



PCI-SIG® Architecture Overview

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What's all this PCI Stuff Anyway?

- Presentation will cover basic concepts and their evolution from PCI™ through PCI-X™ to PCI Express®
 - ✓ Specs written assuming designers have these key background concepts
 - ✓ High level overview of PCI, PCI-X, and PCI Express

PCI Background



Revolutionary AND Evolutionary

■ PCI

✓ Revolutionary

- Plug and Play jumperless configuration (BARs)
- Unprecedented bandwidth
 - 32-bit / 33MHz – 133MB/sec
 - 64-bit / 66MHz – 533MB/sec
- Designed from day 1 for bus-mastering adapters

✓ Evolutionary

- System BIOS maps devices then operating systems boot and run without further knowledge of PCI
- PCI-aware O/S could gain improved functionality



Revolutionary AND Evolutionary

■ PCI-X

✓ Revolutionary

- Unprecedented bandwidth
 - Up to 1066MB/sec with 64-bit / 133MHz
- Registered bus protocol
 - Eased electrical timing requirements
- Brought split transactions into PCI “world”

✓ Evolutionary

- PCI compatible at hardware *AND* software levels
- PCI-X 266/533 added as “mid-life” performance bump
 - 2133MB/sec at PCI-X 266 and 4266MB/sec at PCI-X 533



Revolutionary AND Evolutionary

- PCI Express (aka PCIe®)
 - ✓ Revolutionary
 - Unprecedented bandwidth
 - x1: 250,500,1000MB/sec in *EACH* direction
 - x16: 4000,8000,16000MB/sec in *EACH* direction
 - “Relaxed” electricals due to serial bus architecture
 - Point-to-point, low voltage, dual simplex with embedded clocking
 - ✓ Evolutionary
 - PCI compatible at software level
 - Configuration space, Power Management, etc
 - Of course, PCIe-aware O/S can get more functionality
 - Transaction layer familiar to PCI/PCI-X designers
 - System topology matches PCI/PCI-X
 - PCIe 2.0 doubled bandwidth from 250MB/s/lane to 500MB/s/lane, PCIe 3.0 to 1GB/s/lane... PCIe 4.0 will double again to 2GB/s/lane!

PCI Concepts

PCI Concepts

- Address spaces
 - ✓ Memory – 64-bit
 - ✓ I/O – 32-bit (non-burstable since PCI-X)
 - ✓ Configuration (“Config”) – Bus/Device/Function

- Key configuration space regs/concepts
 - ✓ Base Address Registers (BARs)
 - 64-bit vs 32-bit addressing
 - ✓ Linked list of capabilities

