



**XILINX**

ALL PROGRAMMABLE™

# Zynq Architecture

**Zynq  
14.2 Version**

# Objectives

## ➤ After completing this module, you will be able to:

- Identify the basic building blocks of the Zynq™ architecture processing system (PS)
- Describe the usage of the Cortex-A9 processor memory space
- Connect the PS to the programmable logic (PL) through the AXI ports
- Generate clocking sources for the PL peripherals
- List the various AXI-based system architectural models
- Name the five AXI channels
- Describe the operation of the AXI streaming protocol

# Outline

- **Zynq All Programmable SoC (AP SoC)**
- **Zynq AP SoC Processing System (PS)**
- **Processor Peripherals**
- **Clock, Reset, and Debug Features**
- **AXI Interfaces**
- **Summary**

# Zynq-7000 Family Highlights

## ➤ Complete ARM®-based processing system

- Application Processor Unit (APU)
  - Dual ARM Cortex™-A9 processors
  - Caches and support blocks
- Fully integrated memory controllers
- I/O peripherals

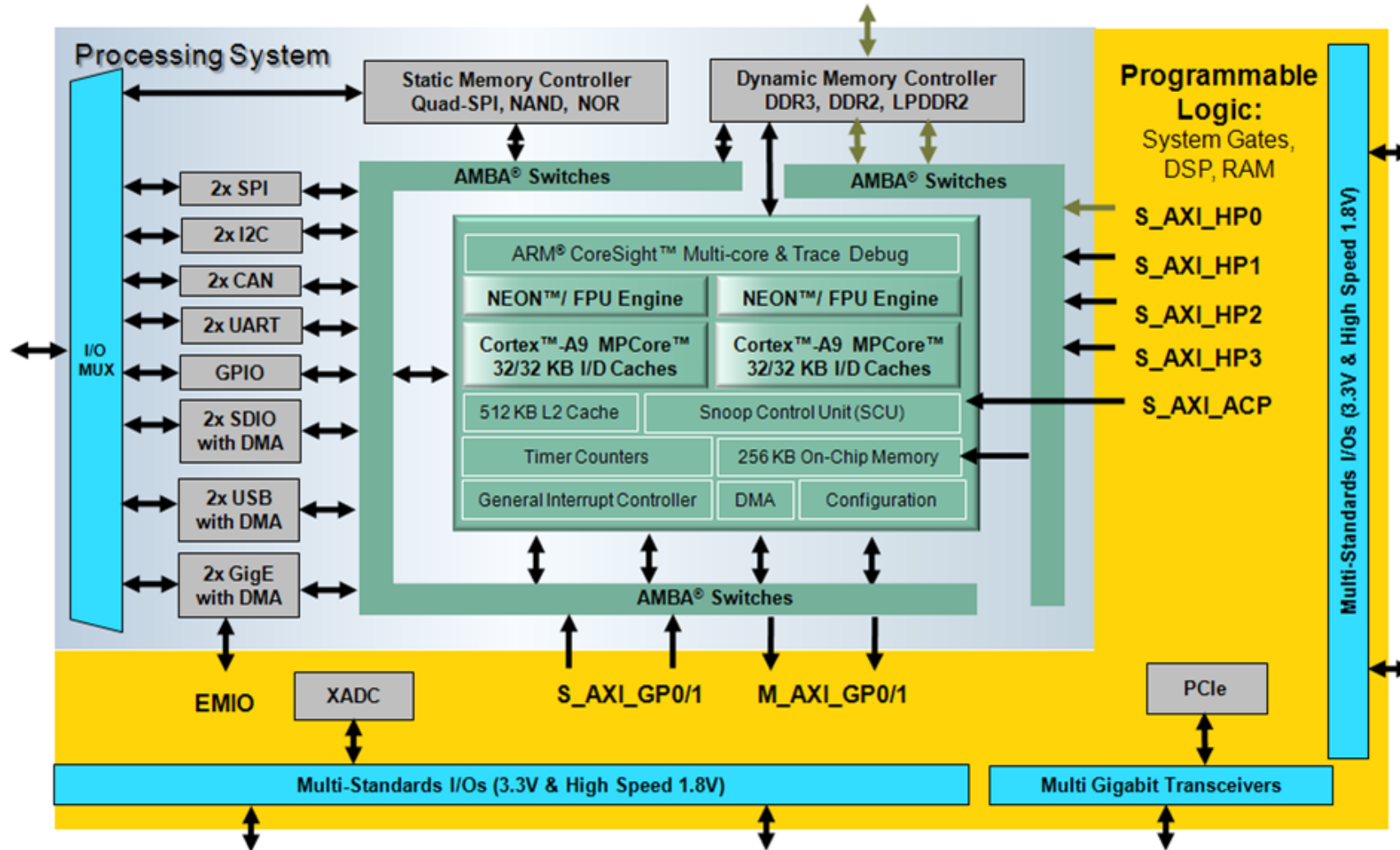
## ➤ Tightly integrated programmable logic

- Used to extend the processing system
- Scalable density and performance

## ➤ Flexible array of I/O

- Wide range of external multi-standard I/O
- High-performance integrated serial transceivers
- Analog-to-digital converter inputs

# Zynq-7000 AP SoC Block Diagram



# The PS and the PL

## ➤ The Zynq-7000 AP SoC architecture consists of two major sections

- PS: Processing system
  - Dual ARM Cortex-A9 processor based
  - Multiple peripherals
  - Hard silicon core
- PL: Programmable logic
  - Shares the same 7 series programmable logic as
    - Artix™-based devices: Z-7010 and Z-7020 (high-range I/O banks only)
    - Kintex™-based devices: Z-7030 and Z-7045 (mix of high-range and high-performance I/O banks)

# ARM Processor Architecture

## ➤ ARM Cortex-A9 processor implements the ARMv7-A architecture

- ARMv7 is the ARM Instruction Set Architecture (ISA)
- ARMv7-A: Application set that includes support for a Memory Management Unit (MMU)
- ARMv7-R: Real-time set that includes support for a Memory Protection Unit (MPU)
- ARMv7-M: Microcontroller set that is the smallest set

## ➤ The ARMv7 ISA includes the following types of instructions (for backwards compatibility)

- Thumb instructions: 16 bits; Thumb-2 instructions: 32 bits
- NEON: ARM's Single Instruction Multiple Data (SIMD) instructions

## ➤ ARM Advanced Microcontroller Bus Architecture (AMBA®) protocol

- AXI3: Third-generation ARM interface
- AXI4: Adding to the existing AXI definition (extended bursts, subsets)

## ➤ Cortex is the new family of processors

- ARM family is older generation; Cortex is current; MMUs in Cortex processors and MPUs in ARM

# ARM Cortex-A9 Processor Power

- **Dual-core processor cluster**
- **2.5 DMIP/MHz per processor**
- **Harvard architecture**
- **Self-contained 32KB L1 caches for instructions and data**
- **External memory based 512KB L2 cache**
- **Automatic cache coherency between processor cores**
- **800-MHz operation (fastest speed grade)**

