



Education

PCI Express Impact on Storage Architectures and Future Data Centers

Ron Emerick, Oracle Corporation

Author: Ron Emerick, Oracle Corporation

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PCI Express Impact on Storage Architectures and Future Data Centers

- PCI Express Gen2 and Gen3, IO Virtualization, FCoE, SSD are here or coming soon. Discussions about PCI Express Storage Devices – what are they? This session describes PCI Express, Single Root and Multi Root IOV and the implications on FCoE, SSD and impacts of all these changes on storage connectivity, storage transfer rates. The potential implications to the Storage Industry and Data Center Infrastructure will also be discussed. This tutorial will provide the attendee with:
 - ◆ Knowledge of PCIe Architecture, PCIe Roadmap, System Root Complexes and IO Virtualization
 - ◆ Expected Industry Roll Out of latest IO Technology and required Root Complex capabilities
 - ◆ Implications and Impacts of FCoE, SSD and IO to storage Connectivity
 - ◆ IO Virtualization connectivity possibilities in the Data Center (via PCI Express)
 - ◆ What does the 2020 & 2025 Data Center look like?

- **IO Architectures**
 - ◆ PCI Express is Here to Stay
 - ◆ PCI Express Tutorial
 - ◆ New PCI Express based architectures
 - ◆ How does PCI Express work
- **IO Evolving Beyond the Motherboard**
 - ◆ Serial Interfaces
 - › InfiniBand, 10 GbE, 40 GbE, 100 GbE
 - › PCIe IO Virtualization
 - ◆ Review of PCI Express IO Virtualization
 - ◆ Impact of PCI Express on Storage

I/O Architecture

- **PCI was introduced in 1996**
 - ◆ Peripheral Component Interconnect
 - ◆ Parallel interface
 - ◆ Standard interface for peripherals – HBA, NIC etc
 - ◆ Many man years of code developed based on PCI
 - ◆ Would like to keep this software investment
- **Performance keeps pushing IO interface speed**
 - ◆ PCI/PCI-X 33 Mhz, 66 Mhz to 133 Mhz
 - ◆ PCI-X at 266 Mhz (DDR) released in 2003
 - › Problems at PCI-X 512 Mhz (QDR) with load and trace length
- **PCI Express introduced in 2004**

PCI Express Introduction

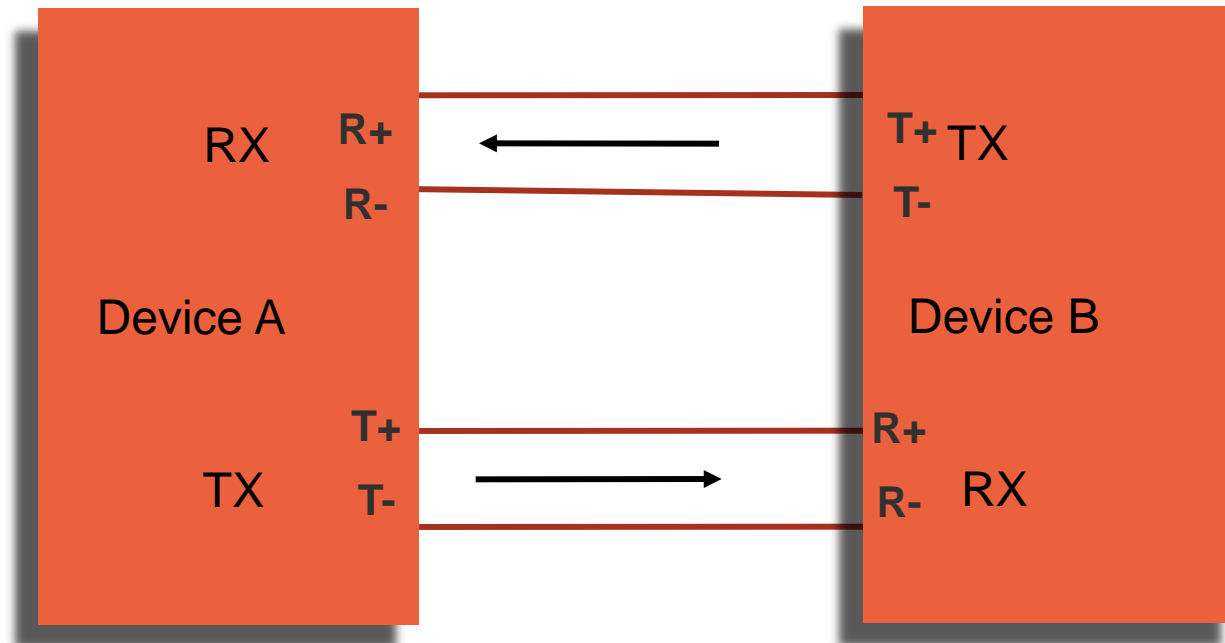
- PCI Express Architecture is a high performance, IO interconnect for peripherals in computing/ communication platforms
- Evolved from PCI and PCI-X™ Architectures
 - ◆ Yet PCI Express architecture is significantly different from its predecessors PCI and PCI-X
- PCI Express is a serial point- to- point interconnect between two devices (4 pins per lane)
- Implements packet based protocol for information transfer
- Scalable performance based on the number of signal Lanes implemented on the interconnect

PCI Express Overview

- **Uses PCI constructs**
 - ◆ Same Memory, IO and Configuration Model
 - ◆ Identified via BIOS, UEFI, OBP
 - ◆ Supports growth via speed increases
- **Uses PCI Usage and Load/ Store Model**
 - ◆ Protects software investment
- **Simple Serial, Point- to- Point Interconnect**
 - ◆ Simplifies layout and reduces costs
- **Chip- to- Chip and Board-to-Board**
 - ◆ IO can exchange data
 - ◆ System boards can exchange data
- **Separate Receive and Transmit Lanes**
 - ◆ 50% of bandwidth in each direction