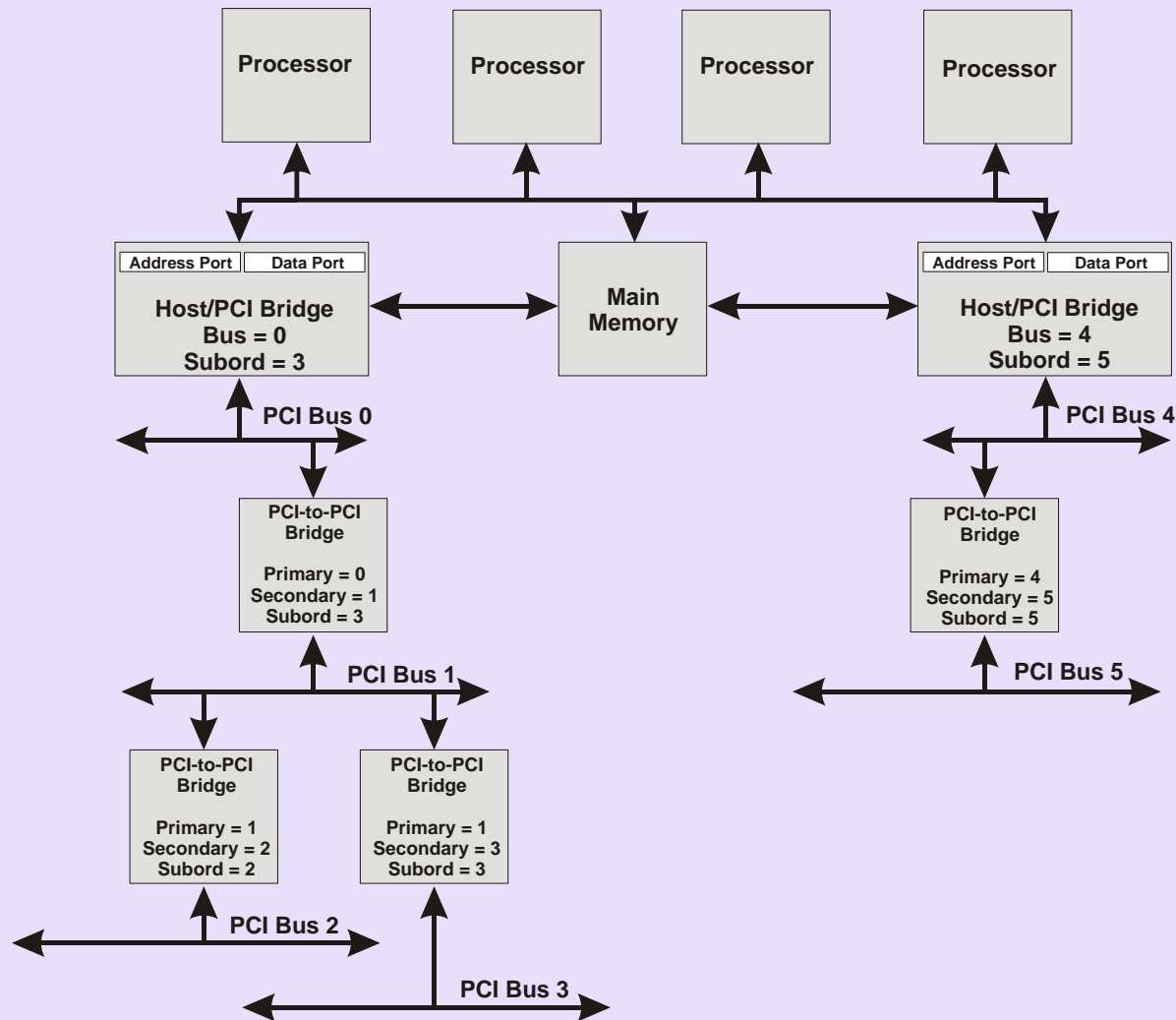
Address Spaces – Memory & I/O

- Memory space mapped cleanly to CPU semantics
 - ✓ 32-bits of address space initially
 - ✓ 64-bits introduced via Dual-Address Cycles (DAC)
 - Extra clock of address time on PCI/PCI-X
 - 4DWORD header in PCI Express
 - ✓ Burstable
- I/O space mapped cleanly to CPU semantics
 - ✓ 32-bits of address space
 - Actually much larger than CPUs of the time
 - ✓ Non-burstable
 - Most PCI implementations didn't support
 - PCI-X codified
 - Carries forward to PCI Express

Address Spaces – Configuration

- Configuration space???
 - ✓ Allows control of devices' address decodes without conflict
 - ✓ No conceptual mapping to CPU address space
 - Memory-based access mechanisms introduced with PCI-X and PCIe
 - ✓ Bus / Device / Function (aka BDF) form hierarchy-based address
 - “Functions” allow multiple, logically independent agents in one physical device
 - E.g. combination SCSI + Ethernet device
 - 256 bytes or 4K bytes of configuration space per device
 - PCI/PCI-X bridges form hierarchy
 - PCIe switches form hierarchy
 - Look like PCI-PCI bridges to software
 - ✓ “Type 0” and “Type 1” configuration cycles
 - Type 0: to same bus segment
 - Type 1: to another bus segment

Configuration Space (cont'd)



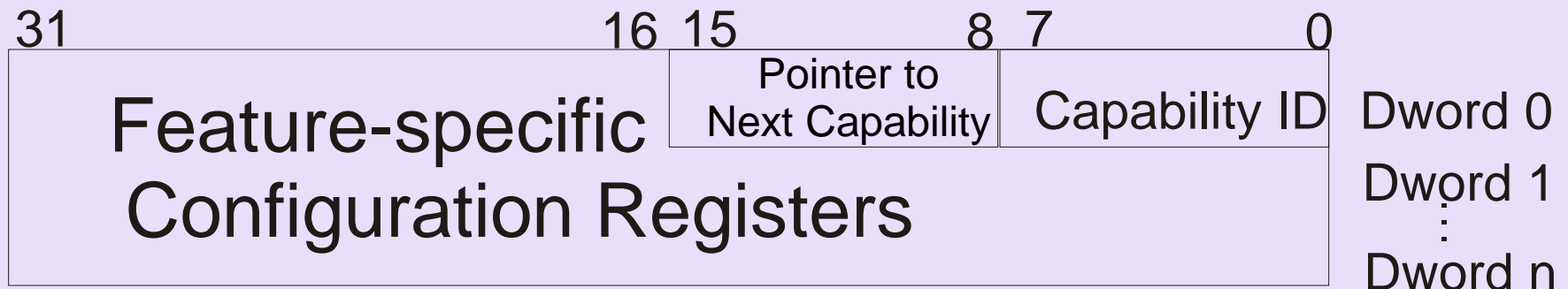
Using Configuration Space

- Device Identification
 - ✓ VendorID: PCI-SIG assigned
 - ✓ DeviceID: Vendor self-assigned
 - ✓ Subsystem VendorID: PCI-SIG
 - ✓ Subsystem DeviceID: Vendor
- Address Decode controls
 - ✓ Software reads/writes BARs to determine required size and maps appropriately
 - ✓ Memory, I/O, and bus-master enables
- Other bus-oriented controls

Byte				Doubleword Number (in decimal)
3	2	1	0	
Device ID		Vendor ID		00
Status Register		Command Register		01
Class Code			Revision ID	02
BIST	Header Type	Latency Timer	Cache Line Size	03
Base Address 0				04
Base Address 1				05
Base Address 2				06
Base Address 3				07
Base Address 4				08
Base Address 5				09
CardBus CIS Pointer				10
Subsystem ID		Subsystem Vendor ID		11
Expansion ROM Base Address				12
Reserved			Capabilities Pointer	13
Reserved				14
Max_Lat	Min_Gnt	Interrupt Pin	Interrupt Line	15

Using Configuration Space – Capabilities List

- Linked list
 - ✓ Follow the list! Cannot assume fixed location of any given feature in any given device
 - ✓ Features defined in their related specs:
 - PCI-X
 - PCIe
 - PCI Power Management
 - Etc...





Using Configuration Space – Extended Capabilities List

- PCI Express only
- Linked list
 - ✓ Follow the list! Cannot assume fixed location of any given feature in any given device
 - ✓ First entry in list is *always* at 100h
 - ✓ Features defined in PCI Express specification



Interrupts

- PCI introduced INTA#, INTB#, INTC#, INTD# - collectively referred to as INTx
 - ✓ Level sensitive
 - ✓ Decoupled device from CPU interrupt
 - ✓ System controlled INTx to CPU interrupt mapping
 - ✓ Configuration registers
 - report A/B/C/D
 - programmed with CPU interrupt number
- PCI Express mimics this via “virtual wire” messages
 - ✓ Assert_INTx and Deassert_INTx

What are MSI and MSI-X?