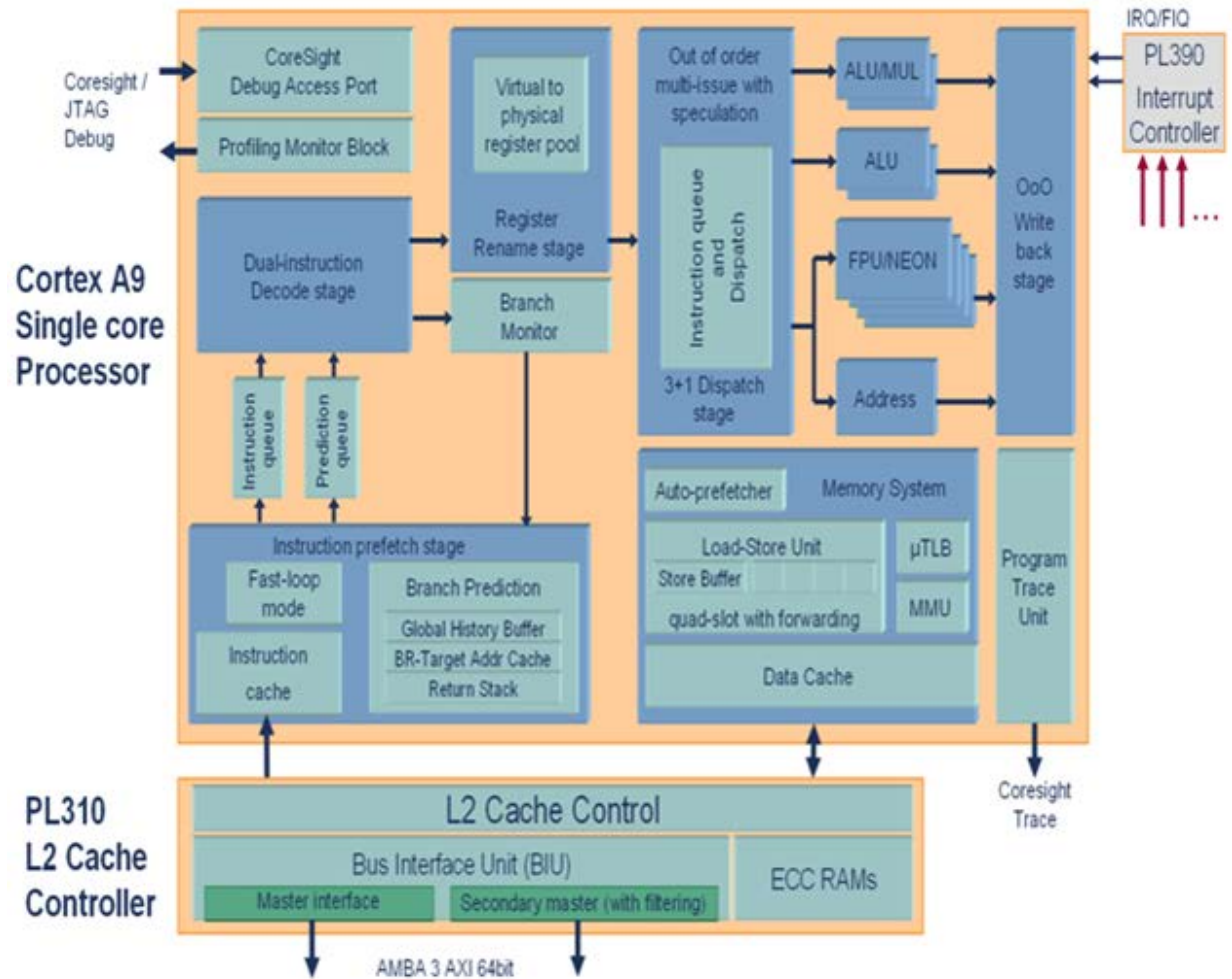


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# ARM Cortex-A9 Processor Micro-Architecture

- Instruction pipeline supports out-of-order instruction issue and completion
- Register renaming to enable execution speculation
- Non-blocking memory system with load-store forwarding
- Fast loop mode in instruction pre-fetch to lower power consumption



# ARM Cortex-A9 Processor Micro-Architecture

## ➤ Variable length, out-of-order, eight-stage, super-scalar instruction pipeline

- Advanced pre-fetch with parallel branch pipeline enabling early branch prediction and resolution
- Multi-issued into
  - Primary data processing pipeline
  - Secondary full data processing pipeline
  - Load-store pipeline
  - Compute engine (FPU/NEON) pipeline

## ➤ Speculative execution

- Supports virtual renaming of ARM physical registers to remove pipeline stalls due to data dependencies
- Increased processor utilization and hiding of memory latencies
- Increased performance by hardware unrolling of code loops
- Reduced interrupt latency via speculative entry to Interrupt Service Routine (ISR)

# PS Components

- **Application processing unit (APU)**
- **I/O peripherals (IOP)**
  - Multiplexed I/O (MIO), extended multiplexed I/O (EMIO)
- **Memory interfaces**
- **PS interconnect**
- **DMA**
- **Timers**
  - Public and private
- **General interrupt controller (GIC)**
- **On-chip memory (OCM): RAM**
- **Debug controller: CoreSight**

# Processing System Interconnect (1)

## ➤ Programmable logic to memory

- Two ports to DDR
- One port to OCM SRAM

## ➤ Central interconnect

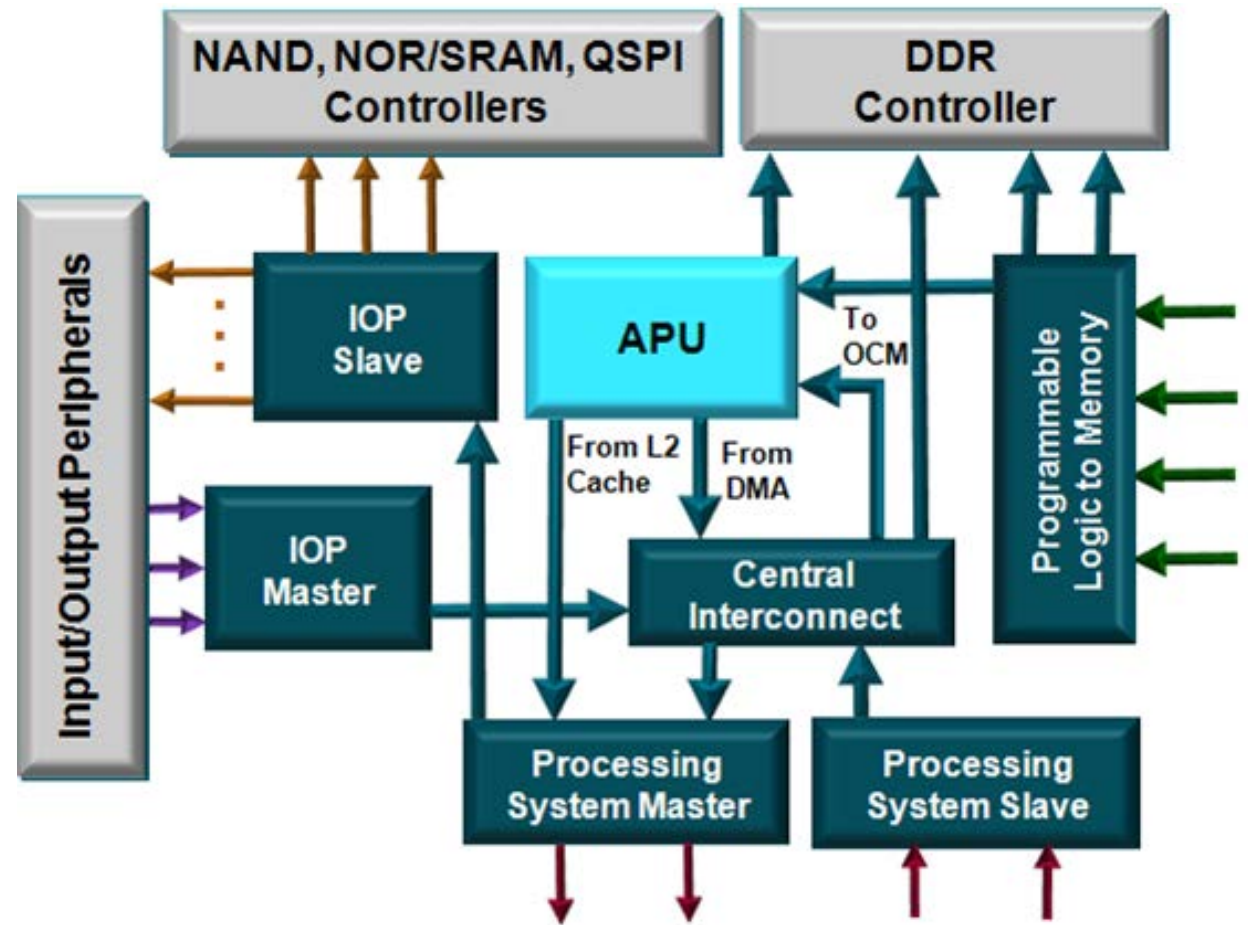
- Enables other interconnects to communicate

