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Day 4: Silicon to System design

Silicon for Embedded Systems – An Overview

Workshop on

“VLSI to System design : Silicon-to-end application approach”

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Speaker Introduction

- **Desikan Srinivasan**
  - **Director of Engineering, CPU Group, Arm Bangalore**

  - **25+ years in VLSI industry**
  - **Design verification**

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Disclaimer

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Arm is working actively with our partners, standards bodies, and the wider ecosystem to adopt a consistent approach to the use of inclusive language and to eradicate and replace offensive terms. We recognise that this will take time. This course contains references to non-inclusive language; it will be updated with newer terms as those terms are agreed and ratified with the wider community.

Contact us at education@arm.com with questions or comments about this course. You can also report non-inclusive and offensive terminology usage in Arm content at terms@arm.com.

Module Syllabus

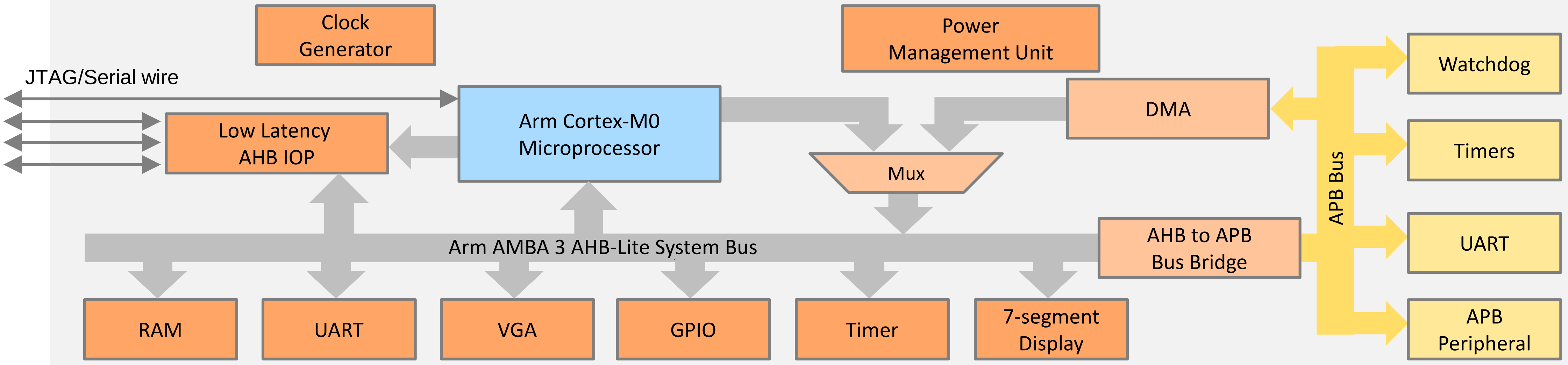
- Building a System on Chip

- Introduction to Embedded Systems
  - CPUs vs. MCUs vs. Embedded Systems
  - Examples of Embedded Systems
  - Options for Building Embedded Systems

- Arm processor-based Design.
  - Cortex-M series processors
  - Salient design features
  - Example MCU using Cortex-M processor

System on Chip (SOC)

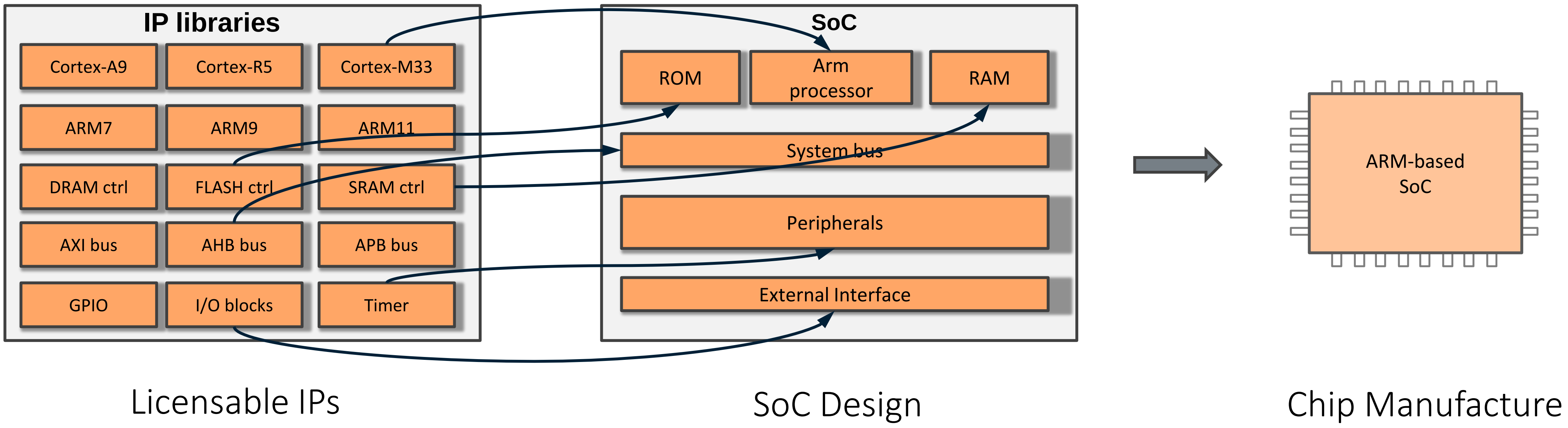
Example Arm-based SoC



An example of an Arm-based SoC

How to design an ARM-based SoC

- Select a set of IP cores from Arm and/or other third-party IP vendors
- Integrate IP cores into a single chip design
- Give design to semiconductor foundries for chip fabrication

