Cyber-Physical Systems

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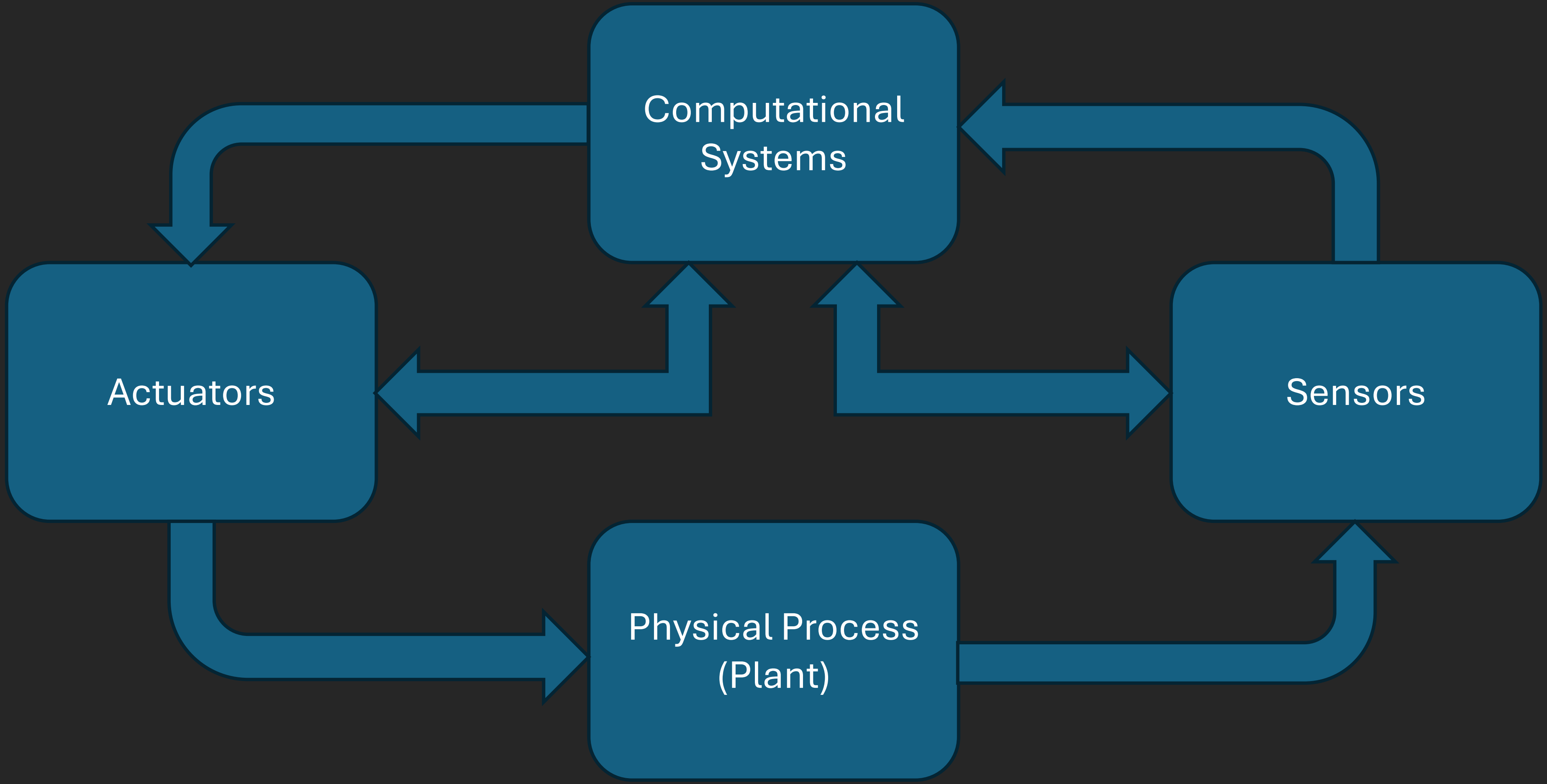
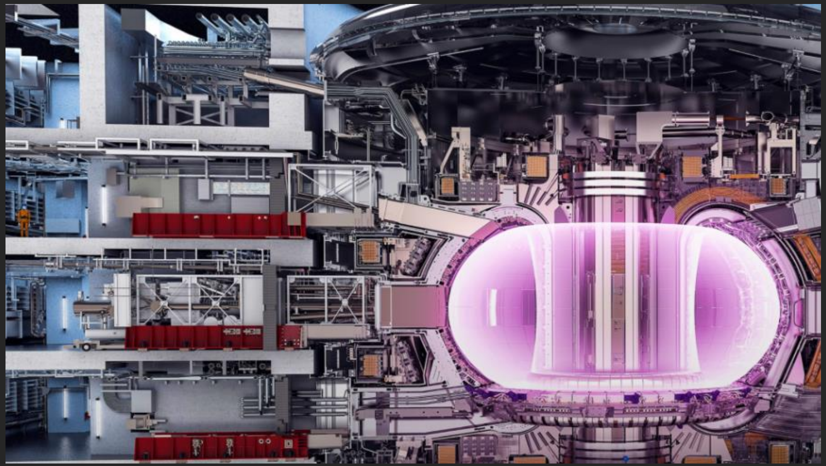
Computational Systems

