IoT Embedded Platforms
Introduction

Departamento de Ingeniería Telemática y Electrónica – Universidad Politécnica de Madrid

Agenda

- Motivation
- Definitions
- Characteristics
- Energy
- Alternatives
- 2024 Gallery
- Future

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Motivation

IoT Embedded Platforms

- Present of IT characterized by terms such as
  - Disappearing computer,
  - Pervasive computing,
  - Ambient intelligence,
  - Cyber-physical systems.
  - IoT

- Basic technologies:
  - Embedded Platforms
  - Communication technologies

Motivation

It's the network!

- […] "*Networked systems of embedded computers ... have the potential to change radically the way people interact with their environment by linking together a range of devices and sensors that will allow information to be collected, shared, and processed in unprecedented ways*"

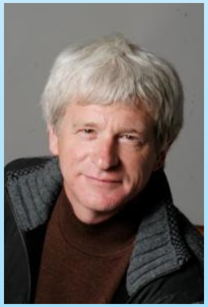
Source. Edward A. Lee, UC Berkeley,

- https://www.youtube.com/watch?v=7zSCnnJE1cs

Motivation

Augmented Reality, a vision for IoT?

- The Immersed Human
- […] “*Real-life interaction between humans (physical space) and cyberspace, enabled by enriched input and output devices on the body and in the surrounding environment*”



Source. J. Rabey UC Berkeley; Nicholas Negroponte MIT

  - https://www.youtube.com/watch?v=O9vAeeJZ9xM

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Definitions

Embedded Platforms: two Views

- Dortmund: [Peter Marwedel, 2006]
  - Systems embedded into a larger product
  - Bought not as information processing systems

- Berkeley: [Edward A. Lee, 2006]
  - Integrates computation with physical processes
  - This is our IoT vision!
  - Cyber-Physical Systems (CPS)

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Characteristics

In IoT EP, we trust!

- Must be dependable
  - Systems can fail …
  - … If assumptions about workload turn out to be wrong
- Must be efficient
  - Code-size, Run-time and Energy
- Dedicated towards a certain application
  - Behavior at run-time used to maximize efficiency

Characteristics

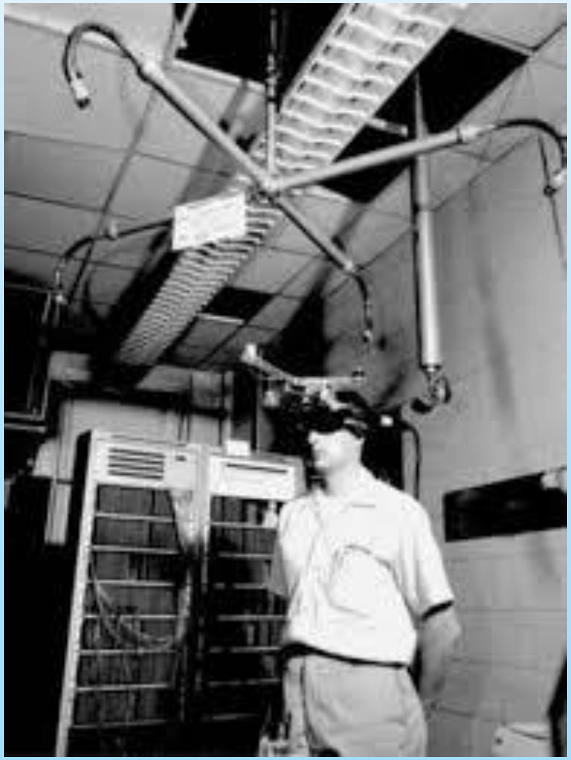
Too Late is Wrong

- Many ES must meet real-time constraints
  - React to stimuli within a time interval
    - Right answers arriving too late are wrong
  - Hard = not meeting a constraint results in a catastrophe
  - Soft = any other time-constraints

Characteristics

No Interface!