PCIe What's A Lane

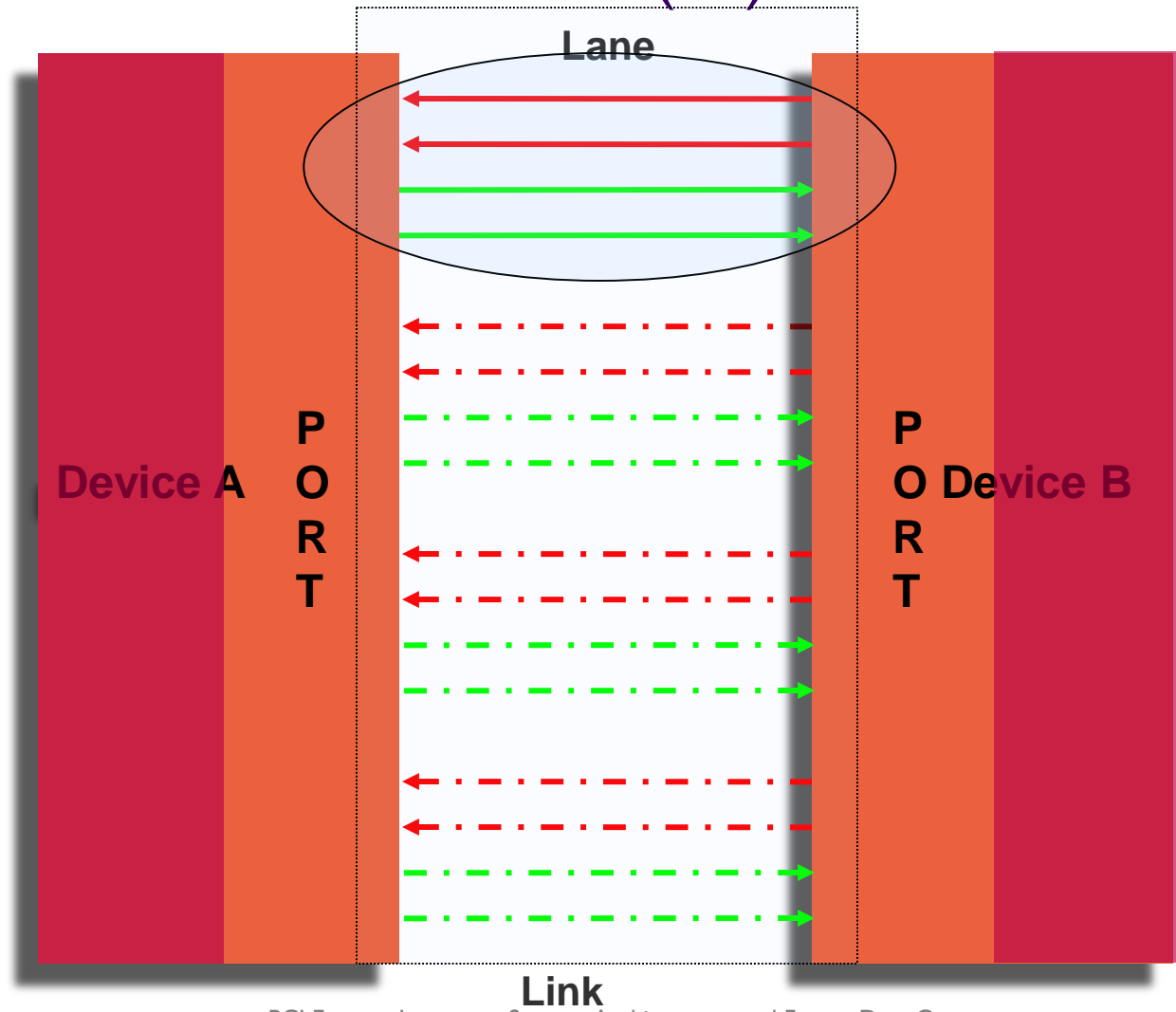
Point to Point Connection Between Two PCIe Devices



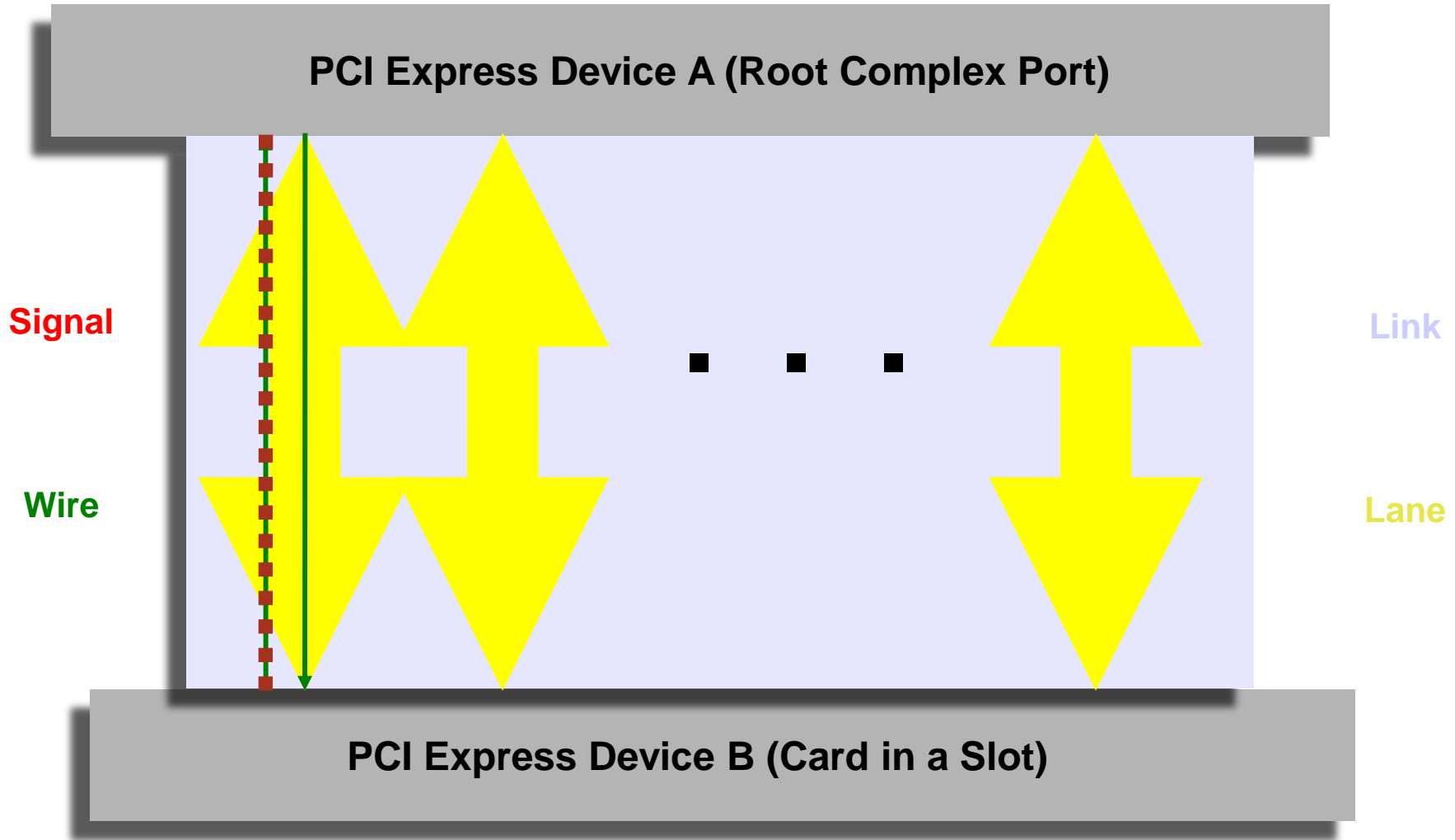
This Represents a Single Lane Using Two Pairs of Traces,
TX of One to RX of the Other