What are Cyber-Physical Systems?



Considerations for Computational Systems

- Real-time interactions
  - Data processing & Control



Considerations for Computational Systems

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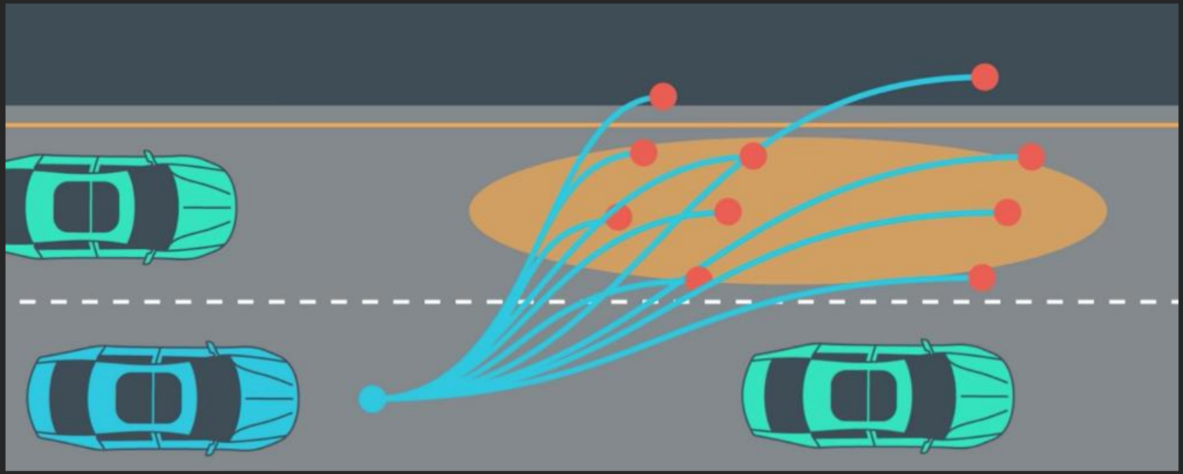
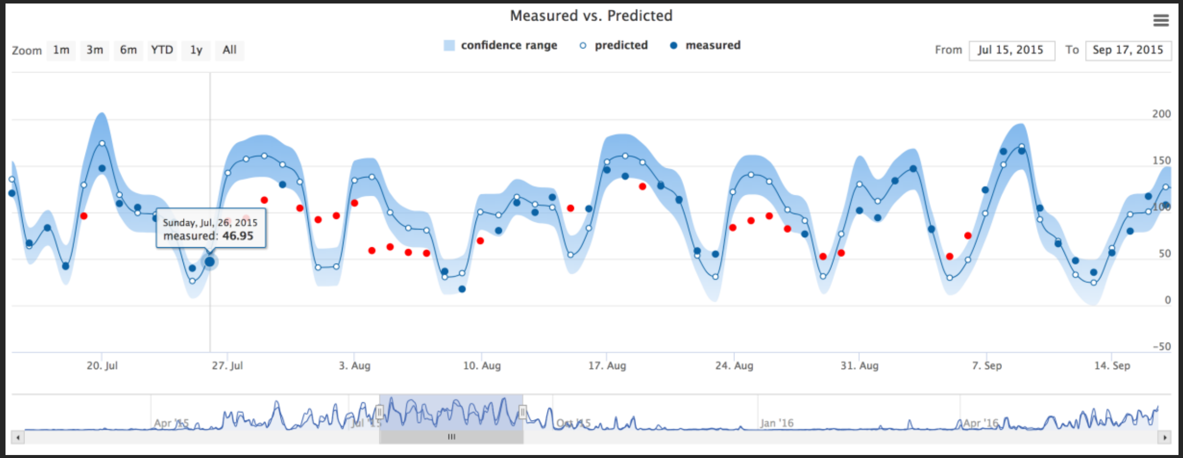
- Autonomy and Decision Making
  - Simulation & AI