- Dedicated user interface
  - No mouse, keyboard and screen
  - https://www.youtube.com/watch?v=Hp7YgZAHLos



Source. Britannica Encyclopedia

Characteristics

Comparison

- IoT Embedded Systems
  - Few applications known at design-time
  - Not programmable by end-user
  - Fixed run-time requirements
  - Additional computing power not useful
  - Criteria = energy efficiency, predictability, …

Characteristics

Comparison

- General Purpose Computing
  - Broad class of applications, usually not known at design time
  - Programmable by end-user
  - No run-time requirements, best effort policy
  - Faster is better
  - Criteria = Cost, average speed

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Energy

Scaling

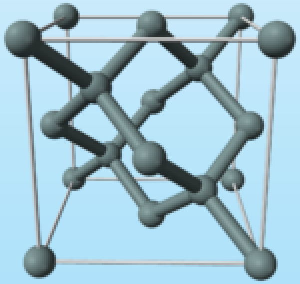
- The number of transistors doubles every two years, roughly speaking (18 months)
  - Moore’s Law
- Why? … Smaller Transistors are manufactured
- Smaller transistors run faster and consume less
  - Frequency follows Moore’s Law
  - Computing performance follows Moore’s Law
  - Power dissipation decrease follows Moore’s Law
  - Typical total power dissipated at chip-level increases

Energy

Scaling Stopped!

- But … from 2004 to our days the scaling has stopped !!

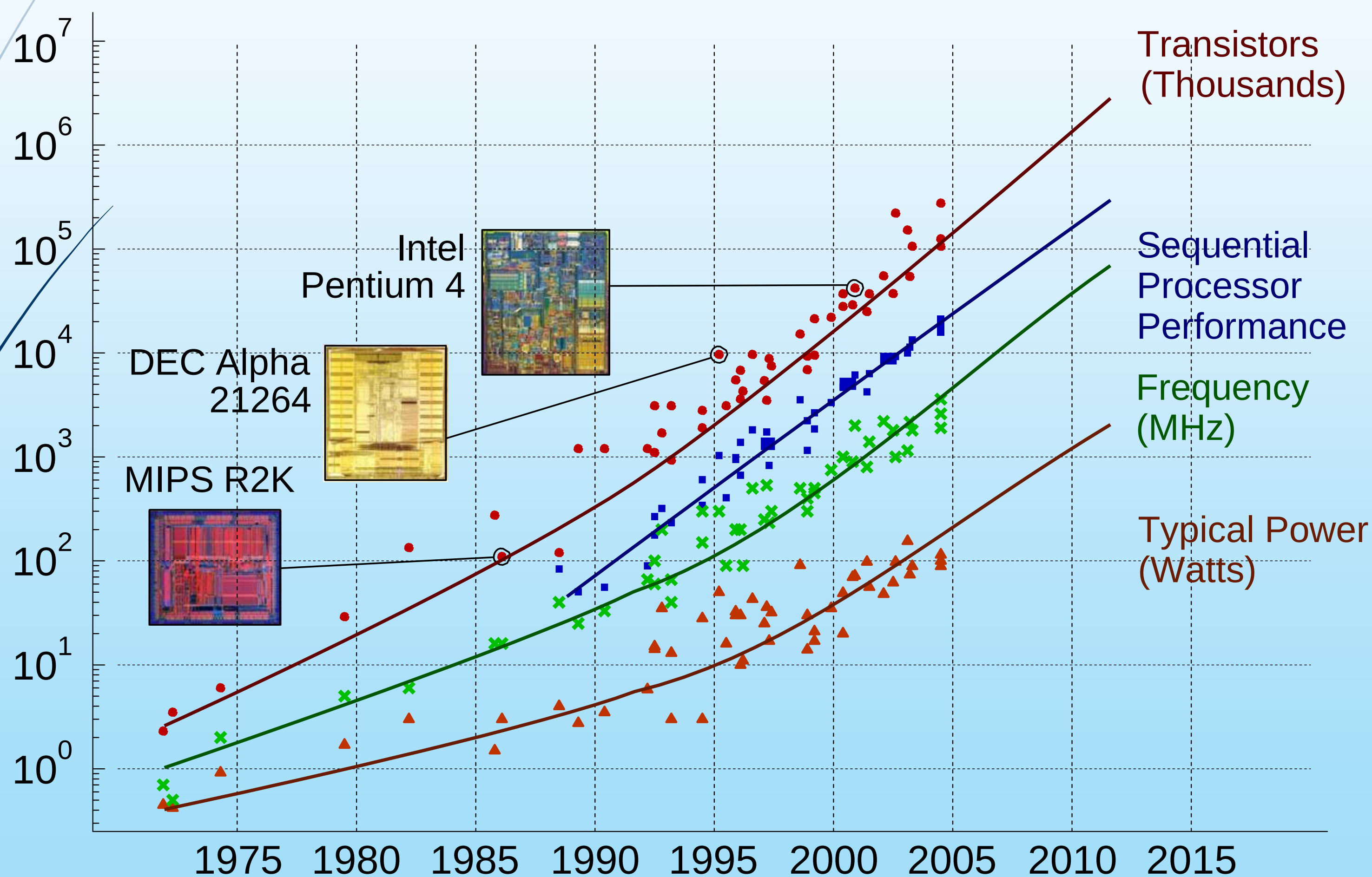
- Current technology node has a 48 nm gate pitch… it means that a TRT is
  - Lattice spacing is 0.543 nm
  - 89 atoms wide
  - Oxide layer is 2 atoms high



