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# Introduction to Embedded Systems Design

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# Introduction

- What is an Embedded System?
  - Application-specific computer system
  - Built into a larger system
- Why add a computer to the larger system?
  - Better performance
  - More functions and features
  - Lower cost
  - More dependability
- Economics
  - Microcontrollers (used for embedded computers) are high-volume, so recurring cost is low
  - "Nonrecurring" cost dominated by software development
- Networks
  - Often embedded system will use multiple processors communicating across a network to lower parts and assembly costs and improve reliability

# Options for Building Embedded Systems

Dedicated Hardware

Software Running on Generic Hardware

| Implementation | Design Cost | Unit Cost | Upgrades & Bug Fixes | Size | Weight | Power | System Speed |
|---|---|---|---|---|---|---|---|
| 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 | mid | easy | small | low | medium to high | very fast |
| Microprocessor + memory + peripherals | low to mid | mid | easy | small to med. | 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 |

# Example Embedded System: Bike Performance Tracker

- Functions
  - Speed and distance measurement
- Constraints
  - Size
  - Cost
  - Power and Energy
  - Weight
- Inputs
  - Wheel rotation indicator
  - Mode key
- Output
  - Liquid Crystal Display
- Low performance MCU
  - 8-bit

# Gasoline Automobile Engine Control Unit

- Functions
  - Fuel injection
  - Air intake setting
  - Spark timing
  - Exhaust gas circulation
  - Electronic throttle control
  - Knock control
- Constraints
  - Reliability in harsh environment
  - Cost
  - Weight

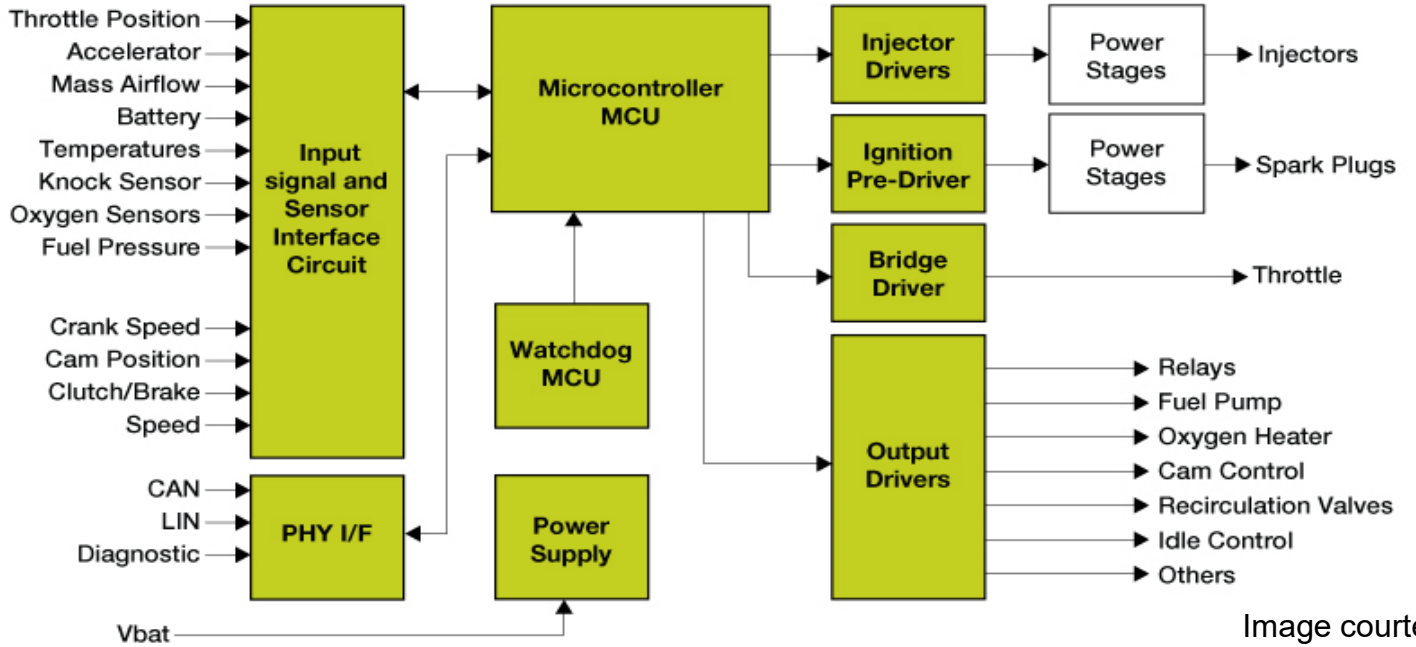



Image courtesy of Freescale

- Many Inputs and Outputs
  - Discrete sensors & actuators
  - Network interface to rest of car
- High Performance MCU
  - 32-bit, 3 MB flash memory, 150 - 300 MHz

What is MISRA?