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- Real-time interactions
  - Data processing & Control
- Autonomy and Decision Making
  - Simulation & AI
- Scalability and Optimization
  - Specialized/custom hardware

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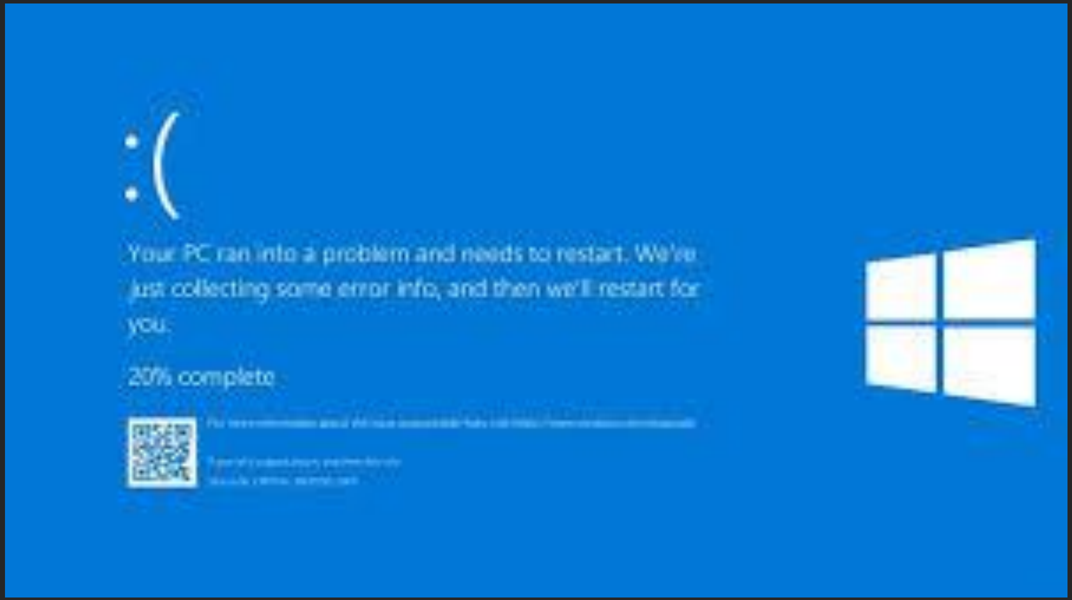
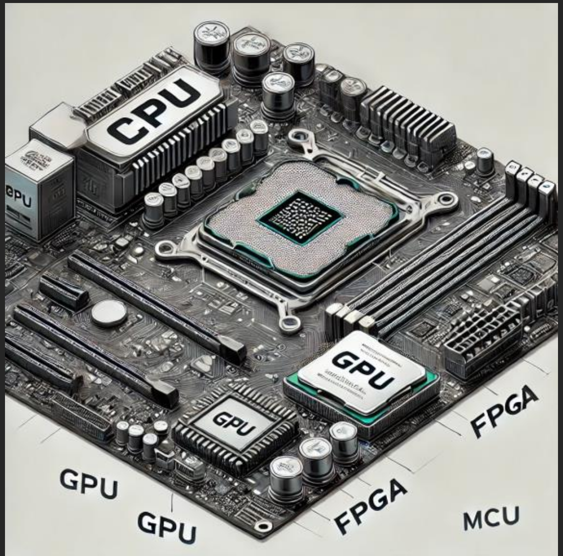
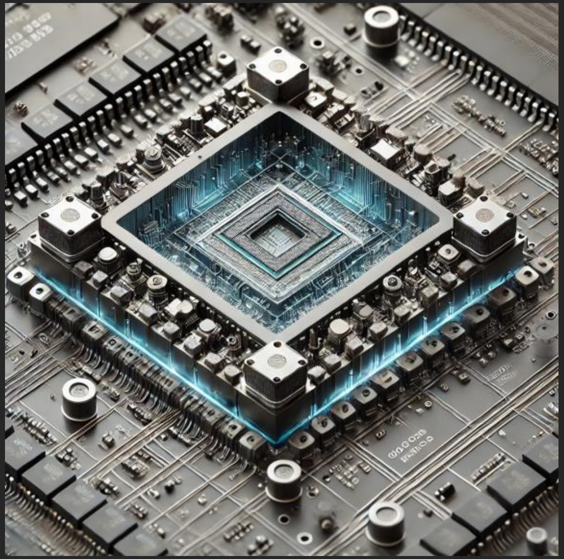
- Real-time interactions
  - Data processing & Control
- Autonomy and Decision Making
  - Simulation & AI
- Scalability and Optimization
  - Specialized/custom hardware
- Safety Criticality
  - Verifiability
  - Testing