- Memory Write replaces previous interrupt semantics
 - ✓ PCI and PCI-X devices stop asserting INTA/B/C/D and PCI Express devices stop sending Assert_INTx messages once MSI or MSI-X mode is enabled
 - ✓ MSI uses one address with a variable data value indicating which “vector” is asserting
 - ✓ MSI-X uses a table of independent address and data pairs for each “vector”
- NOTE: *Boot devices* and any device intended for a non-MSI operating system generally must still support the appropriate INTx signaling!

PCI-X Explained

What is PCI-X?

- “PCI-X is high-performance backward compatible PCI”
 - ✓ PCI-X uses the same PCI architecture
 - ✓ PCI-X leverages the same base protocols as PCI
 - ✓ PCI-X leverages the same BIOS as PCI
 - ✓ PCI-X uses the same connector as PCI.
 - ✓ PCI-X and PCI products are interoperable
 - ✓ PCI-X uses same software driver models as PCI
- PCI-X is faster PCI
 - ✓ PCI-X 533 is up to 32 times faster than the original version of PCI
 - ✓ PCI-X protocol is more efficient than conventional PCI

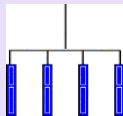
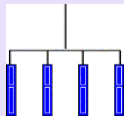
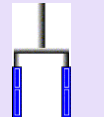
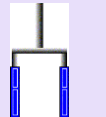
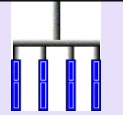
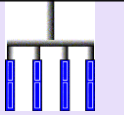
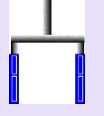
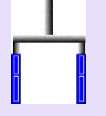






PCI-X Modes and Speeds



Mode 1



Mode 2

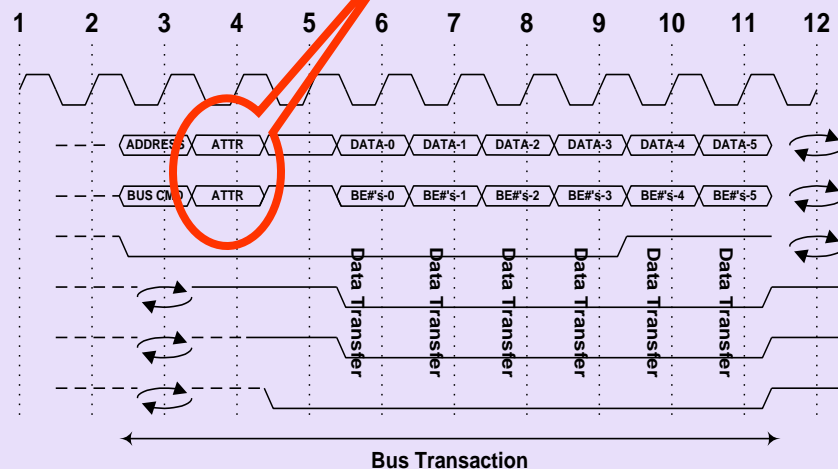
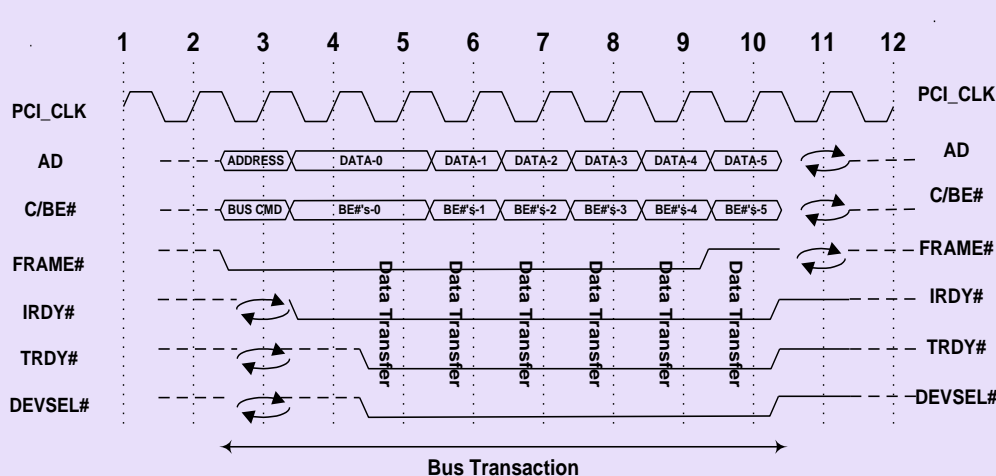
Mode	V _{I/O}	64-Bit		32-Bit		16-Bit	Error Prot	Conf Bytes	DIM
		Slots*	MB/s	Slots*	MB/s				
PCI 33	5V/3.3V		266		133	N/A	par	256	N/A
PCI 66	3.3V		533		266	N/A	par	256	N/A
PCI-X 66	3.3V		533		266	N/A	par or ECC	256	yes
PCI-X 133 (operating at 100 MHz)	3.3V		800		400	N/A	par or ECC	256	yes
PCI-X 133	3.3V		1066		533	N/A	par or ECC	256	yes
PCI-X 266	1.5V		2133		1066	533	ECC	4K	yes
PCI-X 533	1.5V		4266		2133	1066	ECC	4K	yes

* For lower bus speeds, # slots / bus is implementation choice to share bandwidth

PCI 2.x/3.0 vs. PCI-X Mode 1

- Same bus and control signals
- Evolutionary protocol changes
- Clock frequency up to 133 MHz

