Advanced Computer Networks

263-3501-00

Network I/O Virtualization

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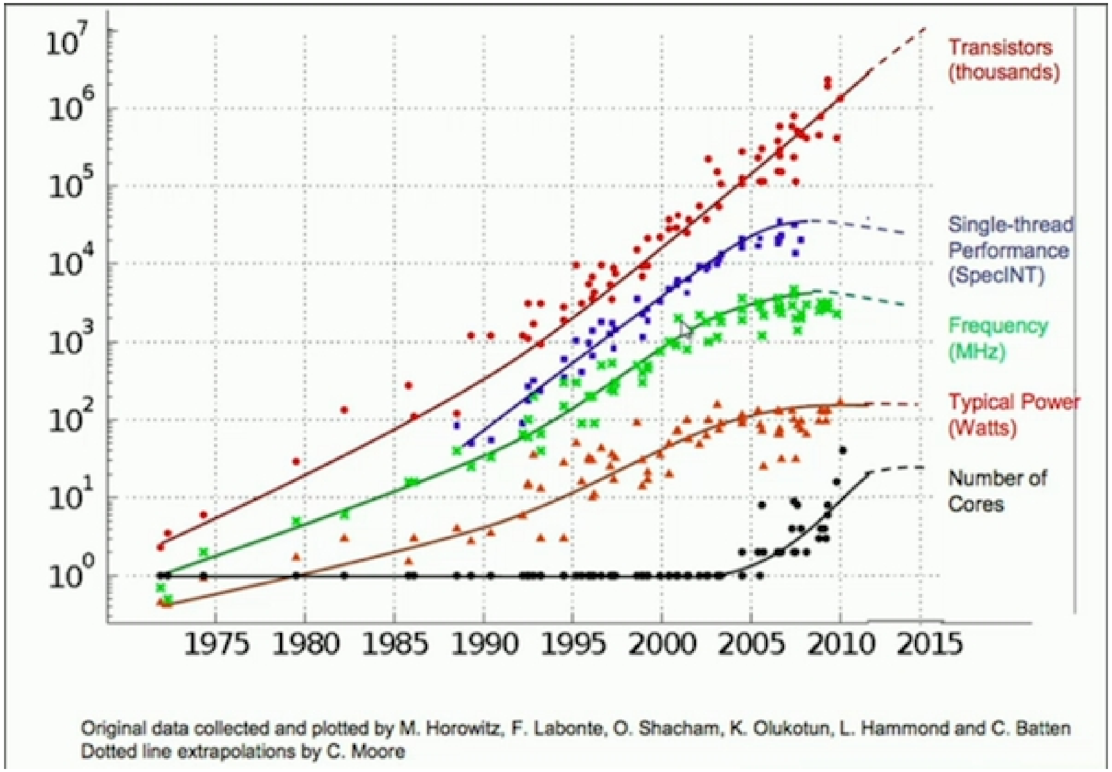
Spring Semester 2017

Outline

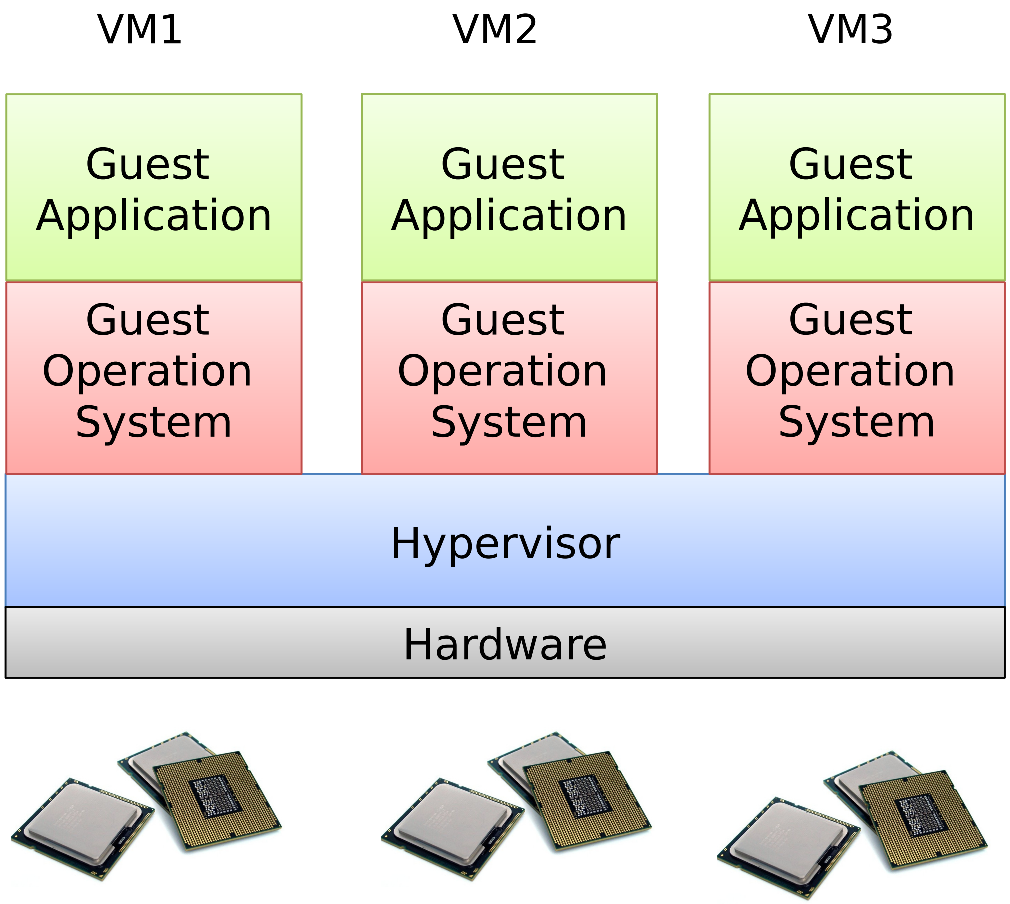
- Last week:
  - Receive Side Scaling
  - User-level networking
- Today:
  - Network I/O Virtualization
  - Paravirtualization
  - SR-IOV

Processor Clock Frequency Scaling Has Ended

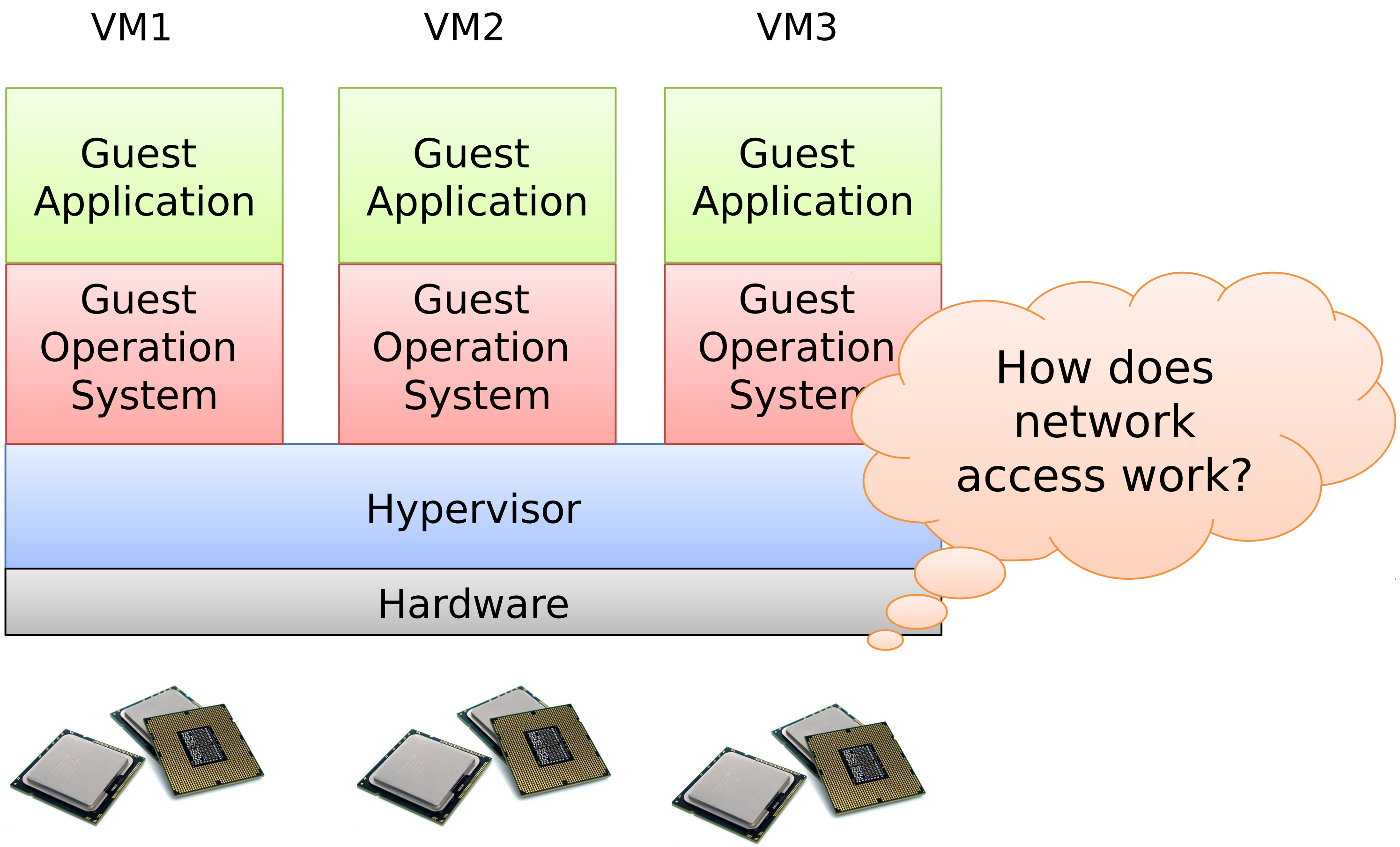


- Moore's Law continues in transistor count
- Industry response: <u>Multi-core</u> (i.e. double the number of cores every 18 months instead of the clock frequency (and power!)