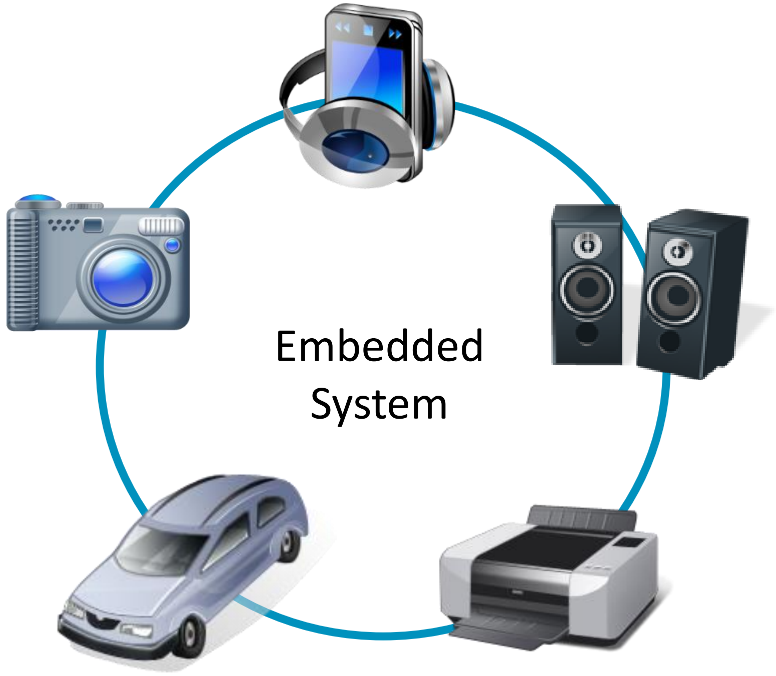


Embedded Systems

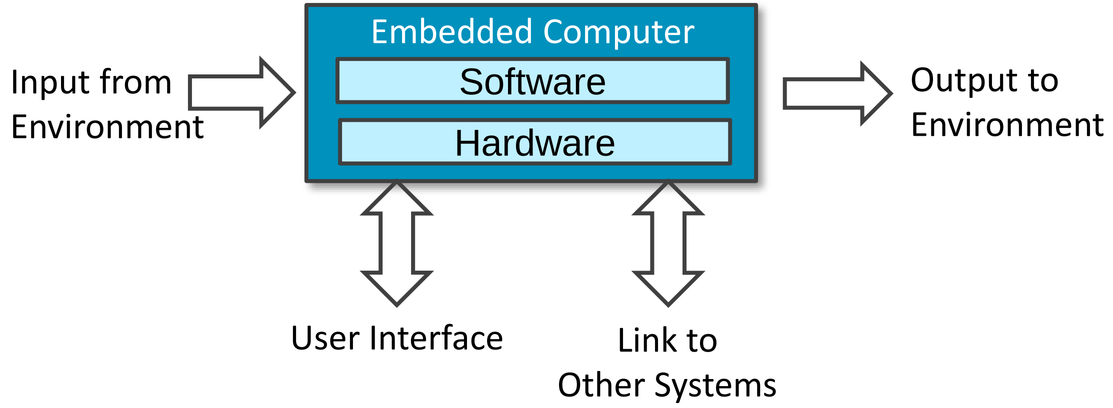
Introduction to Embedded Systems

- What is an embedded system?
  - Application-specific computer system
  - Interacting with its environment
  - Build into a larger system
  - Often with real-time computing constraints

- What is the motivation for building an embedded system?
  - Better performance
  - More functions and features
  - Lower cost e.g. through automation
  - More dependable
  - Lower power



