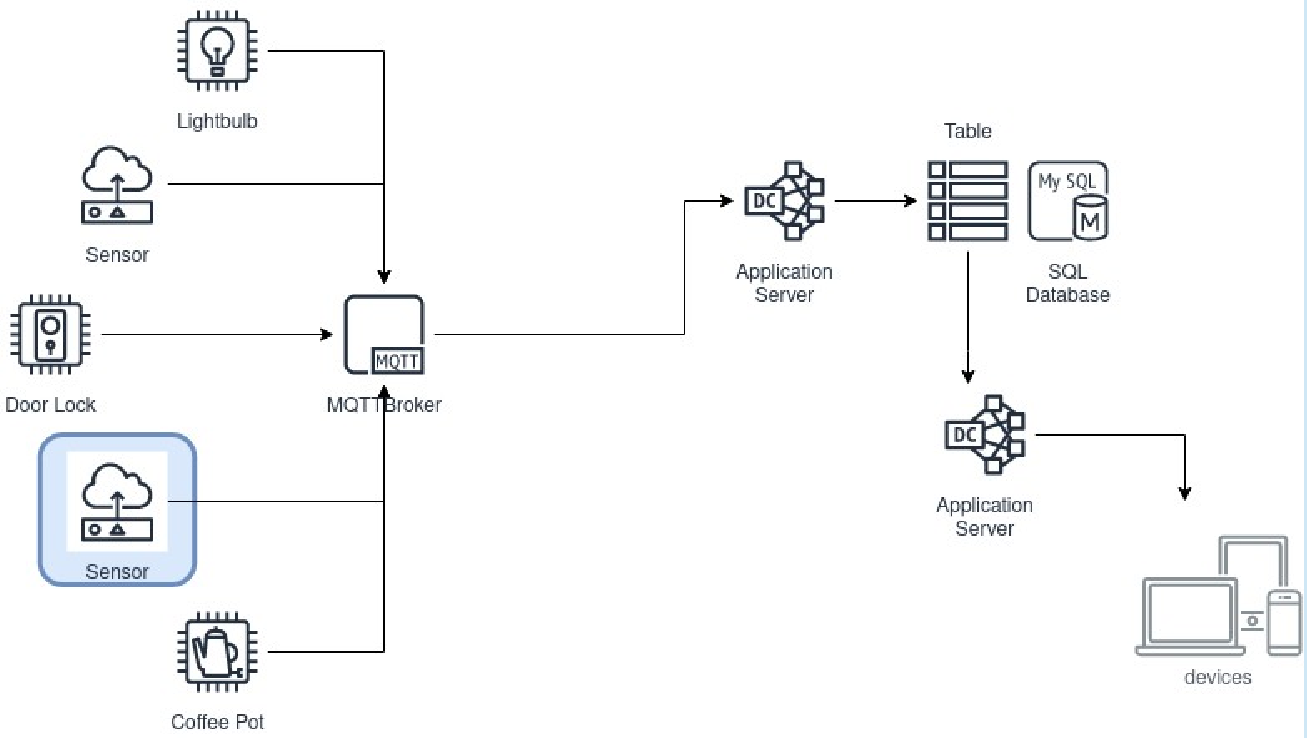
IoT Controllers

Karel Slavicek
Vaclav Oujezsky

2024

Structure of an IoT System



Structure of an IoT System

Outline

- Common internal structures
- Overview of main architecture types
- Key hardware manufacturers and product lines
- IDE

MCUs and Singleboard Computers

- No strict definition and no ambition to create it
- MCU – bare metal programming
- Singleboard computer – operating system
- No sharp border

Hardware design

- MCU (Microcontrollers)
  - Small, compact, all-in-one
  - Suitable for home-made hardware design
  - Simple construction
- Microprocessors – commonly use external RAM memory
  - Complex hardware design
  - Many-layered PCB
  - Higher clock frequency and higher performance

MCU internal structure

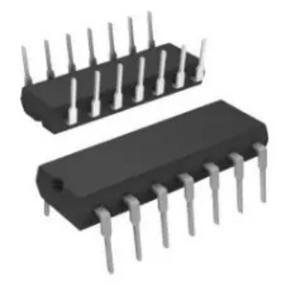
- Von Neumann architecture
  - Memory shared for instructions and data
- Haward architecture
  - Separate memory for instructions and data

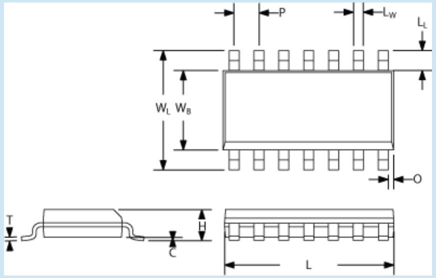
PIC MCU – A bit of history

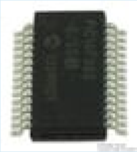
- PIC microcontrollers
- Peripheral Interface Controller
- Originally developed by General Instrument as PIC1650
- Intended to be used with the General Instrument CP1600, the first commercially available single-chip 16-bit microprocessor.
- A pioneer among MCUs for IoT
- Today a bit obsoleted but still used
- Reach history (since 1976)

PIC

- Commonly in DIL type packages, new types also in SOIC and SSOP
- Extremely small amount of RAM (in some models tens of Bytes)
- EEPROM / Flash
- Timers, PWM, ADC
- Constant interrupt response time
- FreeRTOS on PIC18, 24, 32 and dsPIC







PIC

- Harward architecture
- Typically 35 or 70 instructions only
- 12, 14 or 16 bit word
- Small number of instructions
- Commonly 8-bit data bus
- Huge number of types

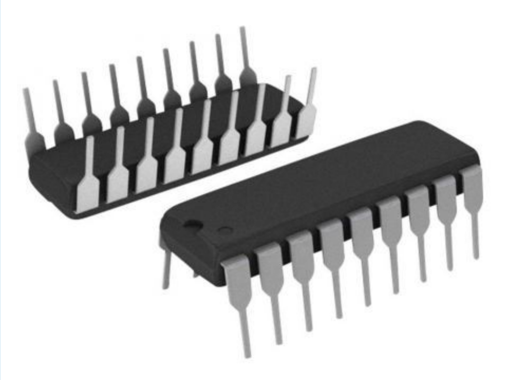
- http://www.microchip.com/maps/microcontroller.aspx
- Programming:
  - PICkit 3
  - GND + V_{DD}, MCLR, ICSPCLK, ICSPDAT
  - MPLAB vs. IDE
  - MPLAB is assembler oriented, now C
  - https://www.microchip.com/en-us/tools-resources/develop/mplab-x-ide