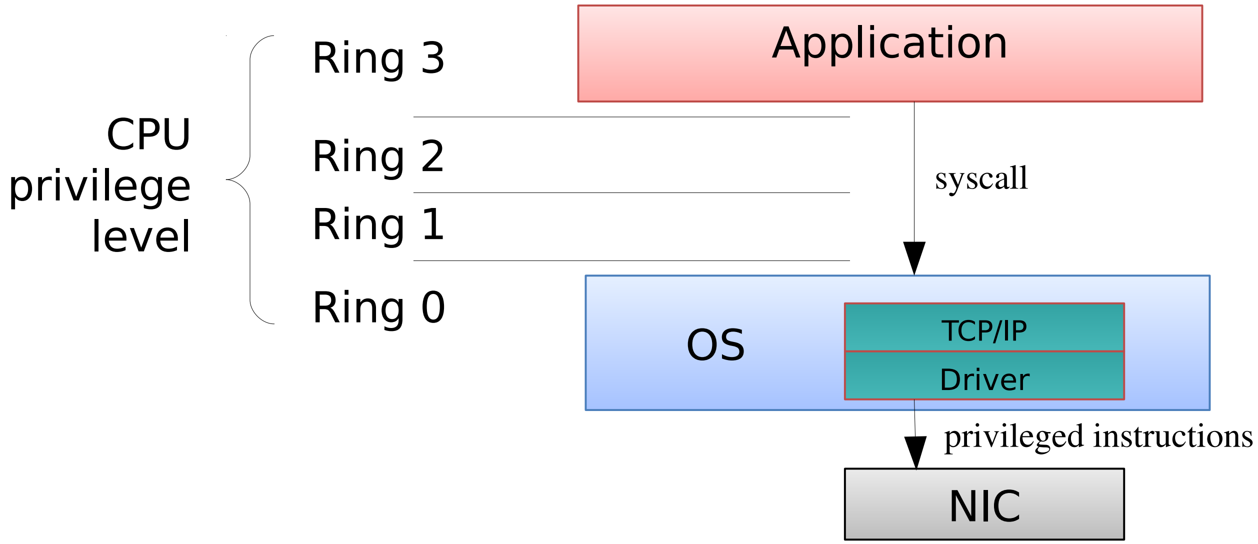
Virtualization and Hypervisors



Virtualization and Hypervisors



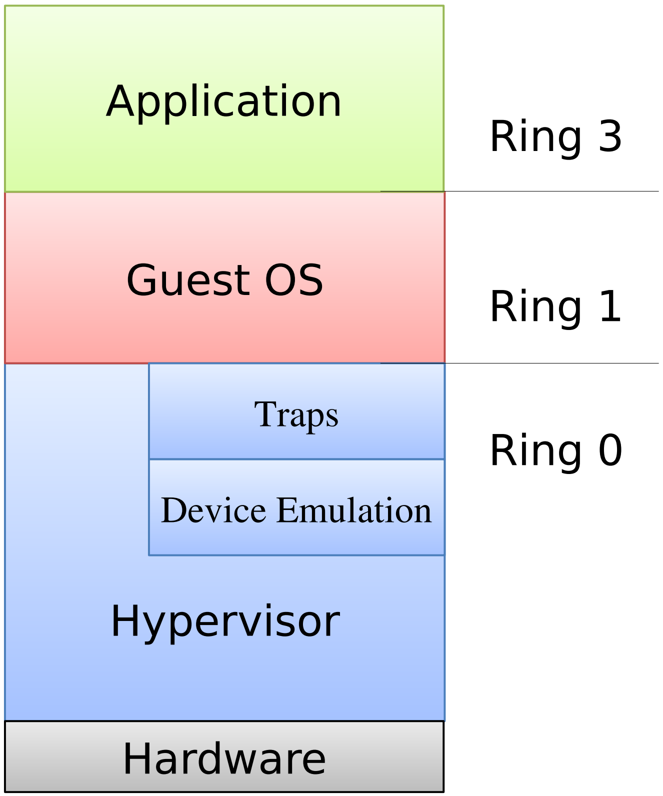
Data Transfer Non-Virtualized X86



1) Application: syscall, e.g., socket.write()
   - Trap into kernel
2) OS driver: issue PCI commands
   - Set up DMA operation
3) NIC:
   - transmit data
   - raise interrupt when done

Option 1: Full Device Emulation

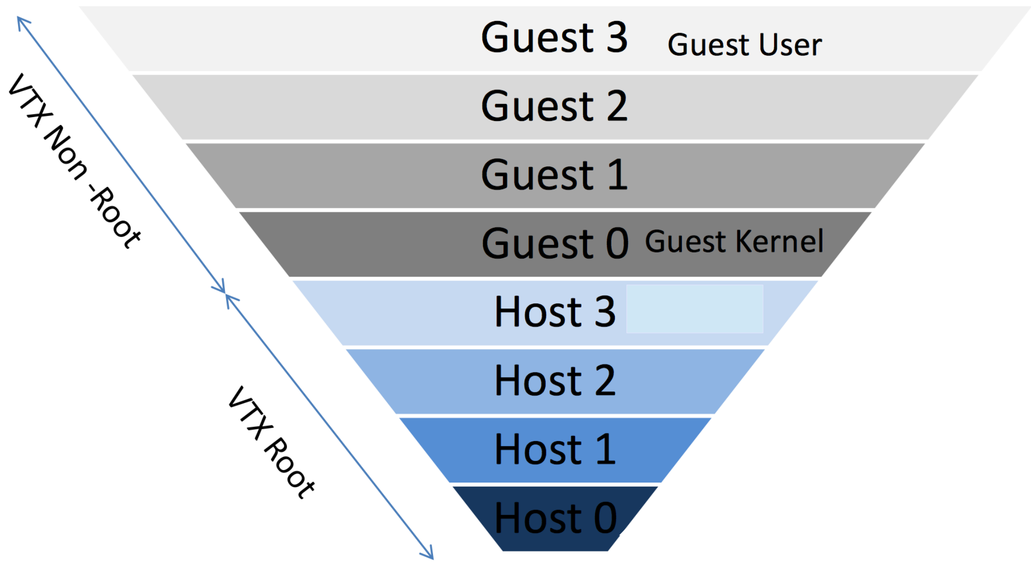
- Guest OS unaware that it is being virtualized
- Hypervisor emulates device at the lowest level
  - Privileged instructions from guest driver trap into hypervisor
- Advantage: no changes to the guest OS required
- Disadvantage:
  - Inefficient
  - Complex

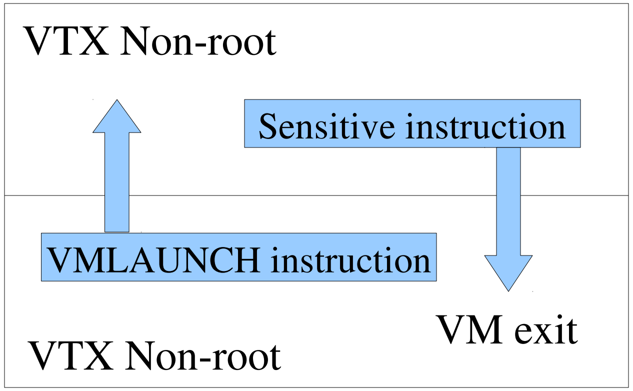


Historical X86 Virtualization Limitations

- Sensitive/privileged instructions when executed in ring 3 may have one of three outcomes:
  1) a fault occurs
  2) the process issues a trap indicating that it wants code in ring 0
  3) Nothing
- Silently failing sensitive instructions make it difficult to implement virtualization

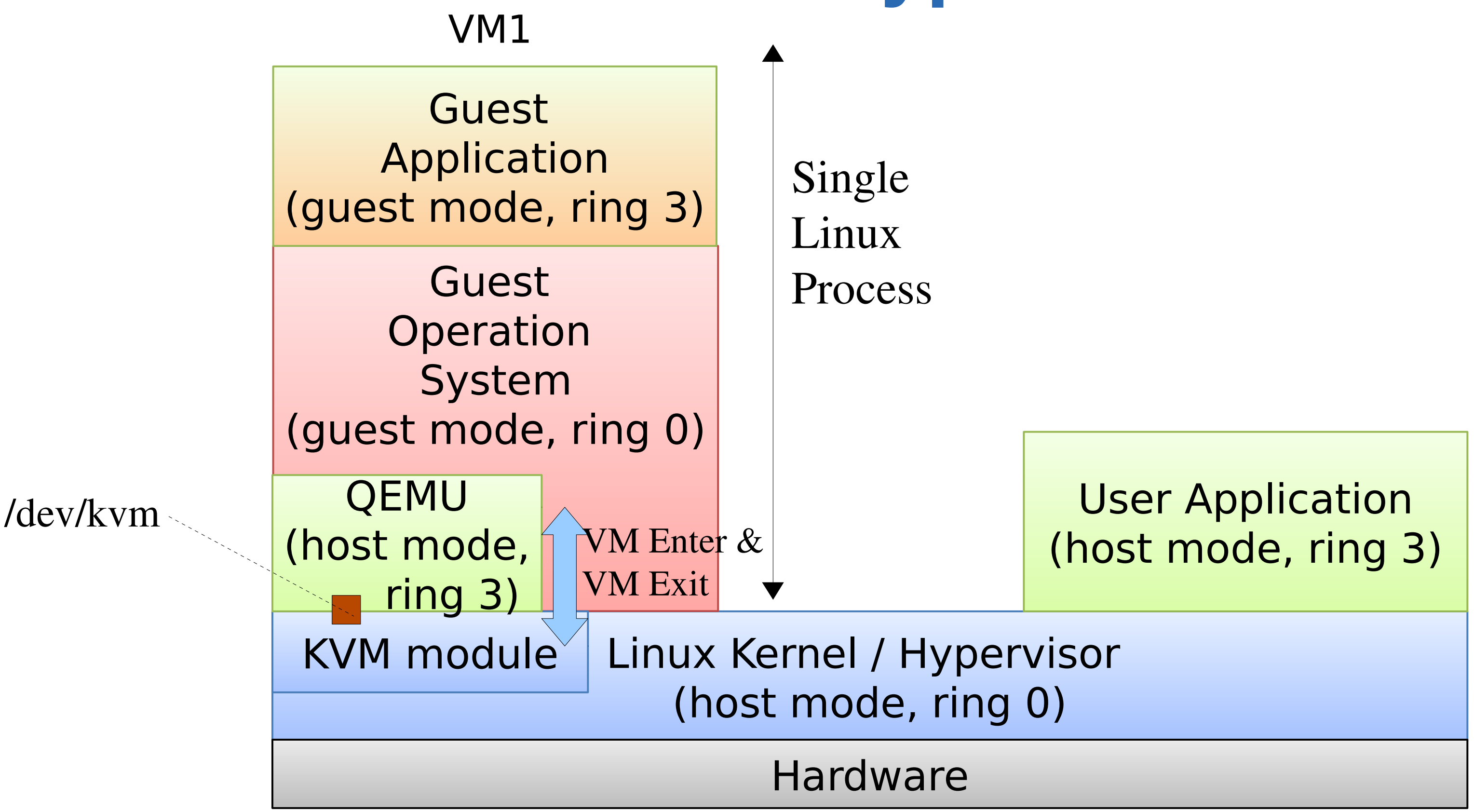
Intel Virtualization Technology VT-x





- Introduces host and guest mode
  - Each with 4 privilege levels
- Protected instructions executed in guest mode, ring 0, generate faults that can be check in host mode