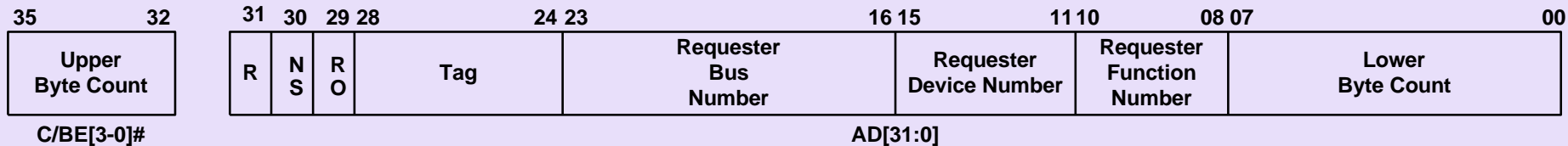
New “Attribute” phase for enhanced features



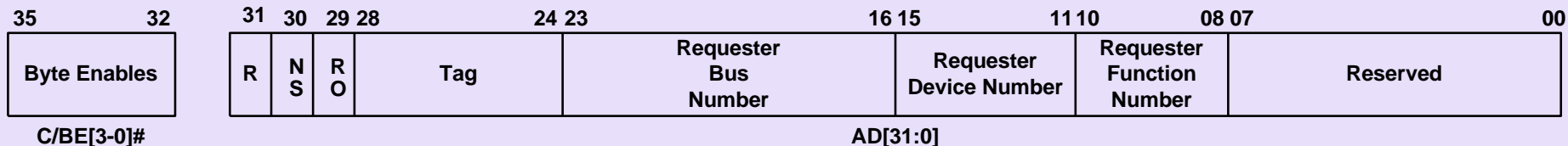
(Common clock)

Transaction Attributes

Requester Attributes for Burst Transactions



Requester Attributes for DWORD Transactions



RO -- Relax ordering

NS -- No Snoop

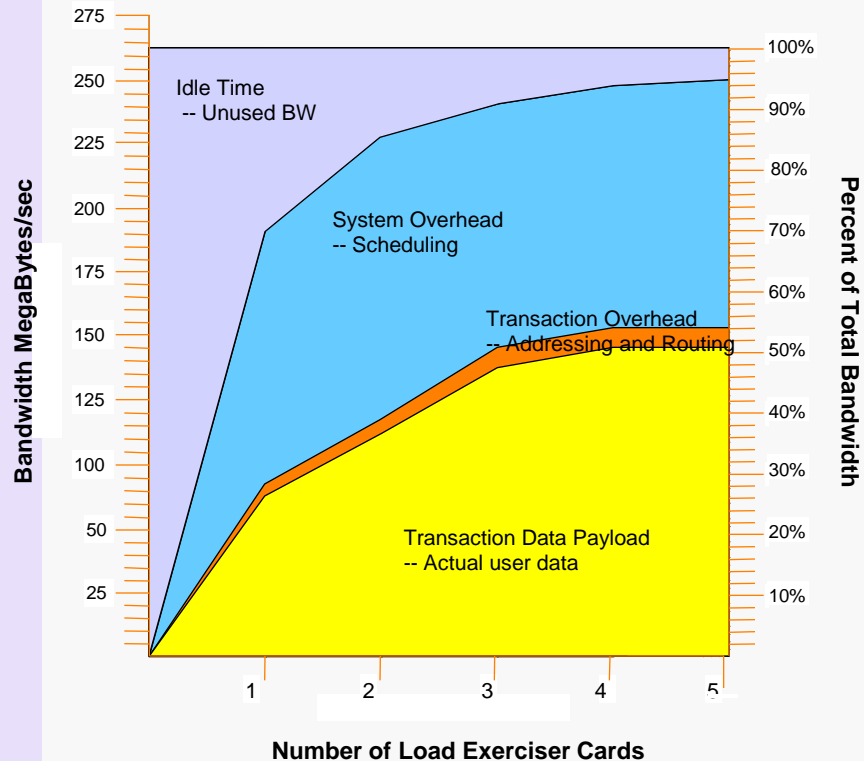
R -- Reserved

Split Transactions

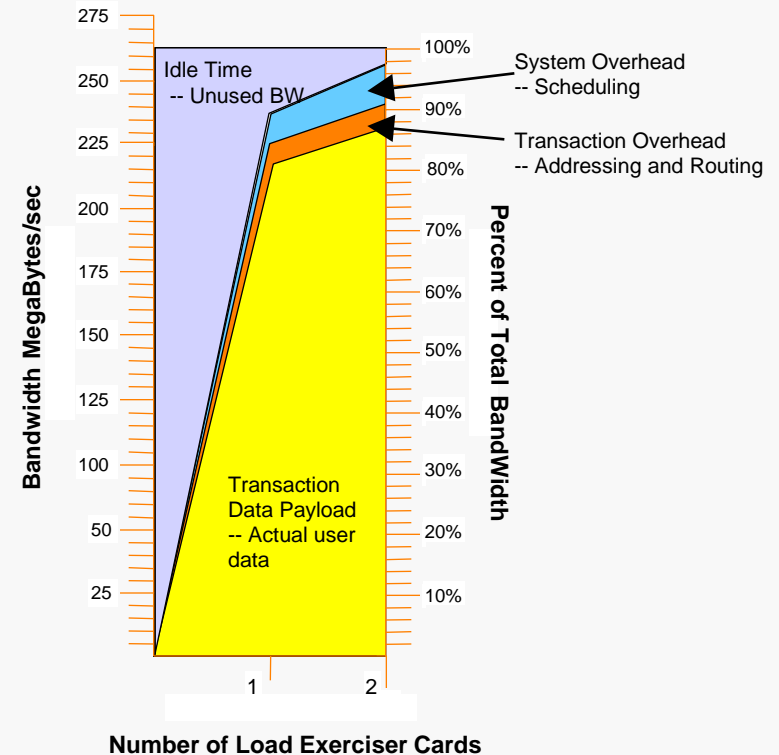
- Bus efficiency of Read almost as good as Write
- Split Completion routed back to requester across bridges using initiator's number and bus number
- Split Transaction components
 - ✓ Step 1. Requester requests bus and arbiter grants bus
 - ✓ Step 2. Requester initiates transaction
 - ✓ Step 3. Target (completer) communicates intent with new target termination, Split Response
 - ✓ Step 4. Completer executes transaction internally
 - ✓ Step 5. Completer requests bus and arbiter grants bus
 - ✓ Step 6. Completer initiates Split Completion