## ➤ Peripheral master

- USB, GigE, SDIO connects to DDR and PL via the central interconnect

## ➤ Peripheral slave

- CPU, DMA, and PL access to IOP peripherals



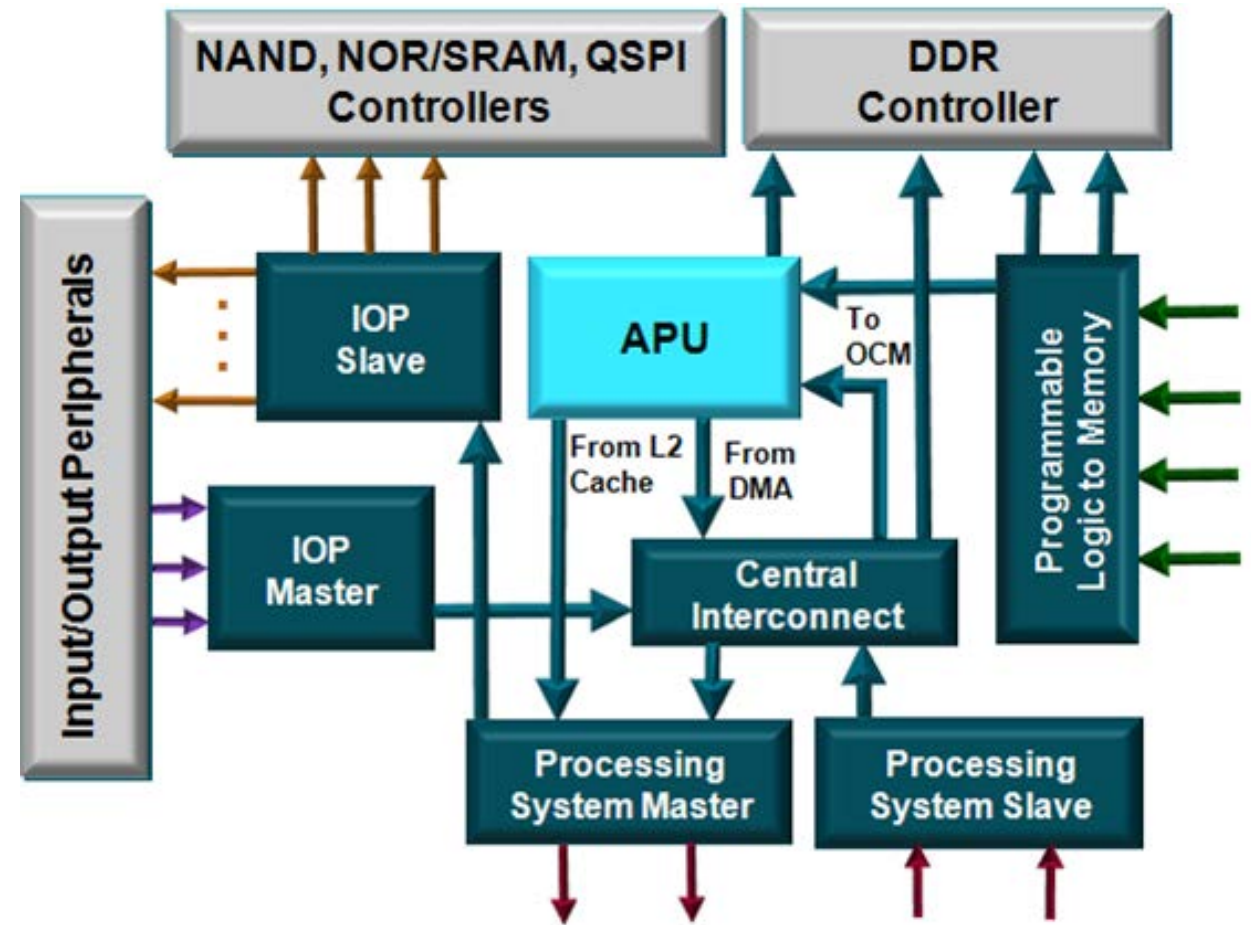
# Processing System Interconnect (2)

## ➤ Processing system master

- Two ports from the processing system to programmable logic
- Connects the CPU block to common peripherals through the central interconnect

## ➤ Processing system slave

- Two ports from programmable logic to the processing system



# Memory Map

- The Cortex-A9 processor uses 32-bit addressing
- All PS peripherals and PL peripherals are memory mapped to the Cortex-A9 processor cores
- All slave PL peripherals will be located between 4000\_0000 and 7FFF\_FFFF (connected to GP0) and 8000\_0000 and BFFF\_FFFF (connected to GP1)

FFFC_0000 to FFFF_FFFF	OCM
FD00_0000 to FFFB_FFFF	Reserved
FC00_0000 to FCFF_FFFF	Quad SPI linear address
F8F0_3000 to FBFF_FFFF	Reserved
F890_0000 to F8F0_2FFF	CPU Private registers
F801_0000 to F88F_FFFF	Reserved
F800_1000 to F880_FFFF	PS System registers,
F800_0C00 to F800_0FFF	Reserved
F800_0000 to F800_0BFF	SLCR Registers
E600_0000 to F7FF_FFFF	Reserved
E100_0000 to E5FF_FFFF	SMC Memory
E030_0000 to E0FF_FFFF	Reserved
E000_0000 to E02F_FFFF	IO Peripherals
C000_0000 to DFFF_FFFF	Reserved
8000_0000 to BFFF_FFFF	PL (MAXI_GP1)
4000_0000 to 7FFF_FFFF	PL (MAXI_GP0)
0010_0000 to 3FFF_FFFF	DDR(address not filtered by SCU)
0004_0000 to 000F_FFFF	DDR(address filtered by SCU)
0000_0000 to 0003_FFFF	OCM

# Zynq AP SoC Memory Resources

## ➤ On-chip memory (OCM)

- RAM
- Boot ROM

## ➤ DDRx dynamic memory controller

- Supports LPDDR2, DDR2, DDR3

## ➤ Flash/static, memory controller

- Supports SRAM, QSPI, NAND/NOR FLASH



# PS Boots First

- **CPU0 boots from OCM ROM; CPU1 goes into a sleep state**
- **On-chip boot loader in OCM ROM (Stage 0 boot)**
- **Processor loads First Stage Boot Loader (FSBL) from external flash memory**
  - NOR
  - NAND
  - Quad-SPI
  - SD Card
  - JTAG; not a memory device—used for development/debug only
  - Boot source selected via package bootstrapping pins
- **Optional secure boot mode allows the loading of encrypted software from the flash boot memory**