# Benefits of Embedded Computer Systems

- Greater performance and efficiency
  - Software makes it possible to provide **sophisticated control**
- Lower costs
  - Less expensive components can be used
  - Manufacturing costs reduced
  - Operating costs reduced
  - Maintenance costs reduced
- More features
  - Many not possible or practical with other approaches
- Better dependability
  - Adaptive system which can compensate for failures
  - Better diagnostics to improve repair time

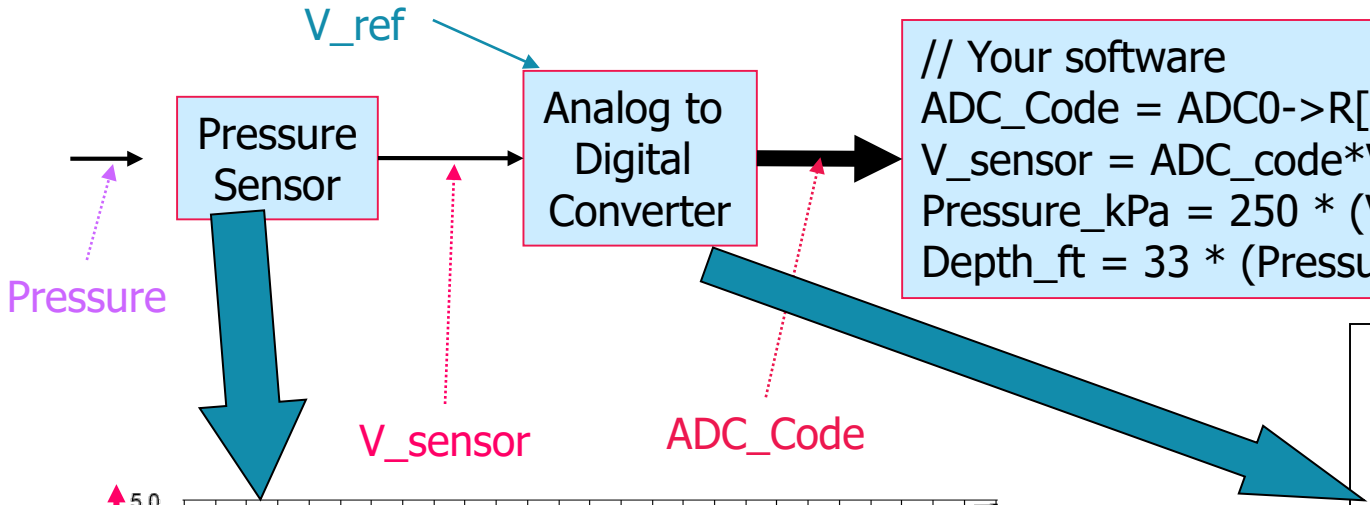
# Embedded System Functions

- Closed-loop control system
  - Monitor a process, adjust an output to maintain desired set point (temperature, speed, direction, etc.)
- Sequencing
  - Step through different stages based on environment and system
- Signal processing
  - Remove noise, select desired signal features
- Communications and networking
  - Exchange information reliably and quickly

# Attributes of Embedded Systems

- Interfacing with larger system and environment
  - Analog signals for reading sensors
    - Typically use a voltage to represent a physical value
  - Power electronics for driving motors, solenoids
  - Digital interfaces for communicating with other digital devices
    - Simple - switches
    - Complex - displays

# Example Analog Sensor - Depth Gauge




```
// Your software
ADC_Code = ADC0->R[0];
V_sensor = ADC_code*V_ref/1023;
Pressure_kPa = 250 * (V_sensor/V_supply+0.04);
Depth_ft = 33 * (Pressure_kPa – Atmos_Press_kPa)/101.3;
```