Efficient PCI-X Protocol

Bandwidth Usage with Conventional PCI Protocols



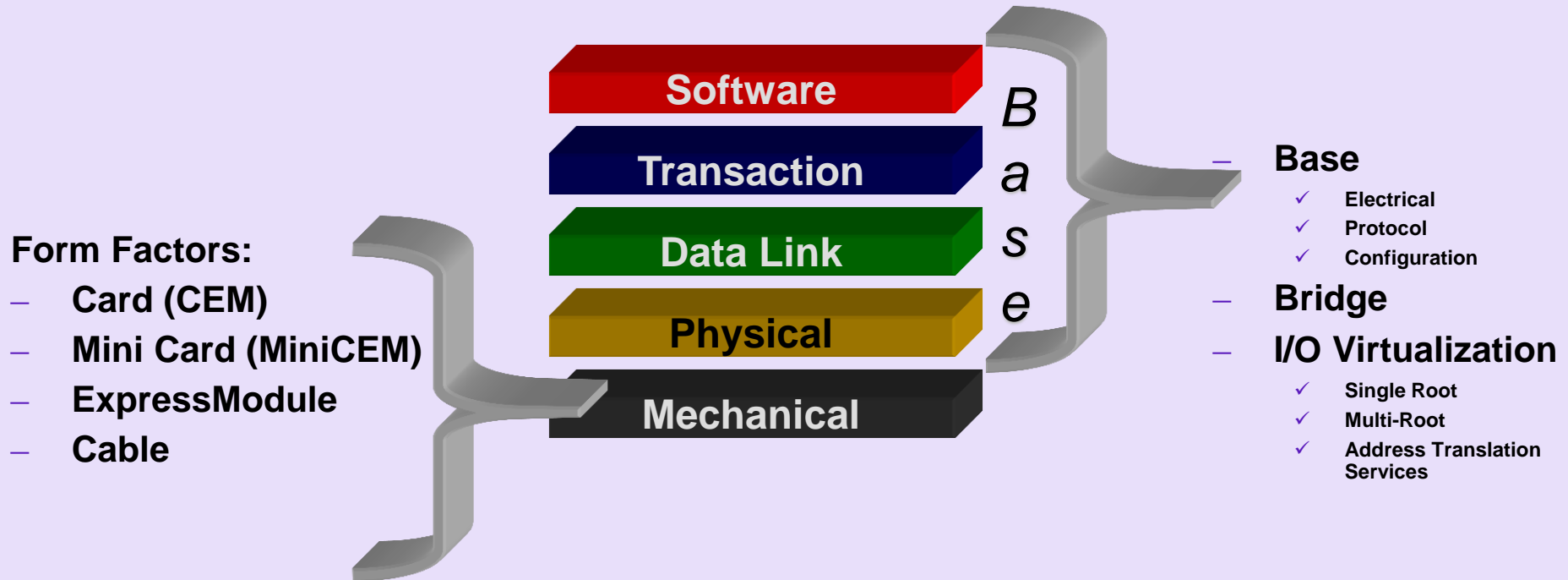
Bandwidth Usage with PCI-X Protocols, included in PCI-X 2.0



The PCI-X protocol is more efficient than traditional PCI.

PCI Express Overview

PCIe Specifications



PCIe Architecture Features

■ PCI Compatibility

- ✓ Configuration and PCI software driver model
- ✓ PCI power management software compatible

■ Performance

- ✓ Scalable frequency (2.5-8GT/s)
- ✓ Scalable width (x1, x4, x8, x16)
- ✓ Low latency and highest utilization (Bandwidth/pin)

■ Physical Interface

- ✓ Point-to-point, dual-simplex
- ✓ Differential low voltage signaling
- ✓ Embedded clocking
- ✓ Supports connectors, modules, cables

■ Protocol

- ✓ Fully packetized split-transaction
- ✓ Credit-based flow control
- ✓ Hierarchical topology support
- ✓ Virtual channel mechanism

■ Advanced Capabilities

- ✓ CRC-based data integrity, hot plug, error logging

■ Enhanced Configuration Space

- ✓ Extensions and bridges into other architectures



PCIe Speed Evolution

- Introduced at 2.5GT/sec
 - ✓ Commonly called 2.5GHz
 - PCI-SIG eventually adopts GigaTransfers per Second (GT/s) terminology
 - ✓ 100 MHz reference clock provided
 - Eases synchronization between ends
 - Particularly when Spread Spectrum Clocking is used
 - Optional, but nearly universal in traditional “PC” world
 - ✓ 8b/10b encoding used to provide DC balance and reduce “runs” of 0s or 1s which make clock recovery difficult
- Specification Revisions: 1.0, 1.0a, 1.1

PCIe Speed Evolution (cont'd)

- Speed doubled to 5GT/sec
 - ✓ Reference clock remains at 100 MHz
 - Lower jitter clock sources required vs 2.5GT/sec
 - Generally higher quality clock generation/distribution required
 - ✓ 8b/10b encoding continues to be used
- Specification Revisions: 2.0, 2.1
 - ✓ Devices choosing to implement a maximum rate of 2.5GT/sec can still be fully 2.x compliant!



