Microcontroller architecture

ISA and Microarchitecture

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Basically, it is an abstraction that outlines how a computer’s hardware components interact and work together to process data. Of course it is important. But why?

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- **Power consumption:** Many embedded systems operate on battery power. A microcontroller packed with features but with a high current consumption is not always feasible for battery-operated systems.
- **Cost and size:** Choosing a microcontroller with just enough features to develop the intended functionality is key to saving money, but also in some cases the size, which in turn also reduces the cost.
- **Performance and memory:** Depending on the application, some devices might only run certain OS which is targeted for a specific arquitechture, or maybe they need to be compatible with external memory.

Importance of architecture (cont.)

So, just like buying any other thing, when buying a microcontroller to design an embedded system, you should take into account the size, your budget, the style, among many other things. But the thing with architecture in computer science and embedded systems is that saying “architecture” is really, really broad.

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So, just like buying any other thing, when buying a microcontroller to design an embedded system, you should take into account the size, your budget, the style, among many other things. But the thing with architecture in computer science and embedded systems is that saying “architecture” is really, really broad.

Why? you may ask... Well, in the beginning we had very simple circuits compared to those nowadays. We also had one way to program them: 1’s and ’0s. But today we have a huge variety of variables, even with circuits themselves, since we’re not limited to Microcontrollers(µCs or MCUs) and Microprocessors(µPs), we also have Digital Signal Processors (DSPs), Field Programmable Gate Arrays (FPGAs), System-on-Chips (SoCs), and Application Specific Integrated Circuits (ASICS).

Different kinds of architectures

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So, let us explore some different kinds of architectures.

ISAs

Instruction Set Architecture

An Instruction Set Architecture (ISA) is part of the abstract model of a computer that defines how the CPU is controlled by the software. The ISA acts as an interface between the hardware and the software, specifying both what the processor is capable of doing as well as how it gets done. [2]

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The ISA provides the only way through which a user is able to interact with the hardware. It can be viewed as a programmer's manual because it is the portion of the machine that's visible to the assembly language programmer, the compiler writer, and the application programmer.

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- **MIPS:** Based in RISC and used in many network systems.
- **AVR:** 8-bit RISC, which we will explore and use in this course.

Microarchitecture

Microarchitecture

Microarchitecture is the implementation of the ISA in hardware. It defines how a processor's internal components are organized and interact to execute the instructions described by the ISA.

ISAs can be executed in different implementations of hardware, so, a microarchitecture (or µarch) is the description of that exact thing.

Microarchitecture (cont.)

Microarchitectures are usually represented as diagrams that describe the interconnections of the various microarchitectural elements of the machine, which may include gates, registers, arithmetic ALUs and even larger elements. These diagrams generally also include the buses.

Memory hierarchy

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- Registers
- Cache
- RAM
- Flash
- EEPROM

Memory hierarchy (cont.)

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  - **L1**: The fastest, and also the smallest. Usually found inside the CPU. Stores recently used instructions or data that are most likely to be requested again soon.
  - **L2 & L3**: Typically external. Store additional information that may be needed by the processor in order to run efficiently; they are slightly slower than Level 1 but still provide quick access when necessary.

Memory hierarchy (cont.)

- **Flash**: A type of non-volatile memory in which data persists even after the power is turned off, it is cheap, small and reliable.

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- **EEPROM**: Electrically Erasable Programmable Read-Only Memory. Offers faster byte-level writes and erases, making it suitable for applications with occasional updates (e.g., configuration settings). Still, flash provides higher storage density, better endurance through wear-leveling, and is more cost-effective for larger storage capacities and applications that require frequent data updates.

Real architectures

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How do architectures really look?

Von-Neumann Architecture

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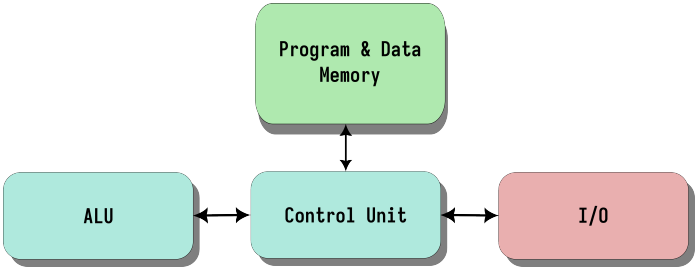
- Single memory space: Program instructions and data share the same memory.
- Unified bus: A single bus is used for transferring both instructions and data between memory and the CPU.
- Execution bottleneck: Since instructions and data share the same bus, the system can experience delays (known as the Von Neumann bottleneck) when fetching instructions and data alternately.