# Configuring the PL

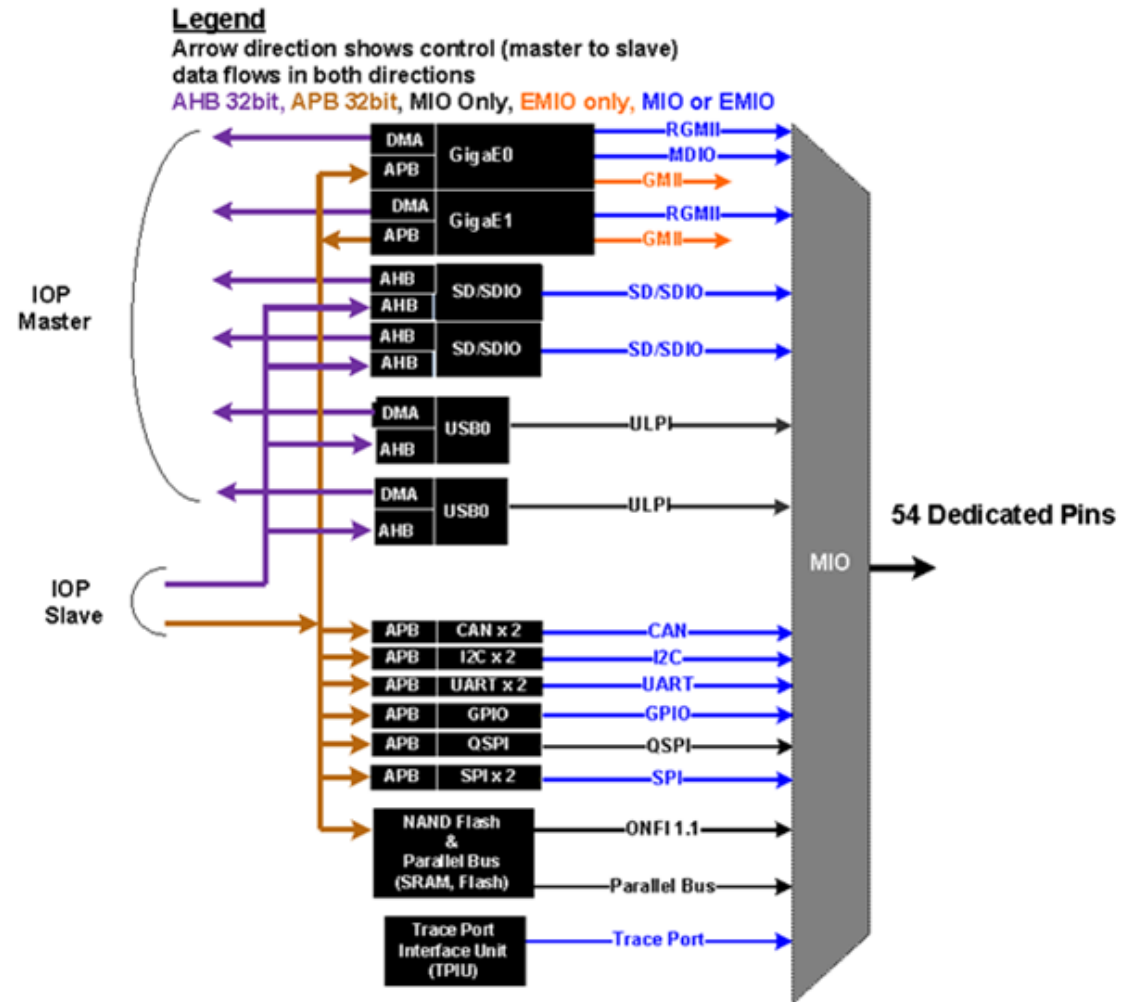
- **The programmable logic is configured after the PS boots**
- **Performed by application software accessing the hardware device configuration unit**
  - Bitstream image transferred
  - 100-MHz, 32-bit PCAP stream interface
  - Decryption/authentication hardware option for encrypted bitstreams
    - In secure boot mode, this option can be used for software memory load
  - Built-in DMA allows simultaneous PL configuration and OS memory loading

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- ***Processor Peripherals***
- Clock, Reset, and Debug Features
- AXI Interfaces
- Summary

# Input/Output Peripherals

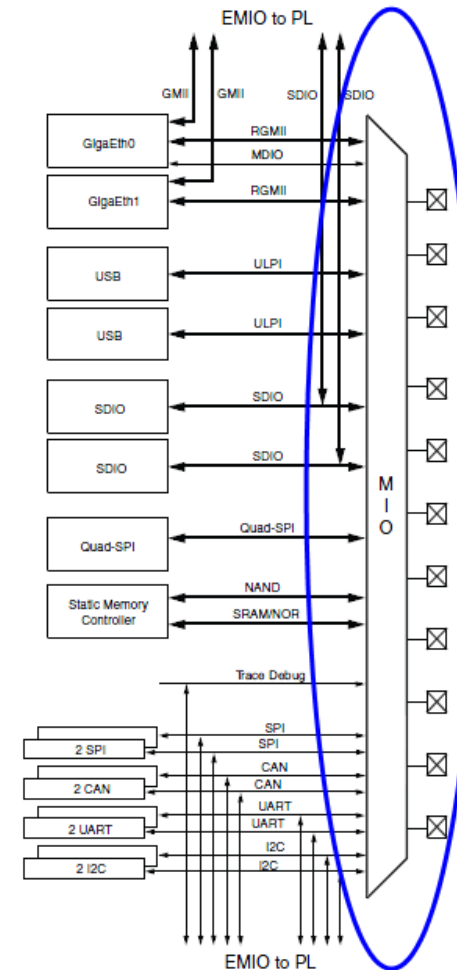
- Two GigE
- Two USB
- Two SPI
- Two SD/SDIO
- Two CAN
- Two I2C
- Two UART
- Four 32-bit GPIOs
  - NAND, NOR/SRAM, Quad SPI
- Trace ports



# Multiplexed I/O (MIO)

## ➤ External interface to PS I/O peripheral ports

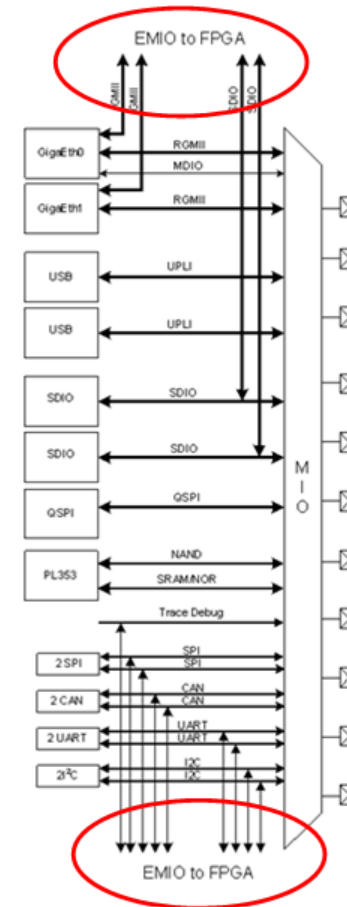
- 54 dedicated package pins available
- Software configurable
  - Automatically added to bootloader by tools
- Not available for all peripheral ports
  - Some ports can only use EMIO



# Extended Multiplexed I/O (EMIO)

## ➤ Extended interface to PS I/O peripheral ports

- EMIO: Peripheral port to programmable logic
- Alternative to using MIO
- Mandatory for some peripheral ports
- Facilitates
  - Connection to peripheral in programmable logic
  - Use of general I/O pins to supplement MIO pin usage
  - Alleviates competition for MIO pin usage