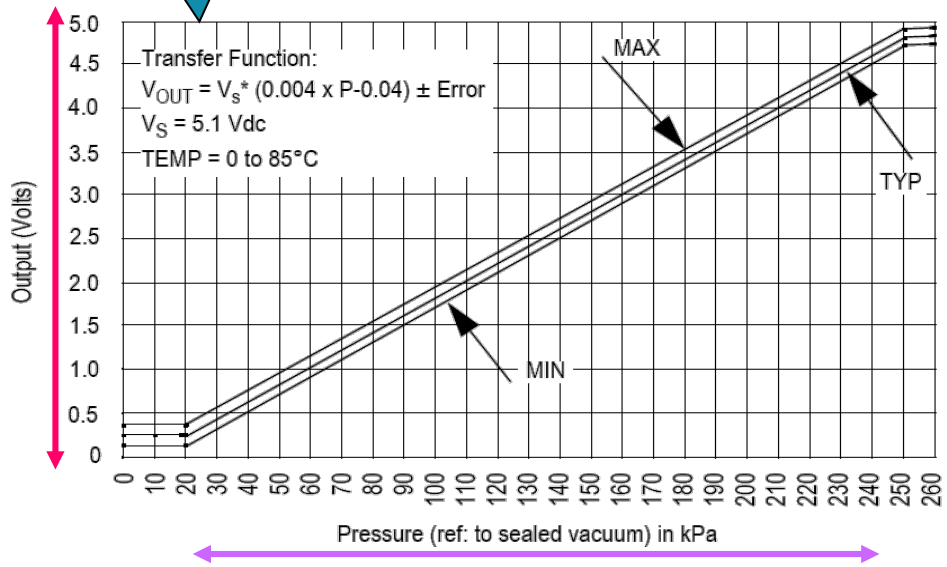
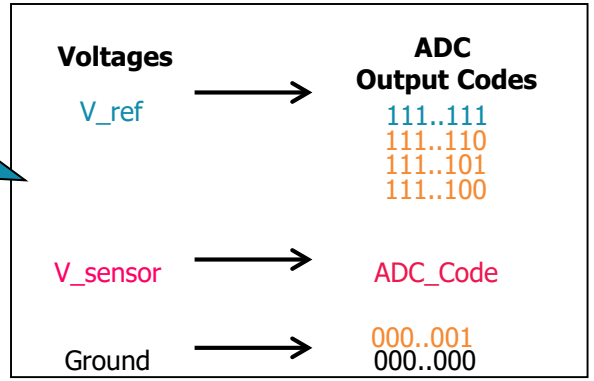