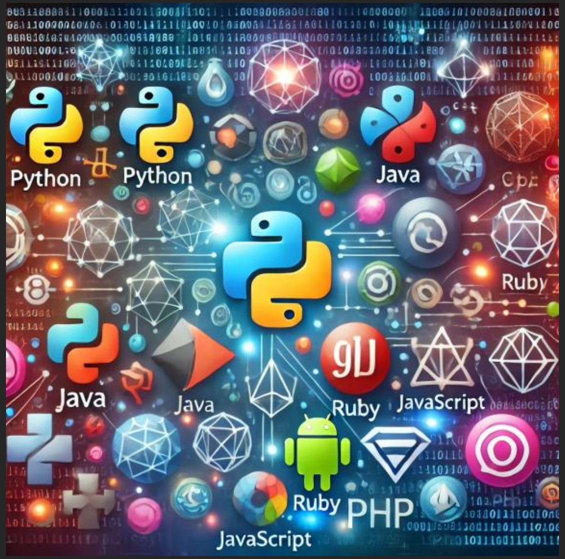


Overview

- Types of Computational Systems
- Computer Architectures and Instruction Sets
- Computer Programming languages





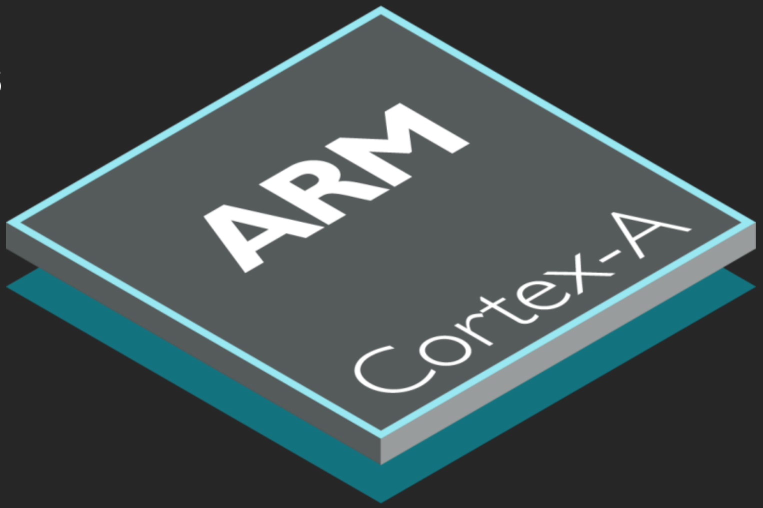


Microprocessor (CPU)

