Embedded Systems
-An Introduction

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Embedded Systems

- Suggested Textbooks:
  - Raj Kamal, “Embedded systems Architecture, Programming and Design”, Third Edition, Tata McGraw Hill, 2017.
  - Rob Toulson and Tim Wilmshurst, “Fast and Effective Embedded Systems Design – Applying the ARM mbed”, Elsevier, 2017.
  - Arnold S. Berger, “Embedded Systems Design: An Introduction to Processes, Tools, and Techniques”, CRC Press, 2002.
- Other sources
  - Lecture notes
  - Handouts
  - Blogs
  - MOOC courses

Contents

- Definitions
- Characteristics of an Embedded System
- Classifications of Embedded Systems
- Components of an Embedded System
- Examples of Embedded Systems
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- Performance and Benchmarking
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What is a System?

- A black box that takes the input, processes it and provides the required output
- A way of working, organizing or performing one or many tasks according to a fixed set of rules, program or plan
- Example
  - Time display system – A watch
  - Automatic cloth washing system – A washing machine
  - Photograph capturing system – A digital camera

What's an Embedded System?

- An embedded system is an electronic system which is designed to perform limited task using hardware and software.
- An Embedded system is computing system other than a desktop computers- Frank Vahid /Tony
- It is any device that includes a programmable computer but is not itself intended to be a general purpose computer - Wayne Wolf
- Embedded System are electronics systems that contain a Microprocessor, Micro Controller, but we don't think of them as computer. The computer is hidden in the system- Todd D.Mortan
- An embedded system is a System whose principle function is not computational, but which is controlled by computer embedded within it. – Tim Wilmshurst

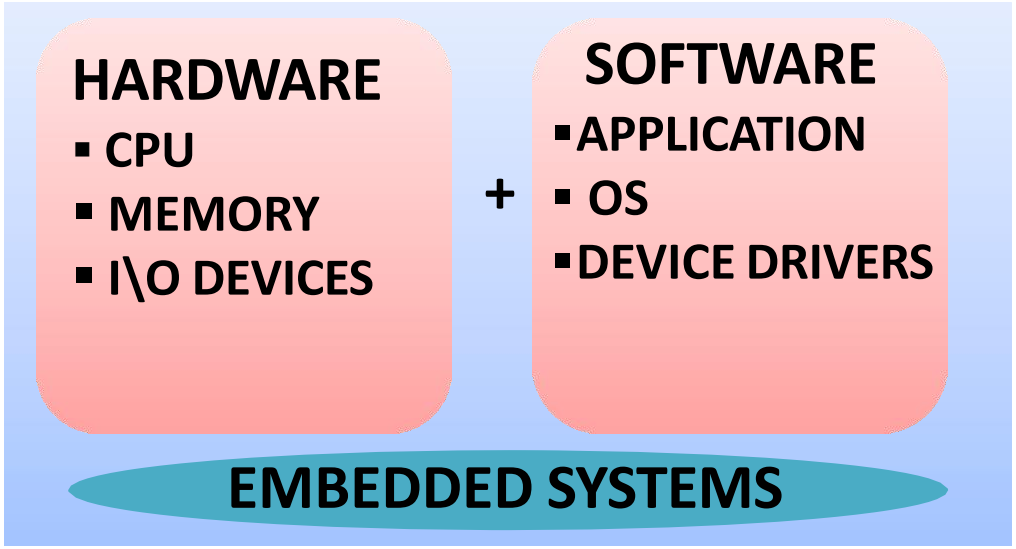
What's an Embedded System?

- It is a dedicated computer based system for an application(s) or product. It may be an independent system or a part of large system. Its software usually embeds into a ROM (Read Only Memory) or flash. – Raj Kamal
- An embedded system is a special-purpose computer system designed to perform one or a few dedicated functions, sometimes with real-time computing constraints. - Michael Barr
- Examples

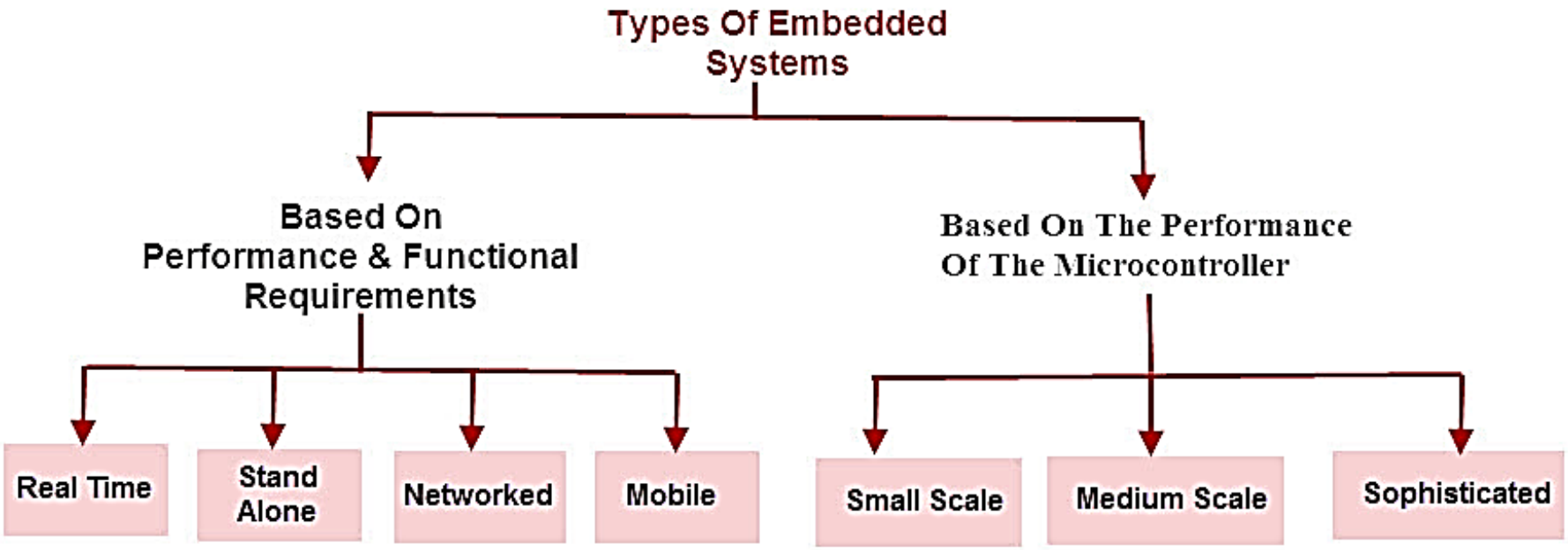
-Digital camera	-Washing machine	-Microwave oven
-Heart monitors	-Laser printers	-Engine controllers
-treadmills	-Debit card readers	-Pacemakers
-Grain analyzers	-Remote controls	-Coffee machine
-Traffic lights	-Radar guns	& many more