PIC12

- Together with PIC10 smallest PIC modules
- 8-pin PDIP / SOI8 package
- PIC12F1572-I/SN (~1.2EUR)
  - 2x 8-bit timer, 1x 16-bit timer, 3x 16-bit PWM with independent timers
  - 3,5kB FLASH, 256B SRAM
  - 10-bit ADC
- PIC12F510-I/P (~2EUR)
  - 2006
  - 8-bit timer/counter
  - 8-bit ADC
  - Flash 1024 words, SRAM 38B
  - < 170 µA @ 2V, 4 MHz

PIC16

- Midrange PIC, smoothly replaced by PIC18
- Example: PIC16C58B-04/P (~2EUR)
  - 2048 12-bit word flash, 73B RAM
  - 18-pin PDIP
  - < 2 mA typical @ 5V, 4 Mhz / 15 µ A typical @ 3V, 32 kHz
  - 8-bit timer
  - For logical operations mainly
  - 1998



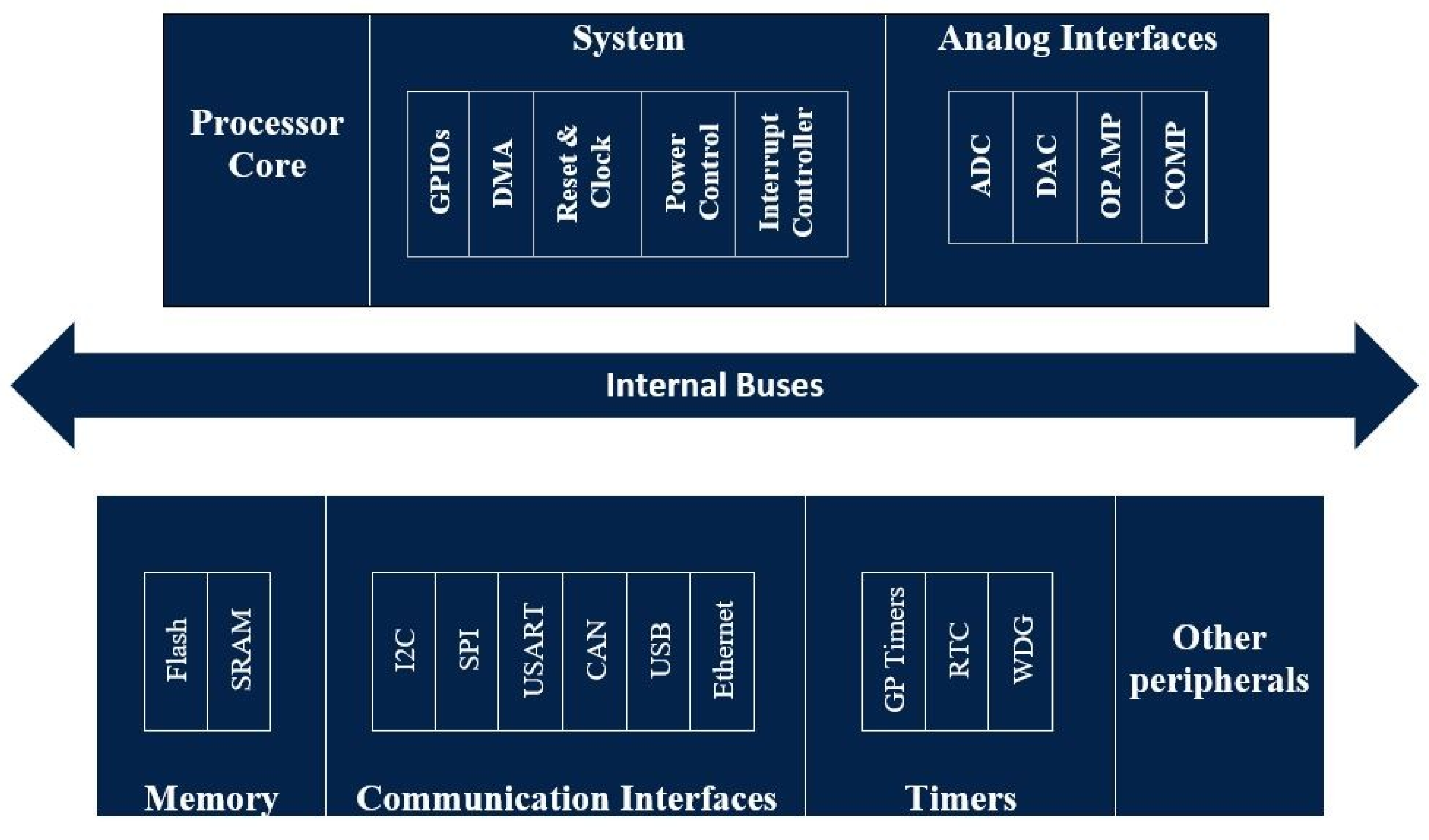
PIC18

- High-end PICmodules
- Most popular PIC today
- PIC18F1220-I/P (~4EUR)
  - 2kB Flash, 256B RAM
  - 7x10bit A/D, 1x10bit PWM, 3x16bit+1x8bit Timers
  - 18-pin PDIP
- PIC-MINI-WEB
  - PIC18F25J10
  - OLIMEX
  - ~16EUR
  - 32KB Flash 1K RAM

Contemporary MCUs

- Architectures
  - ARM
  - RISC-V
  - Proprietary
- Manufacturers
  - Main players
  - Low performance MCUs
  - Part of other equipments