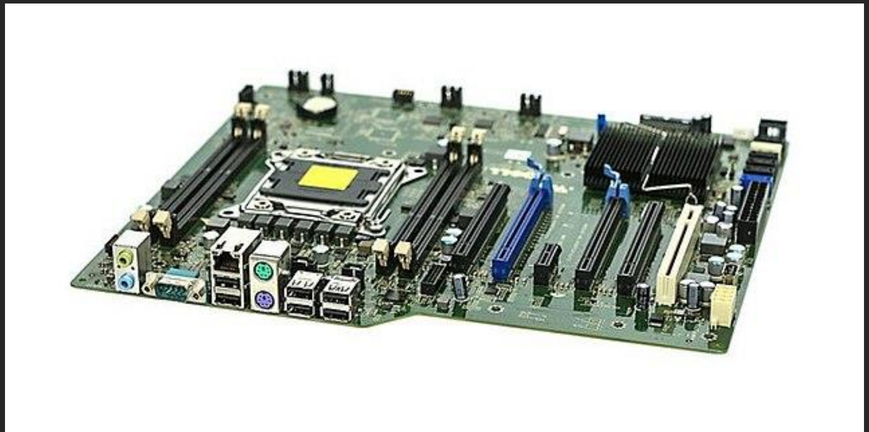
Microprocessors (Central Processing Units or CPUs) are **general-purpose** processors used to execute instructions from computer programs.

Microprocessor

- Aka “Central Processing Unit”
  - Arithmetic, logic, control, and input/output
- Key Features
  - High-speed, sequential execution of tasks
  - Operating systems and multi-threaded applications
- Common Applications
  - Personal computers, data processing tasks
- Examples
  - Intel i5/i7/i9, AMD Ryzen, ARM Cortex-A



Microprocessor Vs Computer



Microprocessor – Key Characteristics

- Clock Speed (GHz)
  - Performance, power consumption, heat generation
- Core Count
  - Parallelism and multi-threaded application speed
- Architecture
  - Software compatibility and optimization performance
- Thermal Design Power
  - Cooling requirements

Microprocessor – Key Characteristics

- Cache Size (L1, L2, L3)
  - Performance, reduces need to fetch data from slower memory
- Memory Support
  - Parallelism and multi-threaded application speed
- Peripheral Support and I/O Interfaces
  - Determines system integration
- Graphics Processing Unit Integration
  - Display and AI support

Microprocessor – Key Characteristics

- Real-Time Capabilities
  - Guarantee response times, hardware interrupt handling
- Instruction Set Extensions
  - Faster processing for multimedia, cryptography, scientific computing
- Security Features
  - Sensitive data and data integrity
- Power Consumption & Efficiency
- Operating Temperatures
  - Industrial, automotive, outdoor applications

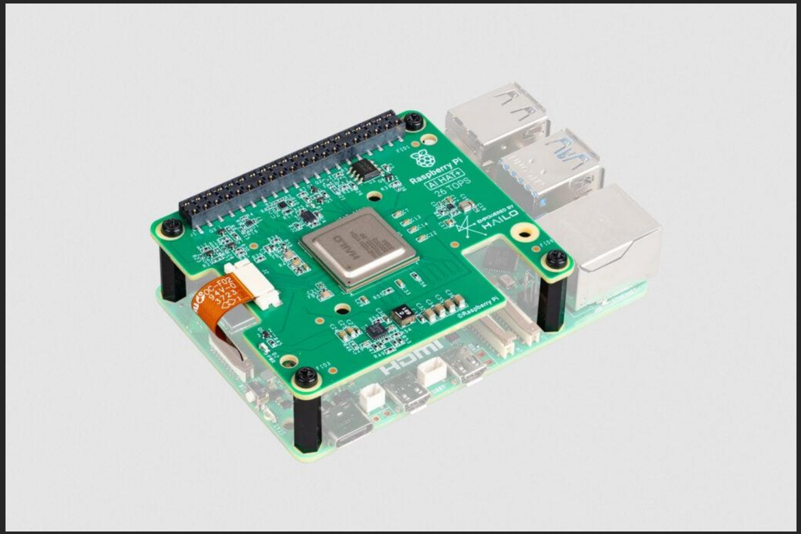
Single Board Computer

- Processor, memory, storage, I/O on a single board
- Key Features
  - Run full operating systems
  - Small form factors, non-modular
- Common Applications
  - IoT, Edge computing, robotics
- Examples
  - Raspberry Pi, Nvidia Jetson