Embedded Systems

- Every embedded system consists of custom built hardware built around a Central Processing Unit (CPU)
- Memory hardware also contains memory chips onto which the software is loaded.



Classification of Embedded Systems

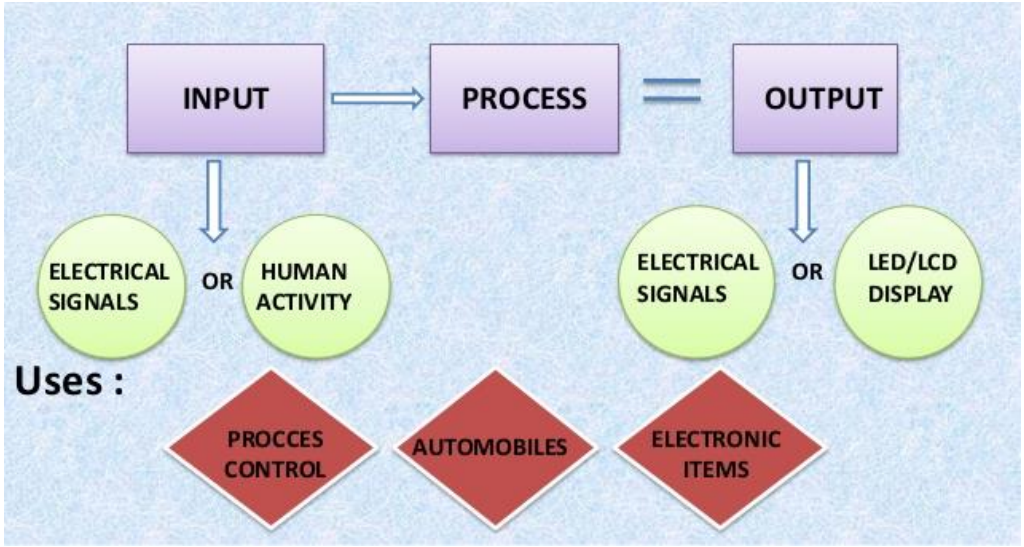


Classification

- Small scale embedded systems: Use 8 bit or 16 bit microcontrollers, and have minimum hardware and software. They are so small and require little power they may be powered by a battery.
- Medium scale embedded systems: Use either one or a few 16 bit or 32 bit microcontrollers, RISCs or DSPs. The hardware and software is more complex as compared to small scale embedded systems.
- Sophisticated embedded systems: The most complex of the three classifications mentioned. Used for cutting-edge applications that need hardware and software Co-design.