MCU general structure



ARM Architecture

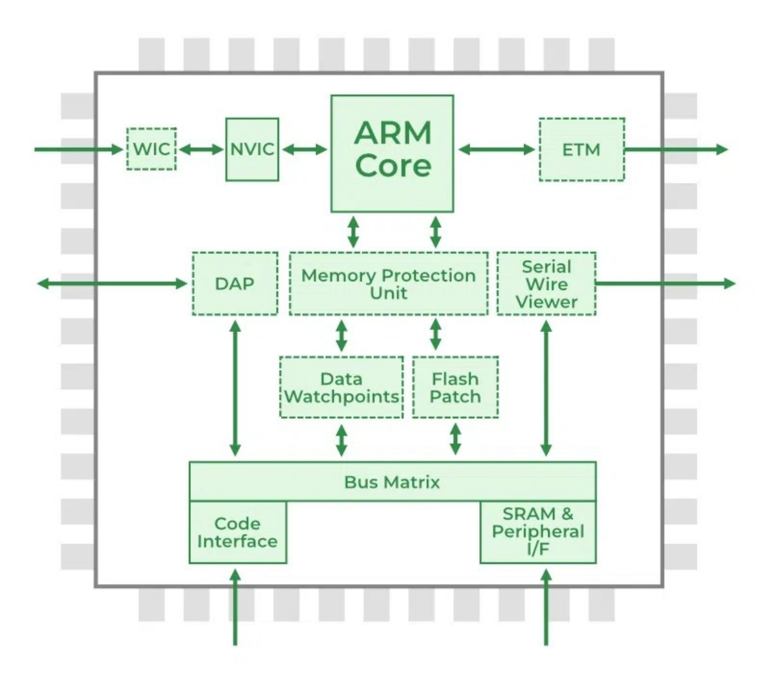
- ARM = Advanced RISC Machines, originally Acorn RISC Machine
- Family of RISC instruction set architectures (ISAs)
- In 1990, Advanced RISC Machines Ltd. As spin-off of Acorn → Arm Holdings plc
- Apple–ARM cooperation → ARM6 (1992)
- Advanced High-performance Bus (AHB) introduced in Advanced Microcontroller Bus Architecture (AMBA) version 2 published by Arm Ltd company. (large bus-widths (64 up to 1024 bits).
- Now: https://www.arm.com architecture design and licence sale

ARM (Acorn RISC Machine)

- 32-bit architecture
- 3 main brabches:
  - ARM Cortex-A
  - ARM Cortex-R
  - ARM Cortex-M
  - ARM Cortex-X allows more custom based modifications

ARM

- Architecture vs. Core
- Architecture e.g. ARMv7 is an ISA (Instruction Set Architecture)
- Core e.g. Cortex M3 implements ISA



ARM architecture

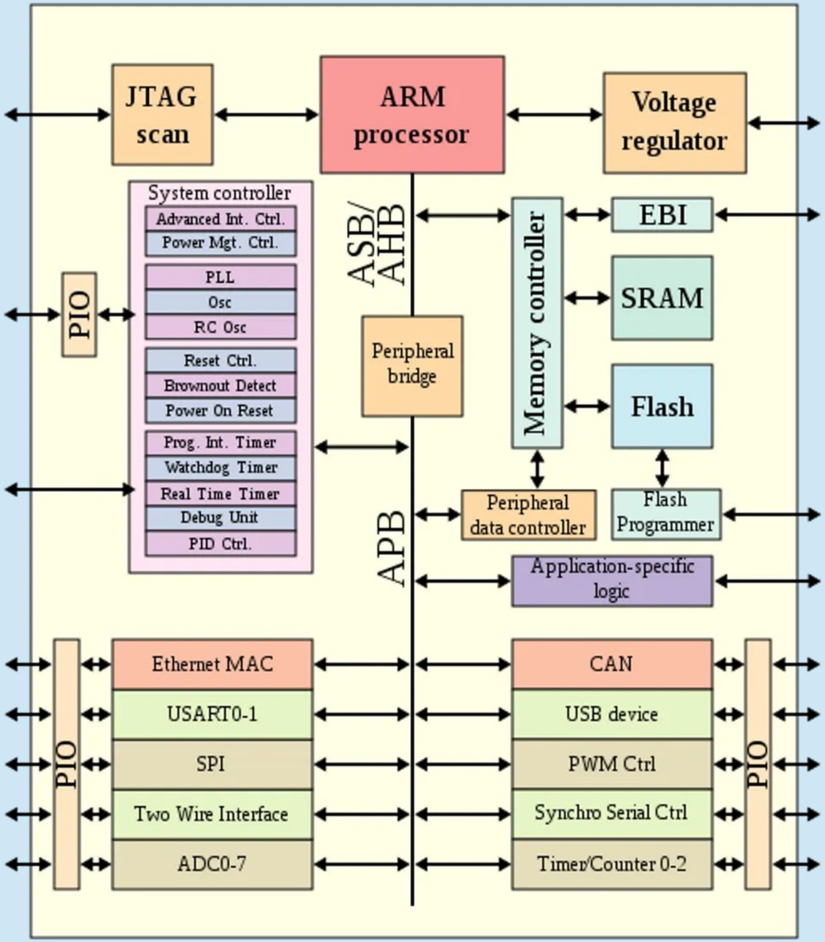
- Up to ARMv6 – history
- ARMv6M –> ARM Cortex M0, M0+
- ARMv7M –> ARM Cortex M3
- ARMv7E-M –> ARM Cortex M4, M7
- ARMv8M –> ARM Cortex M23, **M33**
- ARMv9 –> on the road