PCIe – Multiple Lanes

Links, Lanes and Ports – 4 Lane (x4) Connection



PCI Express Terminology



Transaction Types

Requests are translated to one these types by the Transaction Layer:

- **Memory Read or Memory Write**
 - ◆ Used to transfer data to or from a memory mapped location. Protocol also supports a locked memory read transaction variant.
- **IO Read or IO Write**
 - ◆ Used to transfer data to or from an IO location
 - ◆ These transactions are restricted to supporting legacy endpoint devices.
- **Configuration Read or Configuration Write:**
 - ◆ Used to discover device capabilities, program features, and check status in the 4KB PCI Express configuration space.
- **Messages**
 - ◆ Handled like posted writes. Used for event signalling and general purpose messaging.

PCI Express Throughput

Link Width		X1	X2	X4	X8	X16	X32
Aggregate BW (Gbytes/s)	Gen1 (2004)	0.5	1	2	4	8	16
	Gen2 (2007)	1	N/A	4	8	16	32
	Gen3 (2010)	2	N/A	8	16	32	64

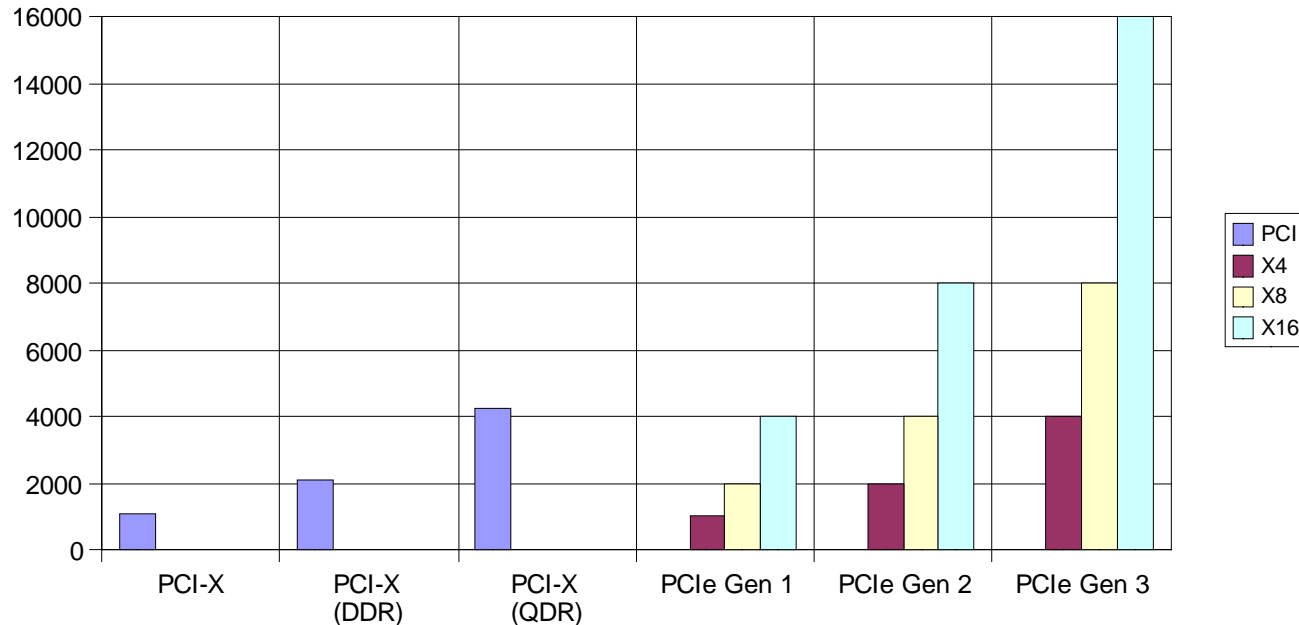
- Assumes 2.5 GT/sec signalling for Gen1
- Assumes 5 GT/sec signalling for Gen2
 - ◆ 80% BW available due to 8 / 10 bit encoding overhead
- Assumes 8 GT/sec signalling for Gen3

Aggregate bandwidth implies simultaneous traffic in both directions
Peak bandwidth is higher than any bus available