**Figure 4. Output vs. Absolute Pressure**

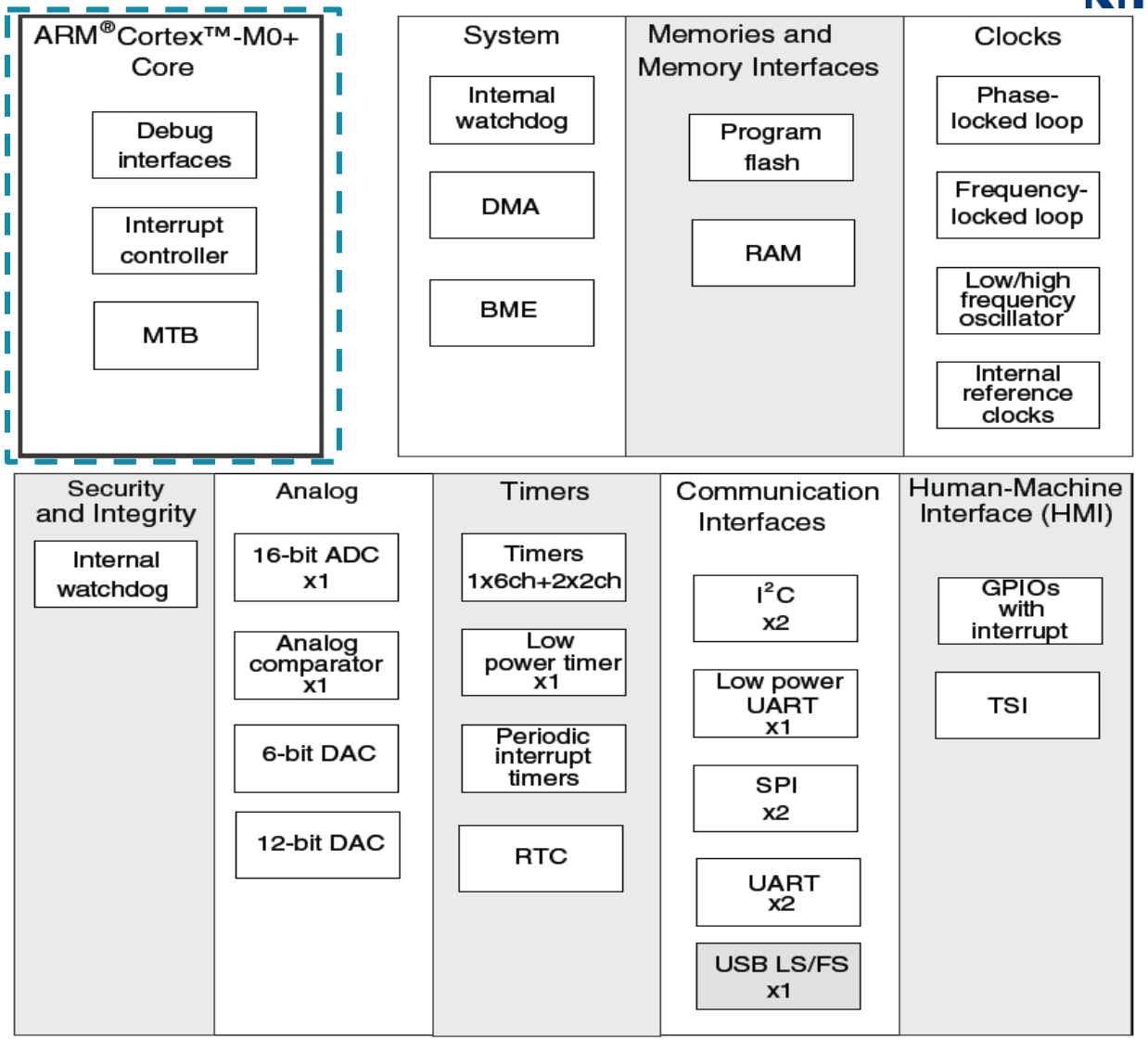



What if the relationship is non-linear/disjoint?

1. Sensor detects *pressure* and generates a proportional *output voltage* V_sensor
2. ADC generates a proportional digital *integer* (code) based on V_sensor and V_ref
3. Code can convert that integer to a something more useful
    1. first a float representing the *voltage*,
    2. then another float representing *pressure*,
    3. finally another float representing *depth*

# Microcontroller vs. Microprocessor

- Both have a CPU core to execute instructions
- Microcontroller has peripherals for concurrent embedded interfacing and control
  - Analog
  - Non-logic level signals
  - Timing
  - Clock generators
  - Communications
    - point to point
    - network
  - Reliability and safety