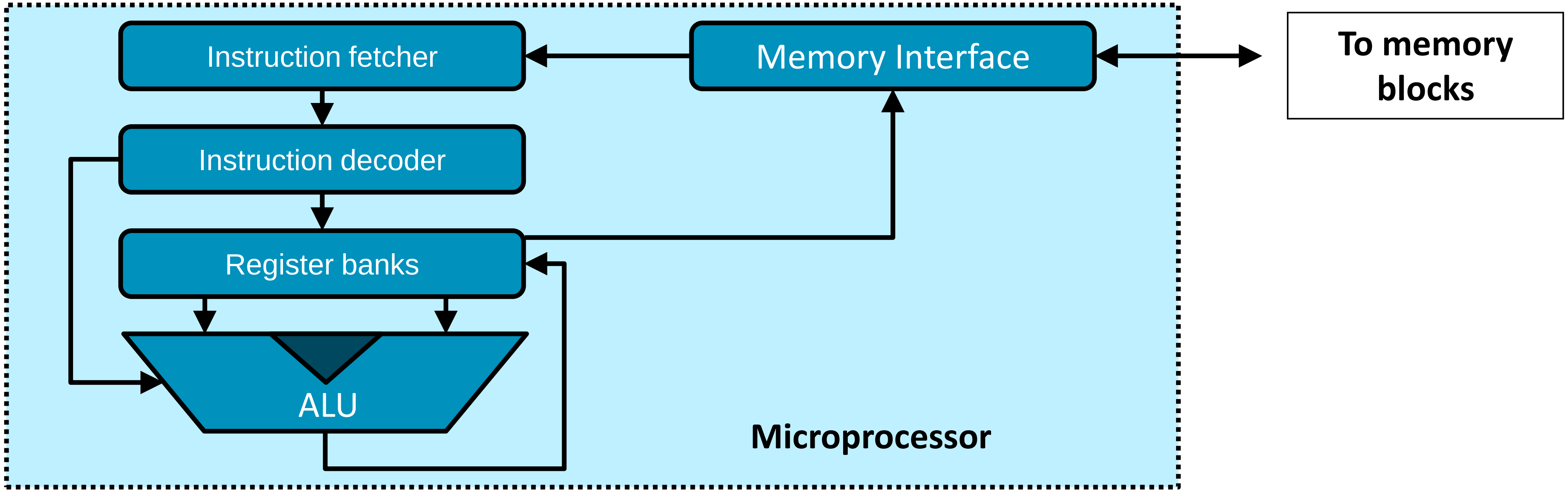
Macroscopic view on a device level



Microscopic view on a functionality level

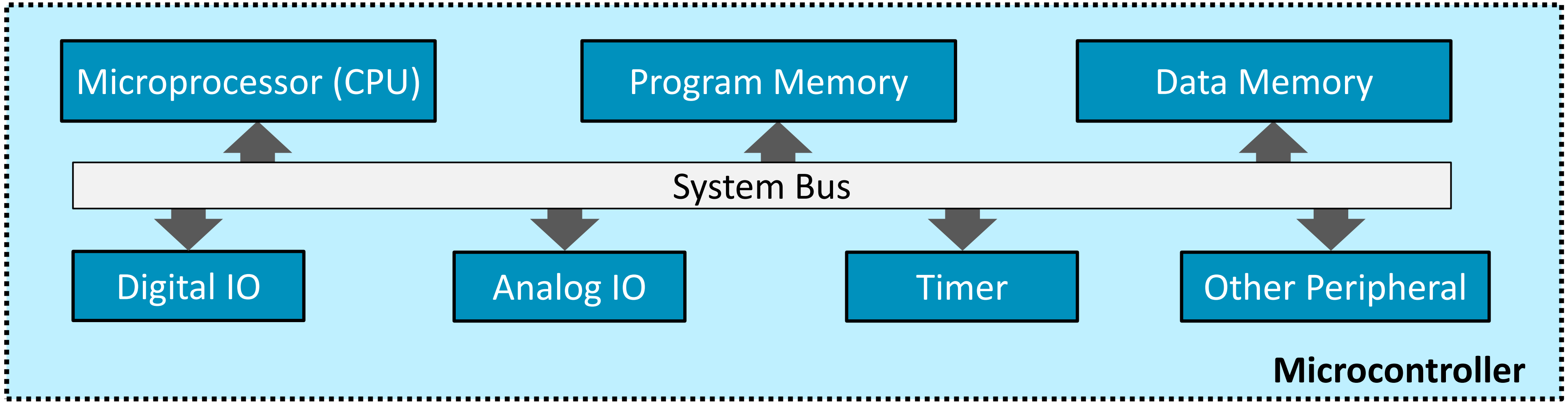
From a Processor to an Embedded System

- Microprocessor (central processing unit, CPU)
  - Typically defined as a single processor core that supports at least instruction fetching, decoding, and executing
  - Normally can be used for general-purpose computing, but needs to be supported with memory and Input/Outputs (IOs)



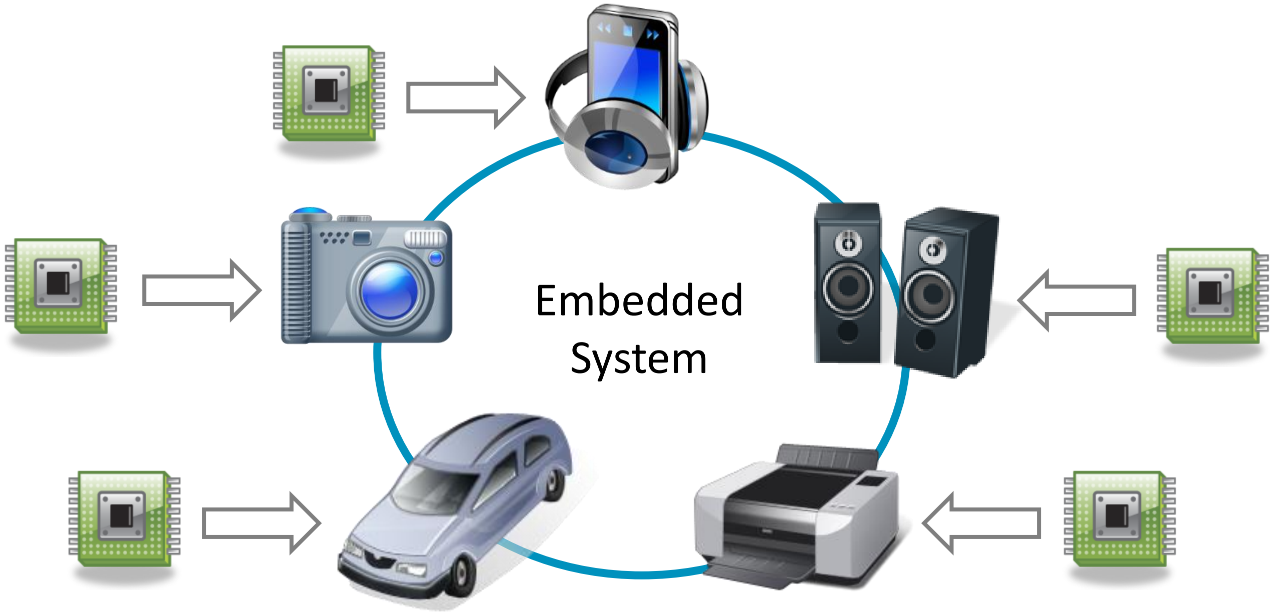
From a Processor to an Embedded System

- Microcontroller (microcontroller unit, MCU)
  - Typically has a single processor core
  - Has memory blocks, digital IOs, analog IOs, and other basic peripherals
  - Typically used for basic control purpose, such as embedded applications



From a Processor to an Embedded System

- Embedded system
  - Typically implemented using MCUs
  - Often integrated into a larger mechanical or electrical system
  - May have real-time constraints



Example Embedded System: Bike Computer

Functions:
- Speed measurement
- Distance measurement

Constraints:
- Size
- Cost
- Power and energy
- Weight

Inputs:
- Wheel rotation indicator
- Mode key

Output:
- Liquid crystal display

Use low-performance microcontroller:
- 9-bit, 10 MIPS

Input:
Wheel rotation
Mode key

Output:
Display speed and distance

Example: Gasoline Automobile Engine Control Unit

Functions:
- Fuel injection
- Air intake setting
- Spark timing
- Exhaust gas circulation
- Electronic throttle control
- Knock control

Many inputs and outputs:
- Discrete sensors and actuators
- Network interface to rest of car

Constraints:
- Reliability in harsh environment
- Cost
- Size

Use high-performance microcontroller:
- E.g. 32-bit, 3 MB flash memory, 50-300 MHz

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Introduction to the Internet of Things (IoT)

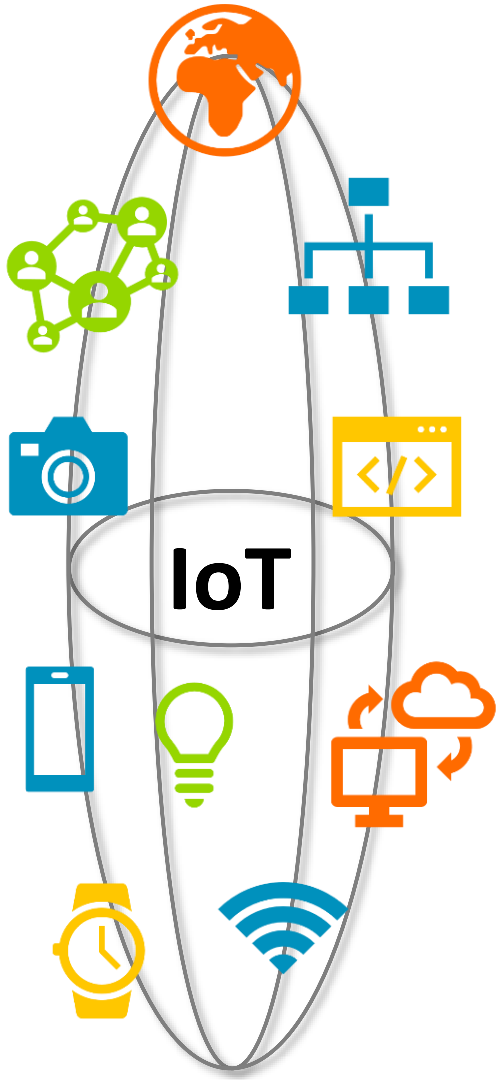
- IoT generally refers to a world in which a large range of objects are addressable via a network

Why IoT?