ARM Cortex M based MCUs

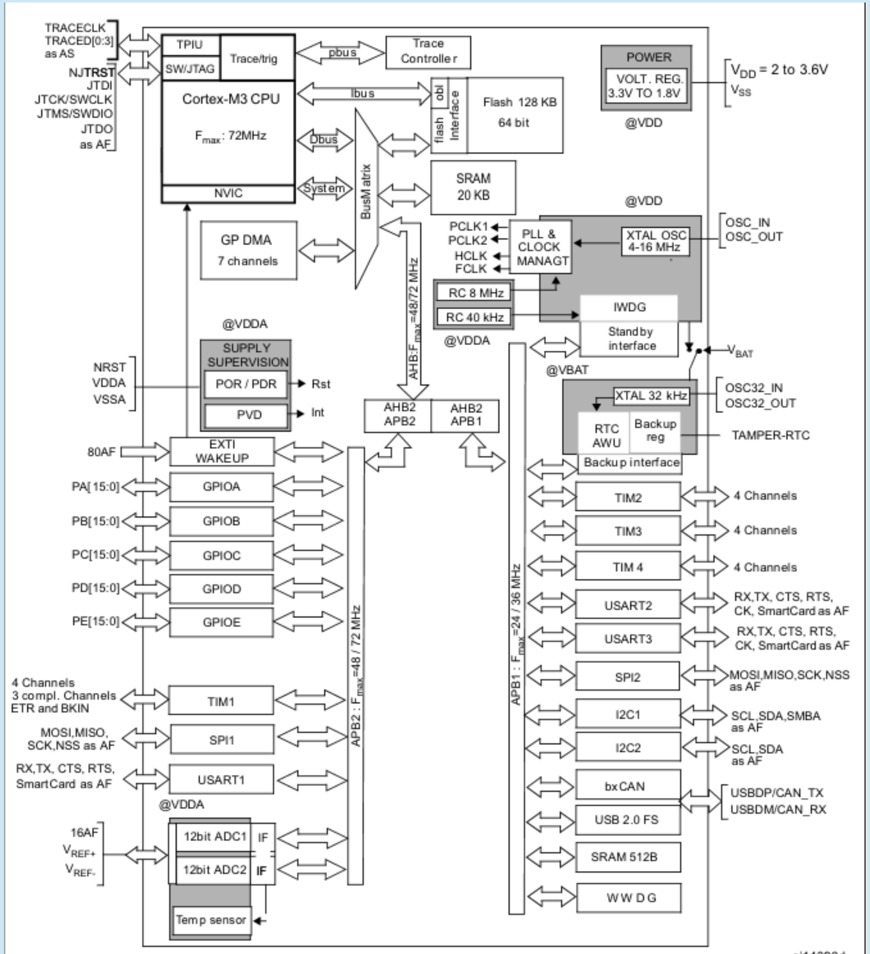
- **2004	Cortex-M3**
- 2007	Cortex-M1
- 2009	Cortex-M0
- **2010	Cortex-M4**
- **2012	Cortex-M0+**
- 2014	Cortex-M7
- 2016	Cortex-M23
- **2016	Cortex-M33**
- 2018	Cortex-M35P
- 2020	Cortex-M55
- 2022	Cortex-M85

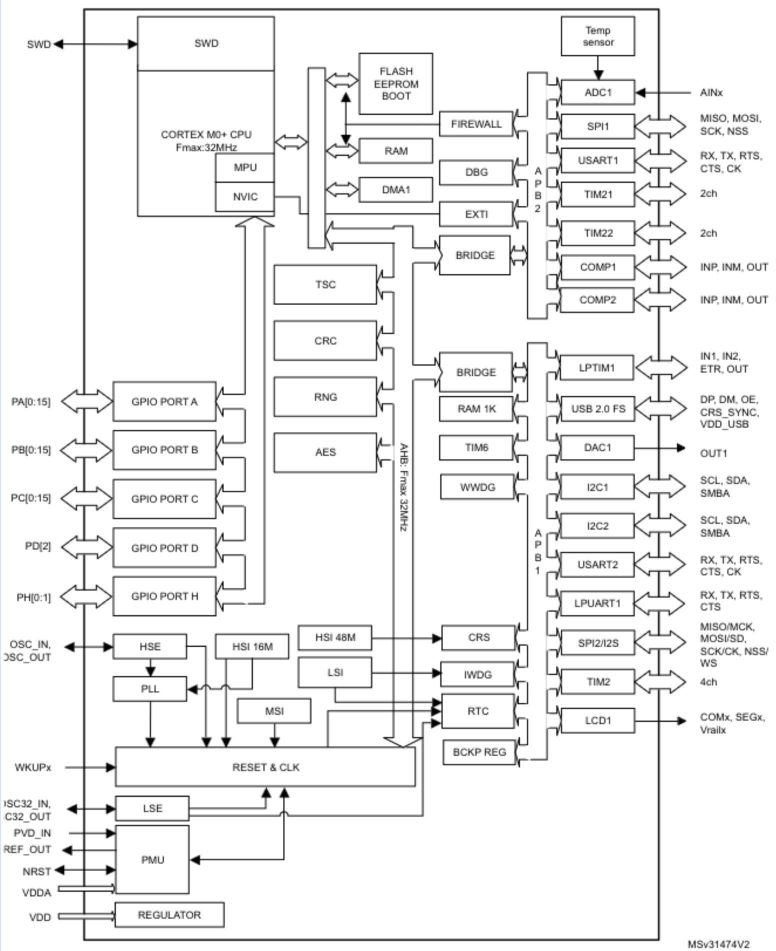
ARM architecture

- Processor
- Memory controller
- AHB (Advanced High-performance Bus)
- APB (Advanced Peripheral Bus)
- Peripherals