Source. Wikipedia

Energy

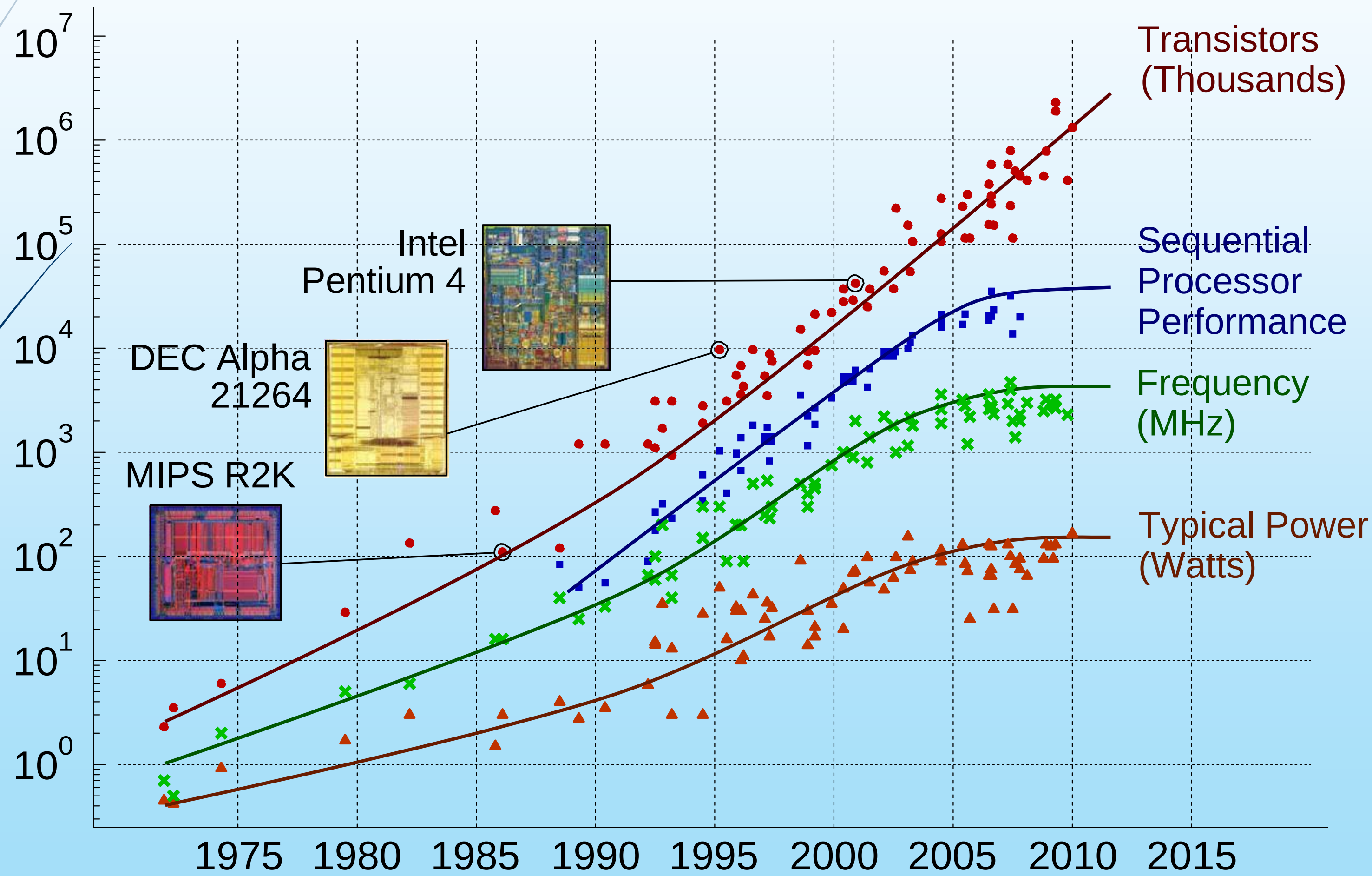
Exponential Scaling for Single Processor