PCI-X vs PCIe Throughput

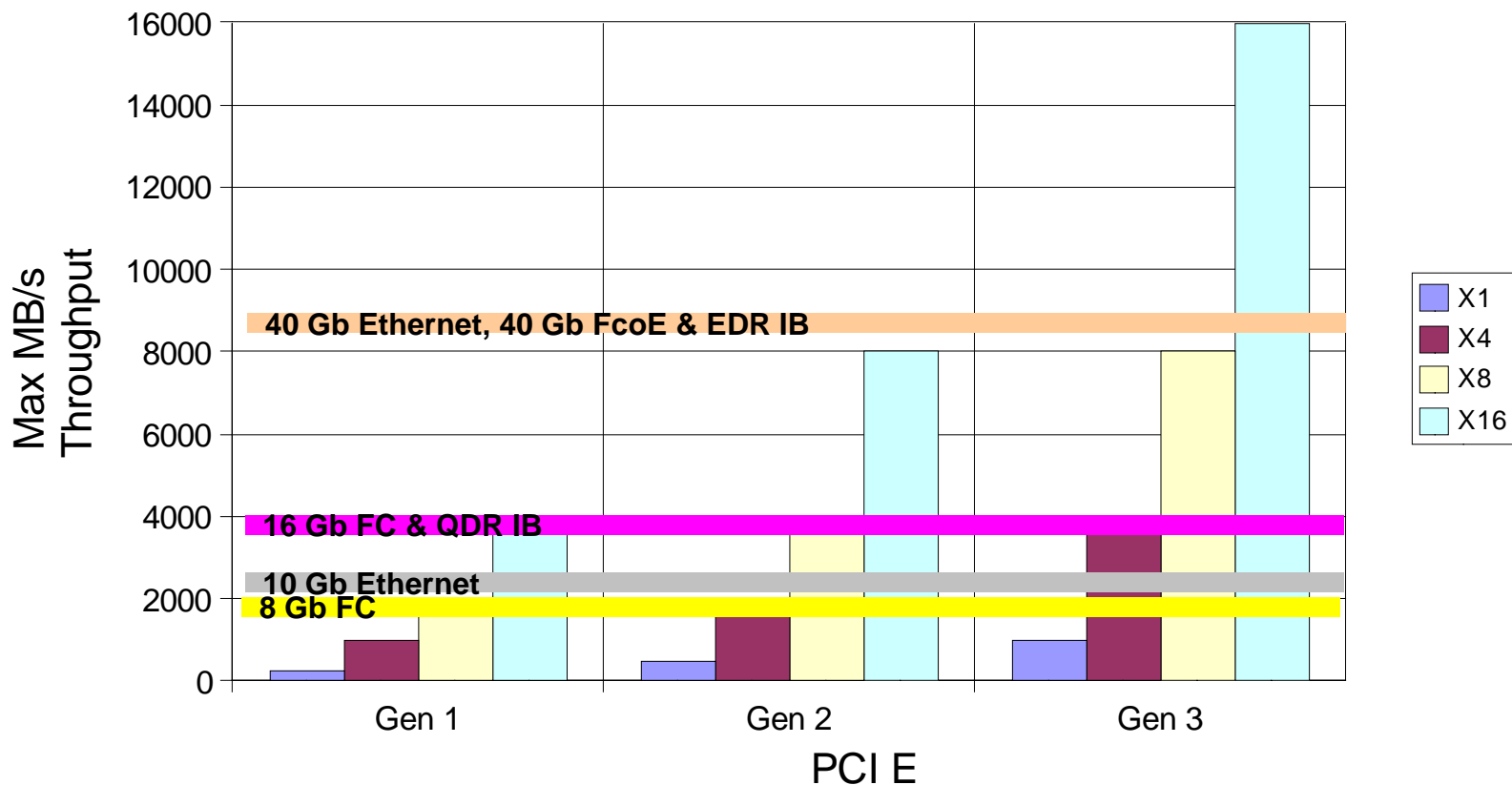
How does PCI-X compare to PCI Express?

PCI-X vs PCI Express

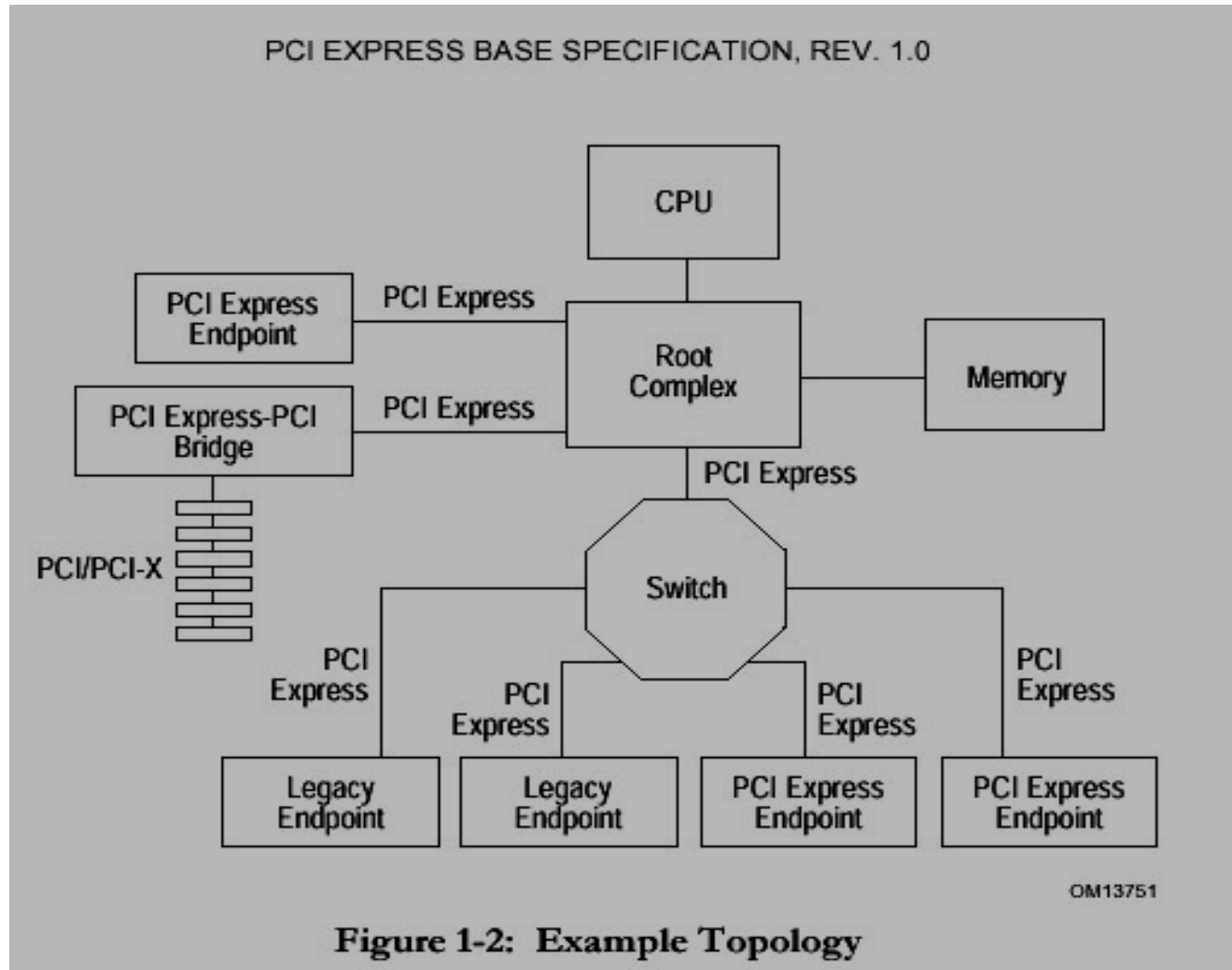


- PCI-X QDR maxs out at 4263 MB/s per leaf
- PCIe x16 Gen1 maxs out at 4000 MB/s (4 GB/s)
- PCIe x16 Gen3 maxs out at 16000 MB/s (16 GB/s)