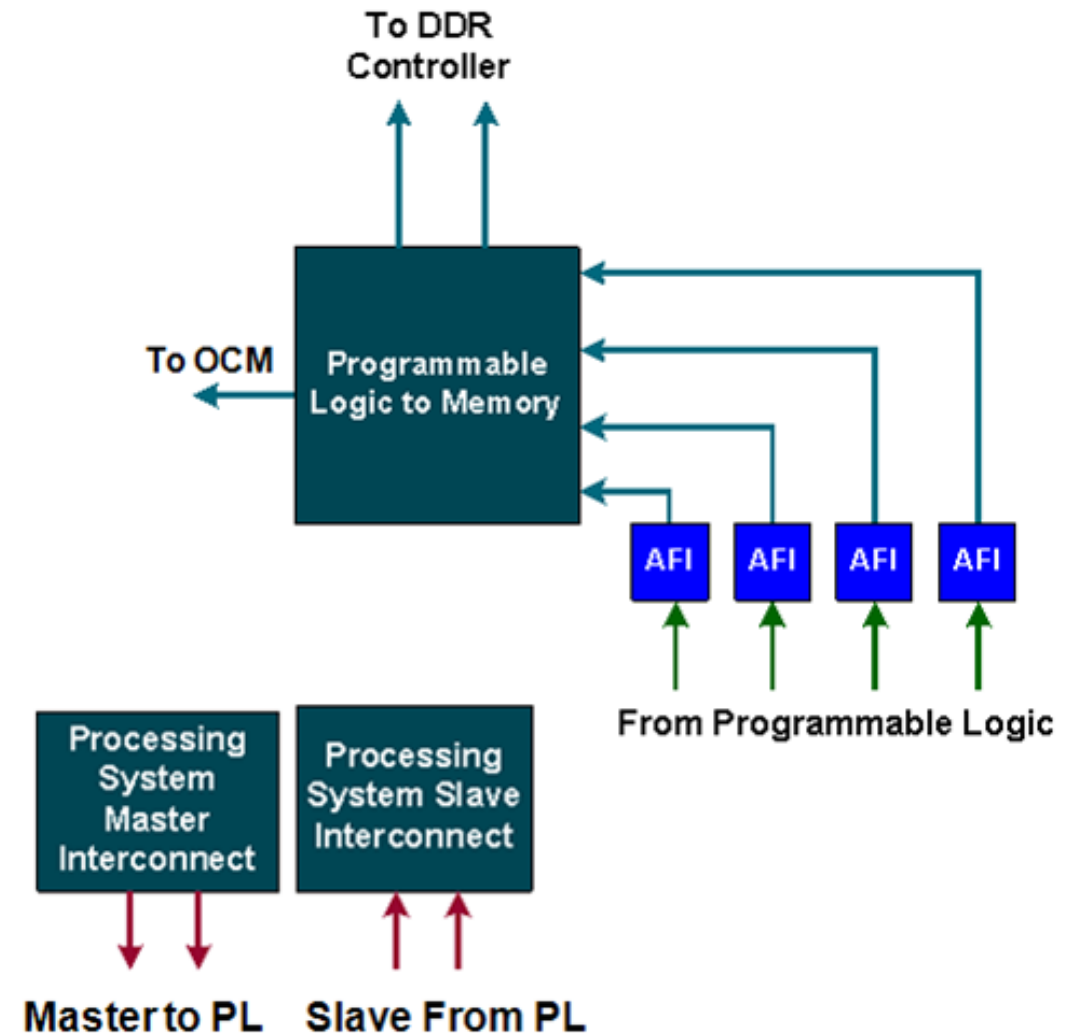
# PS-PL Interfaces

## ➤ AXI high-performance slave ports (HP0-HP3)

- Configurable 32-bit or 64-bit data width
- Access to OCM and DDR only
- Conversion to processing system clock domain
- AXI FIFO Interface (AFI) are FIFOs (1KB) to smooth large data transfers

## ➤ AXI general-purpose ports (GP0-GP1)

- Two masters from PS to PL
- Two slaves from PL to PS
- 32-bit data width
- Conversation and sync to processing system clock domain



# PS-PL Interfaces

- **One 64-bit accelerator coherence port (ACP) AXI slave interface to CPU memory**
- **DMA, interrupts, events signals**
  - Processor event bus for signaling event information to the CPU
  - PL peripheral IP interrupts to the PS general interrupt controller (GIC)
  - Four DMA channel RDY/ACK signals
- **Extended multiplexed I/O (EMIO) allows PS peripheral ports access to PL logic and device I/O pins**
- **Clock and resets**
  - Four PS clock outputs to the PL with enable control
  - Four PS reset outputs to the PL
- **Configuration and miscellaneous**



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# PL Clocking Sources

## ➤ PS clocks

- PS clock source from external package pin
- PS has three PLLs for clock generation
- PS has four clock ports to PL

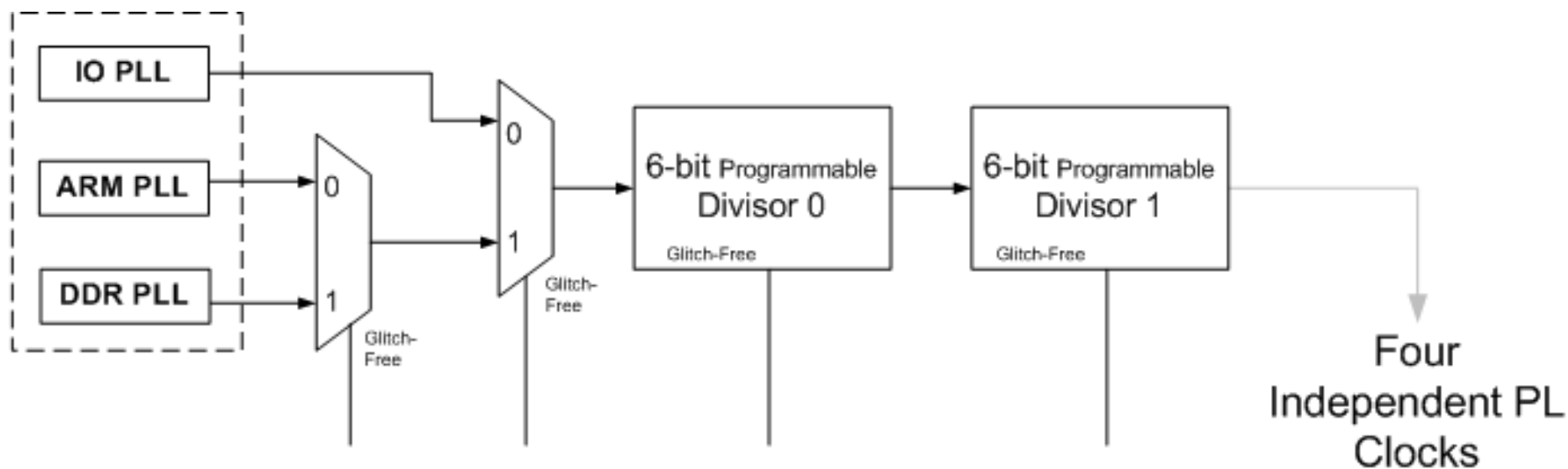
## ➤ The PL has 7 series clocking resources

- PL has a different clock source domain compared to the PS
- The clock to PL can be sourced from external clock capable pins
- Can use one of the four PS clocks as source