Data partially collected by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond

Energy

Power Constrains Single-Processor Scaling



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Energy

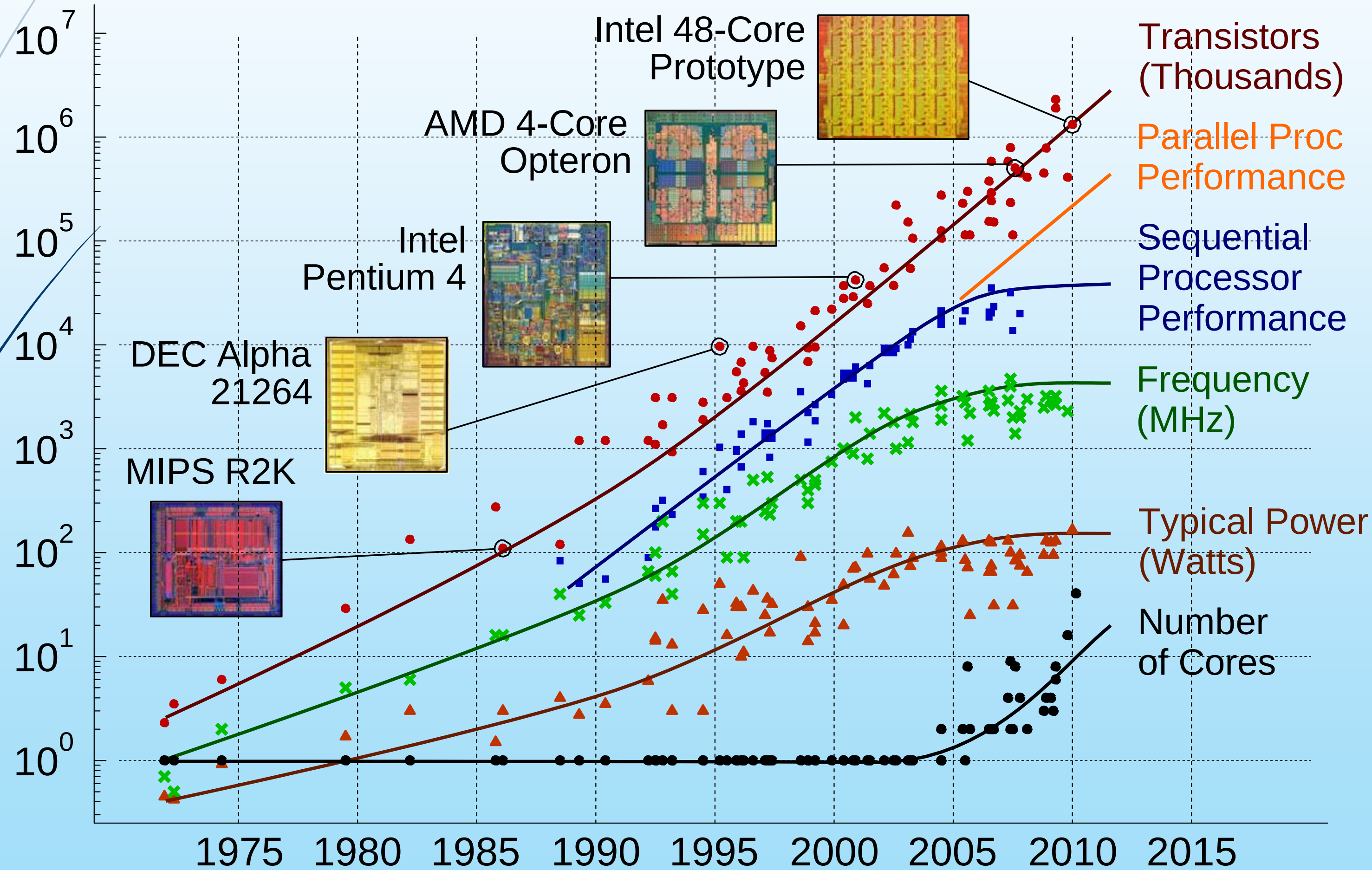
Transition to Multicore

- The problem is how to dissipate the generated heat