# Attributes of Embedded Systems

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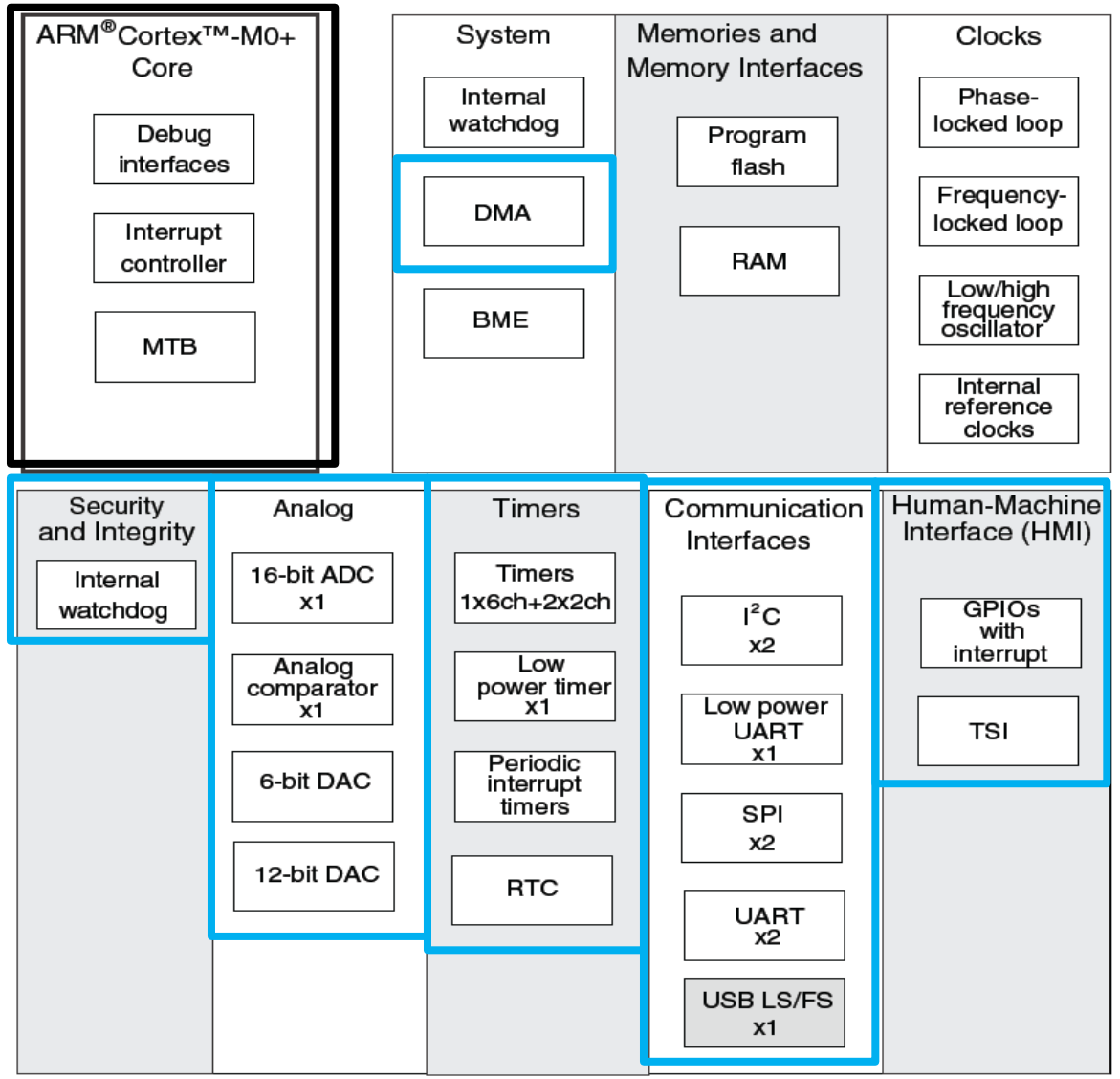
- Concurrent, reactive behaviors
  - Must respond to sequences and combinations of events
  - Real-time systems have deadlines on responses
  - Typically must perform multiple separate activities concurrently