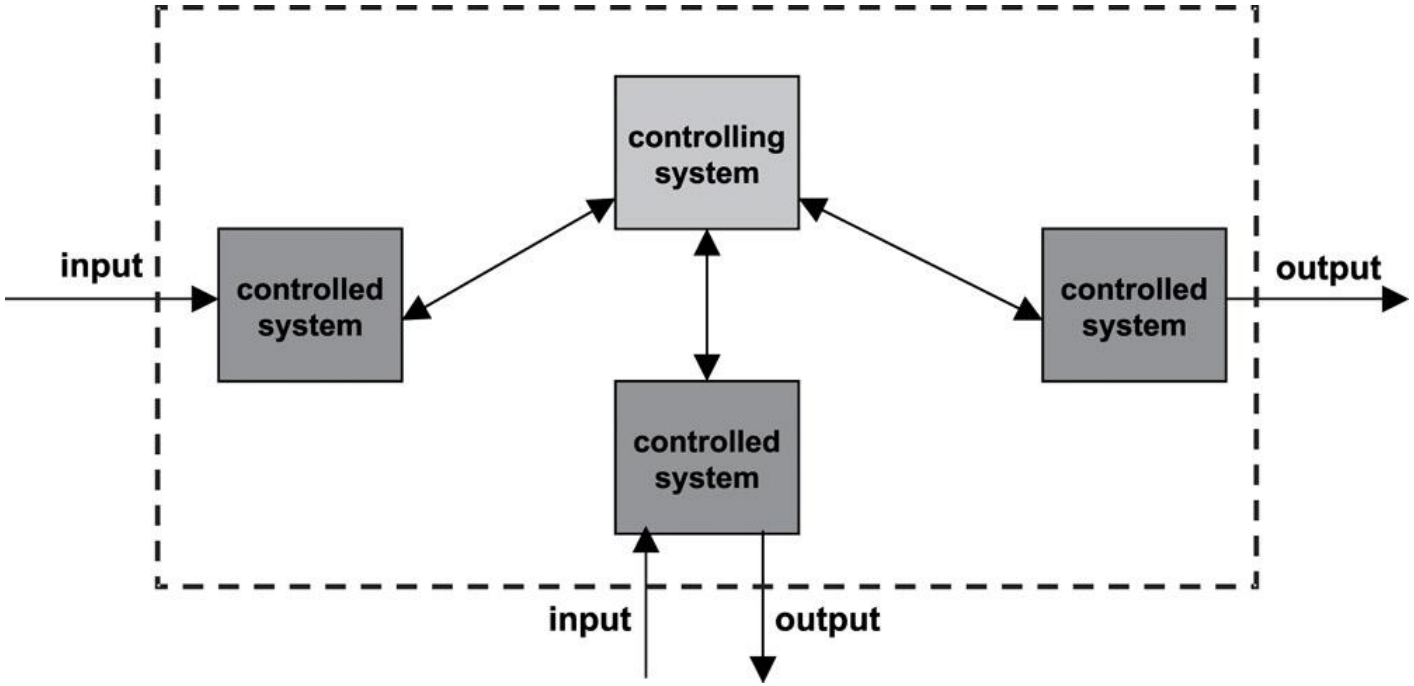
Classification

- Stand alone embedded systems do not require a host system like a computer, it works by itself. It takes the input from the input ports either analog or digital and processes, calculates and converts the data and gives the resulting data through the connected device



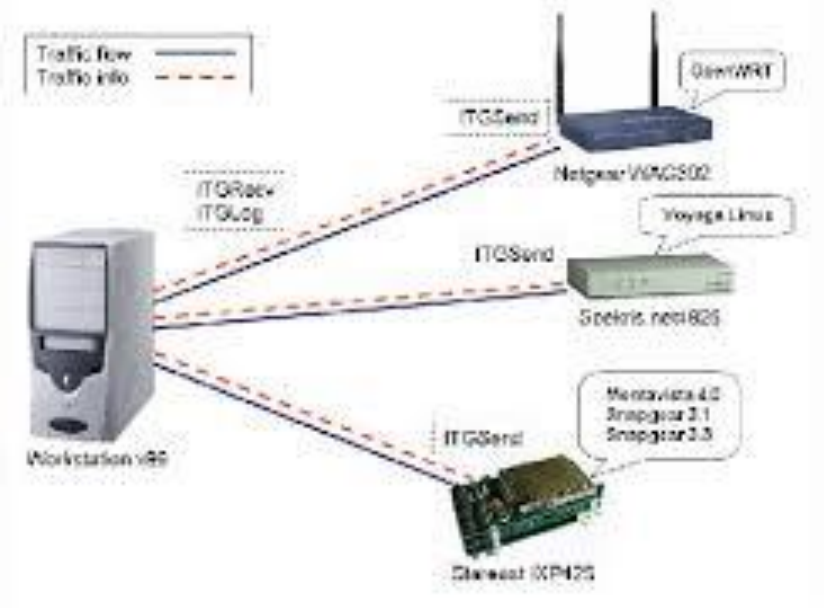
Classification

- Real time embedded systems gives the required o/p in a particular time. These types of embedded systems follow the time deadlines for completion of a task. Classified into two types such as soft and hard real time systems.



Classification

- Networked Embedded Systems are related to a network to access the resources. The connected network can be LAN, WAN or the internet. This type of embedded system is the fastest growing area in embedded system applications.