PCI Express Bandwidth



Sample PCI Express Topology



PCI Express at the SIG (Gen 1)

- PCIe Gen 1.1
 - ◆ Approved 2004/2005
 - › Frequency of 2.5 GT/s per Lane Full Duplex (FD)
 - › Use 8/10 Bit Encoding => 250 MB/s/lane (FD)
 - › $2.5 \text{ GT} @ 1 \text{ bit/T} * 8/10 \text{ encoding} / 8 \text{ bit/byte} = 250 \text{ MB/s FD}$
 - › PCIe Overhead of 20% yields 200 MB/s/lane (FD)
 - › Replace PCI-X DDR and QDR Roadmap
 - › Defined Switches, Bridges and Devices
 - › x16 High Performance Graphics @ 50W (then 75W)
 - › x8, x4, x1 Connectors
 - › (x8 is pronounced as by 8)
 - › Support your lane width and all lower lane widths
 - › Defined Express Module

PCI Express In Industry

- **PCIe Gen 2.0 Shipped in 2008**
 - ◆ Approved 2007
 - › Frequency of 5.0 GT/s per Lane
 - › Doubled the Theoretical BW to 500 MB/s/lane 4 GB per x8
 - › Still used 8/10 bit encoding
 - › Support for Genesco features added (details later)
 - › Power for x16 increased to 225W
 - ◆ Desktop systems started Gen2 x16 slots in Q4 2007
 - ◆ Servers shipping slots 2009
- **Cards Available**
 - ◆ x4, x8 cards – Single/Dual 10 GbE, Dual/Quad GbE, Single/Dual 10 Gb CNA, Single/Dual 4/8 Gb FC, SAS 2.0, IB QDR, Serial Cards, Other Special Cards
 - ◆ x16 High Performance Graphics @ 150W and more
 - ◆ Old PCI technology behind PCIe-PCIX bridge

- **PCIe Gen 3.0**

Base Spec currently at 1.0 (as of Dec 2010)

- › Frequency of 8.0 GT/s per Lane
- › Uses 128/130 bit encoding / scrambling
- › Nearly Doubled the Theoretical BW to 1000 MB/s/lane
- › Support for Genesco features included

Standard for Co-processors, Accelerators, Encryption,
Visualization, Mathematical Modeling, Tunneling

- › Power for x16 increased to 300W
(250 W via additional connector)

- ◆ Express Module Spec is being upgraded to Gen2 then to Gen3
 - › Ron Emerick is the current chair of the EM working group

- **External expansion**

- ◆ Cable work group is active

- **PCIe IO Virtualization (SR / MR IOV)**

- ◆ Architecture allows shared bandwidth

PCI Express In Industry

- **PCIe Gen 3 Will Ship in 2012**
 - ◆ Desktop Systems
 - › x16 High Performance Graphics
 - ◆ Servers with multiple x4 and x8 connectors in 2012
 - ◆ Root Complex's will provide multiple x8, less need for switches
- **First Gen3 Cards Available 2011 - 2013**
 - ◆ Dual 10 Gb CNAs/FC boards (multi personality)
 - ◆ SAS 2.0 16 port, SAS 3.0 8/16 port
 - ◆ x16 High Performance Graphics @ 300 W and more
 - ◆ FDR/EDR InfiniBand
 - ◆ Dual/Quad 10 Gbase-T and Optical
 - ◆ Single/Dual 40 Gb, FCoE, iSCSI, NAS