  - Practical limit is 100 W / cm2
  - Comparable to that of a nuclear plant

- Energy and power constraints have motivated the transition to *multiple processors* integrated onto a single chip

Energy

Multicore Performance Scaling



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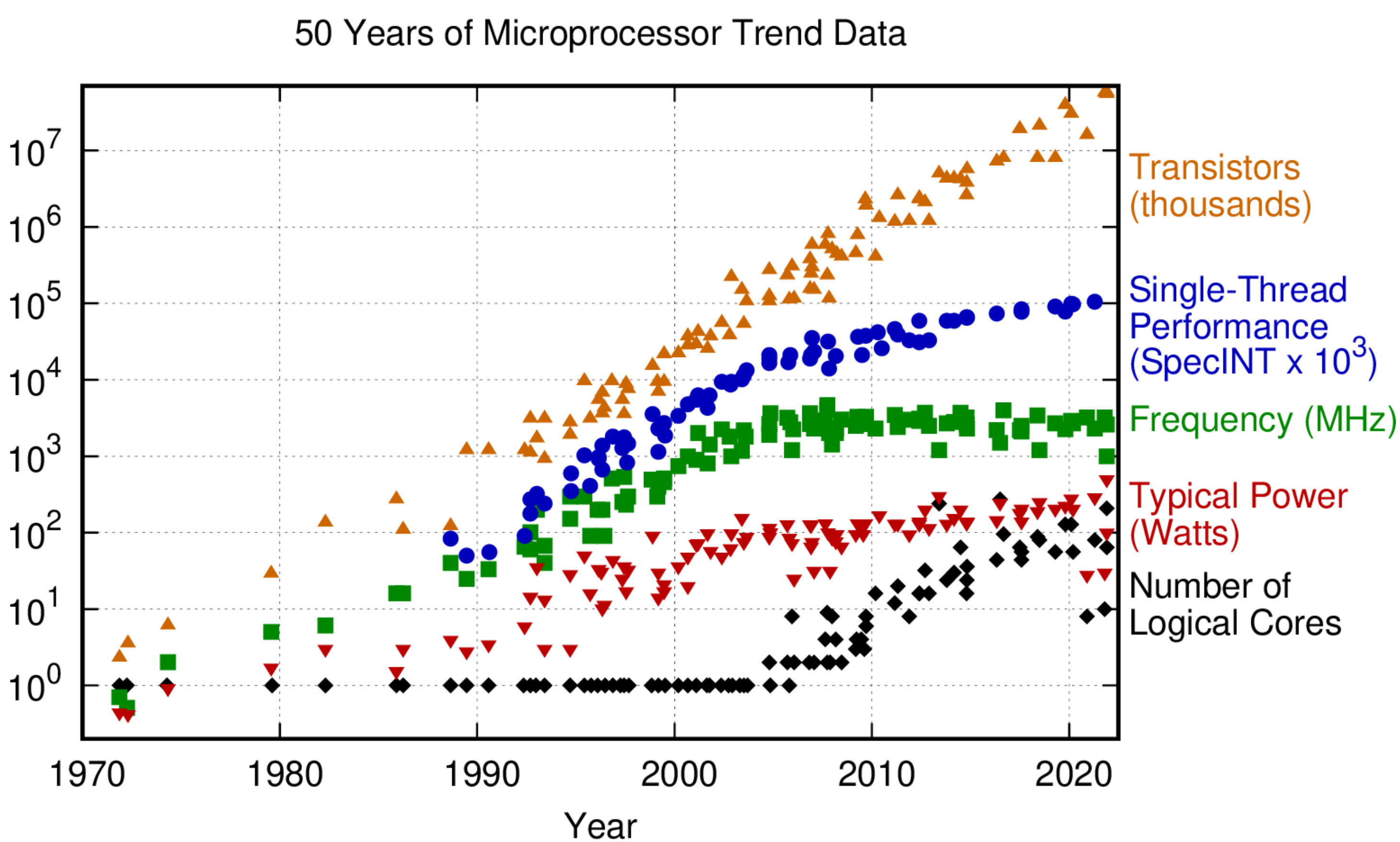
Energy