- Items can have more functionality and become more intelligent
- Items can be managed more easily
- More information becomes available

Objects can include:

- Smart buildings and home appliances
  - Fridges, TVs, cookers
- Civil engineering structures
  - Bridges, railways
- Wearable devices
  - Smart watches, glasses
- Medical devices
  - Smart inhaler, embedded pills



Options for Building Embedded Systems

	Implementation	Design Cost	Unit Cost	Upgrades & Bug Fixes	Size	Weight	Power	System Speed
Dedicated Hardware	Discrete logic	low	mid	hard	large	high	?	very fast
	ASIC	high ($500K/ mask set)	very low	hard	tiny – 1 die	very low	low	extremely fast
	Programmable logic – FPGA, PLD	low to mid	mid	easy	small	low	medium to high	very fast
Software Running on Generic Hardware	Microprocessor + memory + peripherals	low to mid	mid	easy	small to medium	low to moderate	medium	moderate
	Microcontroller (int. memory & peripherals)	low	mid to low	easy	small	low	medium	slow to moderate
	Embedded PC	low	high	easy	medium	moderate to high	medium to high	fast

Microcontroller based embedded system

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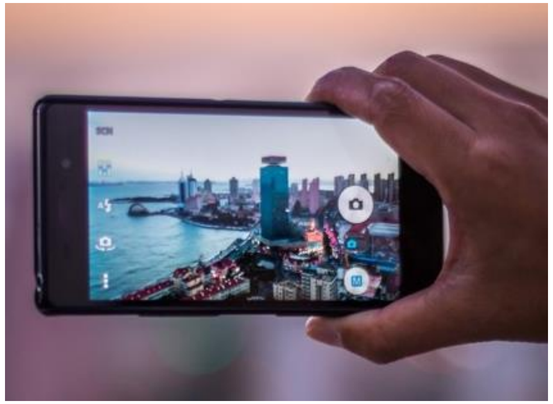
ARM Processor based Silicon

Arm architecture and processors

A family of RISC-based processor architecture

- Architecture well-known for its power efficiency
- Widely used in mobile and IoT devices, e.g., smartphones, connected cars, wearables
- Designed and licensed by Arm to a wide ecosystem of partners
- Arm does not manufacture, but it licenses designs to semiconductor companies, who add their own intellectual property (IP) on top of Arm's IP
- Arm also offers IP other than for processors, such as physical IPs, interconnect IPs, graphics cores, and development tools.

Arm Architecture Profiles



Cortex-A
Highest performance

Designed for high-level operating systems

Cortex-R
Faster responsiveness

Designed for high performance, hard real-time applications

Cortex-M
Smallest/lowest power

Designed for discrete processing and microcontrollers

SecurCore
Tamper resistant

Designed for physical security

Cortex-M Processor Value Proposition

Ease of use	Lower software cost	Pure C target CMSIS support Broad tools and OS support Binary compatible roadmap
Energy efficient	Lower energy cost	Sleep mode support Wake-up Interrupt Controller Low power implementation
Reduced system cost	Lower silicon cost	Thumb-2 code density Area-optimized designs CoreSight debug support

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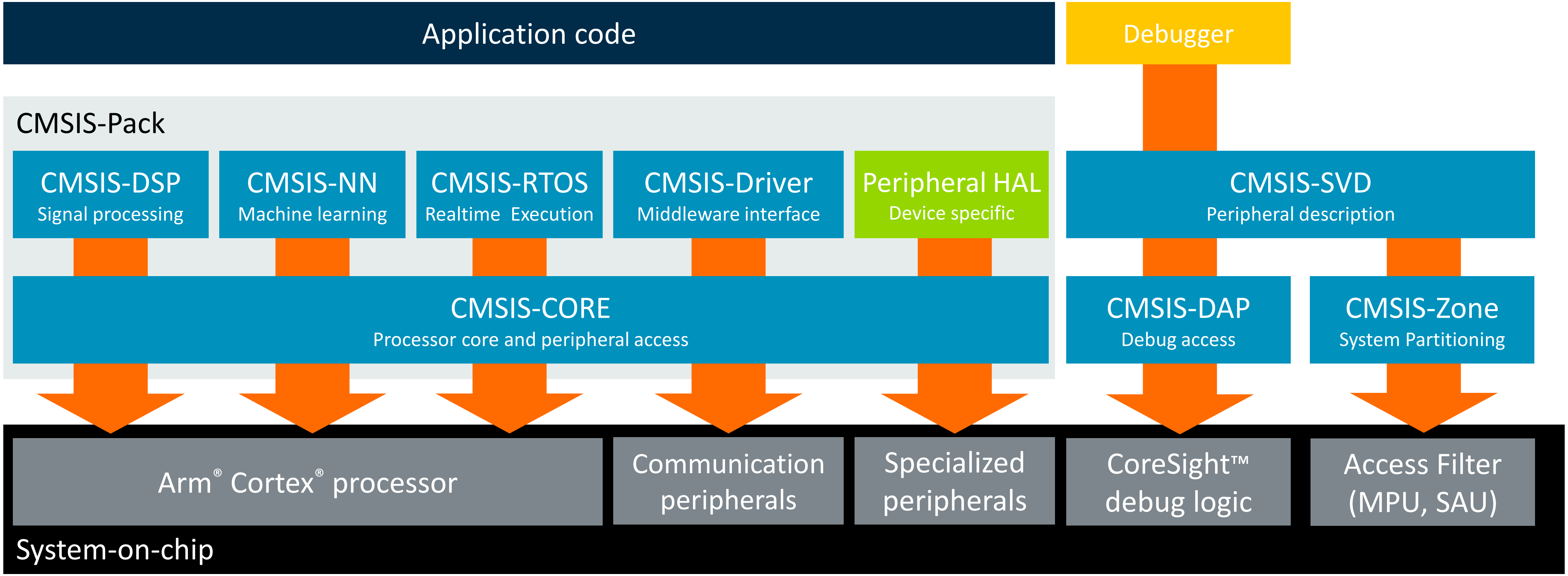
CMSIS Simplifies Connecting Applications To The MCU