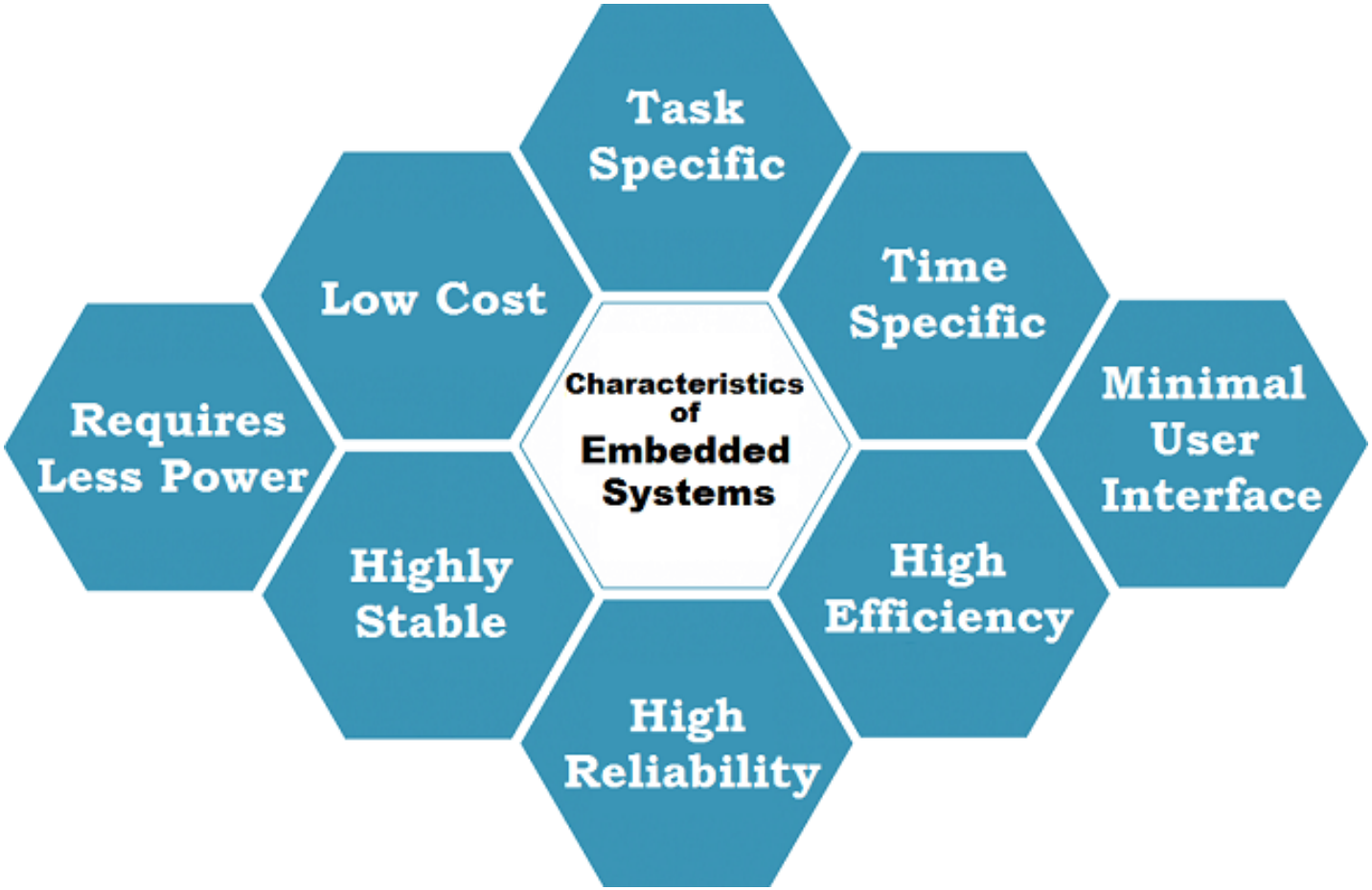
Classification

- Mobile embedded systems are used in portable embedded devices like cell phones, mobiles, digital cameras, mp3 players and personal digital assistants, etc. The basic limitation of these devices is having limited resources.

Characteristics of Embedded Systems

- Perform a specific task
- Memory constrained
- Time constrained
- Low power consumption
- Highly reliable
- Fault tolerant architecture
- Robust
- Simplified user interface (generally no GUI)
- Less human interaction