Multicore Performance Scaling



Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2021 by K. Rupp

Multicore … a Solution?

- The trouble with multicore (D. Patterson)

Source. D. Patterson, The Trouble with Multicore. IEEE Spectrum. June 30th 2010.

- The problem with threads (E. A. Lee)

Source. E. A. Lee, The Problem with Threads. IEEE Computer. Vol. 39, Issue 5, May 2006

- Homework: read the first paper and summarize the main ideas by Oct. 16th

Energy

Processor Consumption

- Approximate energy consumption in 28 nm processor
  - One 64-bit floating-point multiply-add = 50 pJ
  - Access to a 1K-256 bit on-chip SRAM = 50 pJ
  - Moving 64 bits 1mm on-chip = 64 pJ/mm
  - Reading 64 bits from external DRAM = 4000 pJ

Source: *Bill Dally, Stanford University, Nvidia Chief Scientist*

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Motivation

Intuitive Idea

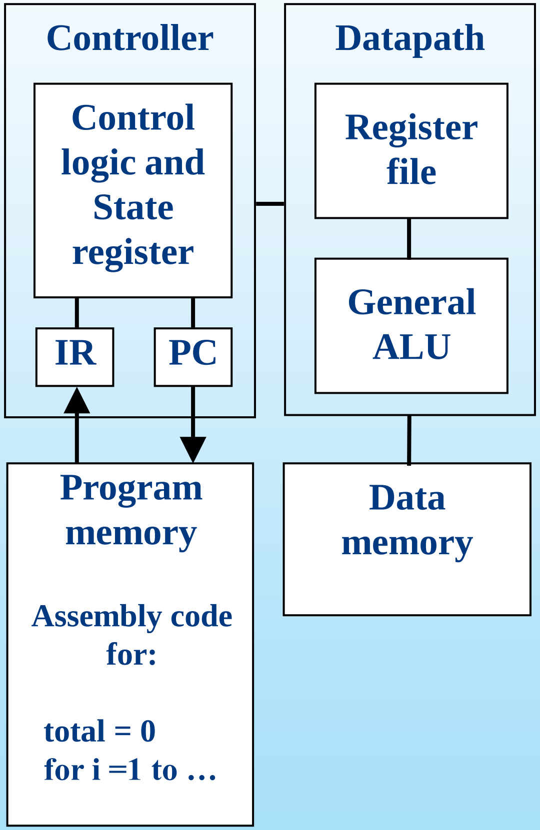
```
total = 0;
for (i = 0; i < N; i++){
   total += M[i]
}
```

- What are the available technologies today to solve this problem?