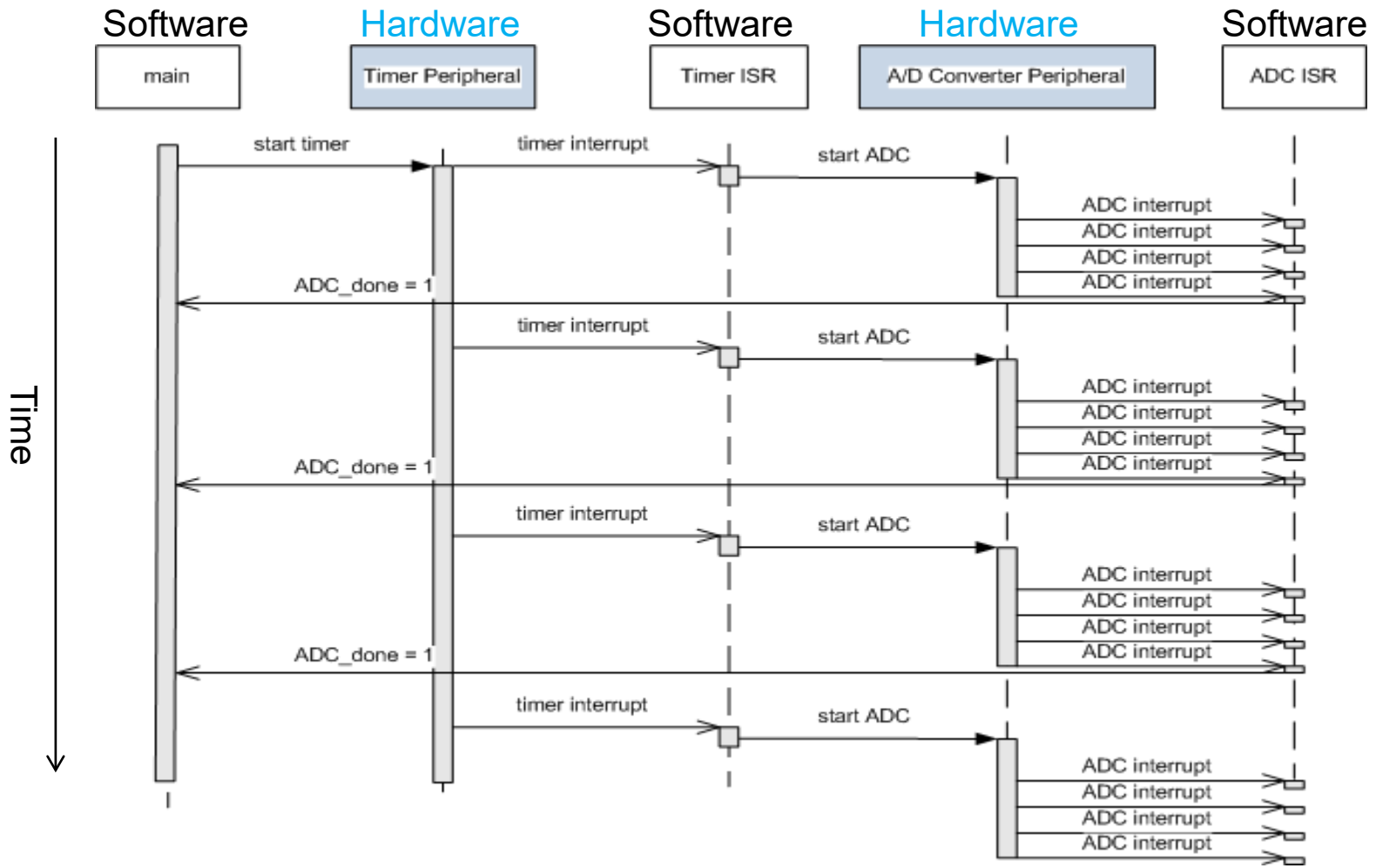
ARM

# MCU Hardware & Software for Concurrency

- CPU executes instructions from one or more thread of execution
- Specialized hardware peripherals add dedicated concurrent processing
  - DMA - transferring data between memory and peripherals
  - Watchdog timer
  - Analog interfacing
  - Timers
  - Communications with other devices
  - Detecting external signal events
- Peripherals use ***interrupts*** to notify CPU of events



# Concurrent Hardware & Software Operation




- Embedded systems rely on both MCU ***hardware peripherals*** and ***software*** to get everything done on time

# Attributes of Embedded Systems

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- Fault handling
  - Many systems must operate independently for long periods of time, requiring system to handle likely faults without crashing
  - Often fault-handling code is larger and more complex than the normal-case code

- Diagnostics
  - Help service personnel determine problem quickly



ARM

# Constraints

- Cost
  - Competitive markets penalize products which don't deliver adequate value for the cost
- Size and weight limits
  - Mobile (aviation, automotive) and portable (e.g. handheld) systems
- Power and energy limits
  - Battery capacity
  - Cooling limits
- Environment
  - Temperatures may range from -40°C to 125°C, or even more

# Impact of Constraints

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- Microcontrollers used (rather than microprocessors)
  - Include peripherals to interface with other devices, respond efficiently
  - On-chip RAM, ROM reduce circuit board complexity and cost
- Programming language
  - Programmed in C rather than Java (smaller and faster code, so less expensive MCU)
  - Some performance-critical code may be in assembly language
- Operating system
  - Typically no OS, but instead simple scheduler (or even just interrupts + main code) (foreground/background system)
  - If OS is used, likely to be a lean RTOS