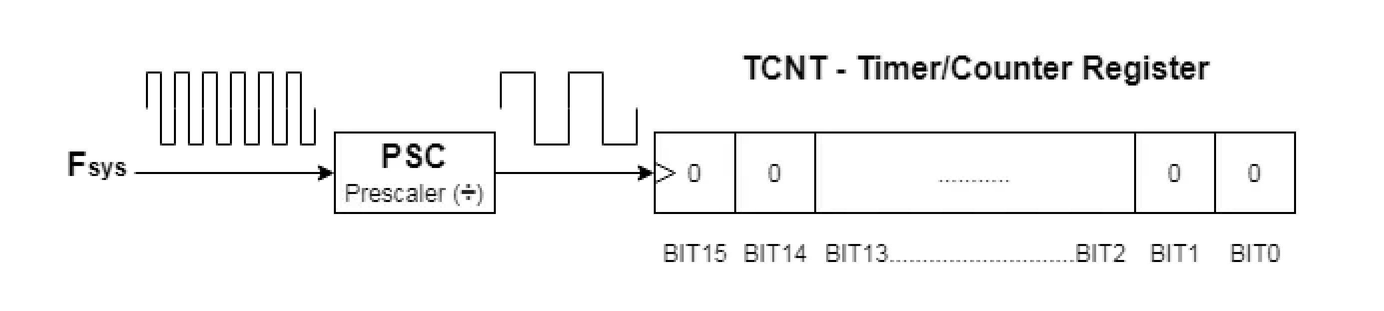


ARM architecture

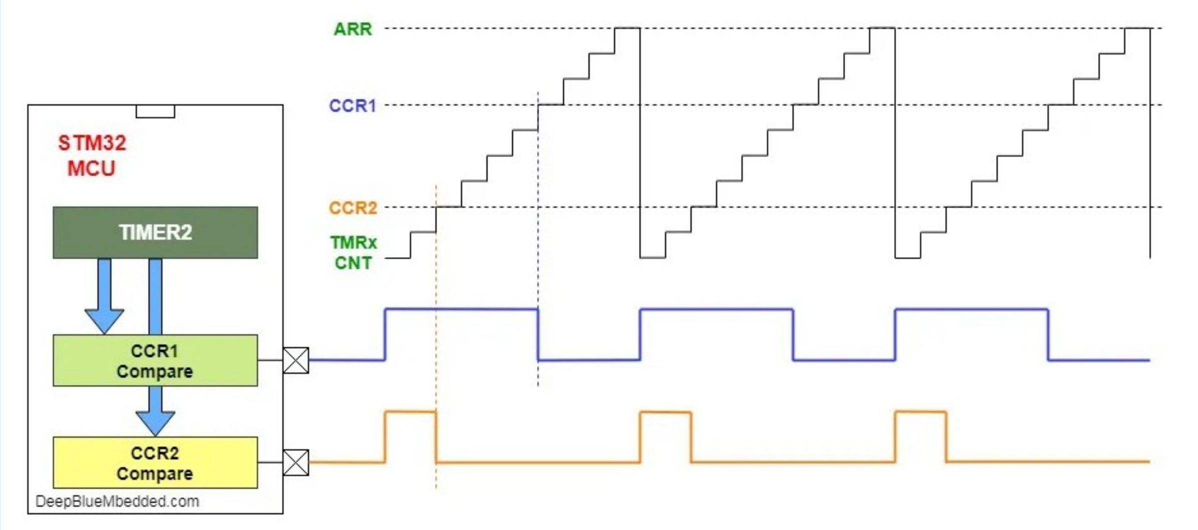




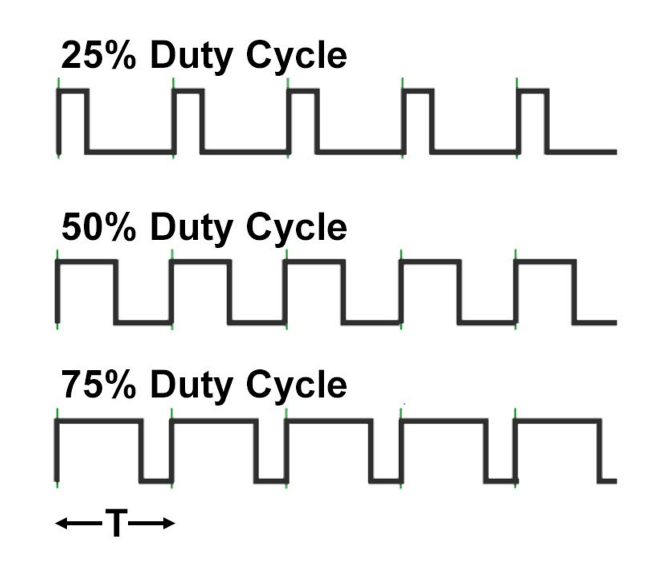
Timers



TCNT - Timer/Counter Register
Fsys
PSC
Prescaler (÷)
0
0
....
0
0
BIT15 BIT14 BIT13..........................BIT2 BIT1 BIT0

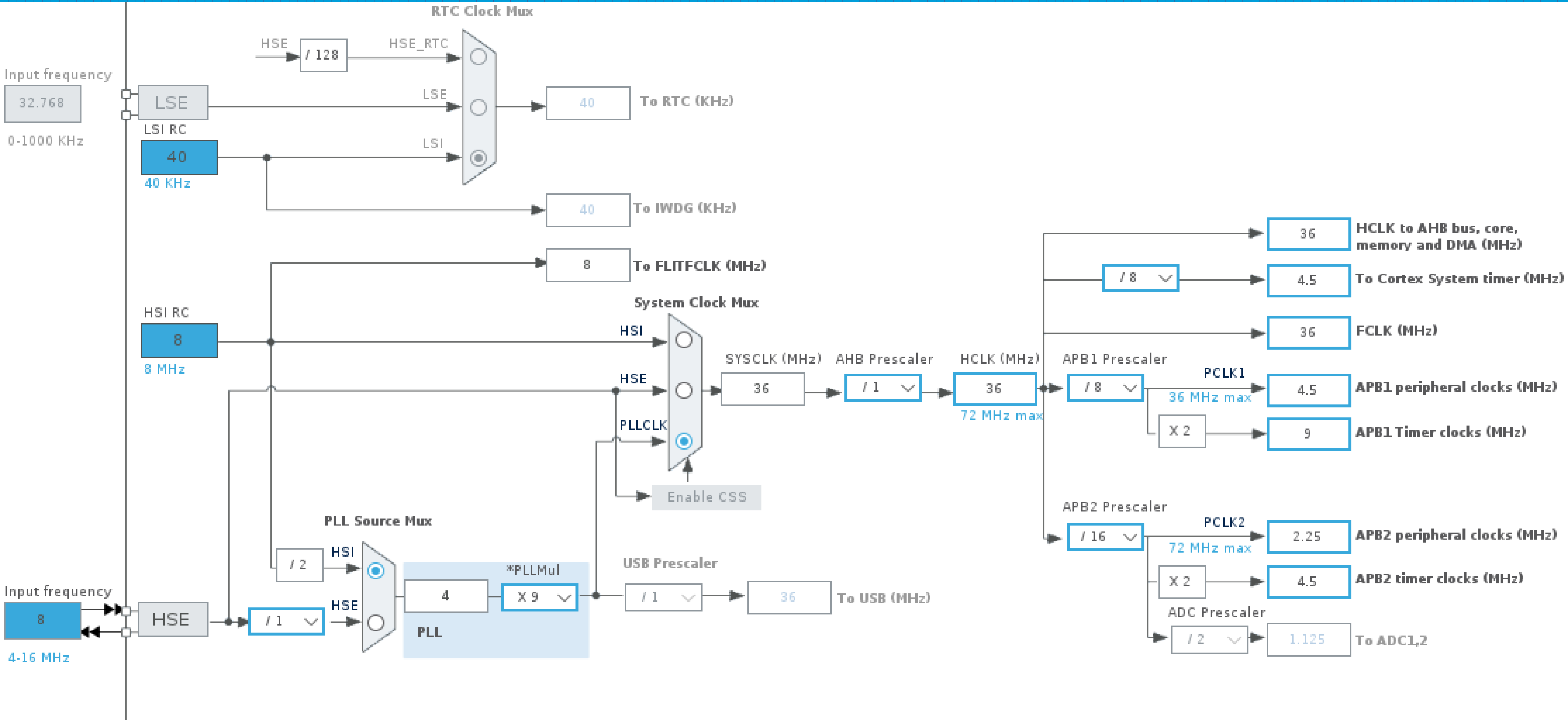


ARR
CCR1
CCR2
TMRx CNT
STM32 MCU
TIMER2
CCR1 Compare
CCR2 Compare
DeepBlueMbedded.com