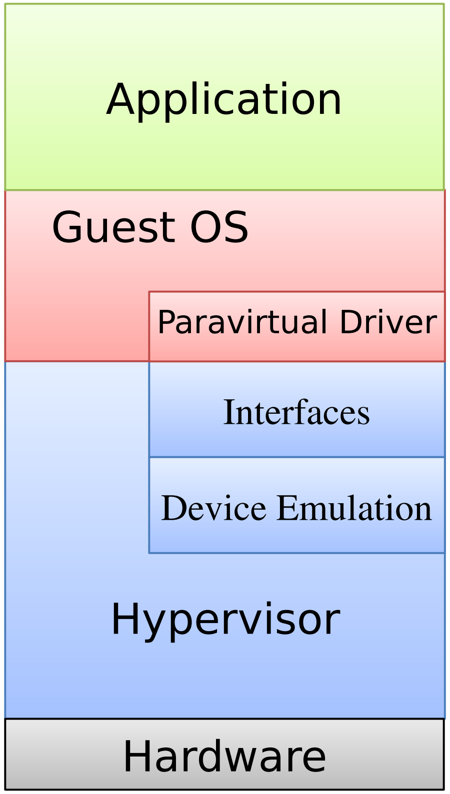
KVM Hypervisor



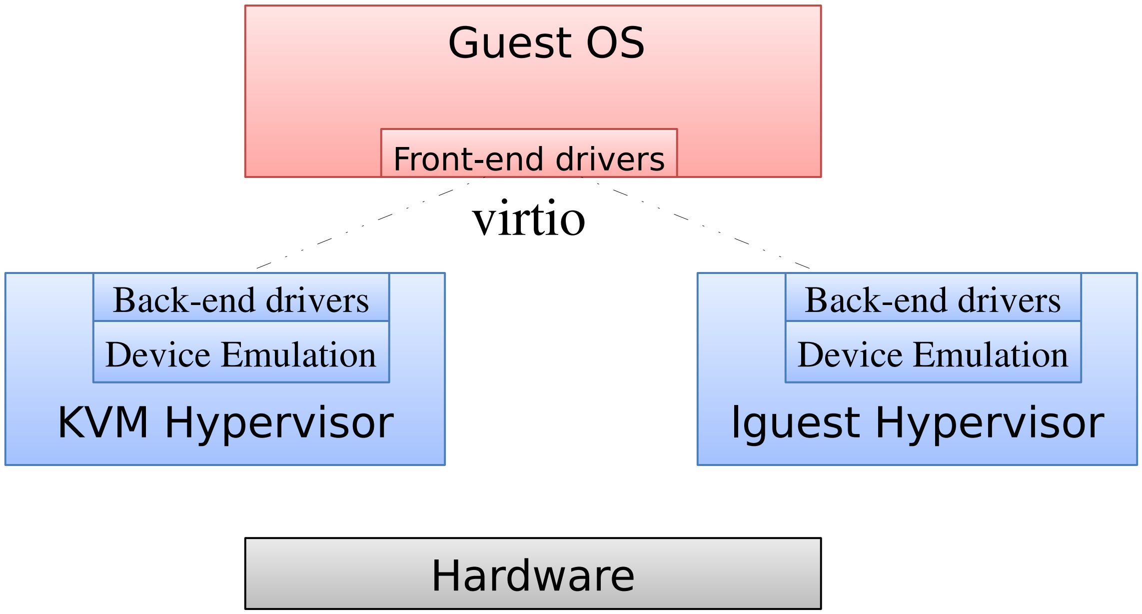
- Starting new guest = starting QEMU process
- QEMU process interacts with KVM through ioctl on /dev/kvm to
  - Allocate memory for guest
  - Start guest in guest mode ring 0
- I/O requests from guest OS trap into KVM (VM exit)
- KVM on VM exits forwards requests to QEMU for emulation
  - Unless its a simple request then it forwards the request to the kernel

Option 2: Paravirtualization

- Guest OS aware that it is being virtualized
  - Runs special paravirtual device drivers
- Hypervisor cooperates with guest OS through paravirtual interfaces
- Advantage:
  - Better performance
  - Simple
- Disadvantage:
  - Requires changes to the guest OS



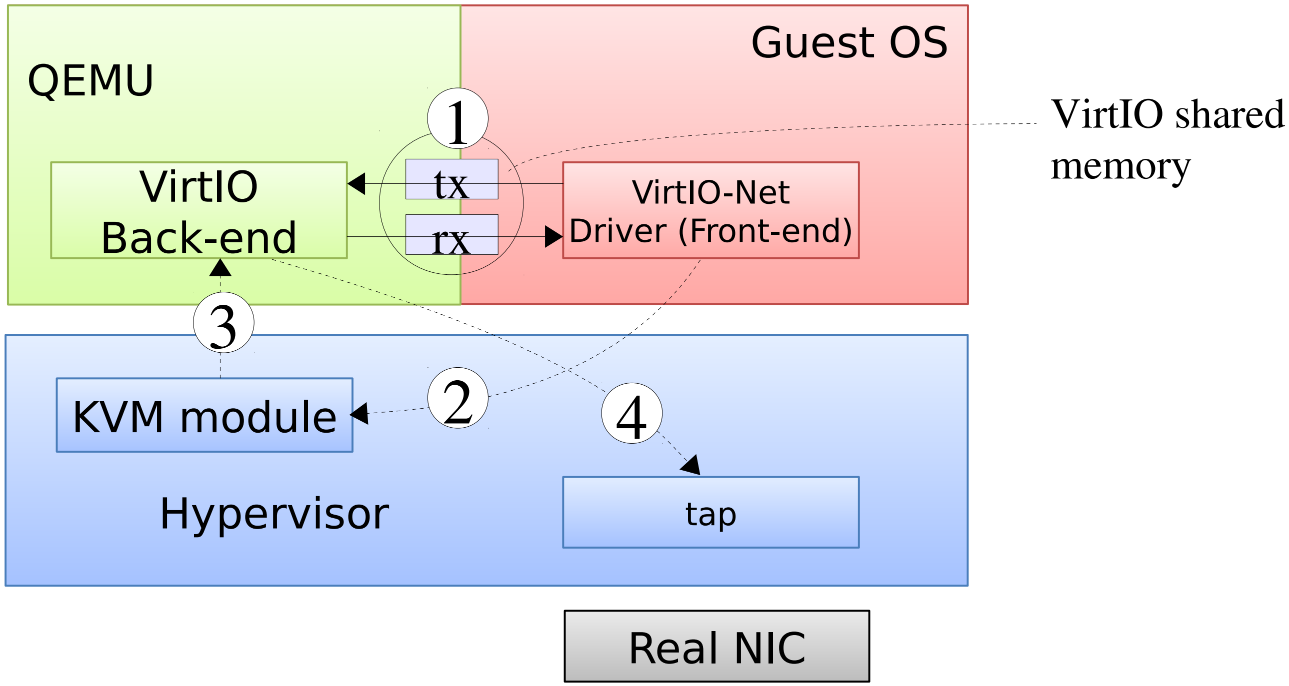
Paravirtualization with VirtIO



- VirtIO: I/O virtualization framework for Linux
  - Framework for developing paravirtual drivers
  - Split driver model: front-end and back-end driver
  - APIs for front-end and back-end to communicate

VirtIO and KVM

Systems@ETH Zürich



1) VirtIO-Net driver adds packet to shared VirtIO memory

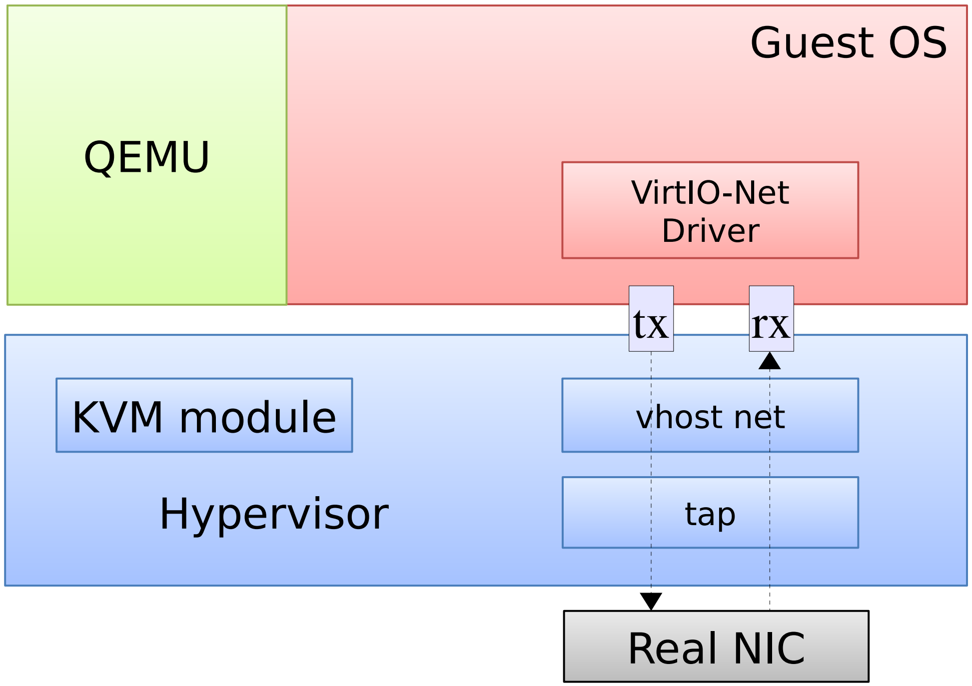
2) VirtIO-Net driver causes trap into KVM

3) KVM schedules QEMU VirtIO Back-end

4) VirtIO back-end gets packet from shared VirtIO memory and emulates I/O (via system call)

5) KVM resumes guest

Vhost: Improved VirtIO Backend



- Vhost puts VirtIO emulation code into the kernel
  - Instead of performing system calls from userspace (QEMU)

Where are we?