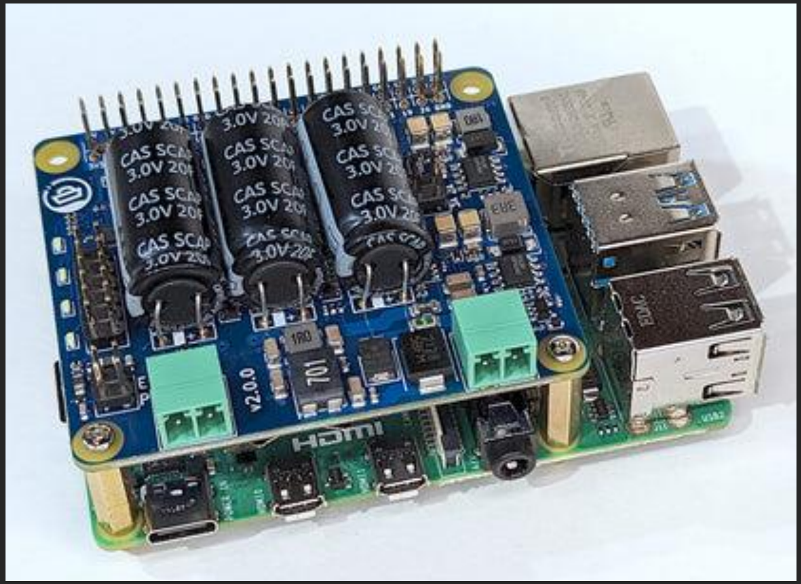
SBC – Key Characteristics

- Processor
  - Computational performance
- Memory, storage, and connectivity
  - Non-modular characteristics
- Graphics and Video Support
  - “headless” operating systems
- OS Support
  - Determines software compatibility and real-time support
- Power Supply, Formfactor, and Size
  - Determines physical constraints

SBC – Key Characteristics



- Expansion Options
  - Can extend capabilities
- Environmental Factors
  - Dust, temperature, ventilation, vibration, humidity
- Community and Support
  - Ease of implementation



Graphics Processing Units (GPUs)

- Specialized hardware designed for accelerating parallel processes associated with image, video, and tensor computation.
- Key Features
  - Tensor Processing Units (TPU) - generalized GPUs designed for tensor computation (deep learning, high dimension matrix multiplication)
  - Improved energy and computational efficiency
- Common Applications
  - Image/video rendering, LM (detection, classification, LLMs)
- Examples
  - Nvidia GeForce RTX, AMD Radeon RX, Google Corel

GPUs – Key Characteristics

- Architecture, CUDA Cores, Stream Processors
  - Governs task performance (ray tracing, ML training, simulations)
- VRAM and Memory Bandwidth
  - Governs the size of model and amount of data, and access speed
  - Example: Computer vision - Memory ~ Model Size * Batch Size
- Clock Speed
  - Heat dissipation, computation speed, power consumption
- Power Consumption, Form Factor, Interface
  - Determines physical constraints

GPUs – Key Characteristics

- Cooling Solutions
  - Governs scalability
- Multi-GPU support
  - Governs scalability
- Display Outputs
  - Type and number of ports
- OS and Software Support
  - GPUs are not stand-alone computational systems

Field Programable Gate Array (FPGA)

- FPGAs are customizable hardware devices that allow developers to program logic circuits post-manufacturing.
- Key Features
  - Tailored to specific tasks for low latency, high performance
  - Reconfigurable, ideal for precise timing
- Common Applications
  - Real time data acquisition, signal processing, communications
- Examples
  - Xilinx Zynq, Intel Stratix, Altera.