## ➤ Synchronizing the clock between PL and PS is taken care of by the architecture of the PS

## ➤ PL cannot supply clock source to PS

# Clocking the PL

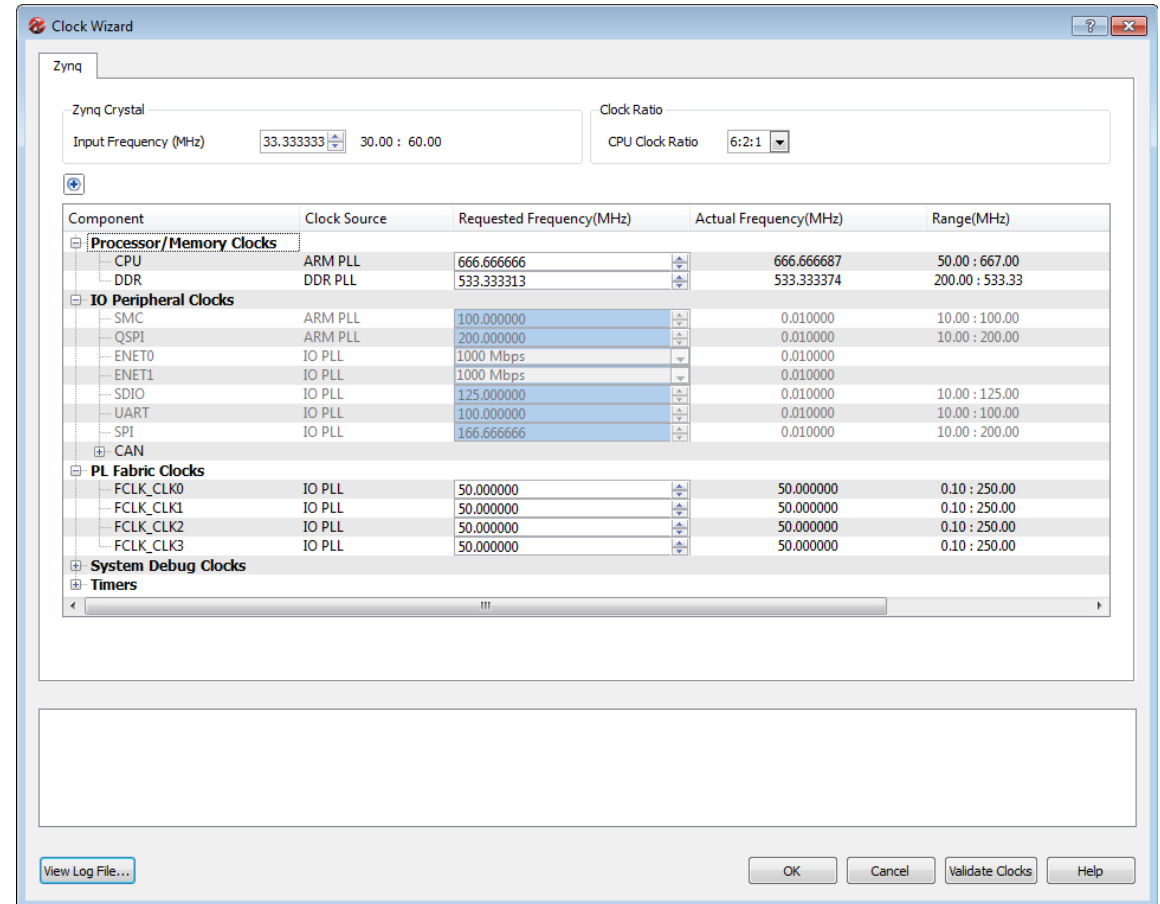


PL Fabric Clock	Control Register	Mux Ctrl Field	Mux Ctrl Field	Divisor 0 Ctrl Field	Divisor 1 Ctrl Field
PL Fabric 0	FPGA0_CLK_CTRL	SRCSEL, 4	SRCSEL, 5	DIVISOR 0, 13:8	DIVISOR 1, 25:20
PL Fabric 1	FPGA1_CLK_CTRL	SRCSEL, 4	SRCSEL, 5	DIVISOR 0, 13:8	DIVISOR 1, 25:20
PL Fabric 2	FPGA2_CLK_CTRL	SRCSEL, 4	SRCSEL, 5	DIVISOR 0, 13:8	DIVISOR 1, 25:20
PL Fabric 3	FPGA3_CLK_CTRL	SRCSEL, 4	SRCSEL, 5	DIVISOR 0, 13:8	DIVISOR 1, 25:20

—▶ FCLKCLK0  
 —▶ FCLKCLK1  
 —▶ FCLKCLK2  
 —▶ FCLKCLK3

# Clock Generation (Using Zynq Tab)

- **The Clock Generator allows the configuration of PLL components for both the PS and PL of the Zynq AP SoC**
  - One input reference clock
- **Access the GUI by clicking the Clock Generation block in the Zynq tab of the SAV**
- **Configure the PS Peripheral Clock in the Zynq tab**
  - PS uses a dedicated PLL clock
  - PS I/O peripherals use the I/O PLL clock and ARM PLL
- **Clock to PL is disabled if PS clocking is present**



# Zynq Resets

## ➤ Internal resets

- Power-on reset (POR)
- Watchdog resets from the three watchdog timers
- Secure violation reset

## ➤ PS resets

- External reset: PS\_SRST\_B
- Warm reset: SRSTB

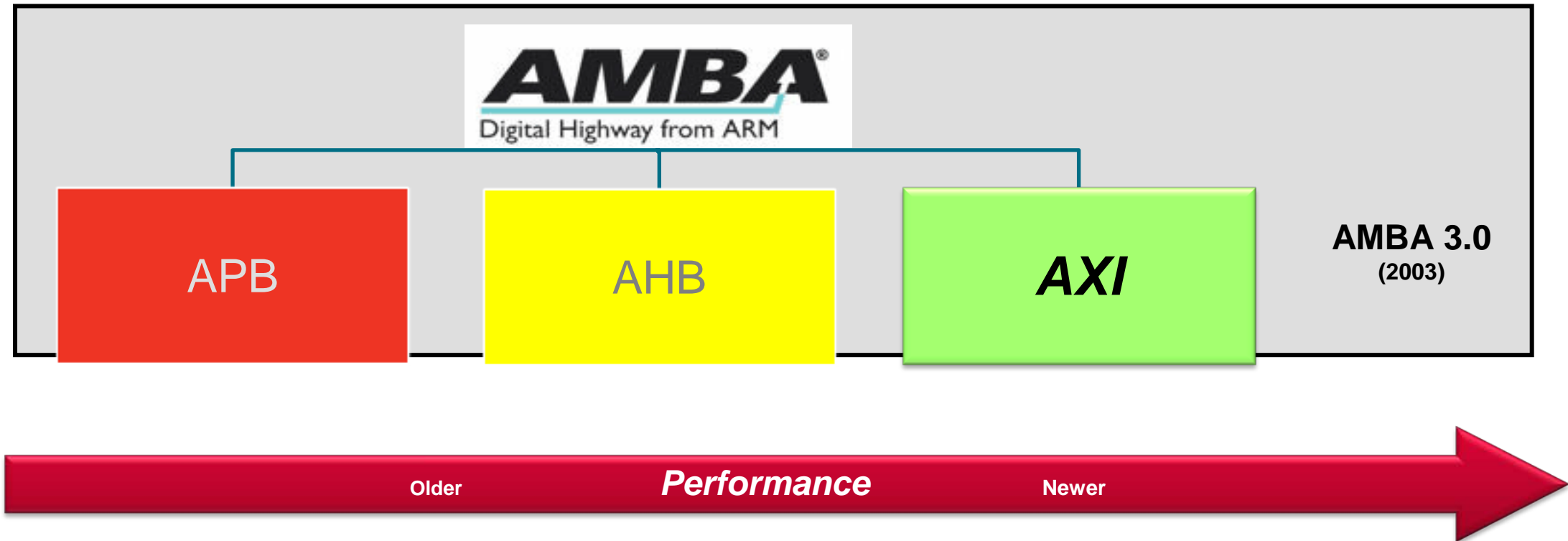
## ➤ PL resets

- Four reset outputs from PS to PL
- FCLK\_RESET[3:0]

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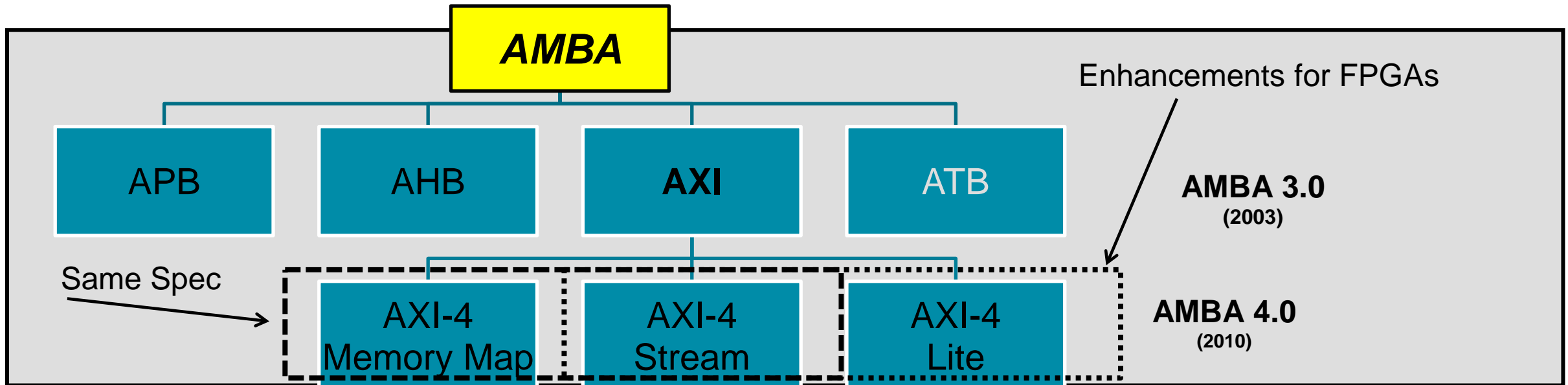
# AXI is Part of ARM's AMBA