Characteristics of Embedded Systems



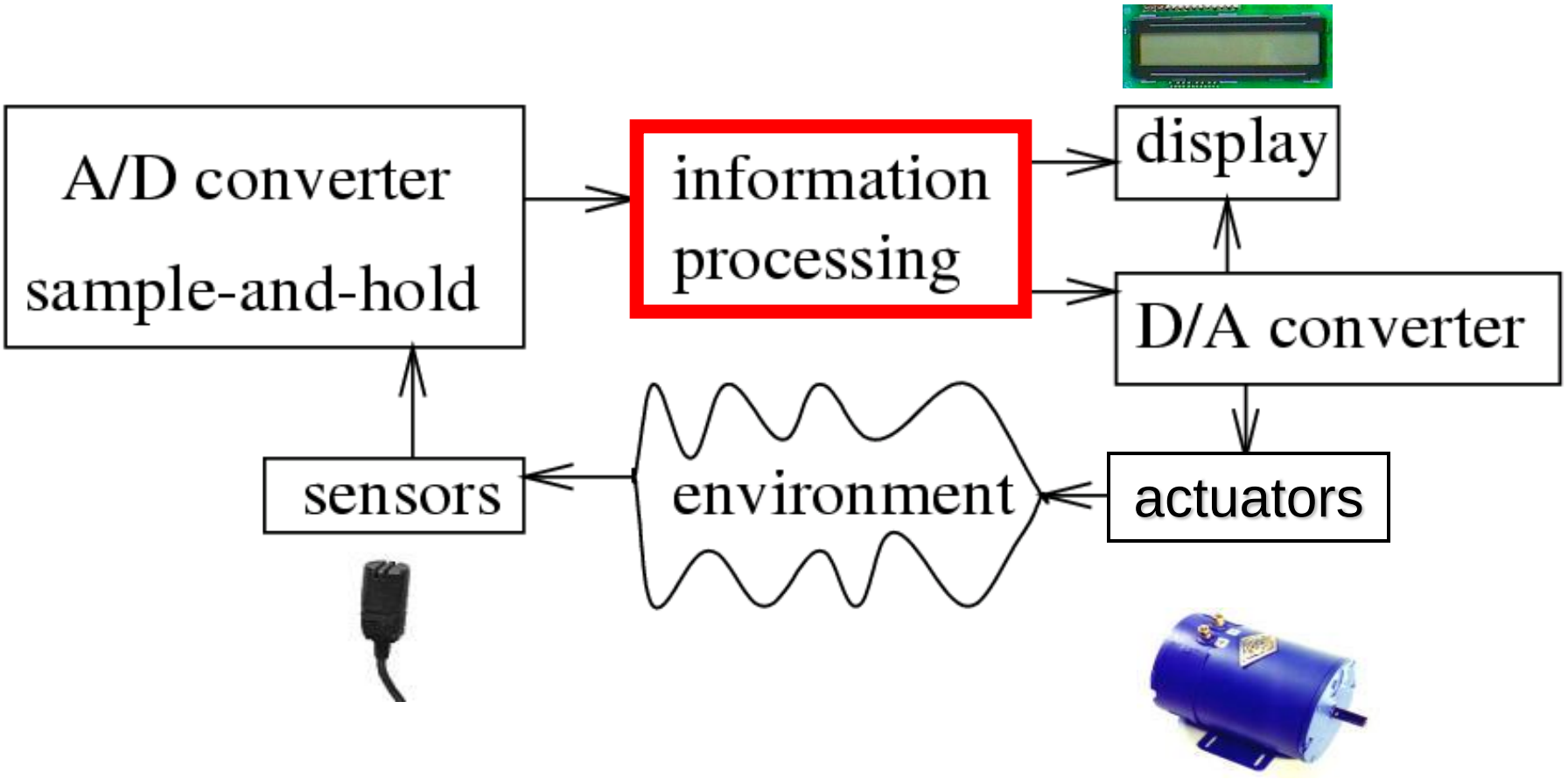
Components of Embedded Systems

- Analog Components
  - Sensors, Actuators, Controllers, …
- Digital Components
  - Processor, Coprocessors
  - Memories
  - Controllers, Buses
  - Application Specific Integrated Circuits (ASIC)
- Converters – A2D, D2A, …
- Software
  - Application Programs
  - Exception Handlers

Hardware

Software

ES: Simplified Block Diagram

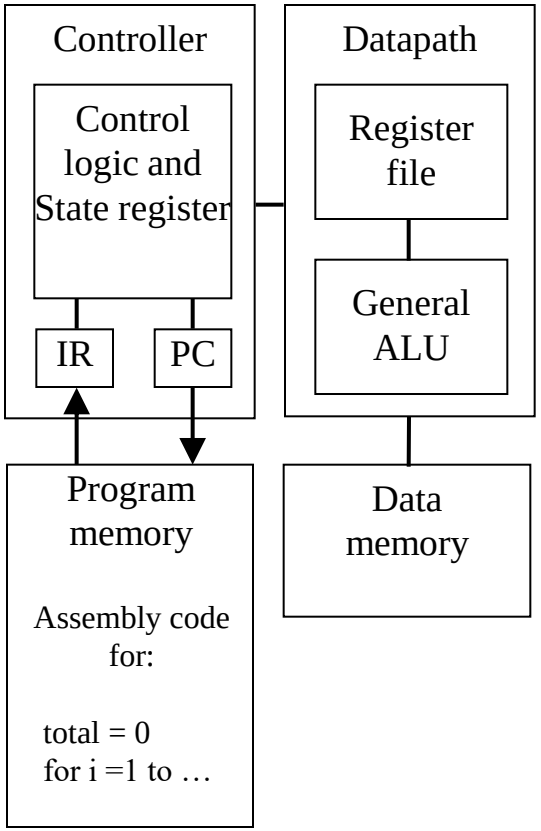


Processors

- What is a processor?
  - Artifact that computes (runs algorithms)
  - Controller and data-path
- General-purpose (GP) processors:
  - Variety of computation tasks
  - Functional flexibility and low cost at high volumes (maybe)
  - Slow and power hungry
- Single-purpose (SP) processors (or ASIC)
  - One particular computation task
  - Fast and power efficient
  - Functional inflexibility and high cost at low volumes (maybe)

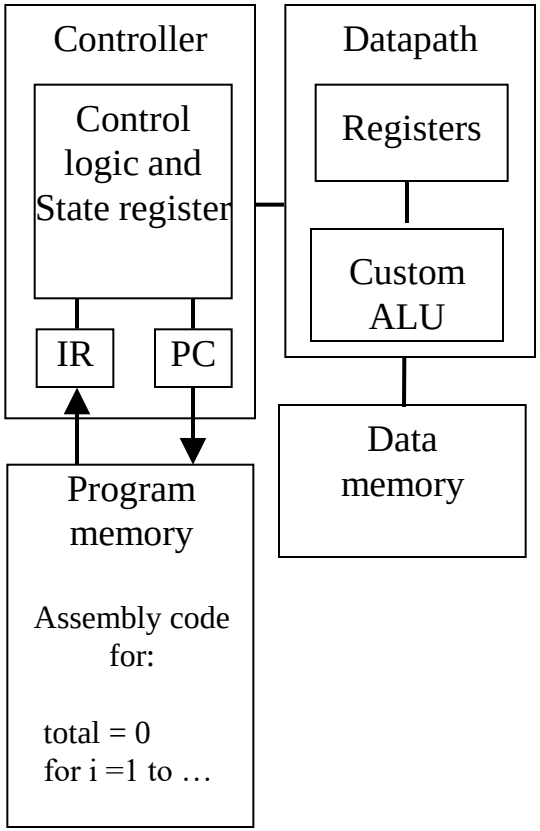
General-purpose processors

- Programmable device used in a variety of applications
- Features
  - Program memory
  - General datapath with large register file and general ALU
- User benefits
  - Low time-to-market and NRE costs
  - High flexibility
- Examples
  - Pentium, Athlon, PowerPC



Application-specific processors (ASICs)

- Programmable processor optimized for a particular class of applications
  - Compromise between general-purpose and ASIC (custom hardware)
- Features
- Program memory
- Optimized data path
- Special functional units
- Benefits
  - Some flexibility, good performance, size and power
- Examples
  - DSPs, Video Signal Processors, Network Processors,..