PCIe Speed Evolution (cont'd)

2 x 5 = ?

PCIe Speed Evolution (cont'd)

$$2 \times 5 = 8 \text{ ???}$$

- Speed “doubled” over PCIe 2.x 5GT/sec
- 8GT/sec electrical rate
 - ✓ 10GT/sec required significant cost and complexity in channel, receiver design, etc.
- Reference clock remains at 100 MHz
 - Very similar requirements to 5GT/sec mode
- Specification Revisions: 3.0
 - ✓ Devices choosing to implement a maximum rate of 2.5GT/sec or 5GT/sec can still be fully 3.0 compliant!

PCIe Speed Evolution (cont'd)

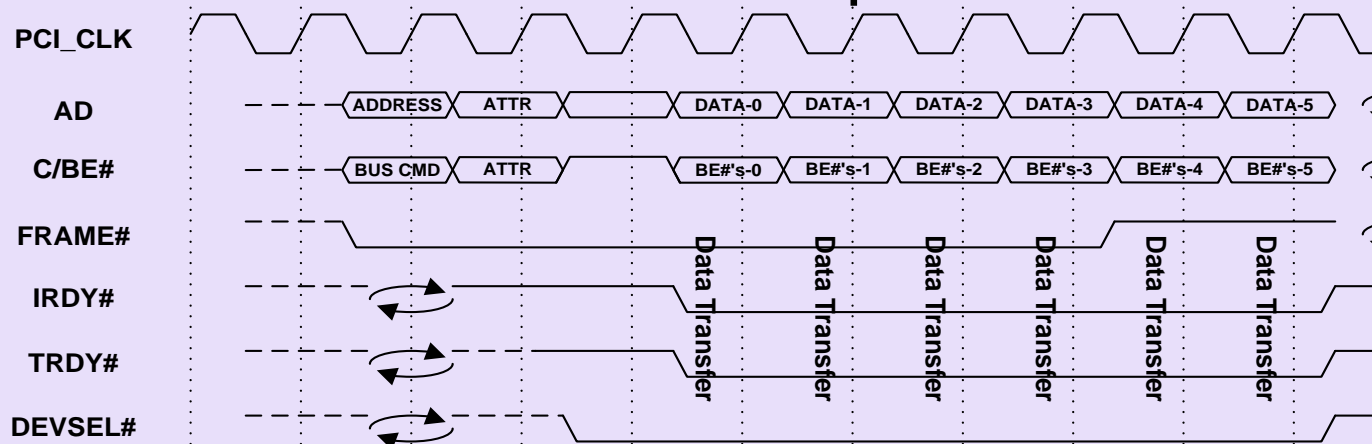
- 128/130 encoding reduces overhead from the 20% loss of 8b/10b
 - ✓ Original plan was scrambling-only for exactly 2x the 5GT/sec bandwidth
 - $5000\text{Mb/sec} / (10\text{bits/byte}) = 500\text{MB/sec per lane}$
 - $8000\text{Mb/sec} / (8\text{bits/byte}) = 1000\text{MB/sec per lane}$
 - ✓ Pure 128/130 encoding is ~1.5% loss

- Scrambling replaces DC-offset and run-length reduction functions of 8b/10b

PCI Express Protocol

PCIe Protocol Overview

■ PCI-X Address/Attribute phases:

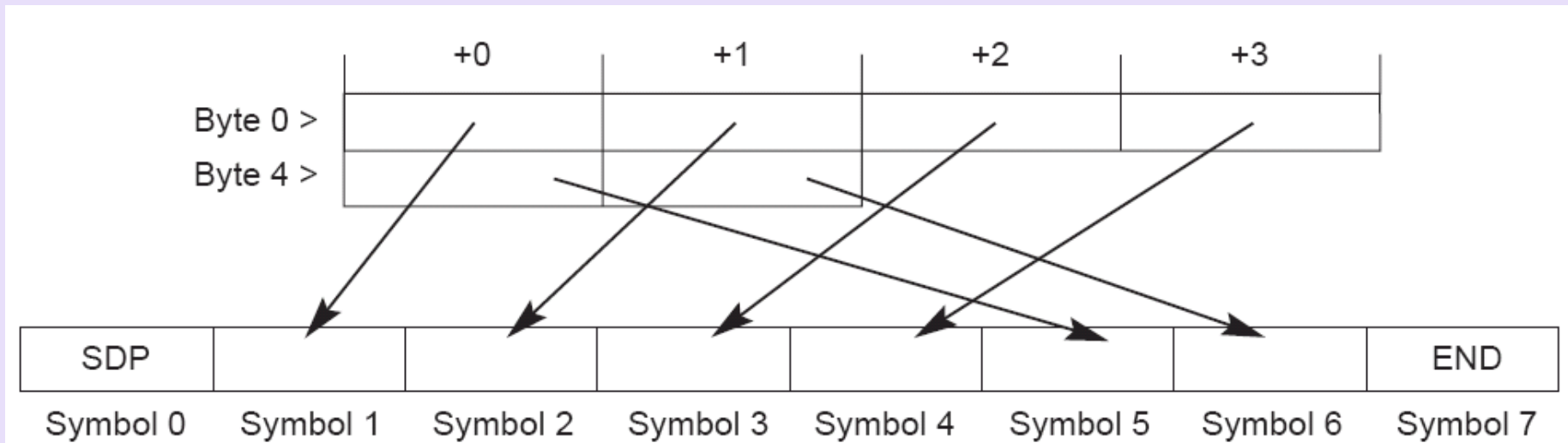


■ Evolved into the PCIe Packet Header:

	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
Byte 0 >	R	Fmt x 1	Type					R	TC		Reserved					T D	E P	Attr		R	Length											
Byte 4 >	Requester ID															Tag							Last DW BE				1st DW BE					
Byte 8 >	Address[63:32]																															
Byte 12 >	Address[31:2]																												R			

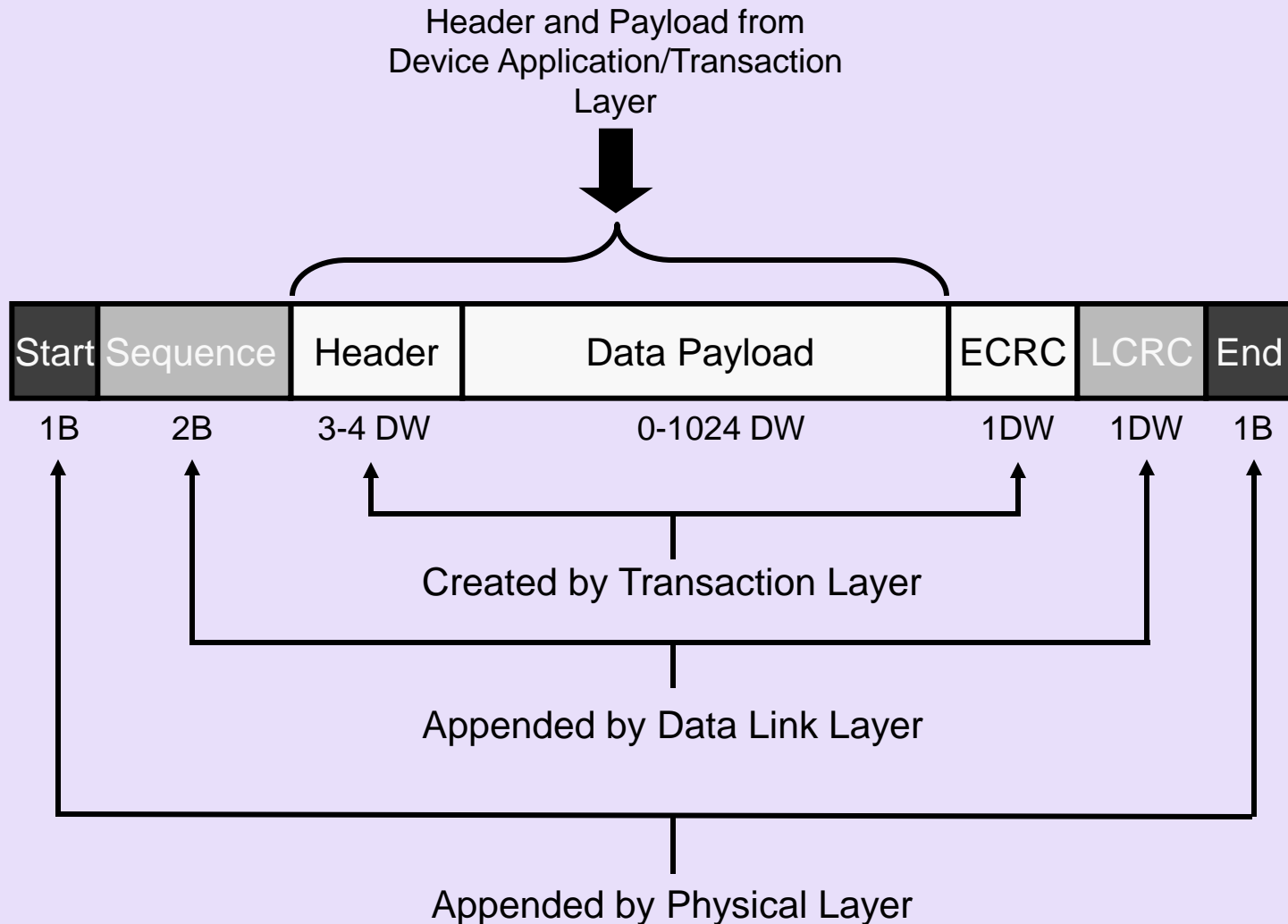
PCIe Protocol Overview

- The packet bytes get converted to 8b/10b (or 128/130 at 8GT/sec) and serialized



- Example above is in 2.5GT/s or 5GT/s mode – symbols are different in 8GT/s mode

