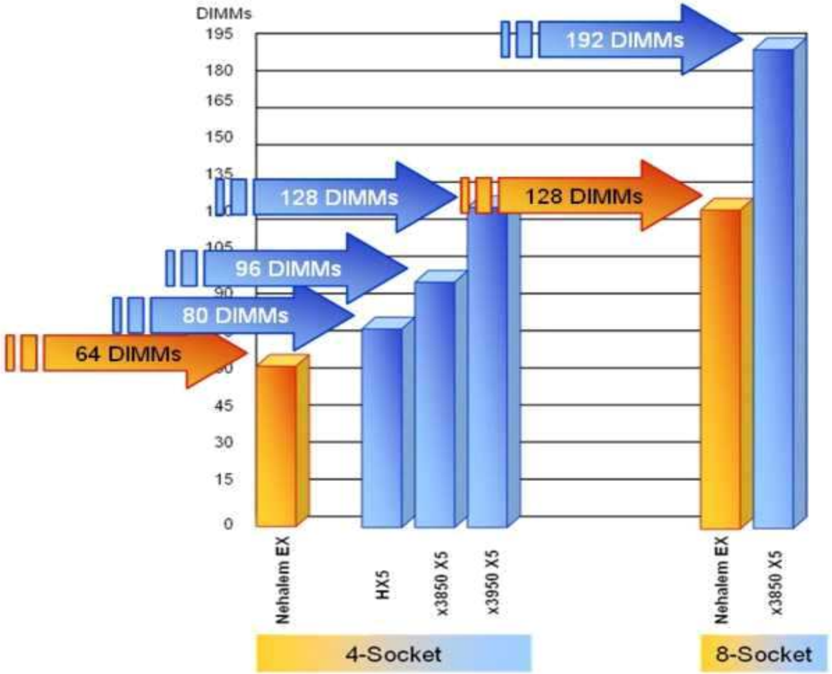
MAX5 for eX5 racks and blades enables systems to support more memory than x86 limits

MAX5 enables up to 2x DIMMs of memory per system



x3690 X5 w/MAX5
(2-socket / 64 DIMMs)

HX5 w/ MAX5
(2-socket / 40 DIMMs)



x3850 X5 w/ MAX5
(8-socket / 192 DIMMs)

x3850 X5 w/ MAX5
(4-socket / 96 DIMMs)

HX5 w/ MAX5
(4-socket / 80 DIMMs)

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Questions ?

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