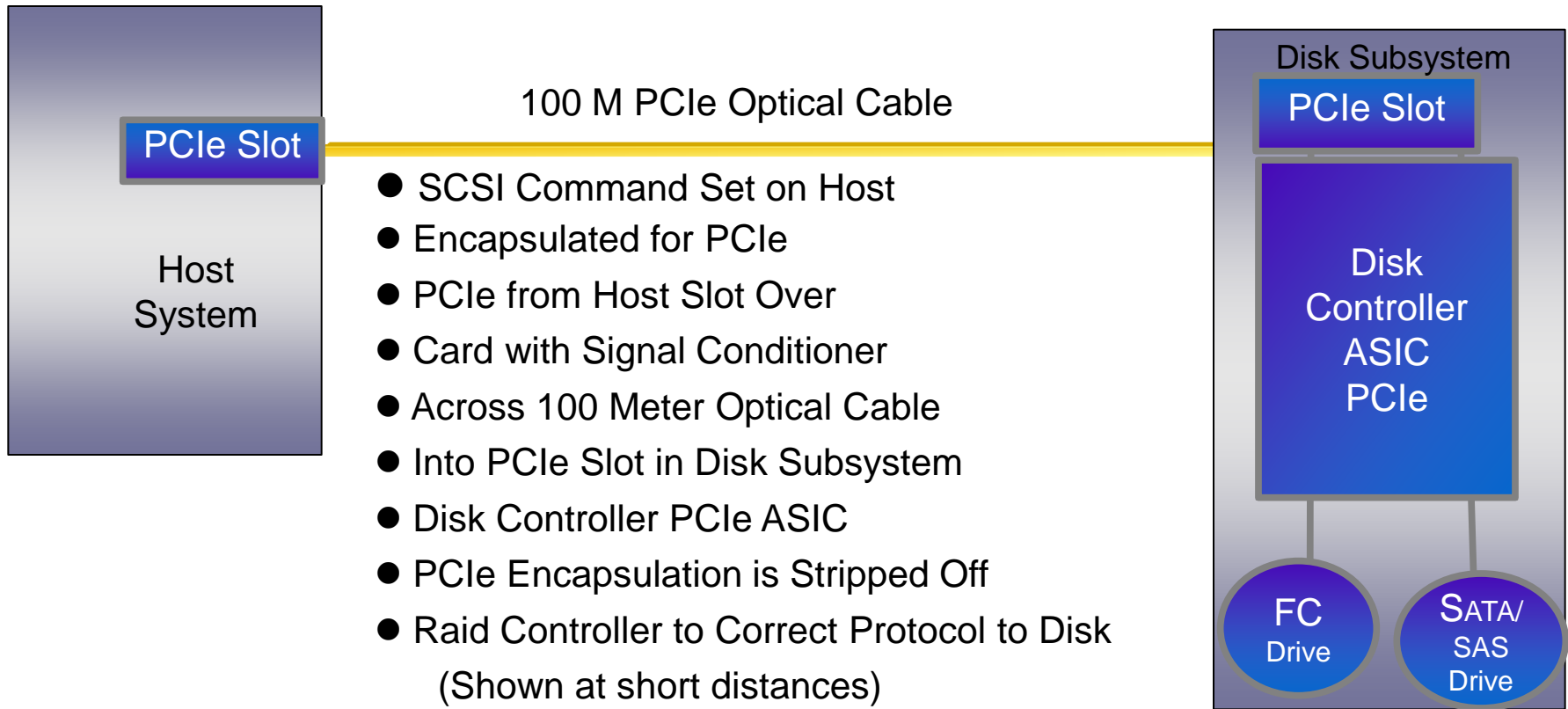
New IO Interfaces

- High Speed / High Bandwidth
 - Fibre channel – 8 Gb, 16 Gb, 32 Gb
 - Storage area network standard
 - Ethernet – 10Gb, 40Gb, 100Gb, FCoE
 - Provides a network based solution to SANs, requires DCB
 - InfiniBand - QDR, FDR, EDR
 - Choice for high speed process to processor links
 - Supports wide and fast data channels
 - SAS 2.0, 3.0 (6 Gb, 12 Gb)
 - Serial version of SCSI offers low cost storage solution
 - SSDs
 - Solid State Disk Drive Formfactor
 - Solid State PCIe Cards
 - Solid State Iru Trays of Flash

PCI Express Based Storage

- **PCI Express SSD Cards (\$\$)**
 - PCIe X8 card with FLASH DIMMS on it
 - Multiple Vendors (many at SNW)
 - Storage Controller on Card
- **PCI Express Storage Trays (\$\$\$)**
 - Trays of FLASH or NVRAM DIMMS
 - PCIe External Interface
 - Requires PCIe Expansion Port (card) in Host
 - Connective via PCIe Cable between Host and Storage
 - Possible to share across multiple Hosts
 - IO directly across PCIe
- **Phase Change Memory coming (\$\$\$\$)**
 - Use in place of FLASH
 - Attach to System Memory Controller

Future Storage Attach Model



Single Root IOV

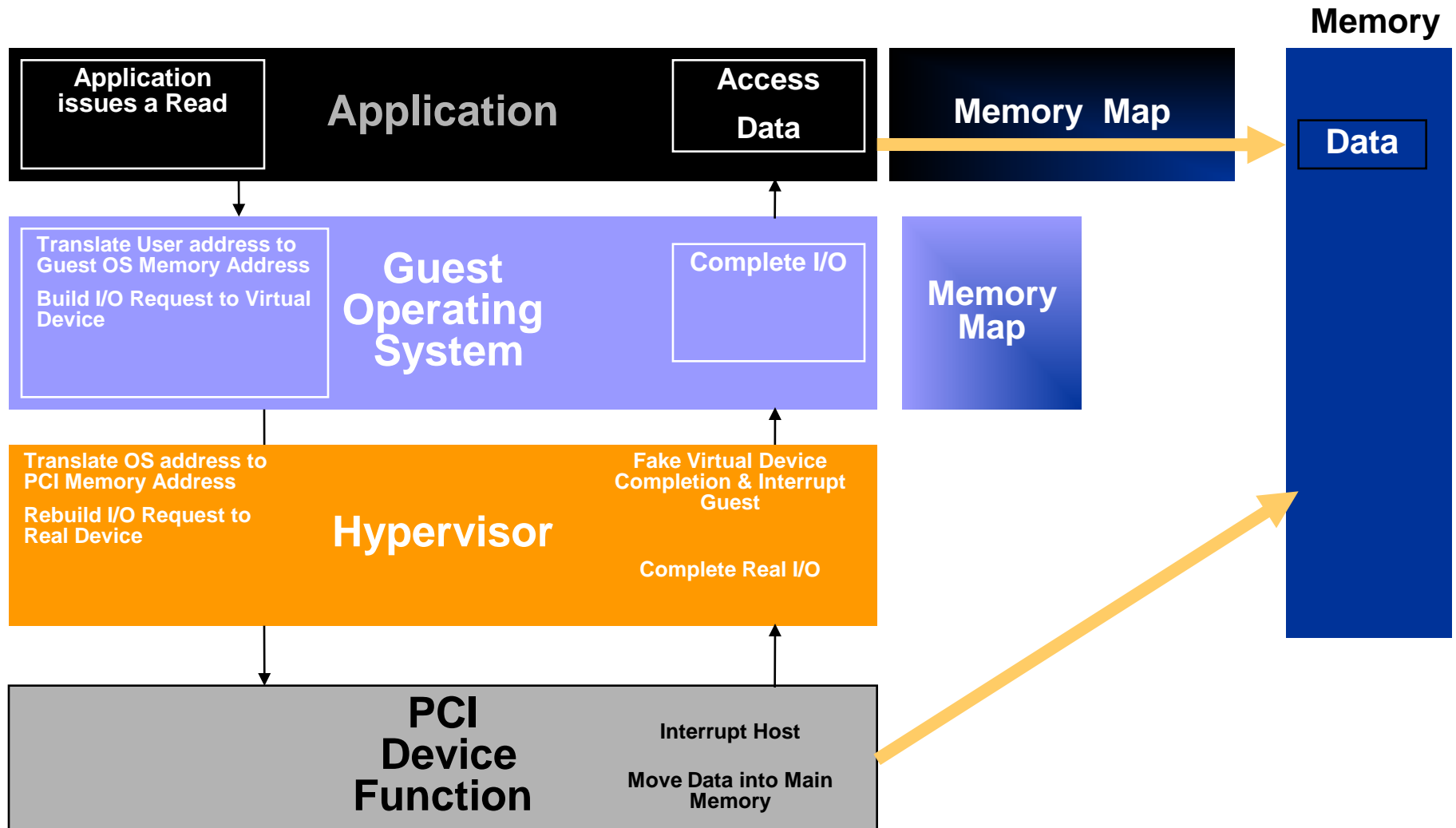
Better IO Virtualization for Virtual Machines