PCIe Protocol Overview

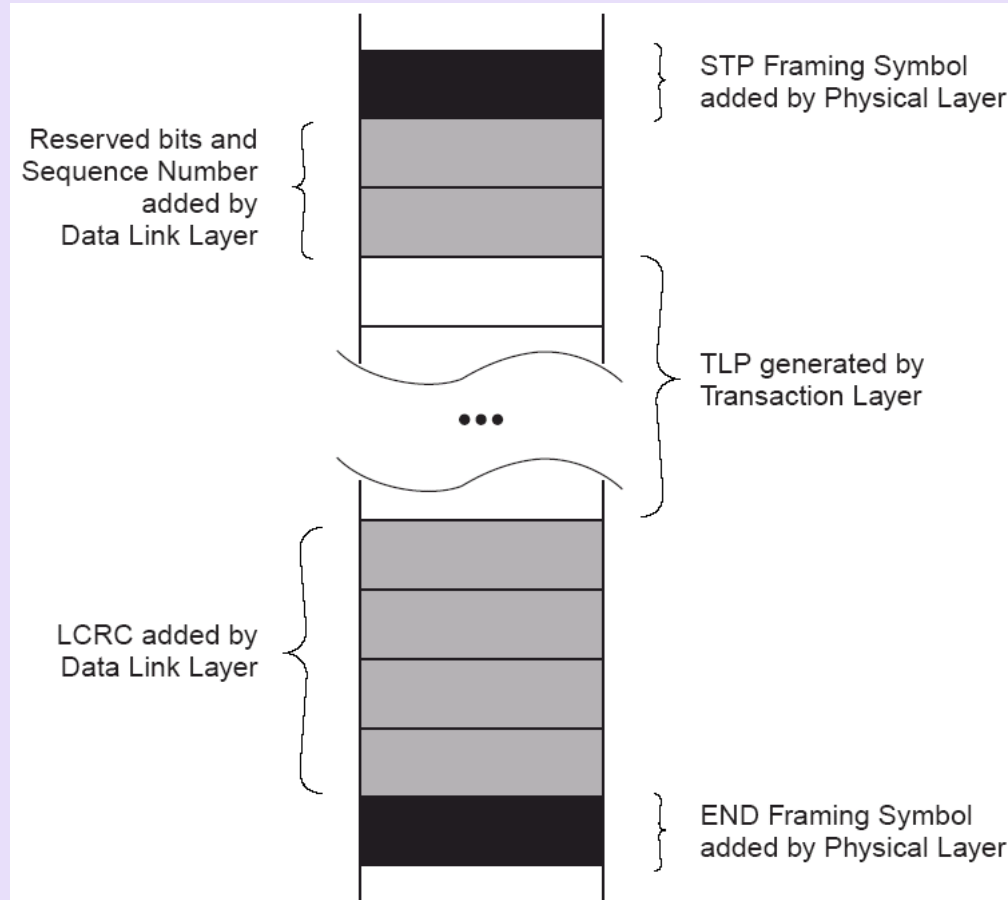


Slightly different in 8GT/s mode

PCIe Protocol Overview

■ Framing varies depending on link width

✓ x1

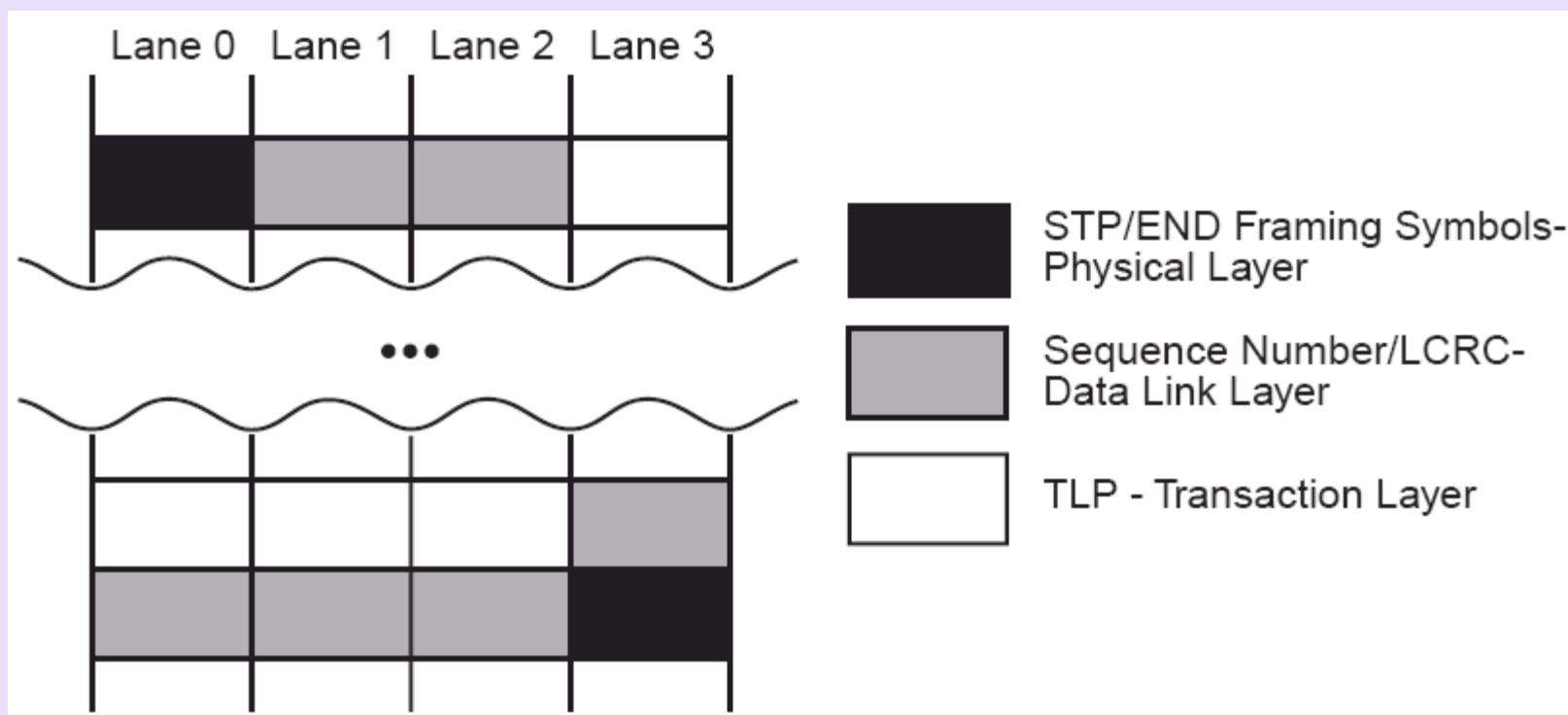


- Example above is in 2.5GT/s or 5GT/s mode – symbols are different in 8GT/s mode

PCIe Protocol Overview

- Framing varies depending on link width

✓ x4



- Example above is in 2.5GT/s or 5GT/s mode – symbols are different in 8GT/s mode

Thank you for attending PCI-SIG Developers Conference Israel 2013

For more information please go to
www.pcisig.com

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