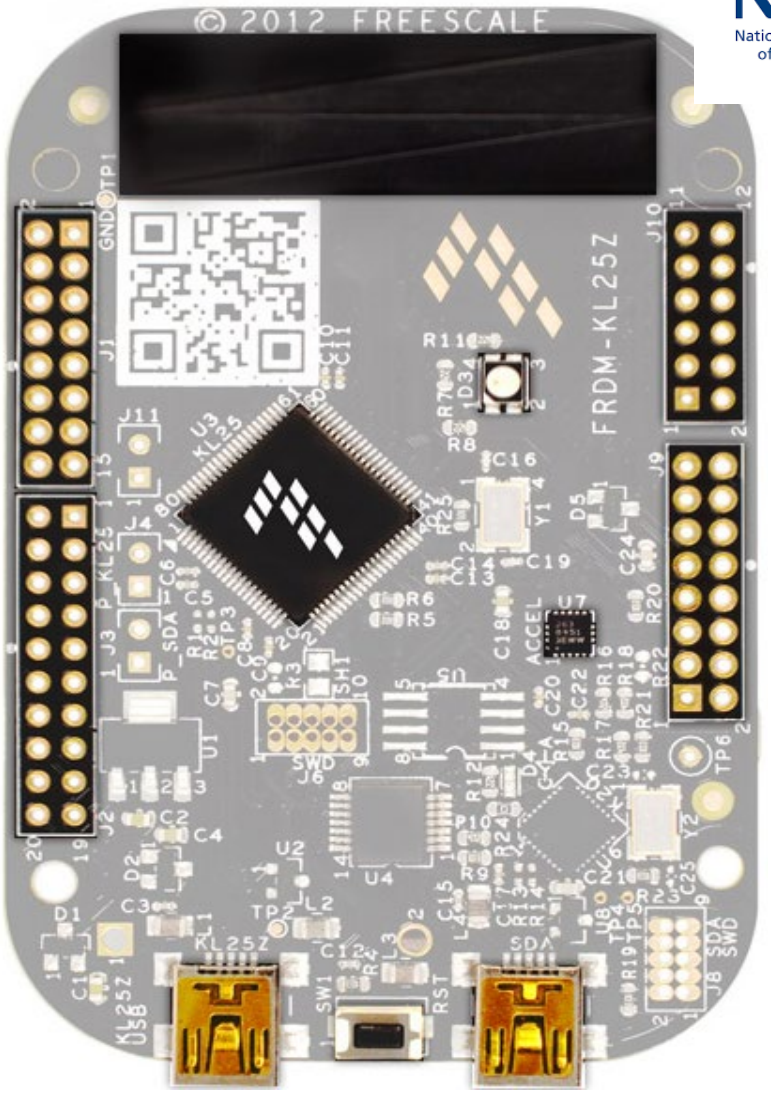


ARM

# Target Board - FRDM-KL25Z

- 32-bit Cortex M0+ Processor Core
- Freescale Kinetis MKL25Z128VLK4 processor
  - Extremely low power use
  - 48 MHz max clock
  - On-chip 128 KB ROM, 16 KB RAM
  - Wide range of peripherals, including USB on-the-go
- FRDM-KL25Z board
  - $24 (SGD)
  - Peripherals: 3-axis accelerometer, RGB LED, capacitive touch slider
  - Expansion ports  are compatible with Arduino shield ecosystem – endless opportunities, low-cost hardware
  - mbed.org enabled - online software development toolchain, reusable code

https://os.mbed.com/platforms/KL25Z/



# Important Admin Stuff before the End for Today!

- For the project – please form your groups and register in LumiNUS.
- You will have the same group for both the labs and the project.
- You only need to register your Project Group in LumiNUS.
- You must only register in LumiNUS after forming a Project Group.
- Those of you who are going to be working remotely the entire semester, please discuss the plan clearly with your team-mates.
  - ** This is only applicable for those with valid reasons.
  - ** I will be sending out a Google Form link for those affected to provide the details.
- Choose your teammates wisely. No changes are allowed once your team is registered in LumiNUS.
- What if you don't have anyone to partner with?

# Next Friday: 20th August 2021

- Please come to the lab according to your lab schedule.

- Each Project Team will receive their Project Kit with all the required components.
- Any team member can collect the kit on behalf of the rest of the team.
- Each student will receive ONE FRDM-KL25Z board.
- Please be extra careful with the board.

- Once collected, you MUST do Lab1 and ensure that your board is working as expected.
- If there are any issues, you must inform the TA before leaving the lab.

# The End!

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- Thank You!
- Lets do a Poll: https://pollev.com/rsnus



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