GP vs SP Processors

General Purpose System	Special Purpose System
• Designed using a microprocessor as the main processing unit.	• Designed using a microcontroller as the main processing unit.
• It contains secondary storage like hard disks etc.	• It does not require secondary memories
• Multiple tasks as per requirement.	• A particular predefined task.
• Expensive compared to SP	• Cheaper compared to a computer.
• It requires huge number of peripheral devices and their controllers	• It is cheaper as it requires less no of peripheral devices and their controllers are microcontroller chip itself.
• OS and other software occupy huge memory space	• RTOS occupy very less memory space

Examples of Embedded System

- Chocolate Vending Machines
- Digital alarm clocks
- Smart watches and digital wrist watches
- Washing machines and dishwashers
- Home security system
- Traffic lights
- Fire alarms and carbon monoxide detectors
- Printers, photocopy, fax machines and scanners
- Digital and video cameras
- Calculators
- Remote control gate keys

Embedded Applications

- Hybrid embedded systems
  - Aerospace, automobiles, robotics, process control, and sensor nets
- Consumer electronics
  - Appliances, office electronics, and home/office automation
- Medical instruments
  - Patient monitoring, MRI, and artificial hearts
- E-Business
  - ATM, wending machines

Aerospace

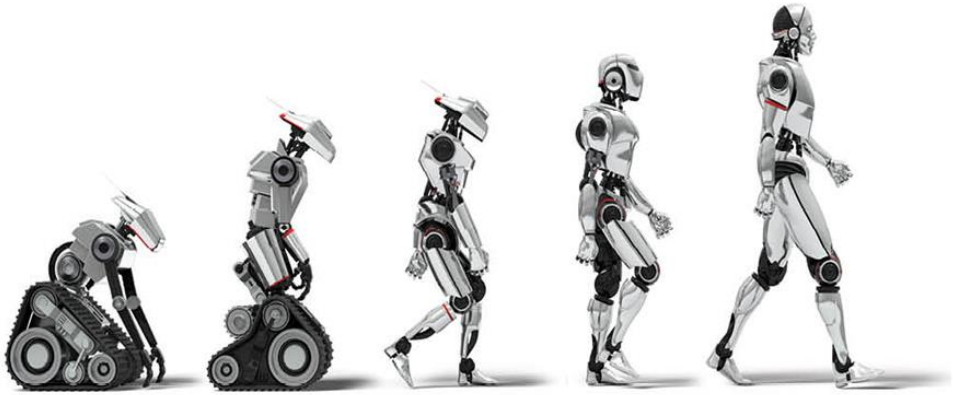
- Flight control
  - Stability: real-time differential feedback loops
- Positioning & navigation
  - GPS, INS
- Instrumentation
  - Data acquisition, display, processing, and archive
- Radar
- Communication

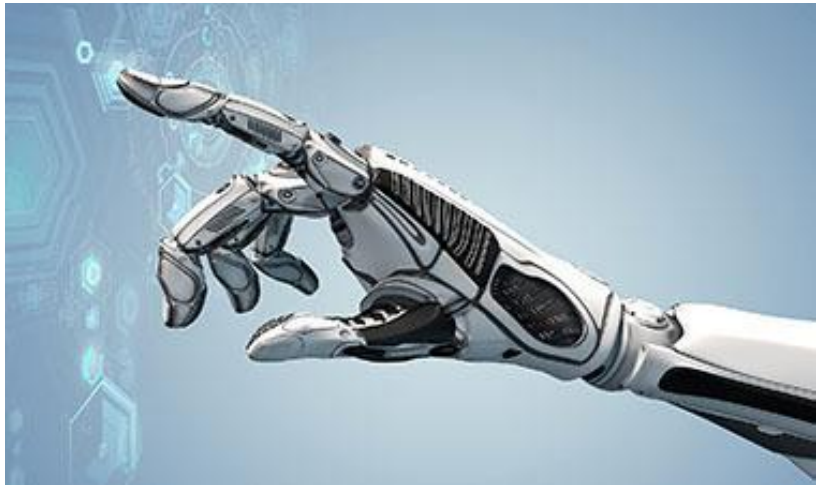
Automobiles

- Engine management
  - Fuel, ignition, timing
- Emission control
- Instrumentation
  - Data acquisition, display, processing, and archive
- Safety & stability
  - Airbags, active control
- Entertainment & comfort
  - Radio, A/C, …

Robotics

- Implies autonomous operation
- N physical degree of freedom
- Artificial intelligence
- Control heavy
- Mission oriented
  - Repair, search, rescue, investigate, and perform physically difficult tasks