25% Duty Cycle
50% Duty Cycle
75% Duty Cycle
T

Internal clock

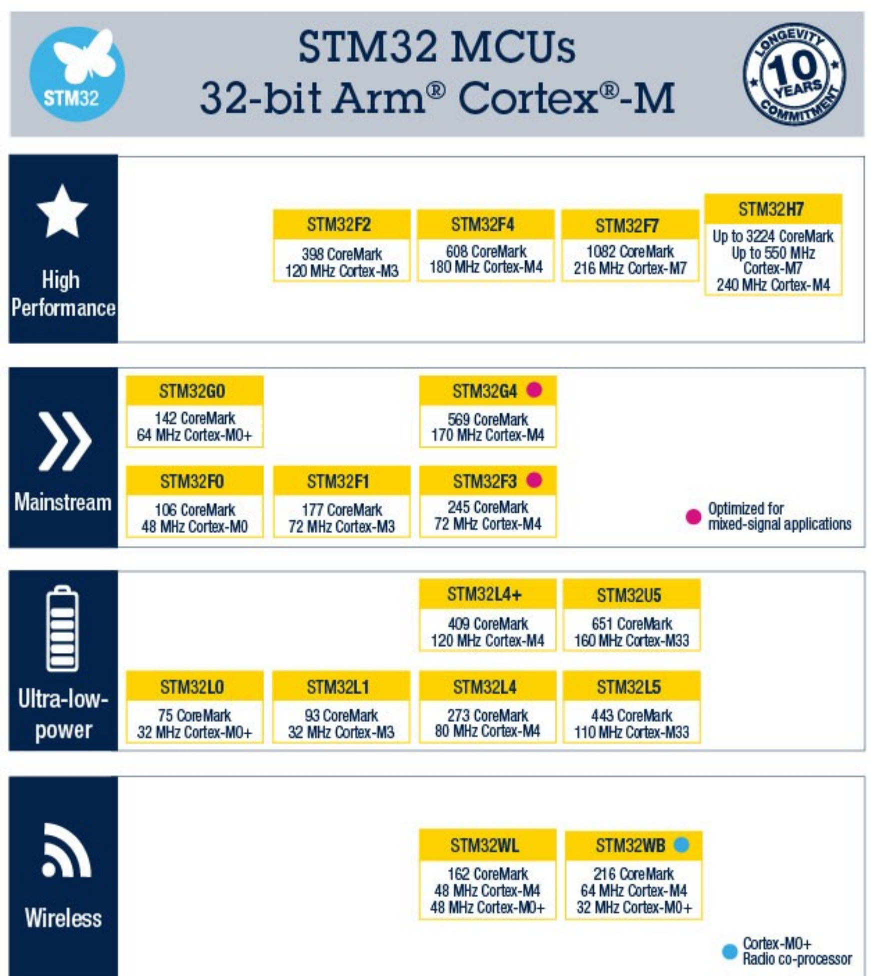


ARM MCU manufacturers

- ST Microelectronics
- Silicon Labs
- NXP
- Renesas
- Microchip
- Texas Instruments
- Many others

ST Microelectronics

- Focused on mainstream and high performance MCUs
- Reach set of interfaces
- Reach set of modules
- Nucleo evalboards



Silicon Labs

- Many wireless chips based on ARM
- EFM series – MCU
- EFR series – radio interface (BT or sub-Ghz)
- Gecko as mascot

SILICON LABS

Silicon Labs

- Zero Gecko, Happy Gecko – ARM Cortex-M0+
- Tiny Gecko, Leopard Gecko, Jade Gecko – ARM Cortex-M3
- Pearl Gecko, Wonder Gecko – ARM Cortex-M4
- EFM32PG22, EFM32PG23, EFM32PG28 – ARM Cortex-M33

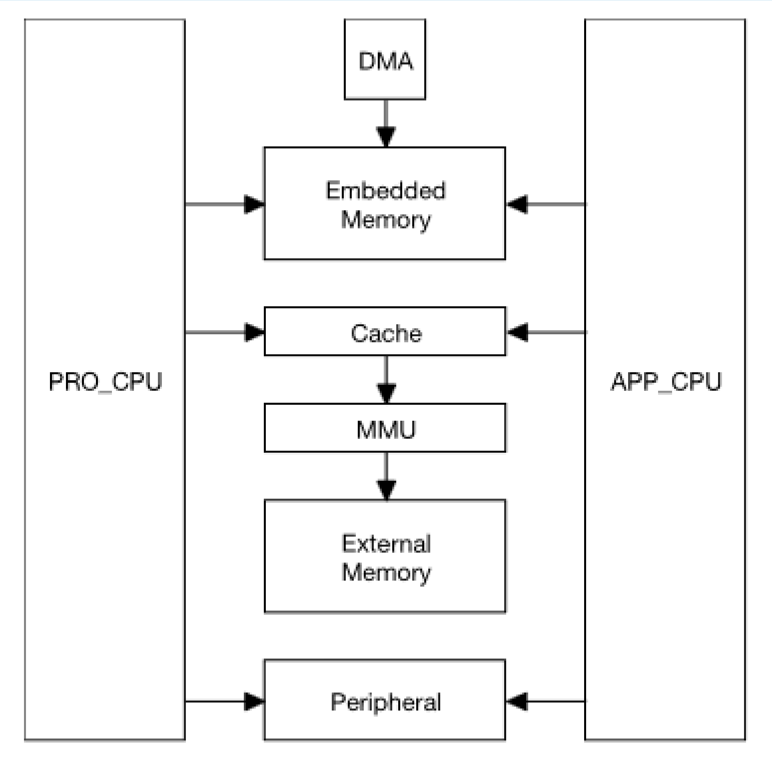
RISC-V

- Open standard instruction set architecture (ISA) based on RISC principles.
- Beginning 2010 at the University of California, Berkeley
- Transferred to the RISC-V Foundation in 2015 → RISC-V International - Swiss non-profit entity since November 2019
- RISC-V instruction set architecture (ISA) are offered under a Creative Commons license or a BSD License.
- Mainline support for RISC-V added to the Linux 5.17 kernel, in 2022.
- https://riscv.org/