**AMBA: Advanced Microcontroller Bus Architecture**

**AXI: Advanced Extensible Interface**

# AXI is Part of AMBA

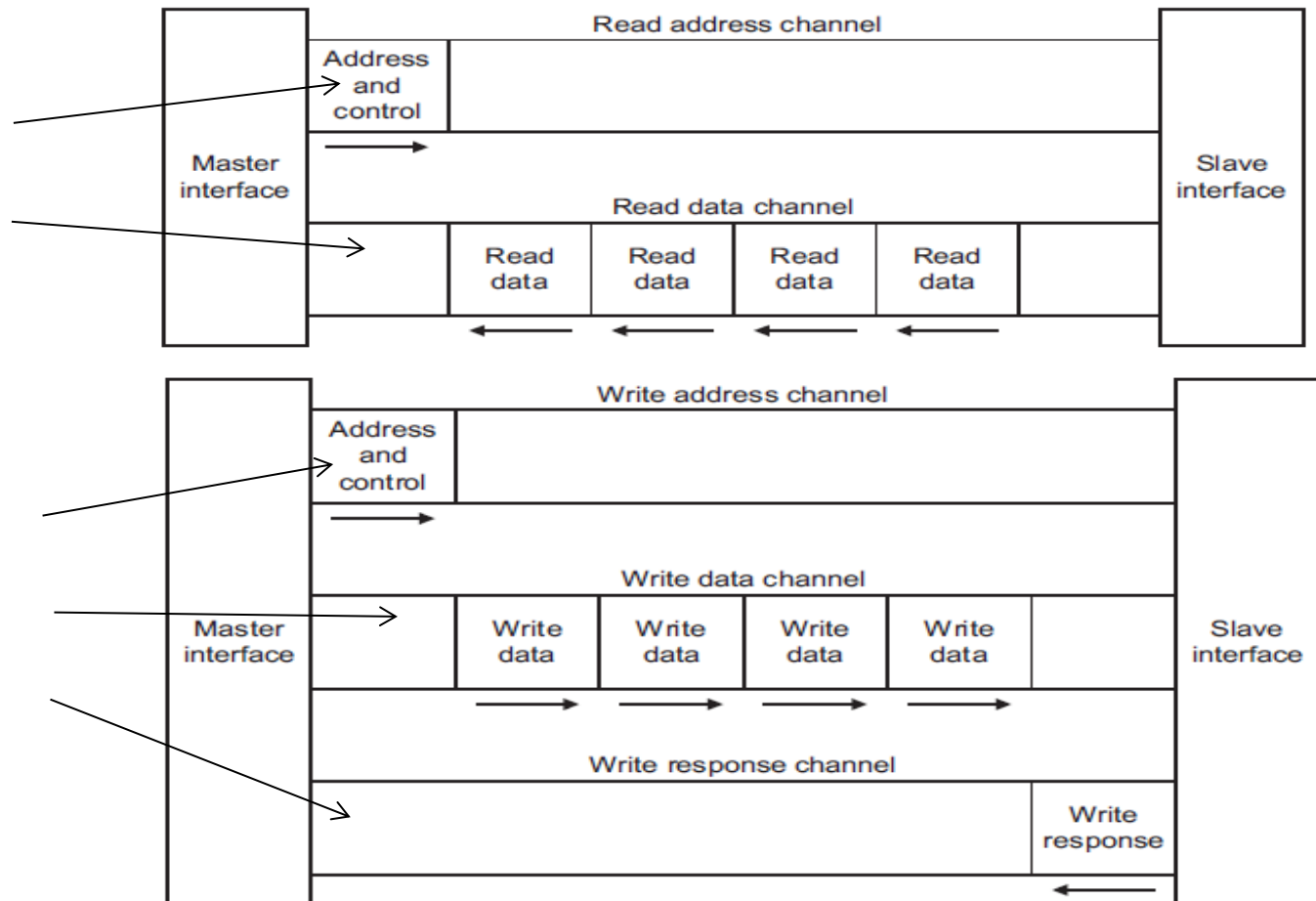


Interface	Features	Similar to
Memory Map / Full (AXI4)	Traditional Address/Data Burst (single address, multiple data)	PLBv46, PCI
Streaming (AXI4-Stream)	Data-Only, Burst	Local Link / DSP Interfaces / FIFO / FSL
Lite (AXI4-Lite)	Traditional Address/Data—No Burst (single address, single data)	PLBv46-single OPB