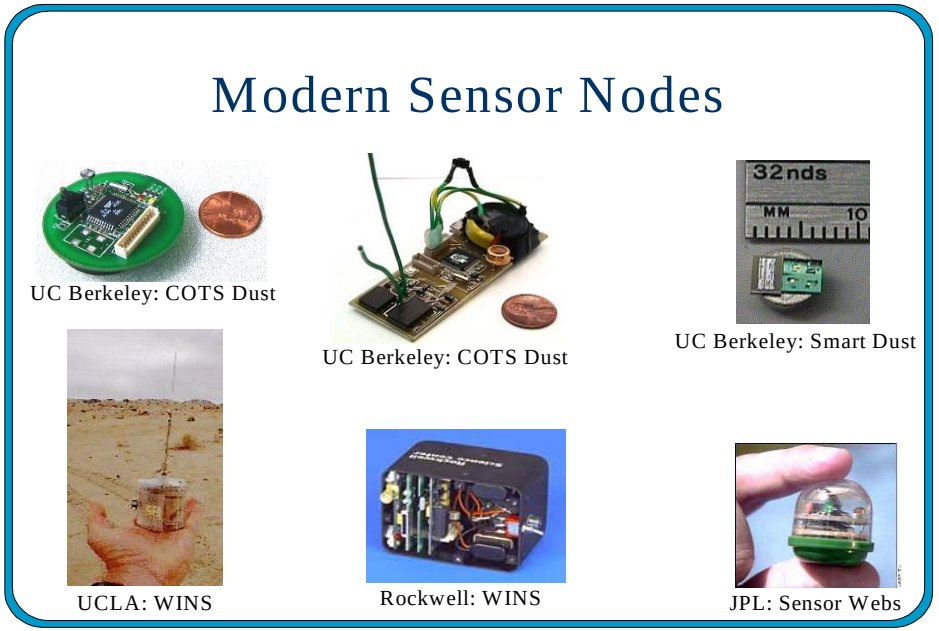


Process Control

- Industrial automation
- Plant monitoring and production control
- Similar to control systems but with emphasis on management

Sensor Nets

- Many sensor nodes each capable of sensing, computation/ storage, and communication
  - Structure safety
  - Search and rescue
  - Military use
- Self organization
- Energy Efficient
- Distributed

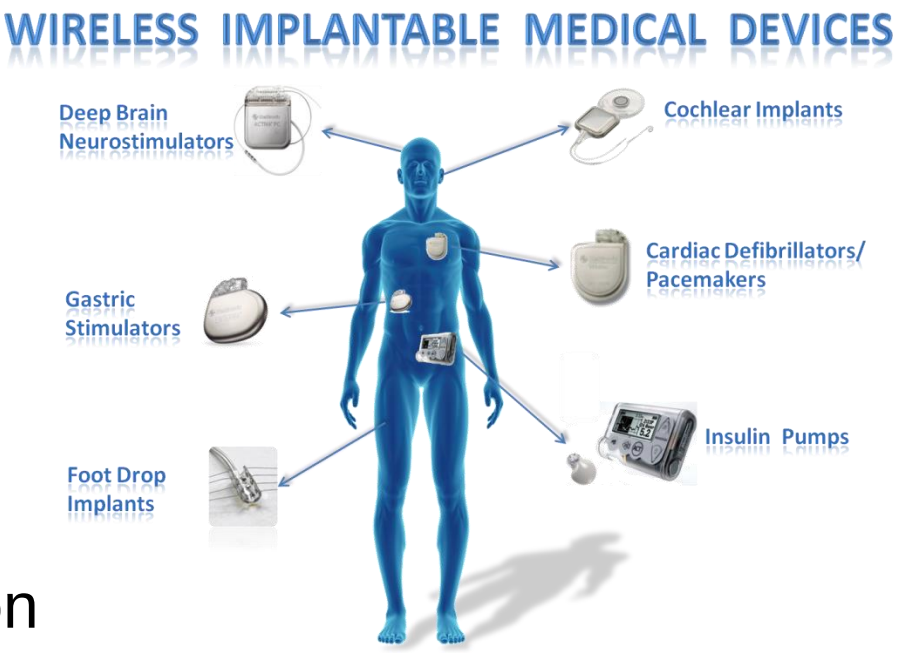


Consumer Electronics

- Home appliances
  - Yesterday's appliances: add computation
  - Tomorrow's appliances: add networking (Internet)
- Office electronics
  - Integration
  - Electronic paper (filing, printing, sending, and receiving)
- Home/office automation
  - Lights and appliances that operate by themselves or with minimal effort

Medical Instruments

- Perform diagnosis (screening/evaluation)
  - Data collection
  - Appraisal of that data
  - Developing a plan of action
- Observation or monitoring
- Sensing and instrumentation
  - Accuracy and precision
- Other applications:
  - Radiation therapy
  - Artificial hearts, arms, legs, …



E-Business

- Information processing systems
  - ATM
  - Scanners
  - Credit-card readers
- Often the interface behind a database
- Automation and convenience

Processor Selection Criteria

- Performance considerations
  - The performance speed of a processor is dependent primarily on its architecture and its silicon design.
  - presence of cache reduces instruction/data fetch timing.
  - Pipelining and super-scalar architectures further improves the performance of the processor.
  - Multi-cores are the new direction in improving the performance.
  - Processor architectures with support for extra instruction can help improving performance for specific applications.
  - size of cache, processor architecture, instruction set etc. has to be taken in to account when comparing the performance.

Processor Selection Criteria

- Power Considerations
  - Increasing the logic density and clock speed has adverse impact on power requirement of the processor.
  - A higher clock implies faster charge and discharge cycles leading to more power consumption.
  - More logic leads to higher power density there by making the heat dissipation difficult.
  - SoC comes with advanced power gating techniques that can shut down clocks and power to unused modules.