Von-Neumann Architecture



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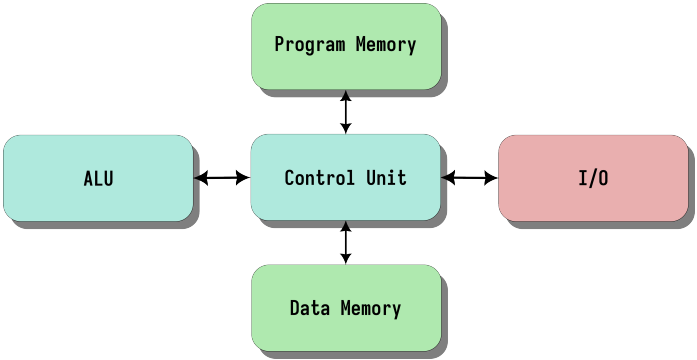
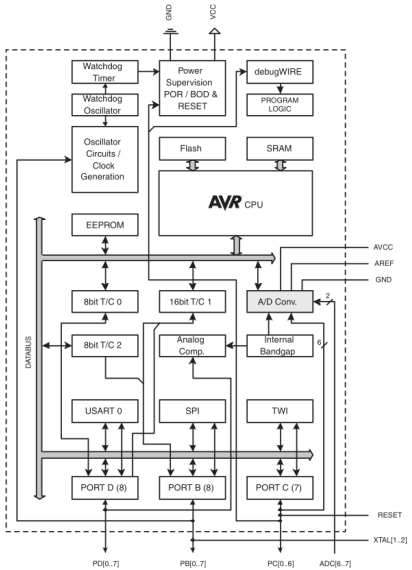
- Separate buses: The CPU can fetch instructions and access data simultaneously because it uses two separate buses for instruction and data transfer.
- Faster execution: This separation reduces the bottleneck since fetching instructions does not interfere with data access.

Harvard Architecture



ATmega328P architecture



The instruction cycle

The instruction cycle is the process by which a microprocessor (or microcontroller) achieves the execution of each instruction. It is the fundamental operation that allow these devices to perform tasks. It constists of the following steps:

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2. Decode: Interpreting what the instruction is meant to do.
3. Execute: Performing the operation specified by the instruction.

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Instructions and microinstructions

A CPU is capable of executing the instructions that the ISA describes and the µarch provides hardware for. There might be instructions, for example, a multiplication instruction, which may involve multiple steps, like to move the data to multiply to a register close to the ALU, and then operate and then move the result to another register. This is: a single ISA instruction might be comprised of multiple microinstructions, however, microinstructions are internal to CPU and they are out of our reach, but they still play a big role in microcontroller architectures.

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5. There is now an instruction to decode and the PC increments.

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5. Other registers or flags might be afected and in turn, signal for the next instruction.

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- Pipelining: RISC designs are highly pipelined, meaning multiple instructions can be processed simultaneously at different stages (fetch, decode, execute).
- Energy efficiency: Simple instructions and faster execution lead to more efficient use of power, which is critical for embedded systems.

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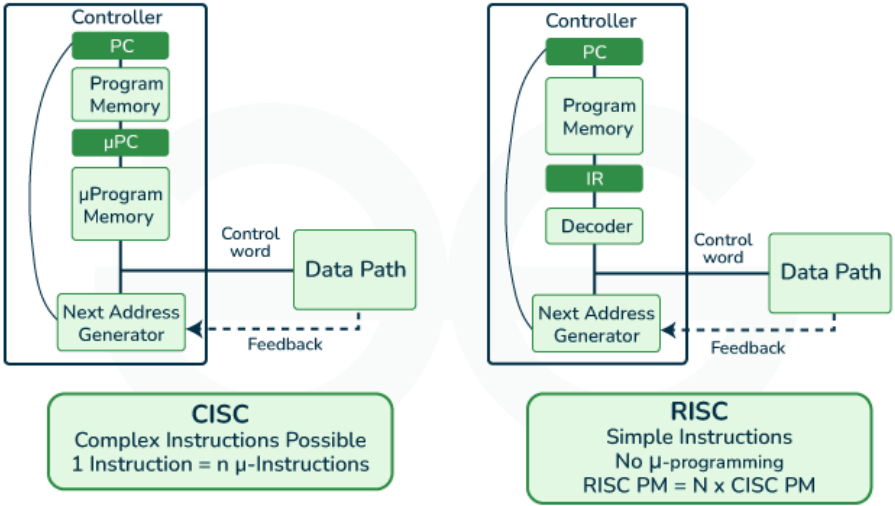
- Direct memory access: CISC instructions can directly operate on memory, reducing the need for multiple load/store instructions.
- Longer instruction execution time: Due to the complexity of CISC instructions, they generally take more clock cycles to execute than RISC instructions.

ATmega328P architecture



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- It is widely used in Arduino boards (e.g., Arduino Uno).
- Features a RISC architecture with 32 general-purpose registers.

Core Features

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- **I/O**: 23 GPIO pins for external interfacing.

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- Only 131 instructions.
- Most instructions execute in a single clock cycle.
- Efficient use of general-purpose registers (32 in total).

Memory Organization

- **Program Memory**: 32 KB Flash for storing code.
- **Data Memory**: 2 KB SRAM for runtime data.
- **EEPROM**: 1 KB for permanent data storage.
- **I/O Memory**: Special function registers (SFR) for controlling peripherals.

Interrupt System

- 24 Interrupt vectors with varying priorities.
- External interrupts: INT0, INT1.
- Internal interrupts: Timer, USART, ADC, etc.
- Can trigger service routines to handle events like I/O changes, timer overflow, etc.

Peripherals Overview

- **Timers/Counters**: Three timers (Timer0, Timer1, Timer2) for timing applications.
- **USART**: Supports serial communication.
- **ADC**: 10-bit ADC for analog-to-digital conversion.
- **SPI/I2C**: Interfaces for communicating with other devices.

Summary

- ATmega328P is an efficient and widely used 8-bit microcontroller.
- Implements RISC and Harvard architecture for high performance.
- Provides ample I/O options and peripherals for various embedded applications.

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Any Questions?

References

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[2] Arm Ltd. *What is Instruction Set Architecture (ISA)? — arm.com*. URL: https://www.arm.com/glossary/isa (visited on 09/24/2024).