Motivation

General Purpose Processors (GPP)

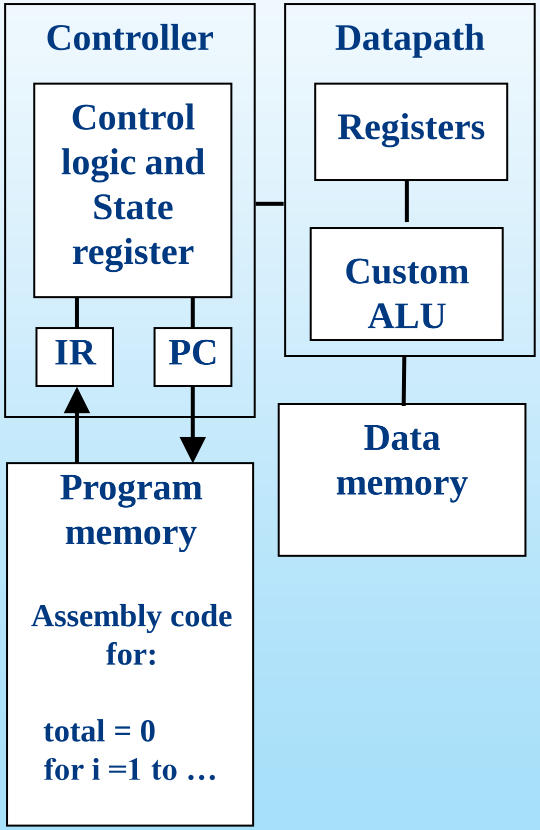
- Features
  - Harvard Architecture
    - Program memory
    - Data memory
  - General datapath
    - Large register file
    - General ALU



Motivation

Specialized Processors (e.g. GPU)

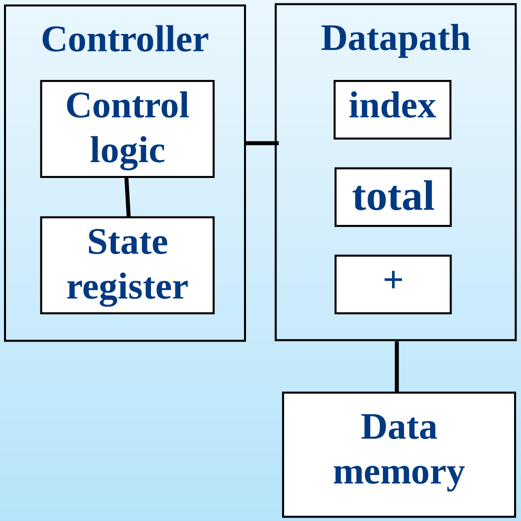
- Optimized for particular processing applications
- Features
  - Harvard Architecture
    - Program memory
    - Data memory
  - Optimized datapath
  - Specialized functional units



Motivation

Field-Programmable Gate Arrays (FPGAs)

- Designed to execute exactly a single program
  - Hardware accelerator
- Features
  - No program memory