- Consistent software framework for Arm Cortex-M and Cortex-A5/A7/A9 based systems

CMSIS 5

- Consistent software framework for Arm Cortex-M and Cortex-A5/A7/A9 based systems



Cortex-M processors serving all applications

Energy grid
Automotive
Environmental
Home automation
Healthcare
Enterprise
Retail

Smart city
Wearables
Farming
Identity & tracking
VR / AR
Building automation
Connected clothing

Robotics
Sensor
Industrial
IoT
Smart lighting
Smart watch
Space

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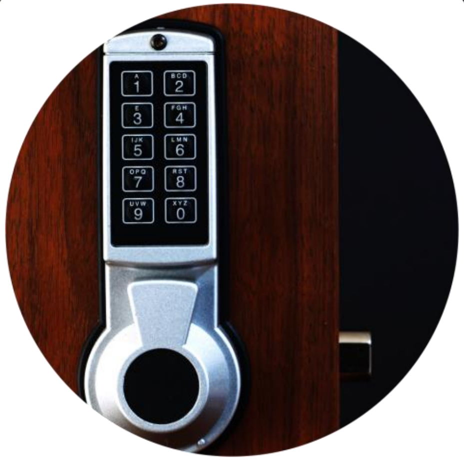
IoT Will Be Everywhere



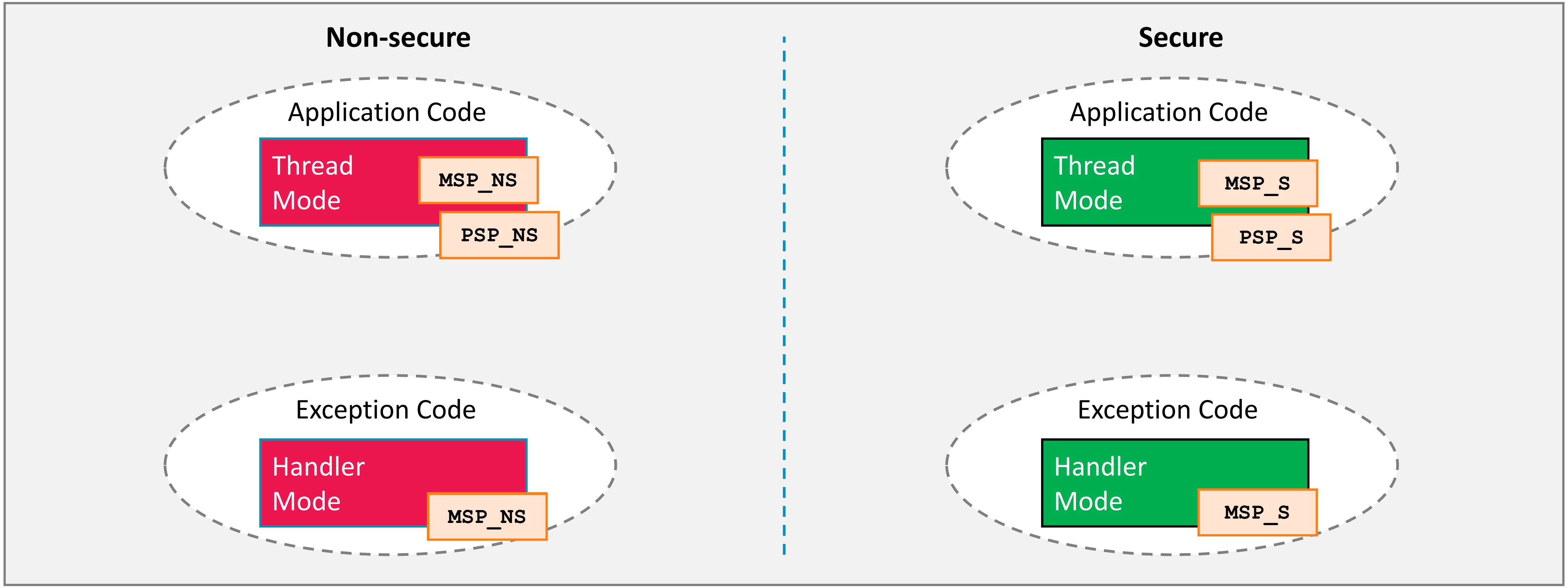
How do we design in robust end-to-end security?

http://www.flickr.com/photos/jurvetson
/7408464122/in/photostream/

Introduction to TrustZone for Armv8-M

- Armv8-M architecture includes optional Security Extension
  - Branded as Arm TrustZone for Armv8-M
- Similar in concept to TrustZone for Armv8-A
  - Implementation is optimized for microcontrollers
- System may be partitioned between secure and non-secure software
- Secure software is highly trusted
  - Has access to more system resources
  - Protected from access by non-trusted code
- To protect the secure software the security extensions provide:
  - Isolated Secure memory for code and data
  - Secure execution state to run Secure code