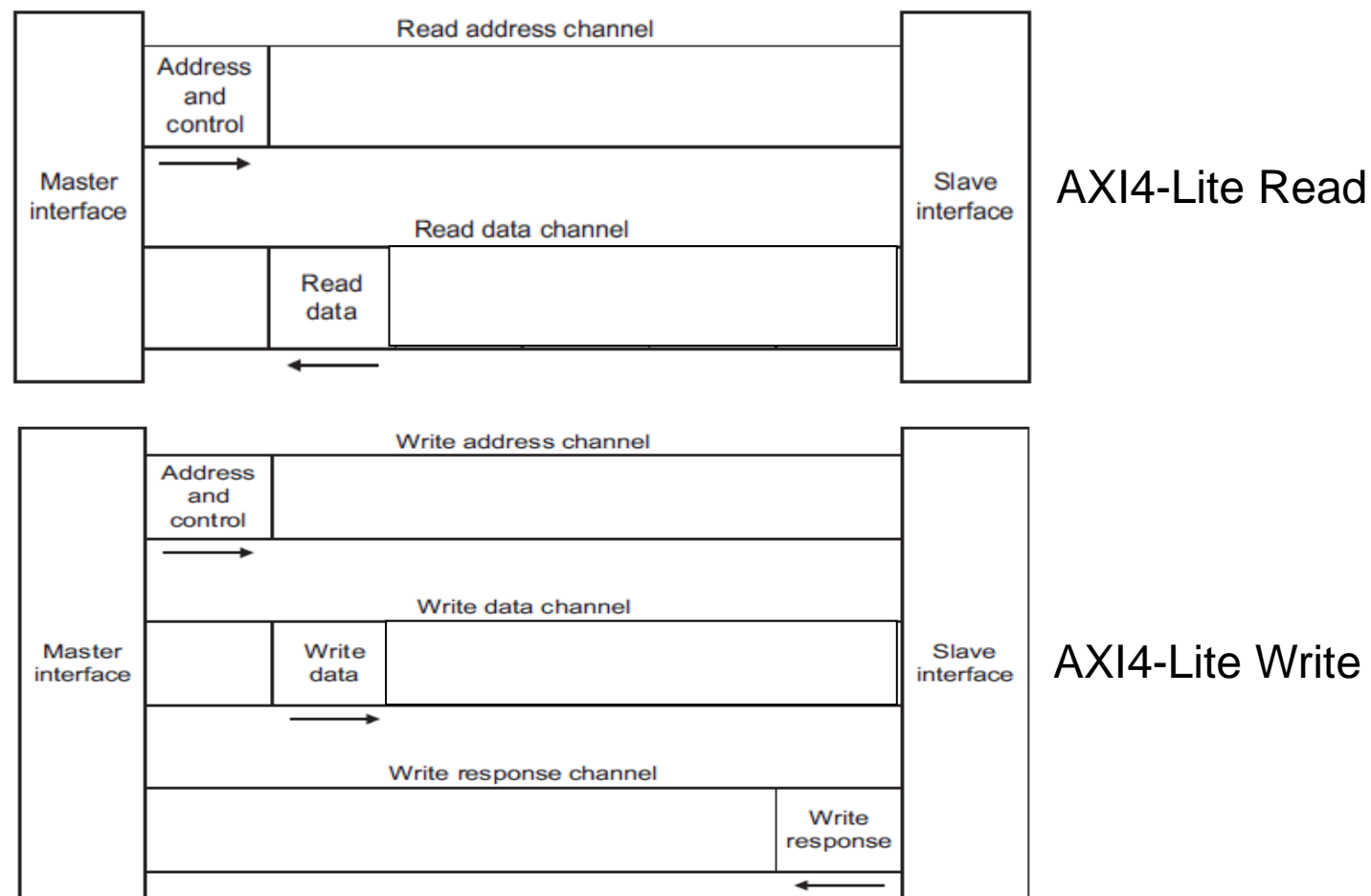
# Basic AXI Signaling – 5 Channels

1. Read Address Channel
2. Read Data Channel
3. Write Address Channel
4. Write Data Channel
5. Write Response Channel



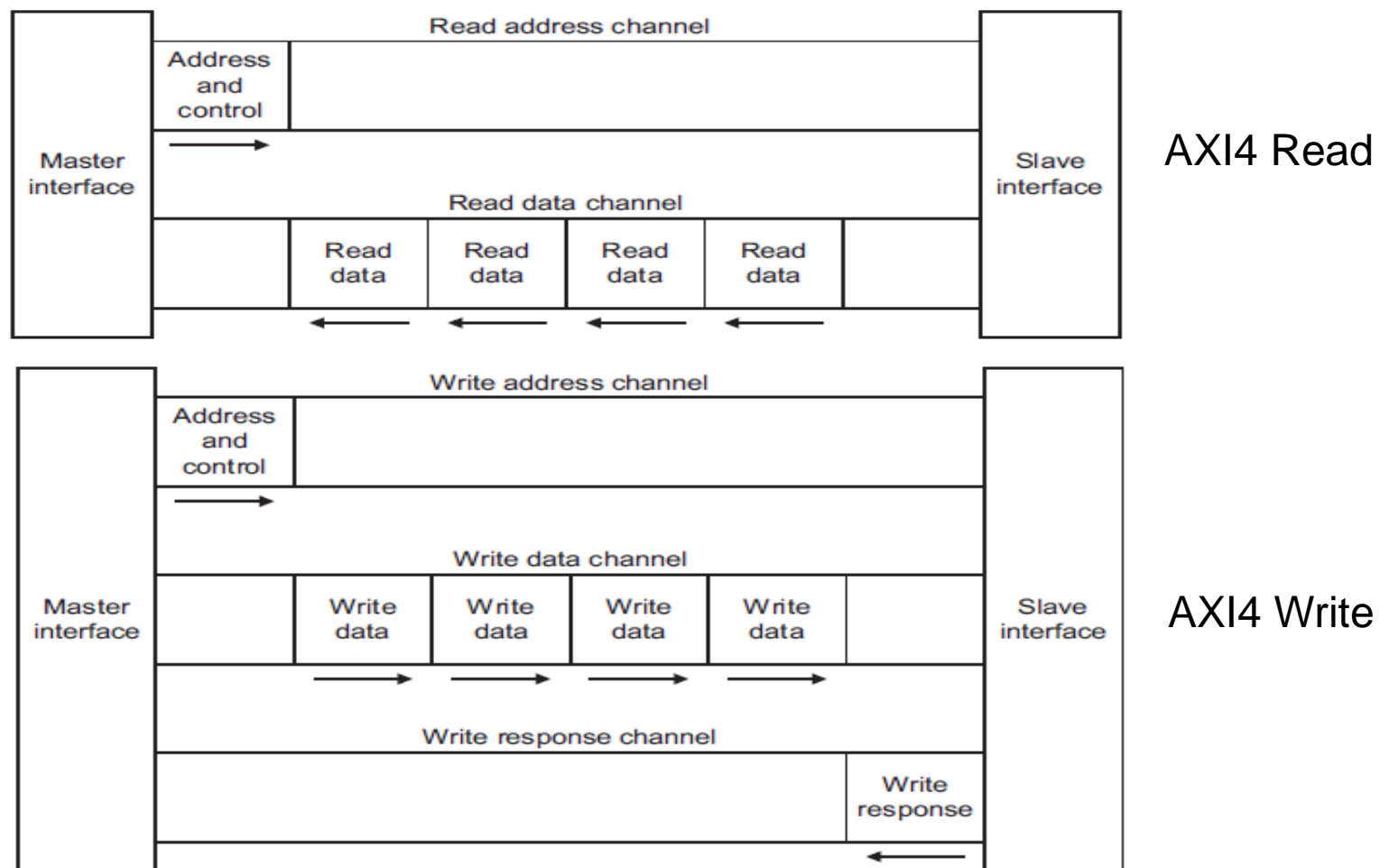
# The AXI Interface—AX4-Lite

- No burst
- Data width 32 or 64 only
  - Xilinx IP only supports 32-bits
- Very small footprint
- Bridging to AXI4 handled automatically by AXI\_Interconnect (if needed)



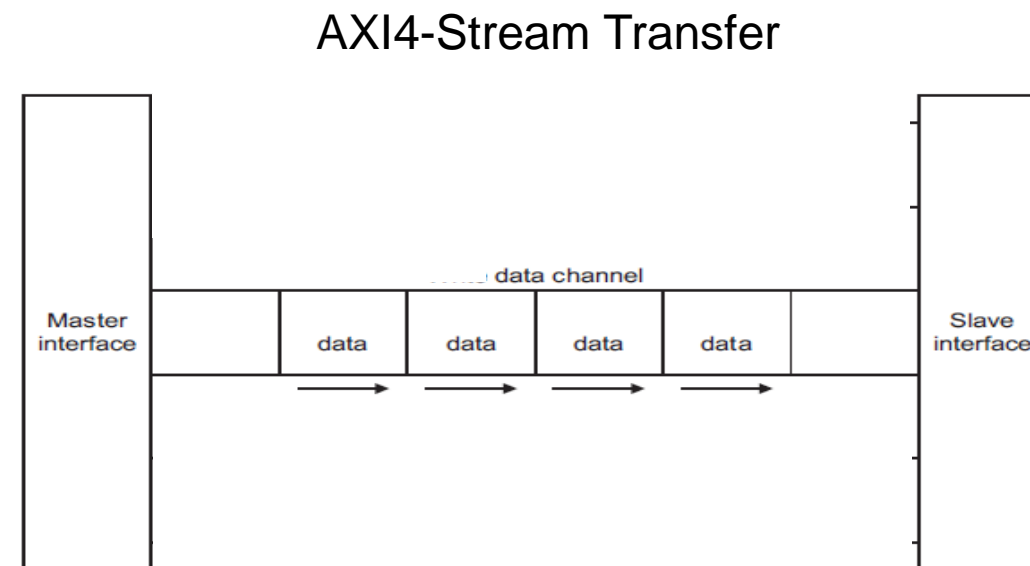
# The AXI Interface—AXI4

- Sometimes called “Full AXI” or “Memory Mapped”
  - Not ARM-sanctioned names
- Single address multiple data
  - Burst up to 256 data beats
- Data Width parameterizable
  - 1024 bits



# The AXI Interface—AXI4-Stream

- **No address channel, no read and write, always just master to slave**
  - Effectively an AXI4 “write data” channel
- **Unlimited burst length**
  - AXI4 max 256
  - AXI4-Lite does not burst
- **Virtually same signaling as AXI Data Channels**
  - Protocol allows merging, packing, width conversion
  - Supports sparse, continuous, aligned, unaligned streams



# Streaming Applications

## ➤ May not have packets

- E.g. Digital up converter
  - No concept of address
  - Free-running data (in this case)
  - In this situation, AXI4-Stream would optimize to a very simple interface

## ➤ May have packets

- E.g. PCIe
  - Their packets may contain different information
  - Typically bridge logic of some sort is needed

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# Summary

- **The Zynq-7000 processing platform is a system on a chip (SoC) processor with embedded programmable logic**
- **The processing system (PS) is the hard silicon dual core consisting of**
  - APU and list components
    - Two Cortex-A9 processors
    - NEON co-processor
    - General interrupt controller (GIC)
    - General and watchdog timers
  - I/O peripherals
  - External memory interfaces

# Summary

- **The programmable logic (PL) consists of 7 series devices**
- **AXI is an interface providing high performance through point-to-point connection**
- **AXI has separate, independent read and write interfaces implemented with channels**
- **The AXI4 interface offers improvements over AXI3 and defines**
  - Full AXI memory mapped
  - AXI Lite
  - AXI Stream
- **Tightly coupled AXI ports interface the PL and PS for maximum performance**
- **The PS boots from a selection of external memory devices**
- **The PL is configured by and after the PS boots**
- **The PS provides clocking resources to the PL**
- **The PL may not provide clocking to the PS**