- Option 1: Full emulation
  - No changes to guest required
  - Complex
  - Inefficient
- Option 2: Paravirtualization
  - Requires special guest drivers
  - Enhanced performance

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Not good enough! Still requires hypervisor involvement, e.g., interrupt relaying

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- Option 1: Full emulation
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- Option 2: Paravirtualization
  - Requires special guest drivers
  - Enhanced performance
- Option 3: Passthrough
  - Directly assign NIC to VM
  - No hypervisor involvement: best performance

Not good enough!
Still requires
hypervisor
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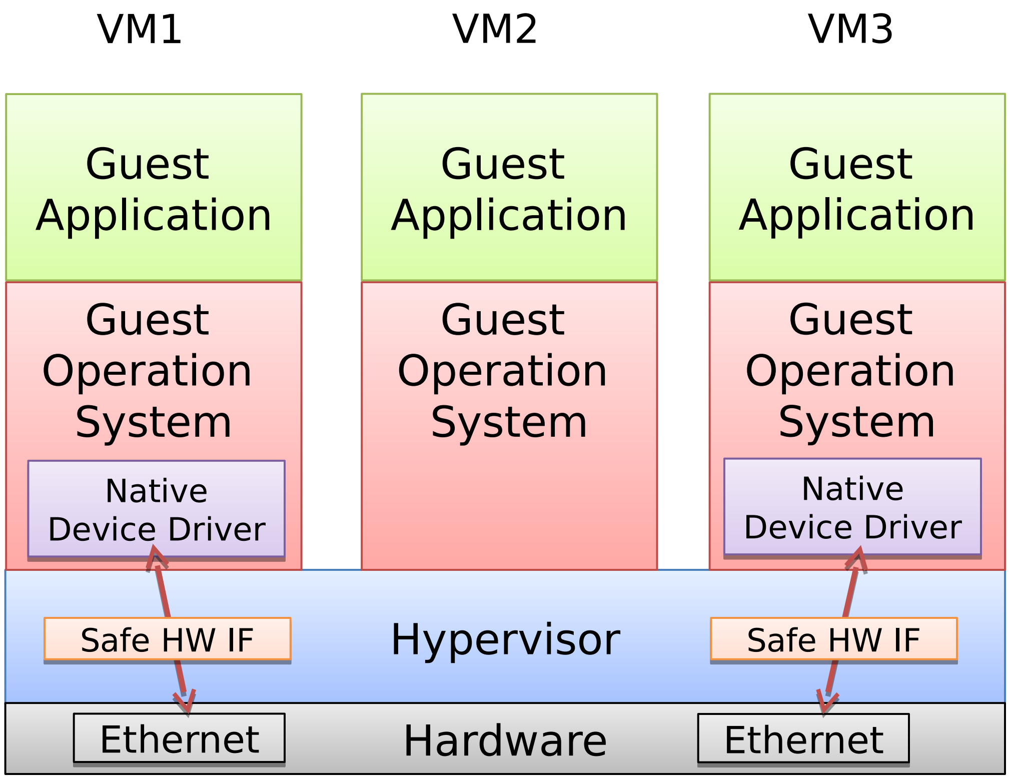
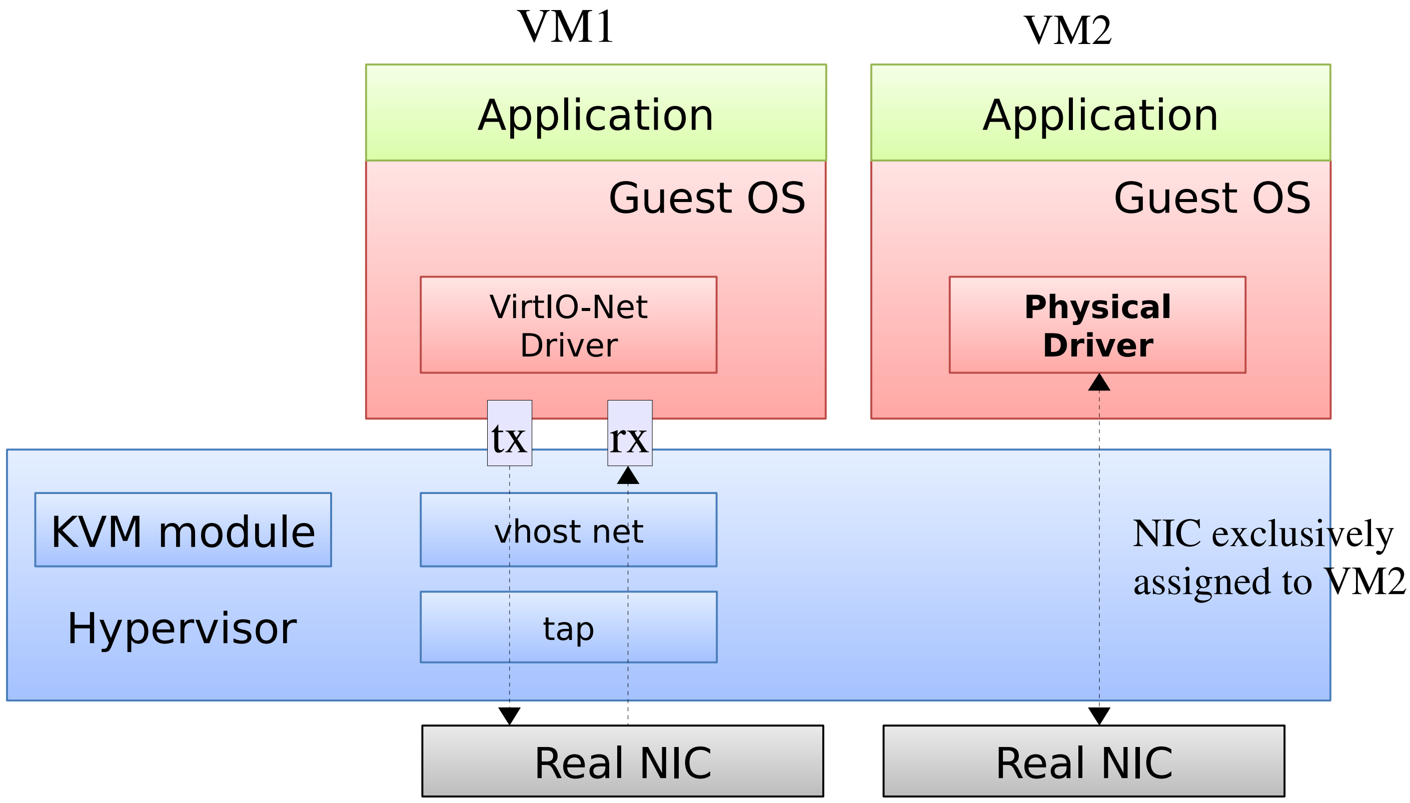
Passthrough / Direct Assignment



Paravirtual vs Passthrough in KVM



Challenges with Passthrough / Direct Assignment

- VM tied to specific NIC hardware
  - Makes VM migration more difficult
- VM driver issues DMA requests using VM addresses
  - Incorrect: VM physical addresses are host virtual addresses (!)
  - Security concern: addresses may belong to other VM
  - Potential solution: let VM translate it's physical addresses to real DMA addresses
    - Still safety problem: exposes driver details to hypervisor, bugs in driver could result in incorrect translations
- Need a different NIC for each VM

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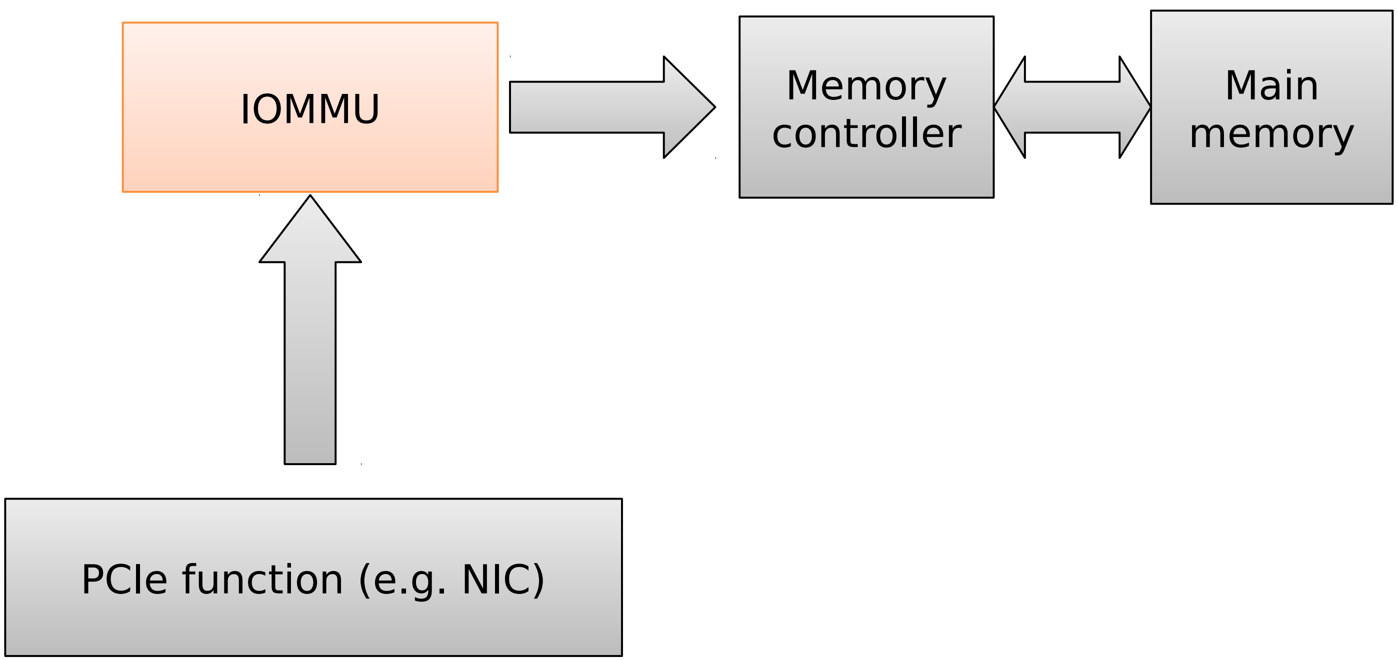
  - Solution: Use an **IOMMU** to translate/validate DMA requests from the device
- Need a different NIC for each VM
  - Solution: **SR-IOV**, emulate multiple NICs at hardware level

Memory Address Terminology

- Virtual Address
  - Address in some virtual address space in a process running in the guest OS
- Physical Address:
  - Hardware address as seen by the guest OS, i.e., physical address in the virtual machine
- Machine address:
  - Real hardware address on the physical machine as seen by the Hypervisor