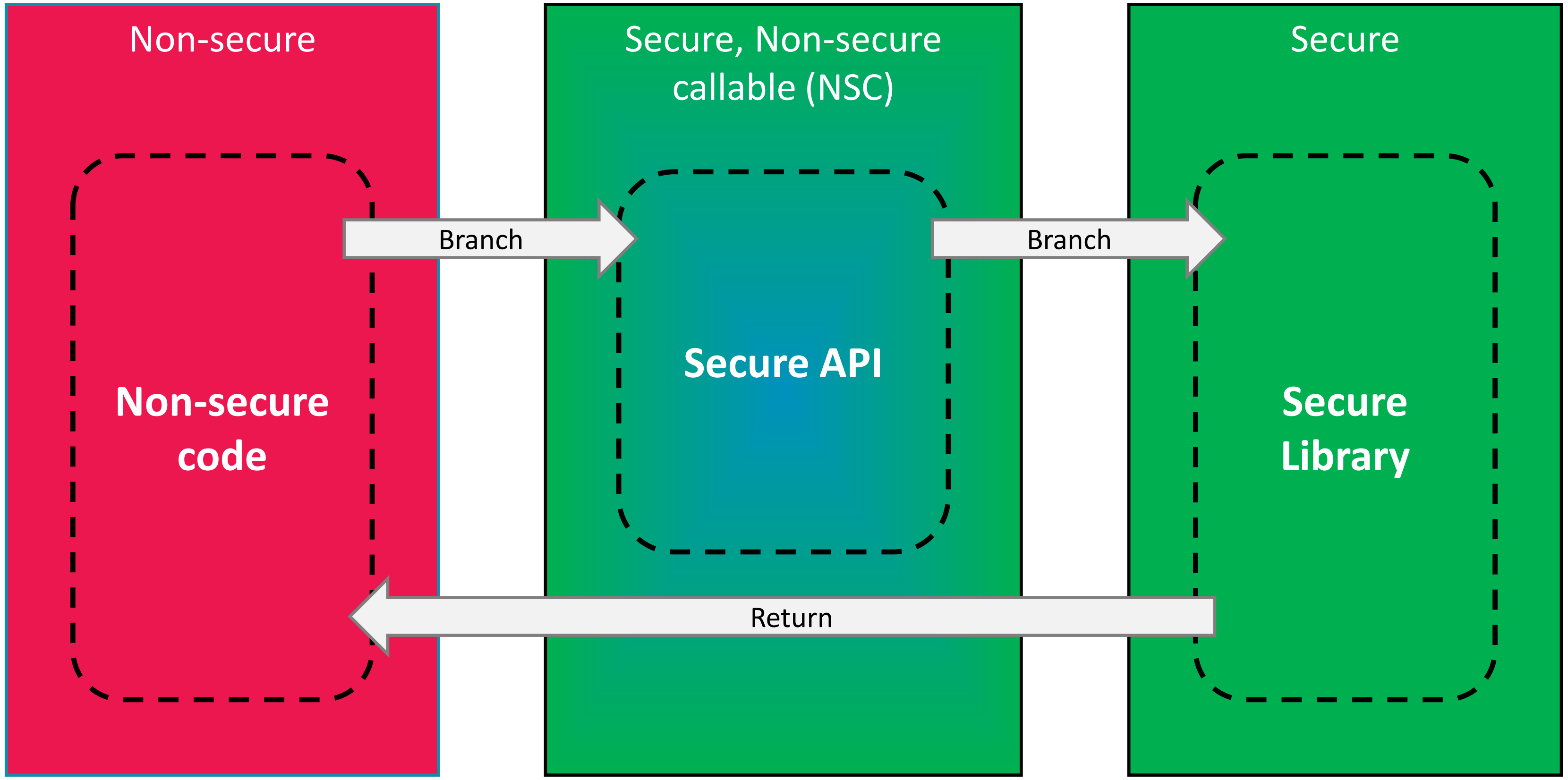
Secure and Non-secure states



Memory security

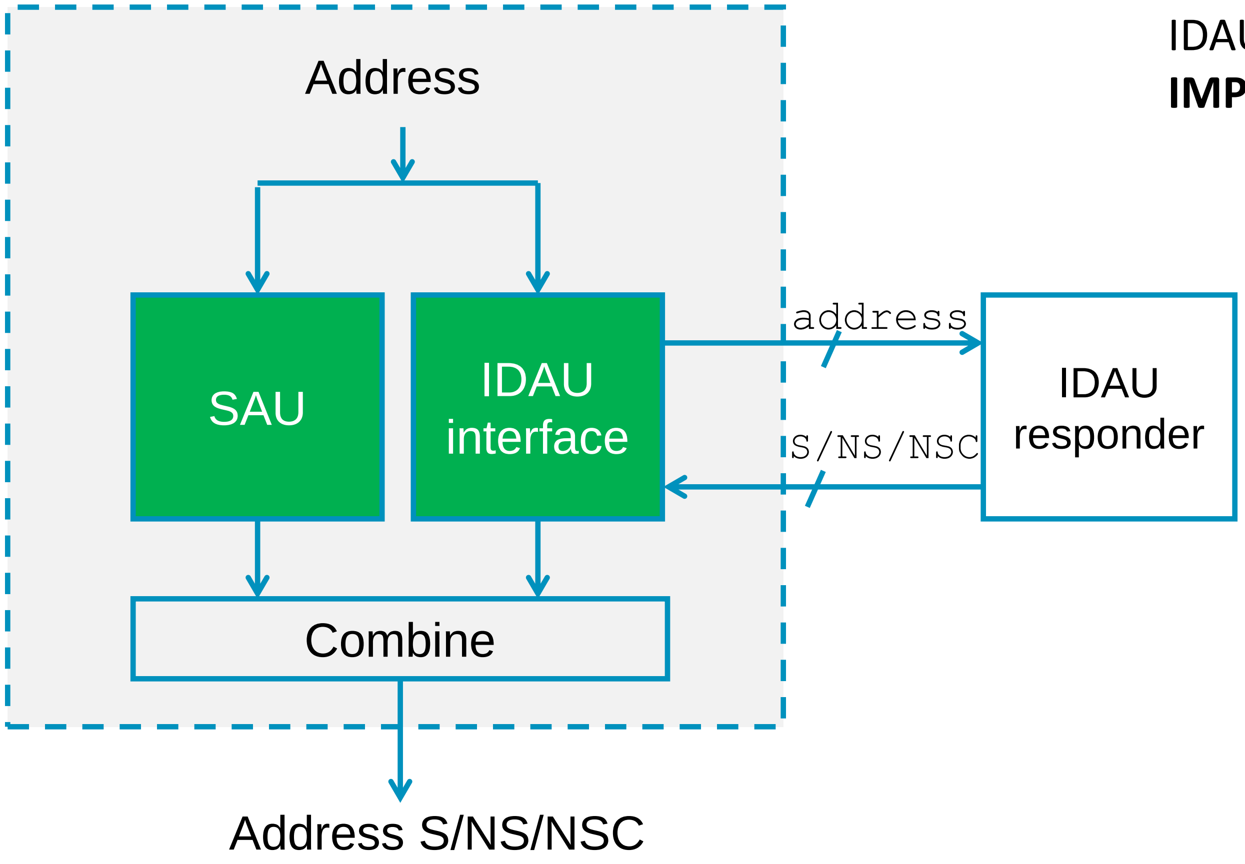
Physical memory is split into Secure and Non-secure regions

- A Secure region can also be Non-Secure Callable (NSC)



Memory security determination

- The security state of a memory region is controlled by the combination of two values
  - Security Attribution Unit (SAU)
  - Implementation Defined Attribution Unit (IDAU)