FPGAs – Key Characteristics

- Logic Elements/Logic Cells
  - Basic Building block, determines the complexity of circuit
- DSP Blocks, Hardware Acceleration, and IP Cores
  - Specialized logic blocks that govern computational abilities
- Memory
  - Governs scale of data that can be processed
- I/O Pin Count and Interface Support
  - Determines capacity for interfacing with external hardware

FPGAs – Key Characteristics

- Configuration Option
  - Governs how the logic is configured on startup
- Development tools and ecosystem
  - IDEs, hardware description languages (HDLs), and debugging tools
- Form Factor, Operating Temperature, Power
  - Governs environmental and physical compatibility
- Security Features
  - Deters tempering, reverse engineering, and unauthorized access

Application-Specific Integrated Circuit (ASIC)

- Custom-designed ICs specific for an application or function, optimized for performance, power efficiency, and cost.
- Key Features
  - Very Expensive to develop and manufacture
  - Highly efficient at a single task
- Common Applications
  - Network routing, cryptocurrency mining, telecommunications
- Examples
  - Bitmain Antminer Series, Sony BIONZ

ASIC – Key Characteristics

- Functionality and Customization
  - The specific task the chip is designed to do
- Cost and Time-to-Market
  - 12-36 month for design and manufacturing
- Manufacturing Technology
  - Governs size of transistor that can be manufactured
  - Photolithography, extreme-ultraviolet, electron beam
- Verification and Testing
  - Functionality, reliability, and design iterations

System-on-Chip (SoC)

- SoCs integrate all components of a computer into a single chip, processor, memory, I/O interfaces, and accelerators
- Key Features
  - High integration reduces power and physical space
- Common Applications
  - Smartphones, tablets, embedded systems
- Examples
  - Qualcomm Snapdragon, Apple A-series, MediaTek, NVIDIA Tegra

Computational Systems

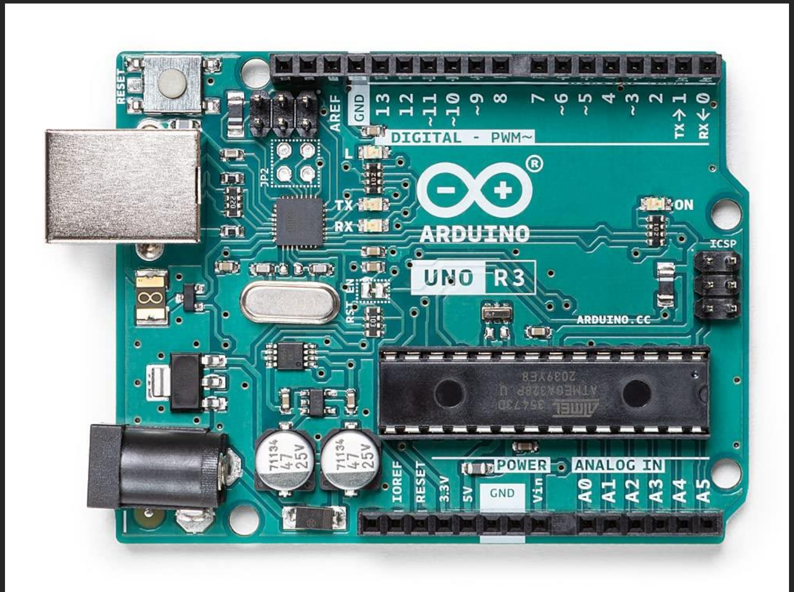
- Microprocessor (CPU)
- Single Board Computer (SBC)
- Graphics Processing Unit (GPU)
- Field Programable Gate Array (FPGA)
- Application Specific Integrated Circuit (ASIC)
- System-on-Chip (SoC)
- Microcontroller (MCU)

Microcontrollers (MCU)

- Compact ICs designed for dedicated control functions
  - Processor, memory, and I/O peripherals on a single chip
- Key Features
  - Optimized for low power consumption
  - Used in repetitive tasks like controlling sensor and actuators
- Sensor control, automotive, smart devices, home automation
  - Hardware oriented, control platforms
- Examples
  - Arduino, ESP32, STM32

MCU – Key Features

- Communication Interfaces
- I/O Pin functionality
  - ADC Sampling frequency, bit rate, PWM or DAC
- Hardware Interrupts
  - Governs real-time safety
- RTOS support
- Wireless connectivity
- Operating voltage



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