IOMMU



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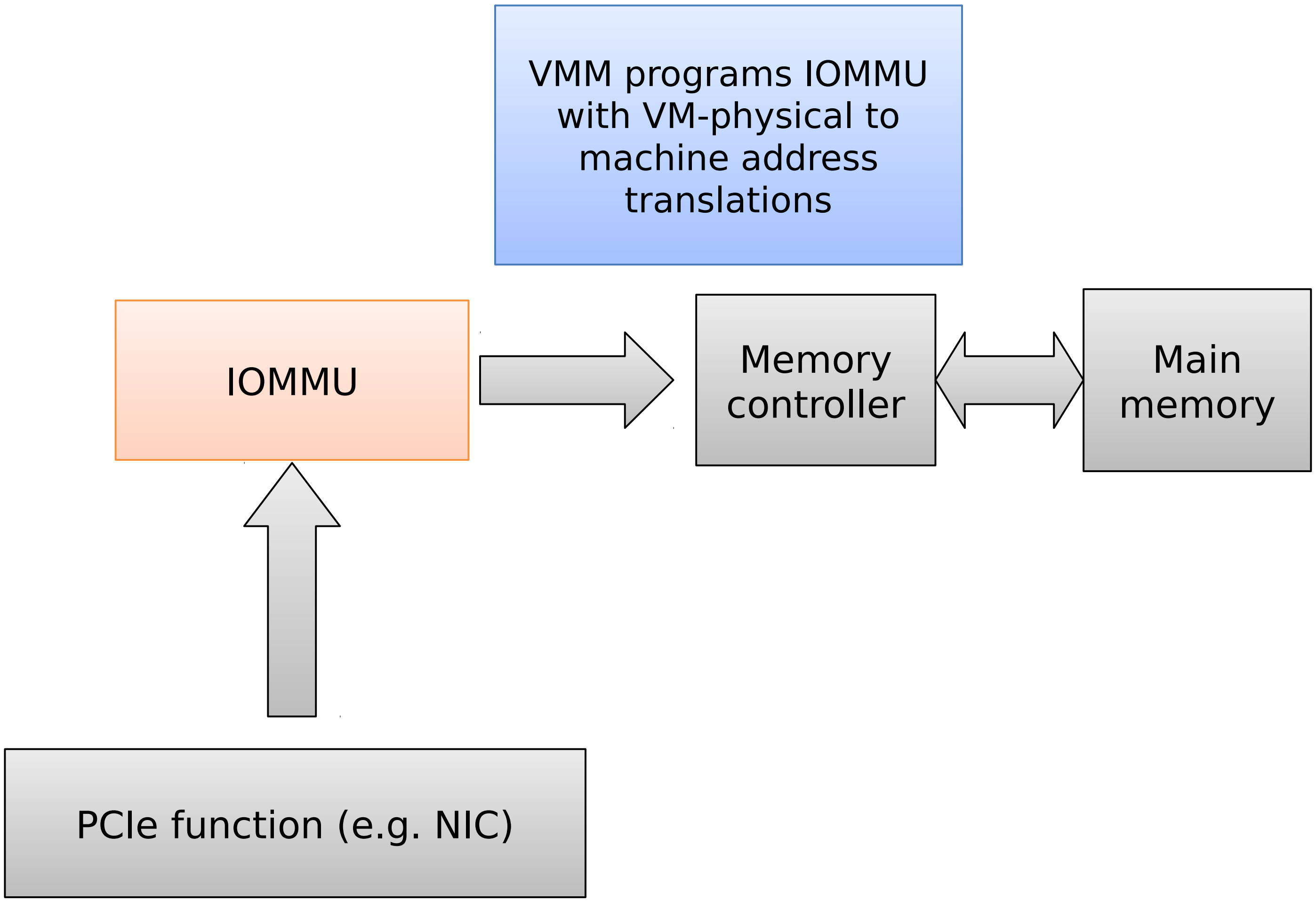
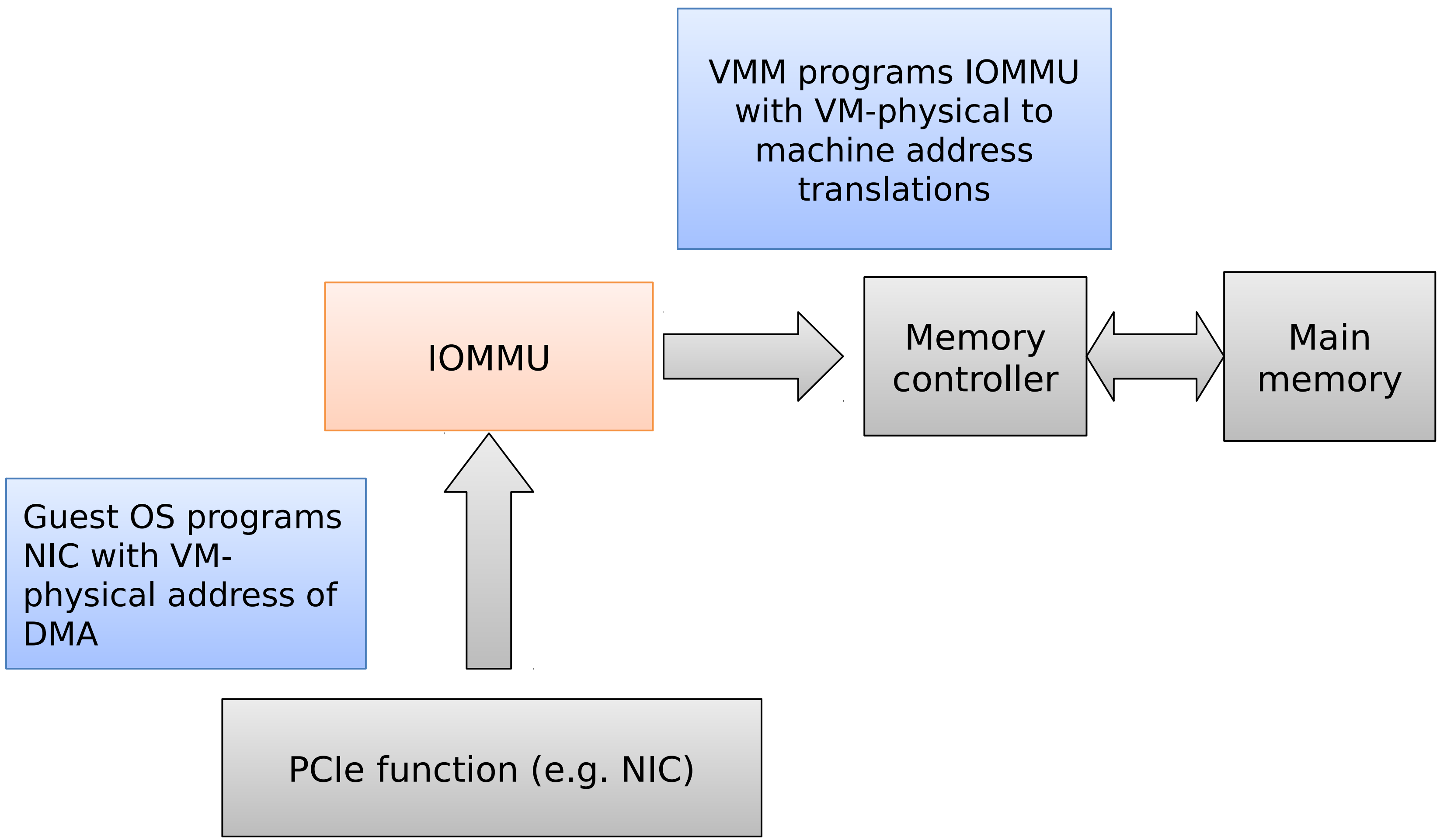

VMM programs IOMMU with VM-physical to machine address translations
IOMMU
Memory controller
Main memory
PCIe function (e.g. NIC)