Share the IO Components

PCIe IOV Provides this Sharing

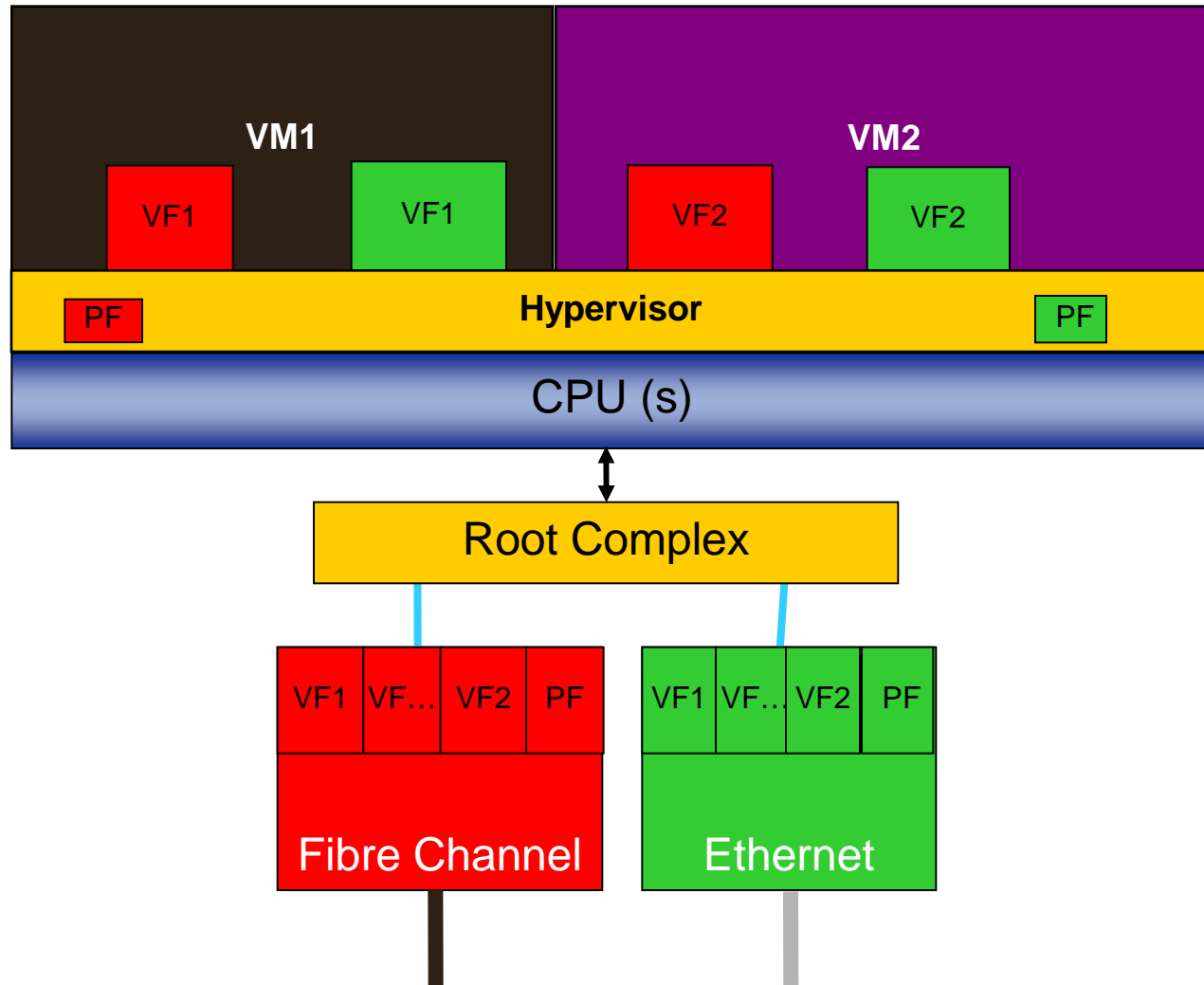
- Root Complexes are PCIe
 - Closer to CPU than 10 GbE or IB
 - Requires Root Complex SW Modifications
- Based Upon PCI SIG Standards
- Allows the Sharing of High Bandwidth, High Speed IO Devices