RISC-V

- 32-bit and 64-bit address space variants, 128-bit still under development
- Dual core, straightforward internal structure
- ISA base + extensions (adding more instructions)
- Practical implementaions still rare, the most know is Espressif ESP32-C3

RISC-V internal architecture



Espressif

- RISC-V architecture
- Oriented to wireless – WiFi and BT
- Two main series:
  - ESP32 – ESP32-S2, ESP32-S3, ESP32-C2, ESP32-C3, ESP32-C6
  - ESP8266 → ESP32-C2

Proprietary MCUs

- **Microchip**
- **Texas Instruments**
- Renesas
- Espressif

ATMEL AVR microcontrolers

- ATMEL AVR serie microcontrollers
- Nordic VLSI (now Nordic Semiconductor)
- 2016 acquired by Michrochip
- **ATtiny**
- **ATmega**
- ATXMega

ATmega

- Atmega 168
- **Atmega 328**
- Atmega 2560
- Atmega 32U4

ATtiny

- Attiny 24/44/84
- Attiny 85
- Attiny 1604
- Serie0 / Serie1
- UPDI

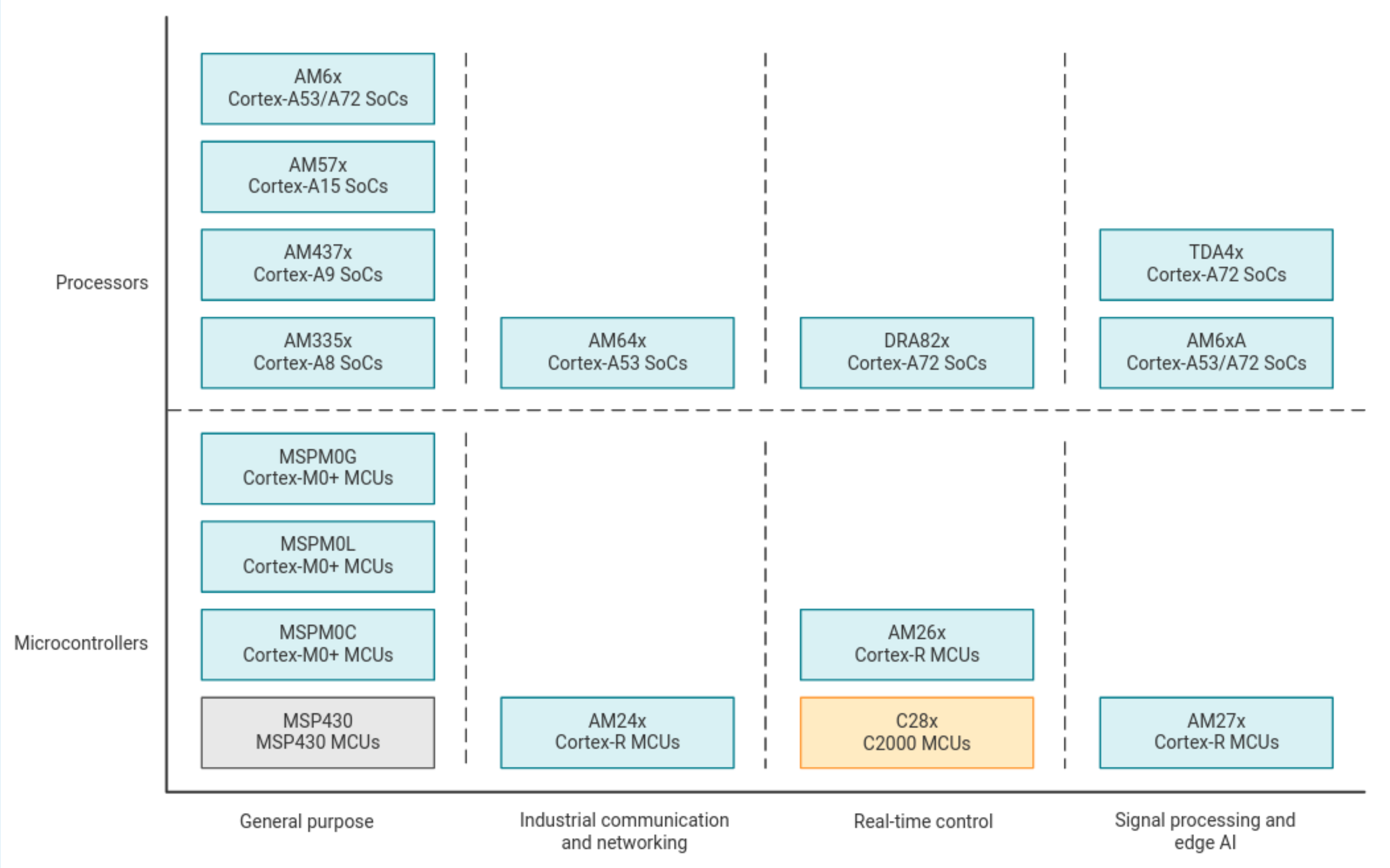
ATtiny

- 1999 ATtiny11, ATtiny11L, ATtiny12, ATtiny12L, ATtiny12V, ATtiny22, ATtiny22L
- 2002 ATtiny15L, ATtiny26, ATtiny26L, ATtiny28L, ATtiny28V
- 2003 ATtiny13, ATtiny13V, ATtiny2313, ATtiny2313V, ATtiny4313
- 2005 ATtiny24, ATtiny24V, ATtiny25, ATtiny25V, ATtiny44, ATtiny44V, ATtiny45, ATtiny45V, ATtiny84, ATtiny84V, ATtiny85, ATtiny85V
- 2006 ATtiny261, ATtiny461, ATtiny861
- 2008 ATtiny13A, ATtiny24A, ATtiny44A, ATtiny48, ATtiny84A, ATtiny88
- 2009 ATtiny4, ATtiny5, ATtiny9, ATtiny10, ATtiny43U, ATtiny261A, ATtiny461A, ATtiny861A, ATtiny2313A
- 2010 ATtiny20, ATtiny40, ATtiny87, ATtiny167
- 2011 ATtiny1634
- 2012 ATtiny441, ATtiny841, ATtiny828
- 2016 ATtiny102(F), ATtiny104(F), ATtiny417, ATtiny817
- 2017 ATtiny212, ATtiny412, ATtiny214, ATtiny414, ATtiny814, ATtiny416, ATtiny816
- 2018 ATtiny202, ATtiny402, ATtiny204, ATtiny404, ATtiny804, ATtiny1604, ATtiny406, ATtiny806, ATtiny1606, ATtiny807, ATtiny1607, ATtiny1614, ATtiny1616, ATtiny3216, ATtiny1617, ATtiny3217