IOMMU



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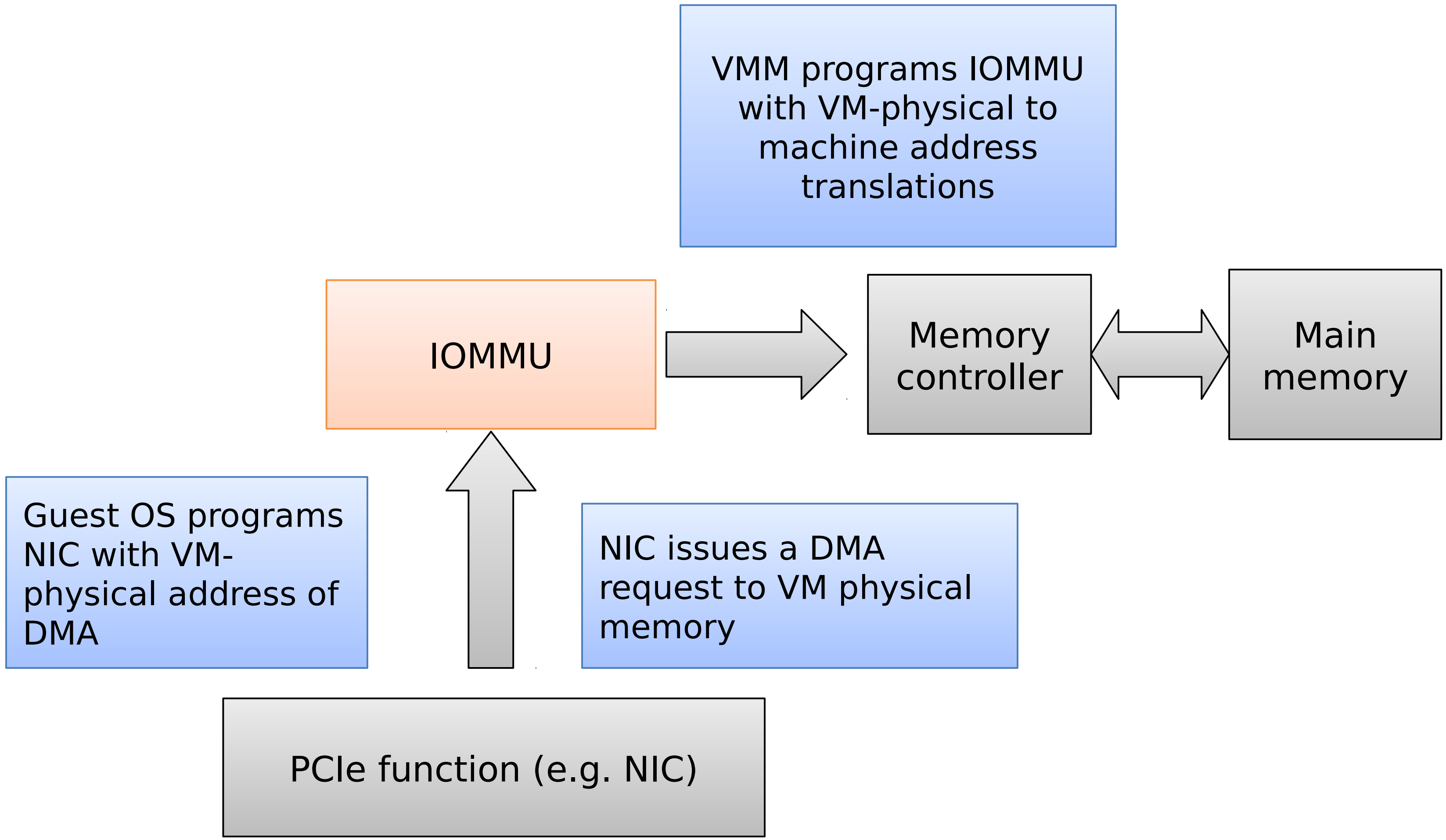
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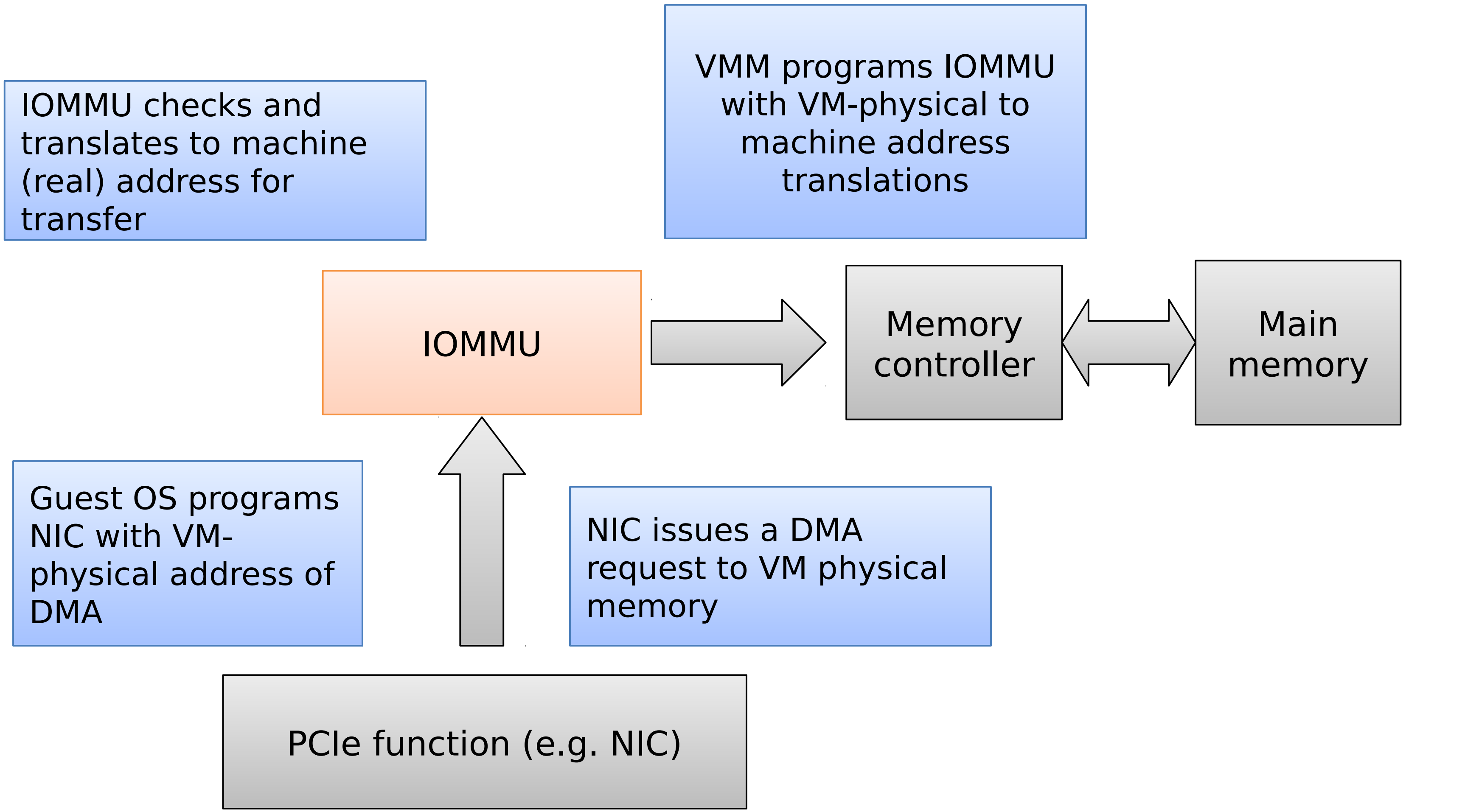
IOMMU checks and translates to machine (real) address for transfer
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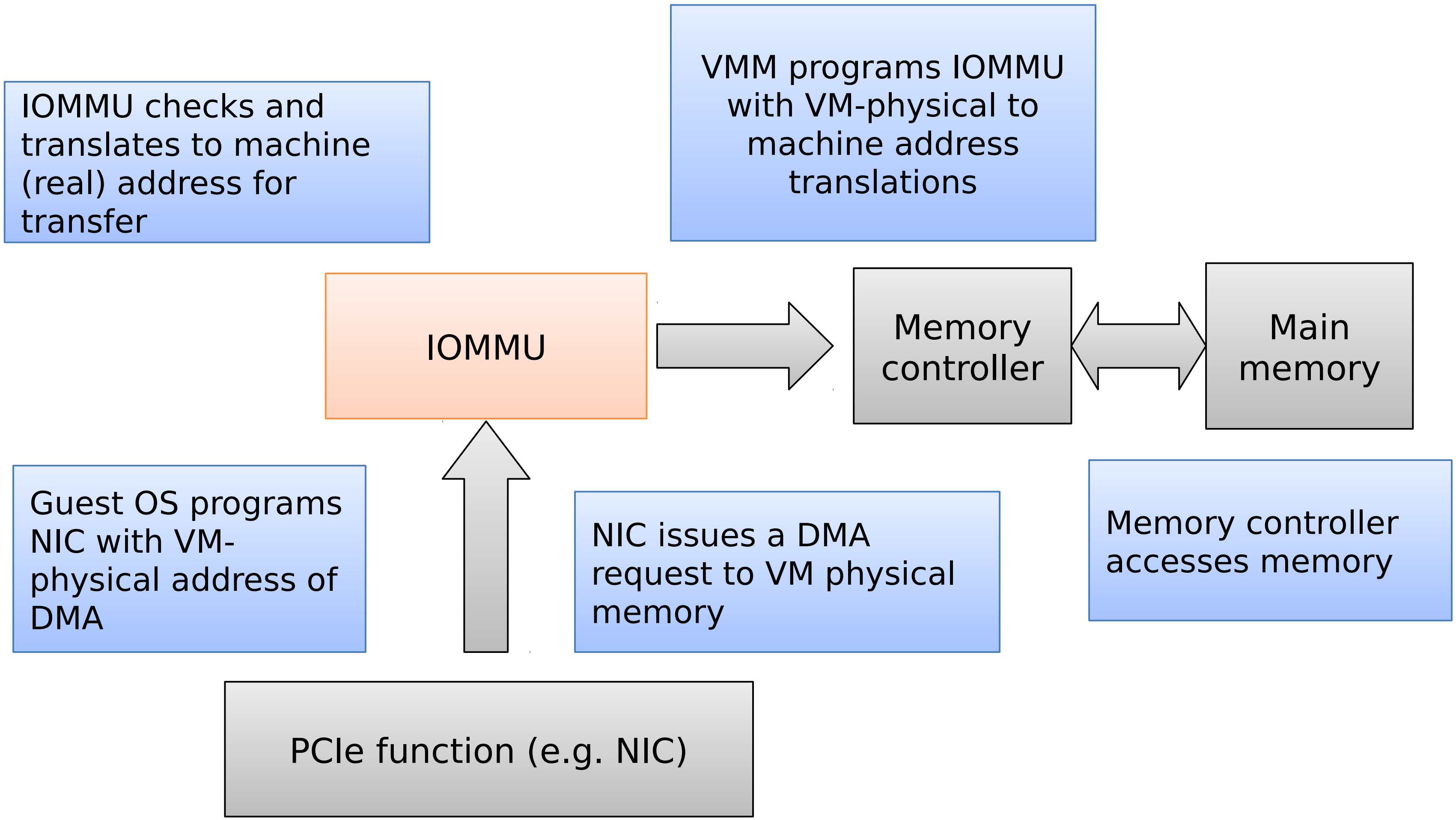

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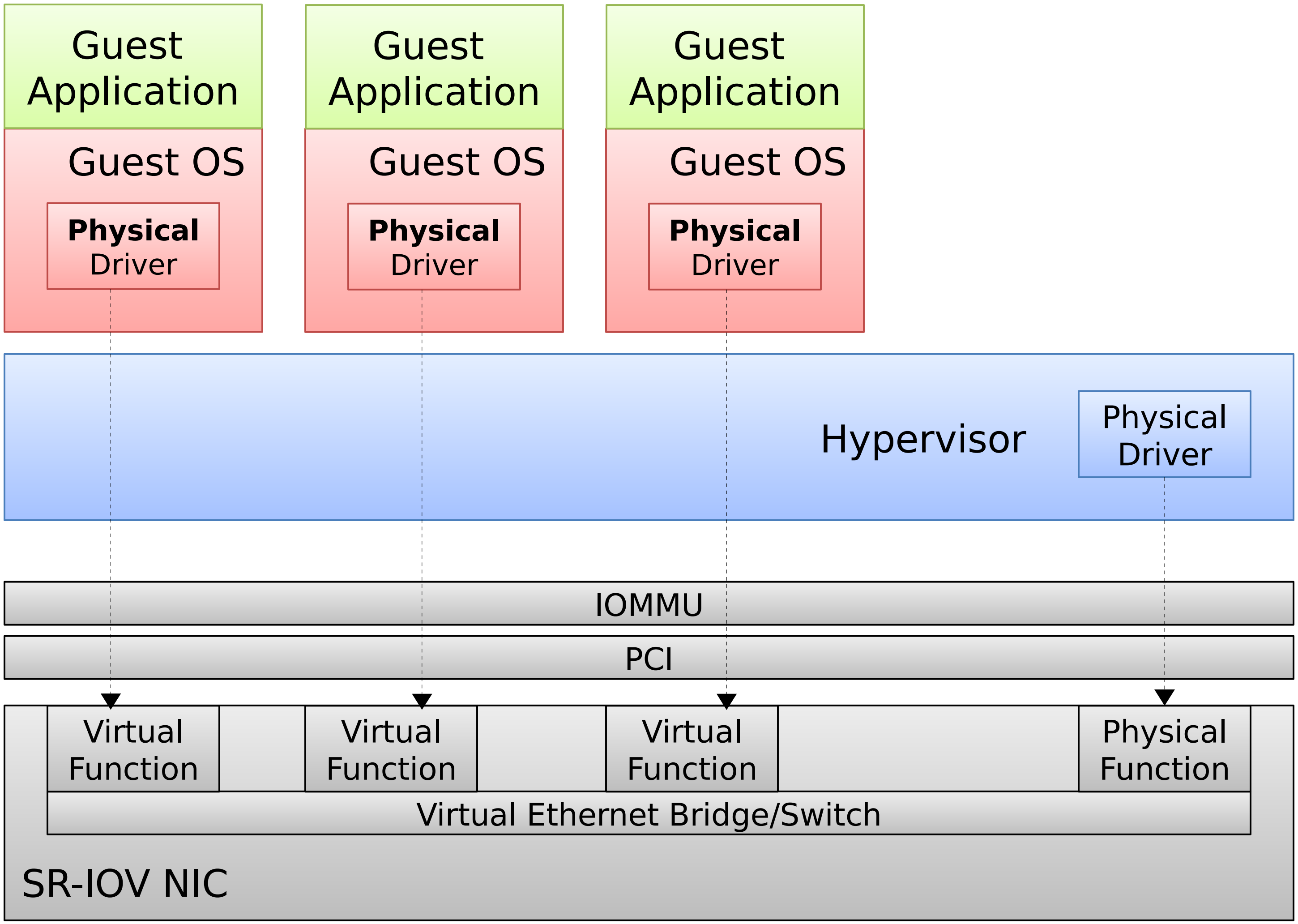
VMM programs IOMMU with VM-physical to machine address translations
IOMMU
Memory controller
Main memory
Guest OS programs NIC with VM-physical address of DMA
NIC issues a DMA request to VM physical memory
Memory controller accesses memory
PCIe function (e.g. NIC)