IDAU is optional and its details are **IMPLEMENTATION DEFINED**

Arm Cortex-M processor portfolio

	Armv6-M	Armv7-M	Armv8-M (TrustZone)
High performance		Cortex-M7: Outstanding performance, control and DSP	Cortex-M85: Maximum performance for control, DSP and ML
Performance efficiency		Cortex-M3: Performance efficiency; Cortex-M4: Mainstream control and DSP	Cortex-M33: Flexibility, control and DSP; Cortex-M35P: Tamper resistance, flexibility, control and DSP; Cortex-M55: Balanced performance and efficiency for control, DSP & ML
Lowest power & area	Cortex-M0: Lowest cost, low power; Cortex-M0+: Highest energy efficiency		Cortex-M23: Smallest area, lowest power

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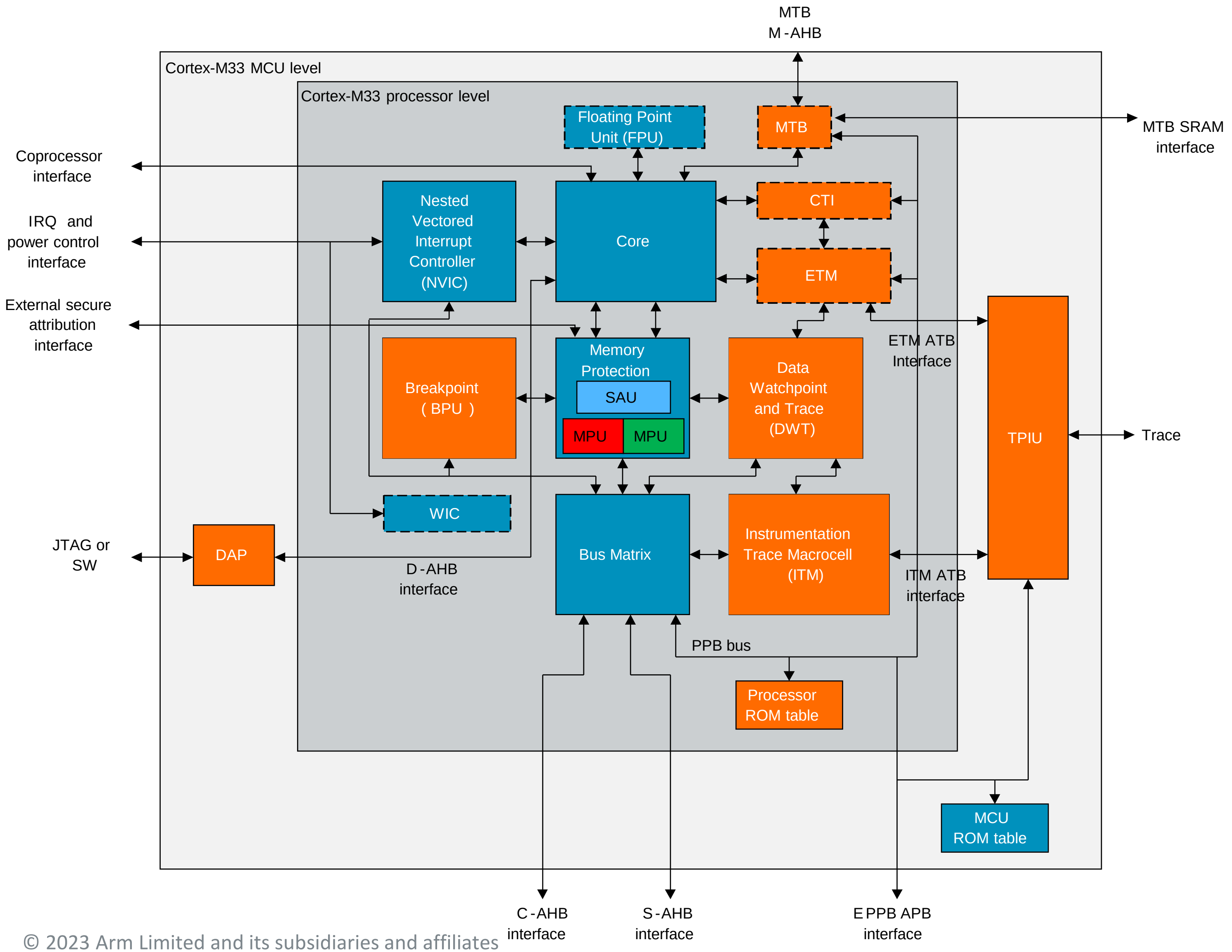
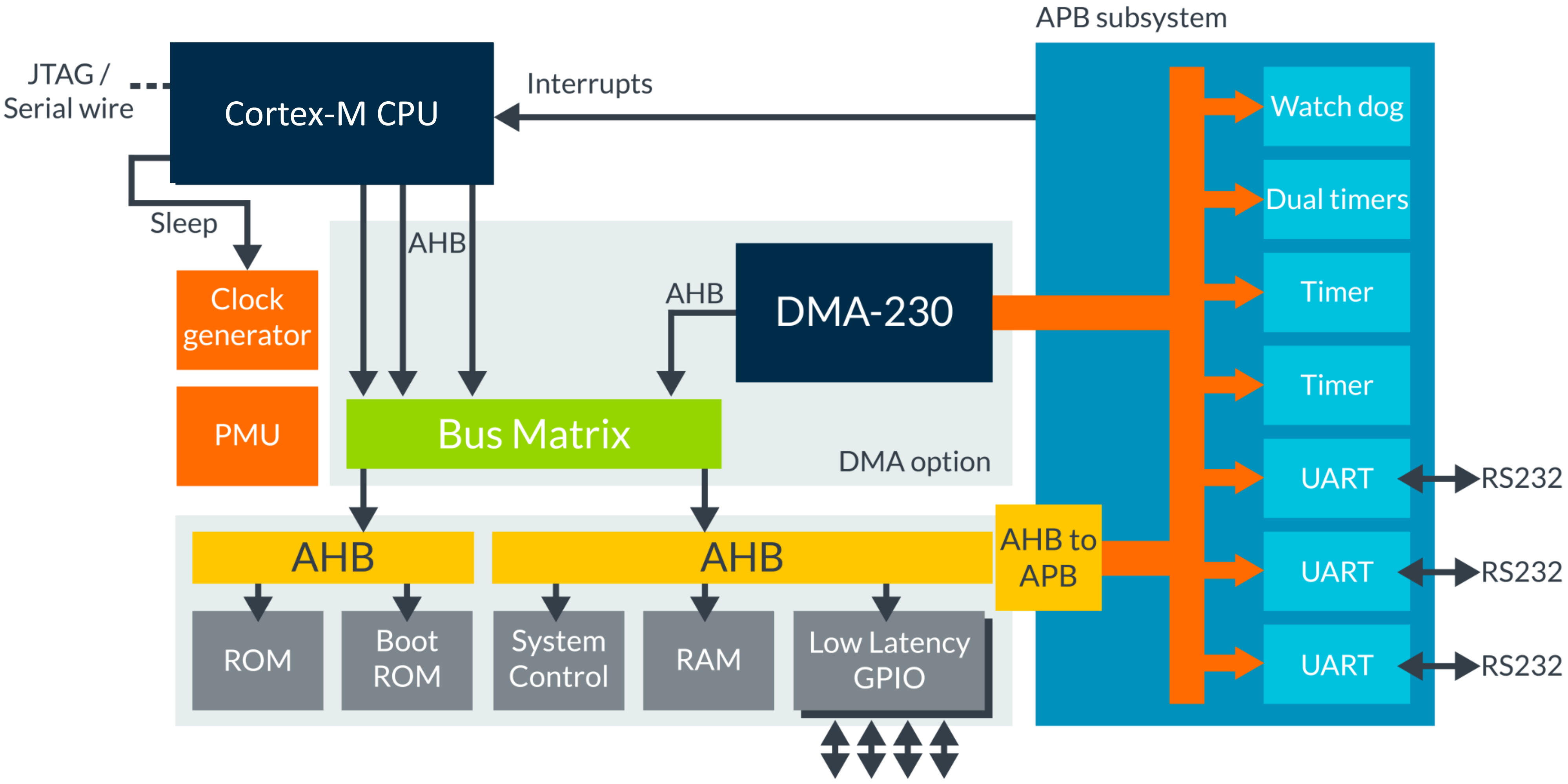
Arm Cortex-M33 Processor