GPP

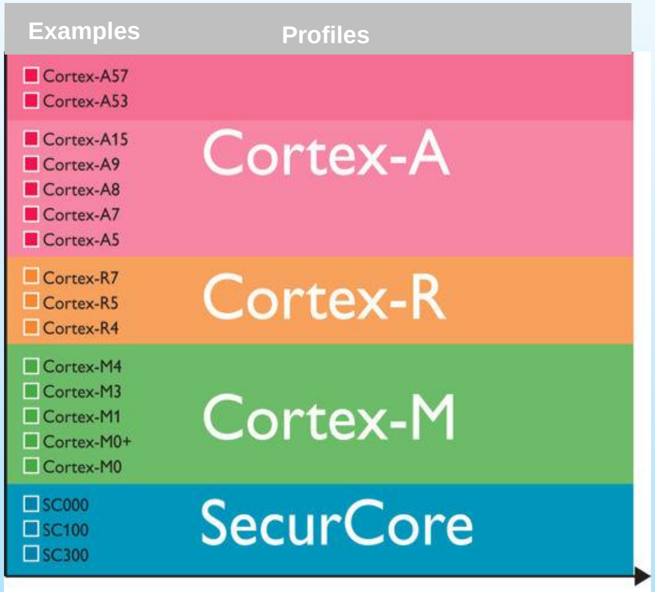
Operating System

- We focus on GPP-based embedded Platforms
- GPPs are good at performing Operating System (OS)-like tasks
  - RT-OS
  - Linux Kernel! … but depends on the available resources
- Best-effort policy to service processes
  - No guarantee deadline

GPP

ARM Processor

- ISA = Instruction Set Architecture
  - Core: STM32L072CZ
    - ARM Cortex M0+
    - Ultra-low-power
    - ARMv7
  - Recently, ARMv8 and ARMv9



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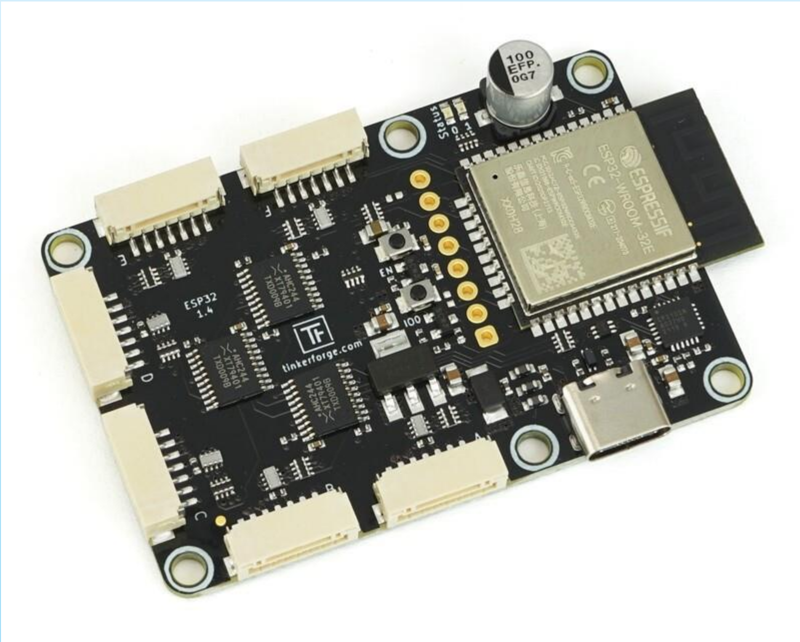
2024 EP Gallery

- Rasperry Pi 5, €57
  - https://www.raspberrypi.org/
  - Quad-core ARM Cortex A-76 SoC
  - Bluetooth 5.0
  - 40-pin GPIO header

2024 EP Gallery

- ESP32 Brick, €45
  - https://www.tinkerforge.com/
  - ESP32 Tensillica Xtensa dual-core LX6 microcontroller
  - This Brick controls others “bricks” (add-on modules)



2024 EP Gallery

- Renegade Elite, €69
  - https://libre.computer/
  - 2 ARM Cortex A-72 + 4 ARM Cortex A-53
  - 4 Mali-T860 GPU
  - PCIe 60-pin expansión header

2024 EP Gallery

- Banana Pi BPI-F3, €75
  - http://www.banana-pi.org
  - Octa-core RISC-V (SpacemiT K1)

- … and many more

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Future

Anytime, anywhere

- Embedded Systems have overtaken market of PCs
- Pervasive computing:
  - Wearable computers
  - “Smart” AI-based consumer products
  - Intelligent buildings
  - Environmental Monitoring
  - Traffic control and communicating vehicles
- Embedded platforms and communication networks provide the basic technology for IoT