SR-IOV

- Single-Root I/O Virtualization
- Key idea: dynamically create new “PCI devices”
  - Physical Function (PF): original device, full functionality
  - Virtual Function (VF): extra device, limited functionality
  - VFs created/destroyed via PF registers
- For Networking:
  - Partitions a network card's resources
  - Direct assignment of VF to VM to implement passthrough

SR-IOV in Action



SolarFlare SFN6122F

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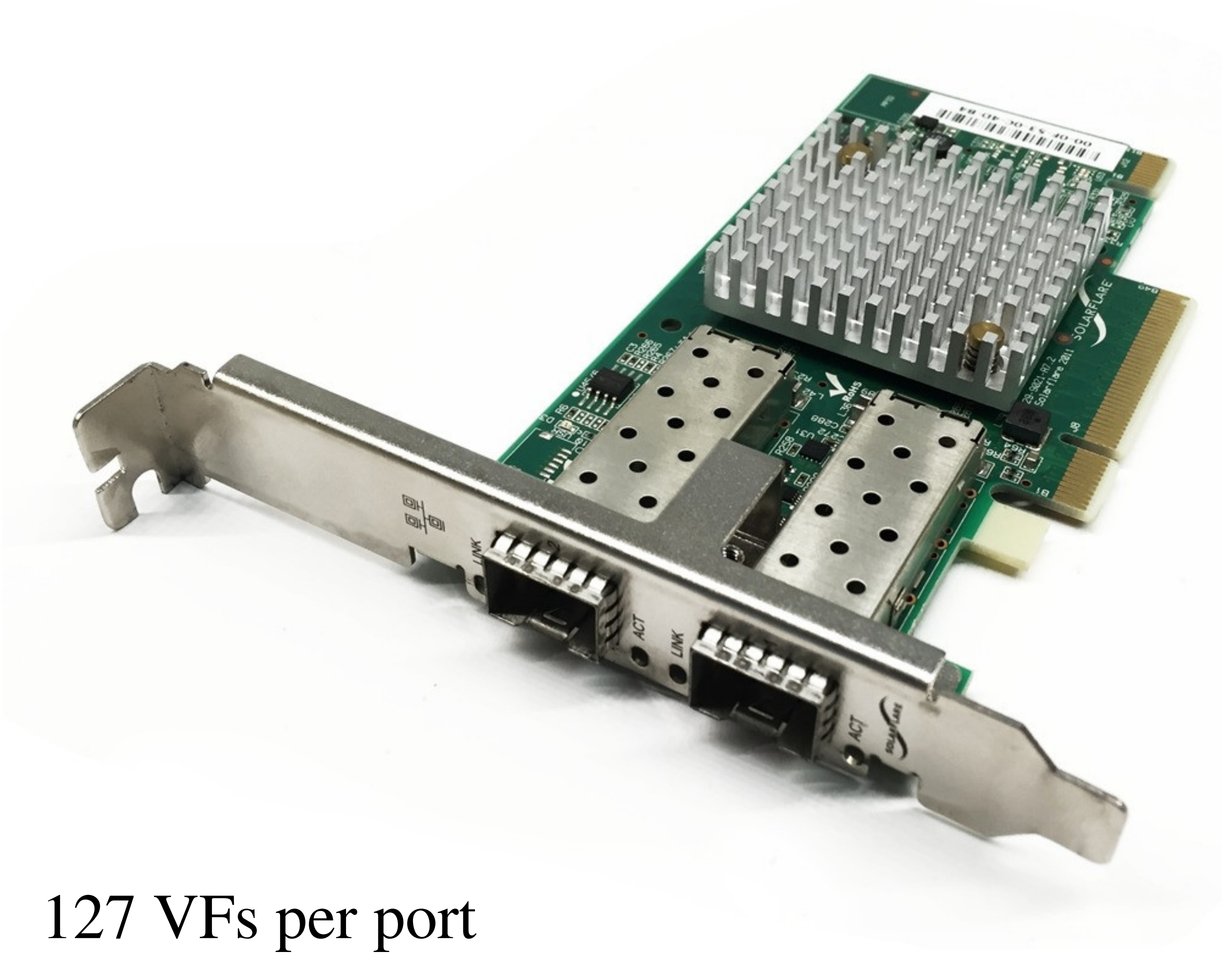
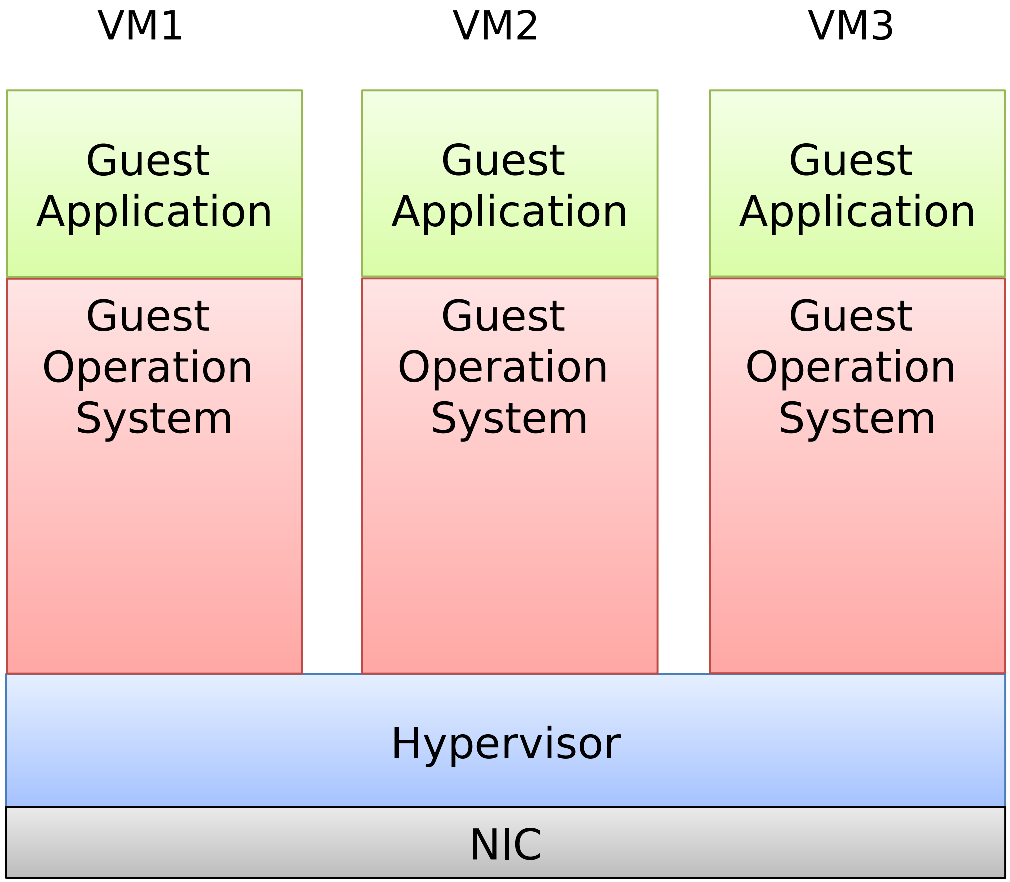


127 VFs per port

Inter-VM communication



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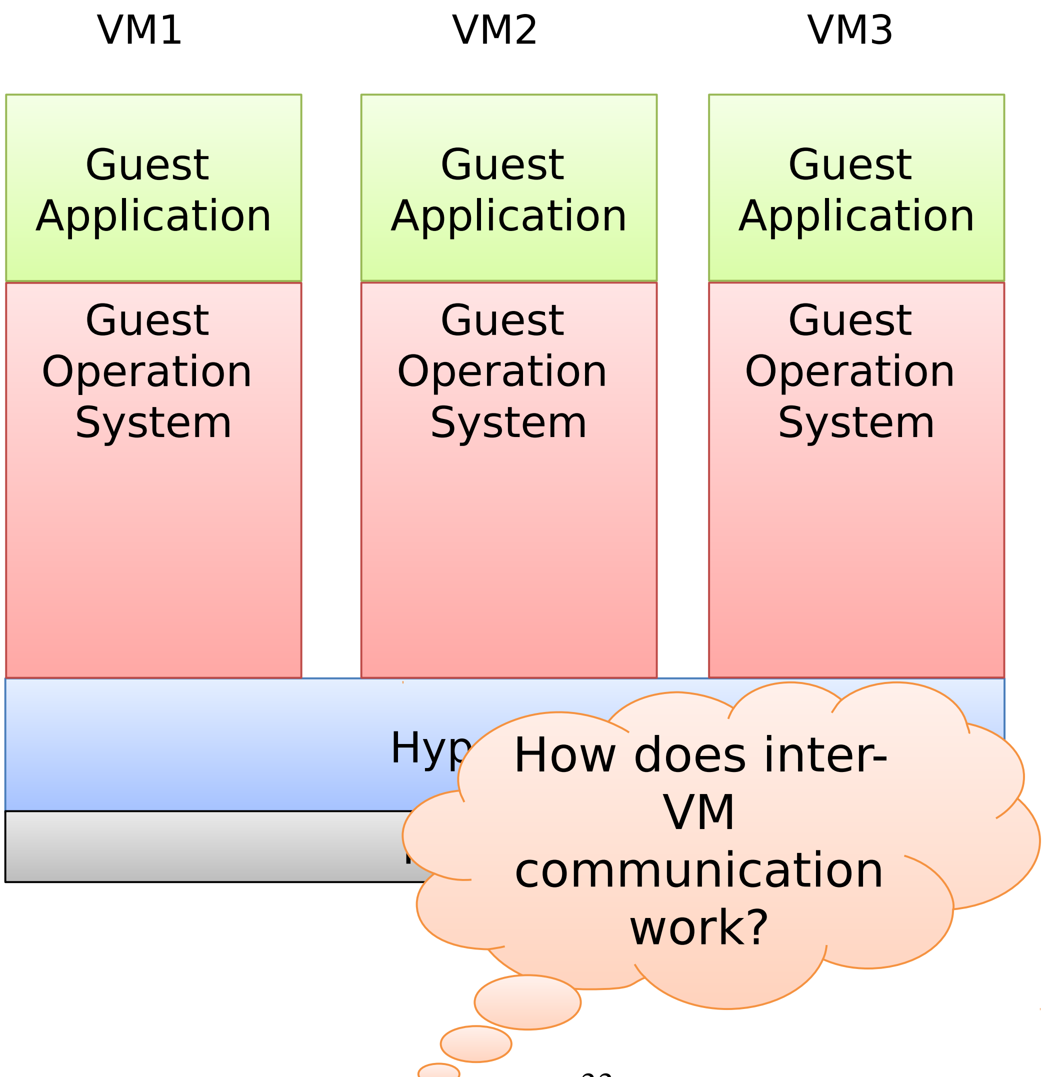
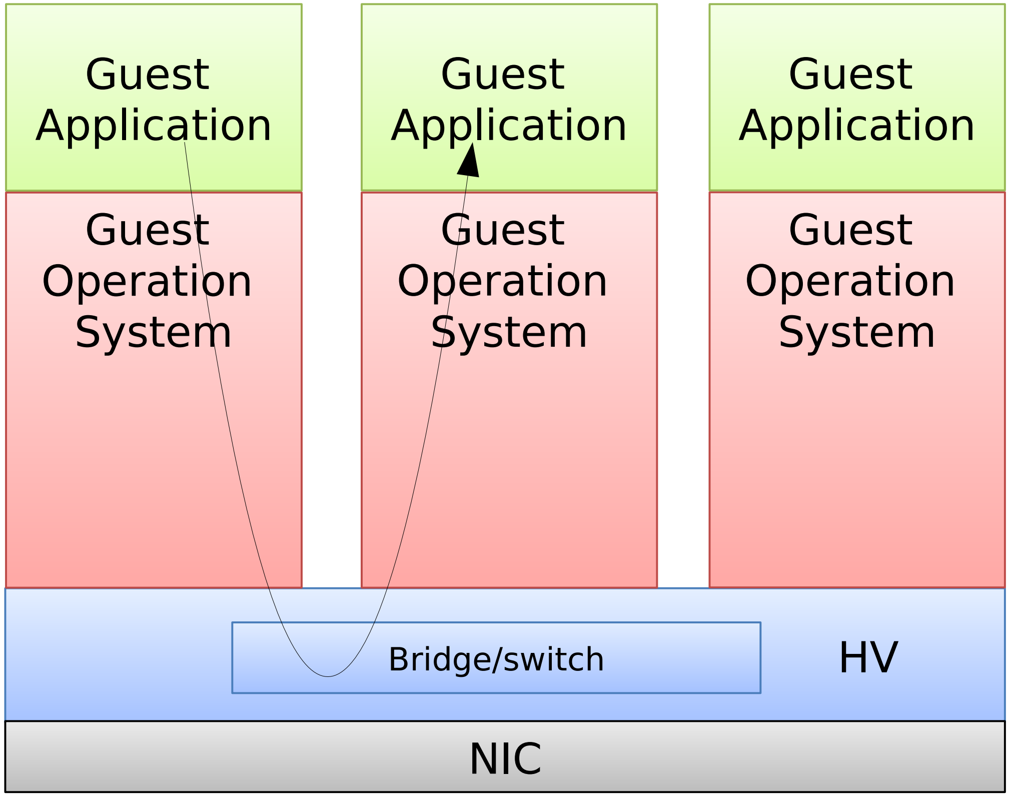