- Mainline profile of Armv8-M
- Synthesizable - configurable RTL
- In-order 2/3 stage pipeline
- Optional Security Extension
- Optional Floating-point Extension (FPv5)
- Optional DSP Extension
- PMSAv8 memory system architecture
- MPU supporting up to 16 regions
- SAU supporting up to 8 regions
- NVIC supporting up to 480 interrupts
- AMBA5 AHB Master Interface
- CoreSight-compliant Debug & Trace
- Ultra-low Power Support with separate power domains
- External coprocessor support
- Optional Custom Datapath Extension(CDE) from r1p0

Example of an Arm based MCU Architecture



Source: https://developer.arm.com/ip-products/subsystem/corstone-foundation-ip/cortex-m-system-design-kit

Summary: Building Embedded Systems using MCUs

- In most embedded systems, MCUs are the best solution as they offer:
  - Low development and manufacturing cost
  - Easy porting and updating; Light footprint
  - Relatively low power consumption
- Increased ‘intelligence’ in embedded microcontroller devices
- An ecosystem of more than 180 Billion Arm-based chips
- Security as a primary design concern
- → Cortex-M provides a strong basis to teach and explore these important concepts

Useful resources

- Free training course on Armv8-M and Cortex-M processors:
  https://www.coursera.org/specializations/cortex-m-architecture-and-software-development

- Architecture Reference Manual:
  https://developer.arm.com/documentation/ddi0553/bp/

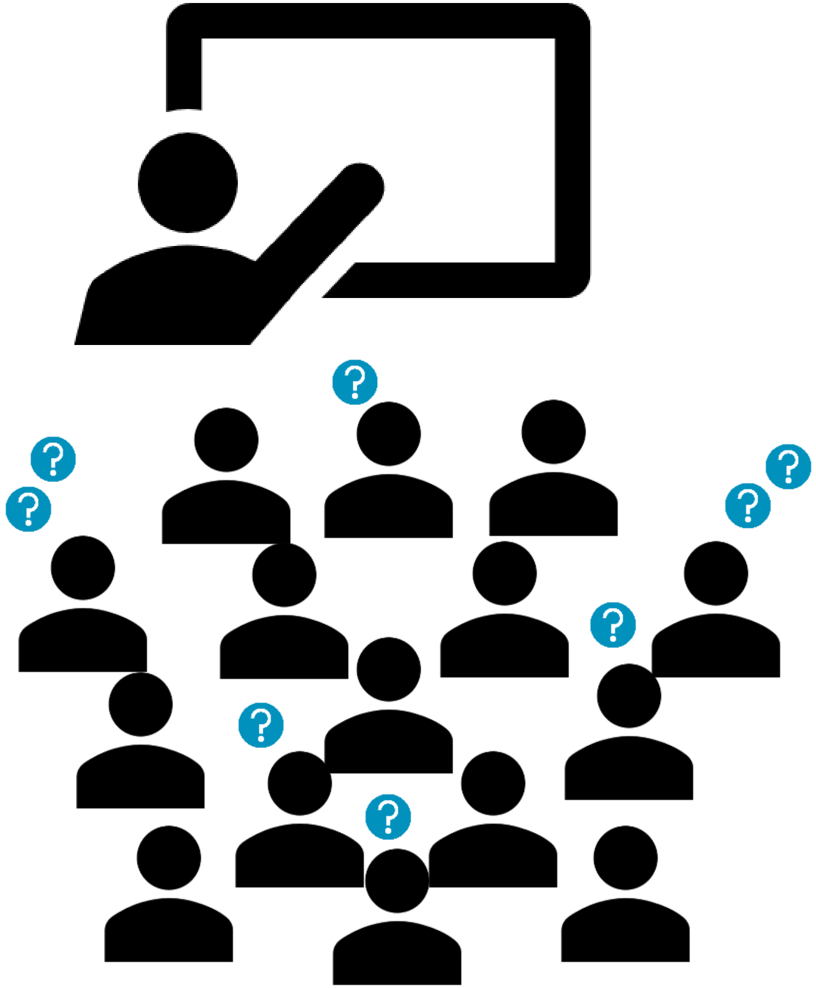
- Cortex-M33 Technical Reference Manual:
  https://developer.arm.com/documentation/100230/latest

- Cortex-M33 Devices Generic User Guide:
  https://developer.arm.com/documentation/100235/latest

- CMSIS:
  https://github.com/ARM-software/CMSIS_5

- Trusted-Firmware-M
  https://www.trustedfirmware.org/projects/tf-m/

Questions & Answers Session



Thank You
Danke
Gracias
Grazie
谢谢
ありがとう
Asante
Merci
감사합니다
धन्यवाद
Kiitos
شكرًا
ধন্যবাদ
תודה