- 2020 ATtiny1624, ATtiny1626, ATtiny1627
- 2021 ATtiny424, ATtiny824, ATtiny426, ATtiny826, ATtiny427, ATtiny827

Texas Instruments

- MSP430
- 16-bit
- Mixed signal
- Low power consumption
- Long history - MSP430-F2xxx, F5xxx, F6xxx
- Memory size and procesing performance comparable to Atmel

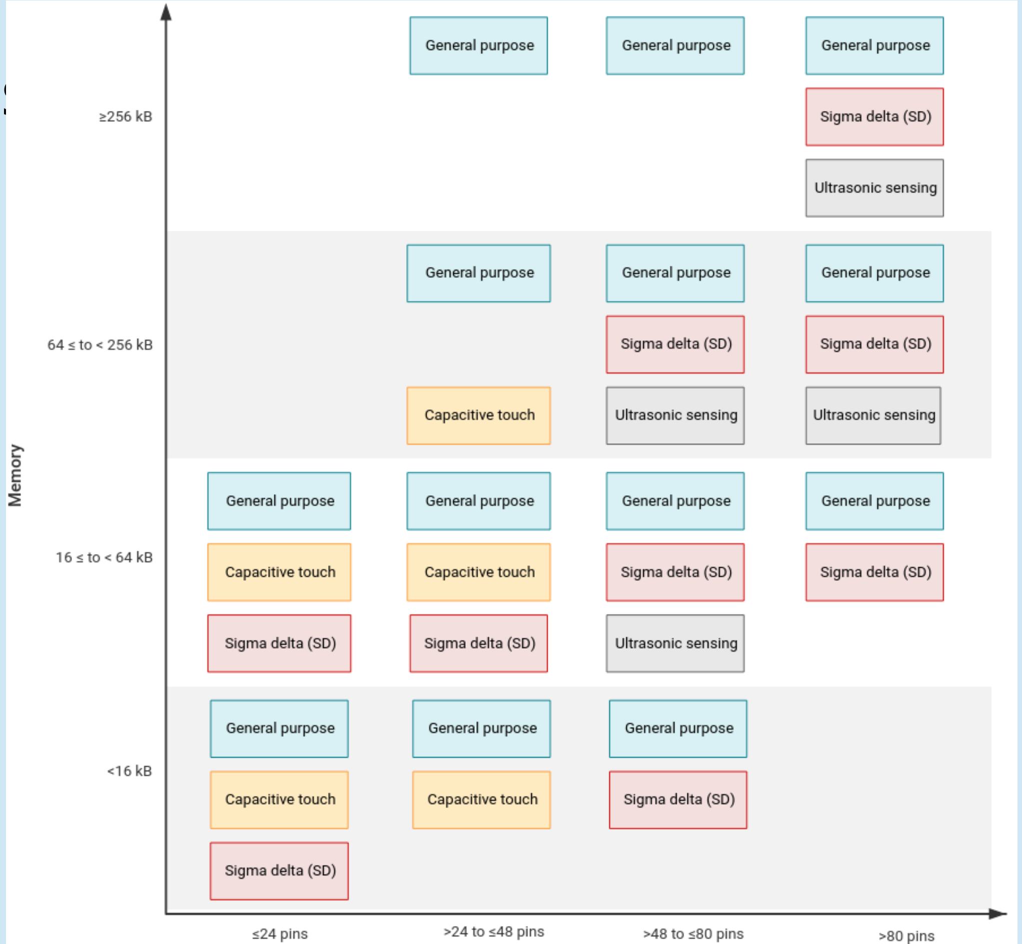
MSP430



AM6x
Cortex-A53/A72 SoCs
AM57x
Cortex-A15 SoCs
AM437x
Cortex-A9 SoCs
Processors
AM335x
Cortex-A8 SoCs
AM64x
Cortex-A53 SoCs
DRA82x
Cortex-A72 SoCs
TDA4x
Cortex-A72 SoCs
AM6xA
Cortex-A53/A72 SoCs
MSPM0G
Cortex-M0+ MCUs
MSPM0L
Cortex-M0+ MCUs
MSPM0C
Cortex-M0+ MCUs
Microcontrollers
AM26x
Cortex-R MCUs
MSP430
MSP430 MCUs
AM24x
Cortex-R MCUs
C28x
C2000 MCUs
AM27x
Cortex-R MCUs
General purpose
Industrial communication and networking
Real-time control
Signal processing and edge AI

MSP430

- Several hundreds MCU types
- IDE: formerly Energie,
  Now CCS (Code Composer Studio)
- For our lab: under design



Linux based MCUs

- Raspberry Pi
- OrangePi
- BananaPi
- NanoPi
- RockPi
- Odroid
- Lantronix
- Gumstix
- Calao systems
- Compulab

Linux based MCUs

- Mostly based on ARM Cortex-A architecture
  - NXP
  - Broadcom
  - RockChip
  - TI (OMAP serie)
- XScale PXA processors
  - Marwell

Related technology

- DSP
- PLD → FPGA
- Wireless chips using ARM architecture

Concluding remarks

- Harware-software co-design
- Hardwade and software developers cooperate
  - Computing power
  - RAM and flash size
  - Number of pins and spectra of interfaces
  - Mechanical dimensions
  - Power consumption

Concluding remarks

- Endless spectra of MCUs suitable for IoT
- Only very few of them in our lab
- Some other available upon request

Thank you for your attention!

Questions and comments?