Switch in Hypervisor



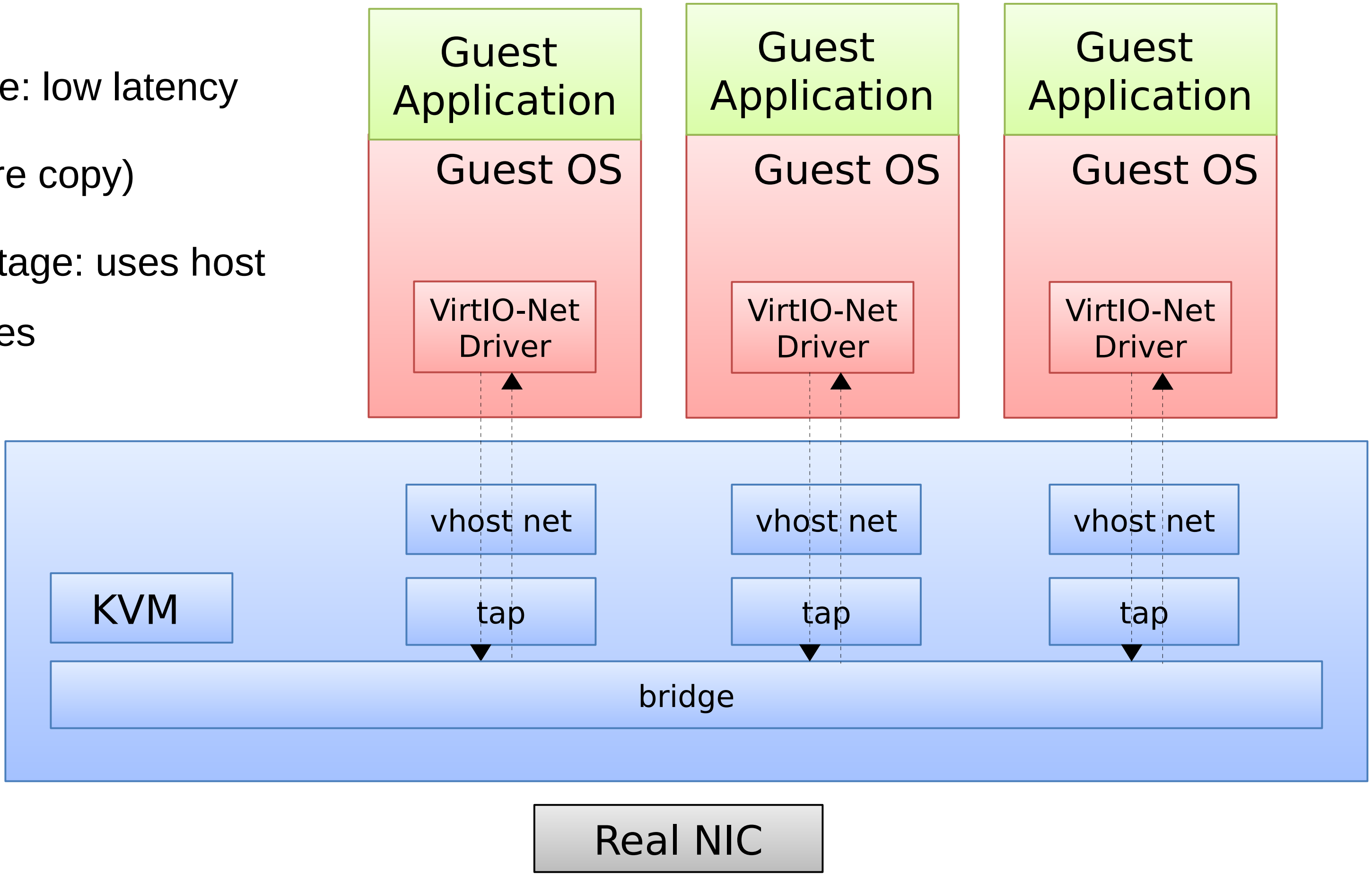
Switched Vhost in KVM

- Advantage: low latency

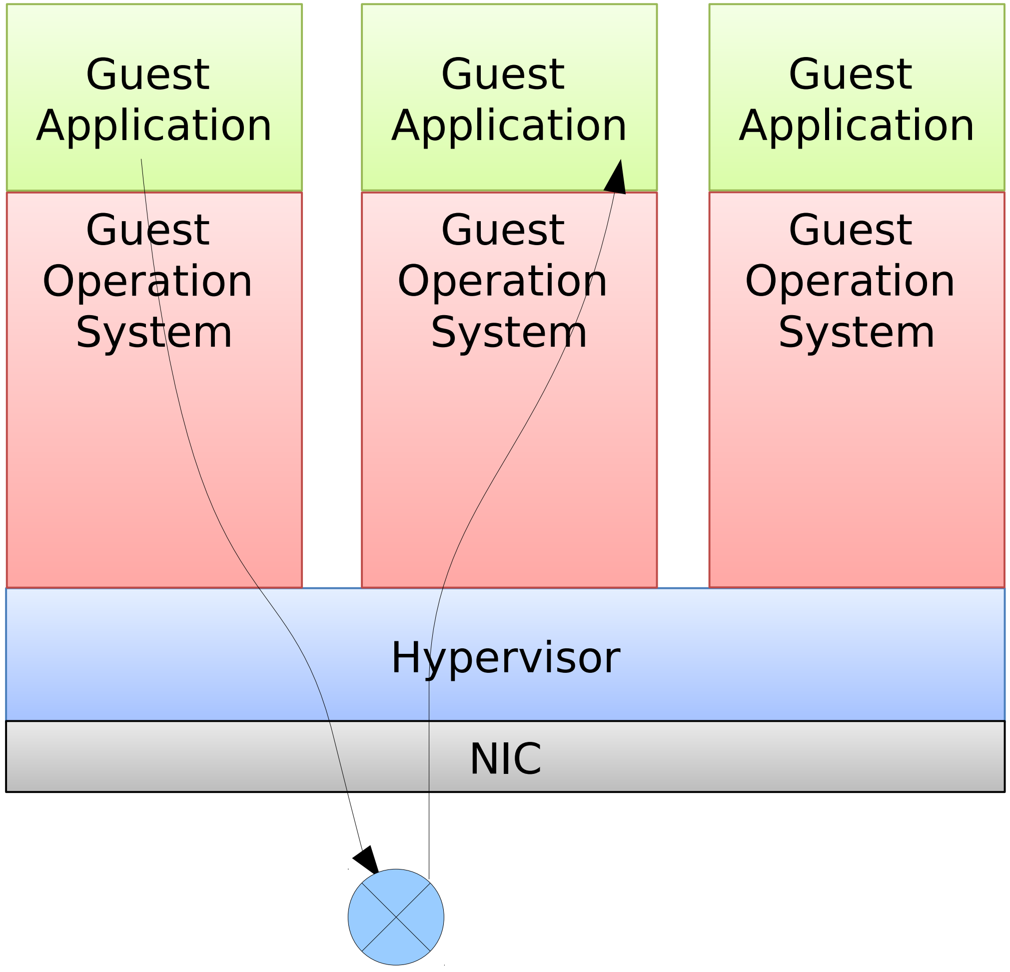
  (1 software copy)

- Disadvantage: uses host

  CPU cycles



Switch Externally...



...either in

- External switch:
  - Simplifies configuration: all switching controlled/configured by the network
  - Latency = 2xDMA + 2hops
- NIC
  - Latency = 2xDMA

Controversial

- External switching in NIC or Switch
  - Extra latency
  - Reduces CPU requirements
  - Hardware vendors like it
  - Better TCAMs on the switch
  - Integration with network management policies

- Software switching in hypervisor
  - Lower latency
  - Higher CPU consumption. But software switches got more efficient over the last years
  - CPU resources are generic and flexible
  - Easy to upgrade
  - Fully support OpenFlow

Moral

- Network interface cards traditionally are the "end point"
- Virtualization may add two more hops
  - Virtual switch in the NIC
  - Virtual switch in the hypervisor
- Inside of a physical machine increasingly resembles a network

References

- I/O Virtualization, Mendel Rosenblum, ACM Queue, January 2012
- Kernel-based Virtual Machine Technology, Yasunori Goto, Fujitsu Technical Journal, July 2011
- VirtIO: Towards a De-Facto Standard For Virtual I/O Devices, Rusty Russel, ACM SIGOPS Operating Systems Review, July 2008