System I/O with a Hypervisor

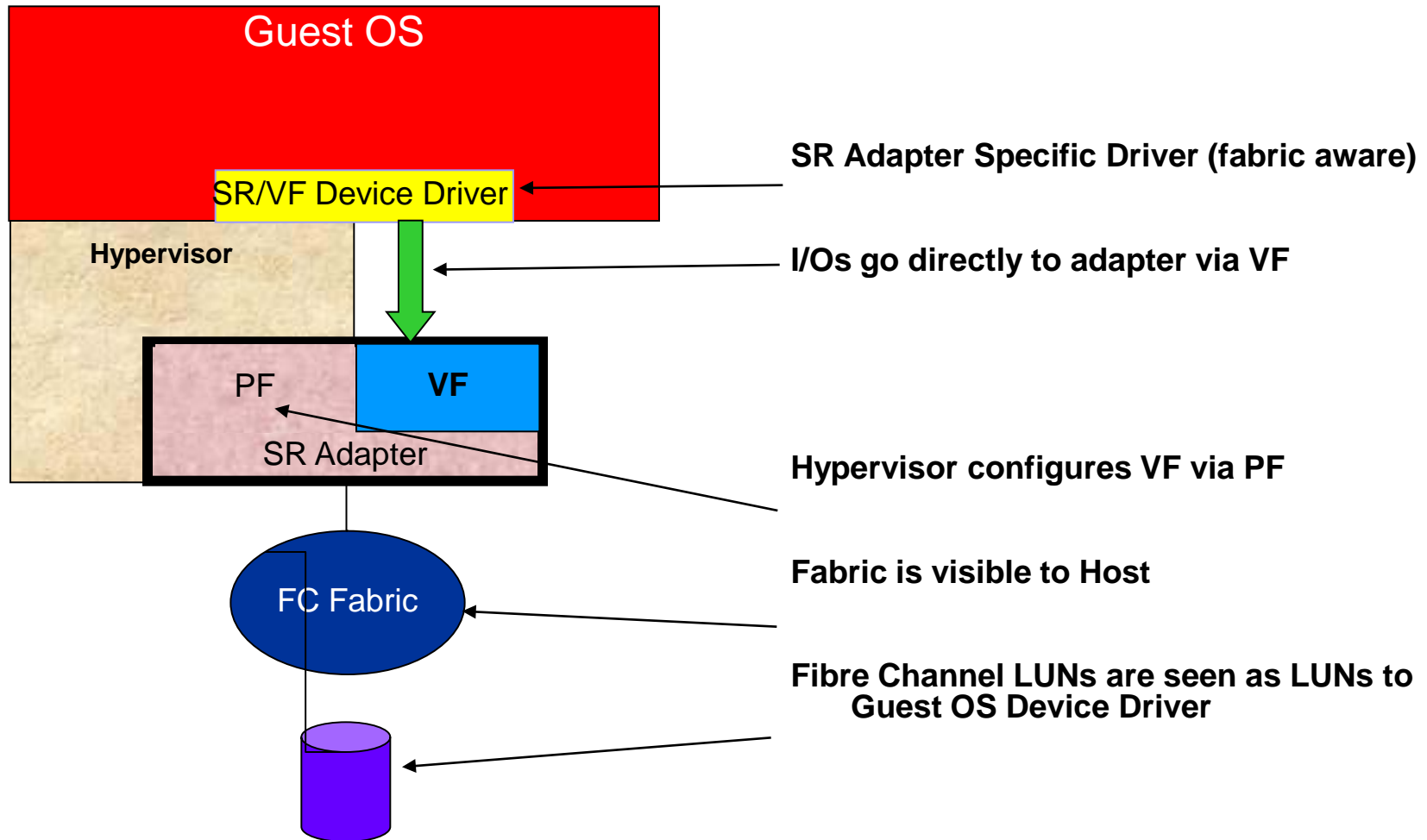


- Before Single Root IOV the Hypervisor was responsible for creating virtual IO adapters for a Virtual Machine
- This can greatly impact Performance
 - Especially Ethernet but also Storage (FC & SAS)
- Single Root IOV pushes much of the SW overhead into the IO adapter
 - Remove Hypervisor from IO Performance Path
- Leads to Improved Performance for Guest OS applications

PCI-SIG Single Root



Fibre Channel & SR Virtualization



- **PCI Express provides**
 - Full Bandwidth Dual Ported 8 & 16 Gb FC
 - Full Bandwidth for QDR, FDR and EDR IB
 - Full Bandwidth SAS 2.0 & 3.0
 - Legacy Support via PCI-X
- **IOV takes it one step further**
 - Ability for System Images to Share IO across OS Images
 - Backplane for Bladed Environments
- **Extension of PCIe**
 - Possible PCIe attached storage devices

Future Data Centers

Data Center in 2013-2016

- **Root complexes are PCIe 3.0**
 - ◆ Integrated into CPU
 - ◆ Multiple Gen3 x8 from each socket
 - ◆ Multicast and Tunneling
 - ◆ PCIe Gen4 in 2016 and beyond
- **Networking**
 - ◆ Dual ported Optical 40 GbE (capable of FCoE, iSCSI, NAS)
 - ◆ 100 GbE Switch Backbones by 2018
 - ◆ Quad 10 Gbase-T and Quad MMF (single ASIC)
 - ◆ Dual/Quad Legacy GbE Copper and Optical
 - ◆ Dual ported FDR & EDR InfiniBand for cluster, some storage
- **Graphics**
 - ◆ x16 Single/Dual ported Graphics cards @ 300 W (when needed)

Data Center in 2013-2016 (2)

- **Storage Access**
 - ◆ SAS 3.0 HBAs, 8 and 16 port IOC/ROC
 - ◆ 16/32 Gb FC HBAs pluggable optics for single/dual port
 - ◆ Multi-function FC & CNA (converged network adapters) at 16/32 Gb FC and 40 Gb FCoE
- **Storage will be:**
 - ◆ Solid State Storage
 - › SSS PCIe Cards, 1 ru trays of FLASH DIMMS
 - › SSS in 2.5" and 3.5" drive formfactor following all current disk drive support models
 - ◆ 2.5" and 3.5" 10K RPM SAS (capacities up to 1 to 2 TB)
 - ◆ 2.5" and 3.5" SATA 2.0 Drives (capacities 500 GB to 4 TB)
 - ◆ SAS 3.0 Disk Arrays Front Ends with above drives
 - ◆ 16/32 Gb FC Disk Arrays with above drives
 - ◆ FDR/EDR IB Storage Heads with above drives

Data Center in 2020-2025

- **Server**
 - ◆ Multicore/multithread/multiprocessor High Speed Processors
 - ◆ Lower power, higher frequency
 - ◆ Memory controllers embedded in processor in lieu of Cores
 - ◆ High Speed IO Coming Out of the Processor
 - ◆ Over to an IO Controller
 - ◆ Possibly over Memory or Coherency Links
 - ◆ High Bandwidth, High Frequency Downstream Ports
 - ◆ IO Interfaces
 - ◆ 100 GbE, Multiport 40 GbE and 10 GbE
 - ◆ HDR and NDR InfiniBand
 - ◆ 32 Gb FC and SAS 4.0 host interfaces ????
 - ◆ Most popular integrated into CPU in lieu of cores
 - ◆ System Interconnects via Tunneling over IO Links
 - ◆ PCIe will probably be considered Legacy

Data Center in 2020-2025

- **Storage**
 - ◆ Phase Change Memory Devices, some attached to host Memory controller
 - ◆ SSD Storage Arrays attached via 100 GbE Switch
 - ◆ 32 Gb FC interfaces
 - ◆ 100 GbE and FCoE interfaces
 - ◆ Spinning Rust will still be around, tier 2 and tier 3 storage
 - ◆ Tape will NOT have died
 - ◆ Dual ported FDR & EDR InfiniBand for cluster, some storage
- **Graphics**
 - ◆ Special processors with graphics controllers in lieu of cores

PCI – Peripheral Component Interconnect. An open, versatile IO technology. Speeds range from 33 Mhz to 266 Mhz, with pay loads of 32 and 64 bit. Theoretical data transfer rates from 133 MB/ s to 2131 MB/ s.

PCI-SIG - Peripheral Component Interconnect Special Interest Group, organized in 1992 as a body of key industry players united in the goal of developing and promoting the PCI specification.

IB – InfiniBand, a specification defined by the InfiniBand Trade Association that describes a channel-based, switched fabric architecture.

Root complex – the head of the connection from the PCI Express IO system to the CPU and memory.

HBA – Host Bus Adapter.

IOV – IO Virtualization

Single root complex IOV – Sharing an IO resource between multiple operating systems on a HW Domain

Multi root complex IOV – Sharing an IO resource between multiple operating systems on multiple HW Domains

VF – Virtual Function

PF – Physical Function

Please send any questions or comments on this presentation to SNIA: tracktutorials@snia.org

**Many thanks to the following individuals
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- SNIA Education Committee

PCI SIG Members

Alex Nicolson