Processor Selection Criteria

- Operating Voltages
  - Each and every processor will have its own operating voltage condition.
  - The operating voltage maximum and minimum ratings will be provided in the respective data sheet or user manual.
- Specialized Processing
  - Apart from the core, presence of various co-processors and specialized processing units can help achieving necessary processing performance.
  - Co-processors execute the instructions fetched by the primary processor thereby reducing the load on the primary.

Processor Selection Criteria

- Price
  - Various considerations discussed above can be taken in to account when a processor is being selected for an embedded design.
  - It is better to have some extra buffer in processing capacities to enable enhancements in functionality without going for a major change in the design.
  - Price will be the determining factor when designing the system and choosing the right processor.

Embedded System Design Challenges

- Amount of Hardware Needed
  - The amount of hardware depends on the application that has to be developed .
  - Hardware not only indicates the processor, but also memory, peripherals.
  - Hardware selection must satisfy the cost and performance.
  - Less hardware – performance issues
  - More hardware – Cost problem
- Process Deadlines
  - Faster hardware or cleverer software
  - Meeting the deadline of all processes in the system while keeping the memory, power dissipation, processor clock rate and cost at minimum is a challenge

Embedded System Design Challenges

- Power Dissipation
  - Turn off unnecessary logic
  - Reduce memory accesses
  - Reduce clock rate
- Flexibility and Upgradeability
  - Ability to offer the different versions of a product for marketing and offering the product in advanced versions later on.
- Reliability
  - Designing reliable product by appropriate design and thorough testing, verification and validation is a challenge

Benchmarking

- Benchmark is the act of running a computer program, a set of programs, or other operations, in order to assess the relative **performance** of an object, normally by running a number of standard tests and trials against it.
- Benchmarking is usually associated with assessing performance characteristics of computer hardware.
- Benchmarks provide a method of comparing the performance of different chip/system architectures.

Benchmark Standards Organizations

- Business Applications Performance Corp. (BAPCo)
  - A nonprofit consortium that distributes a set of objective performance benchmarks for PCs based on popular software applications and operating systems.
- Embedded Microprocessor Benchmark Consortium (EEMBC)
  - Develops meaningful performance benchmarks for the hardware and software used in embedded systems.
  - Focuses on many different usage models, such as automotive, networking and telecom usage models.
- Futuremark Corporation
  - Creates and maintains objective standards of computer and hand held device performance measurement. This is done in cooperation with leading hardware and technology companies.

Benchmark Standards Organizations

- Standard Performance Evaluation Corp. (SPEC)
  - Formed to establish, maintain and endorse a standardized set of relevant benchmarks that can be applied to the newest generation of high performance computers.
  - SPEC produced SPEC CPU, SPECviewperf and SPEC HPC benchmarks.
- Transaction Processing Performance Council (TPC)
  - Defines transaction processing and data base benchmarks to disseminate objective, verifiable TPD performance data to the industry. TPC produced the TPC-C and TPC-H benchmarks.

Activity

- Research two microcontrollers and provide information about them from their datasheets. There are several microcontroller manufacturers which you can investigate including Atmel, Microchip, Freescale, TI, etc. For each microcontroller, report the following information.
  - Clock frequency
  - Bitwidth of the datapath
  - Size of Flash memory
  - Number of pins
  - Does the microcontroller contain an Analog-to-Digital Converter? If so, how many bits of precision does it have?
- Research the Arduino and Raspberry Pi platforms to determine if there are operating systems which can be used on each platform. If there are, list those operating systems and state whether they are open source or not.

Recent Trends

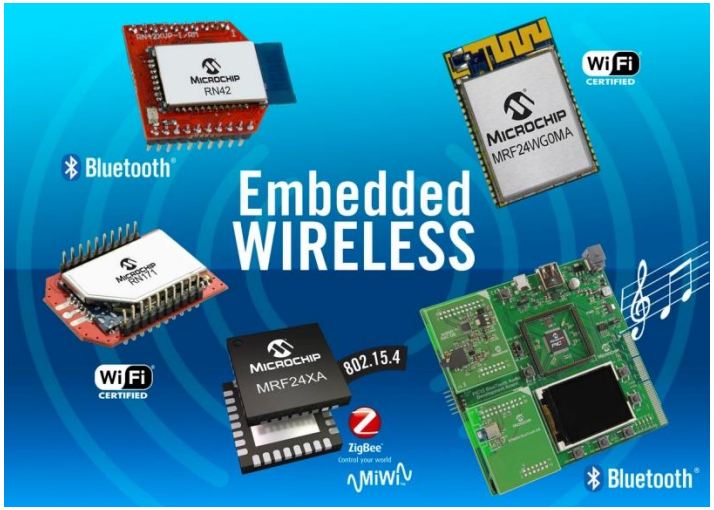
- System on Chip (SoC)
- Wireless Technology
- Multi Core processor
- Multi language support
- Use of Open source Technology
- Automation
- Security
- Power Consumption

System on Chip (SoC)

- A system on a chip or system on chip (SoC or SOC) is an integrated circuit that integrates all components of a computer or other electronic systems.
- SoC integrates a microcontroller (or microprocessor) with advanced peripherals like graphics processing unit (GPU), Wi-Fi module, or coprocessor.
- SoC does not necessarily contain built-in memory.

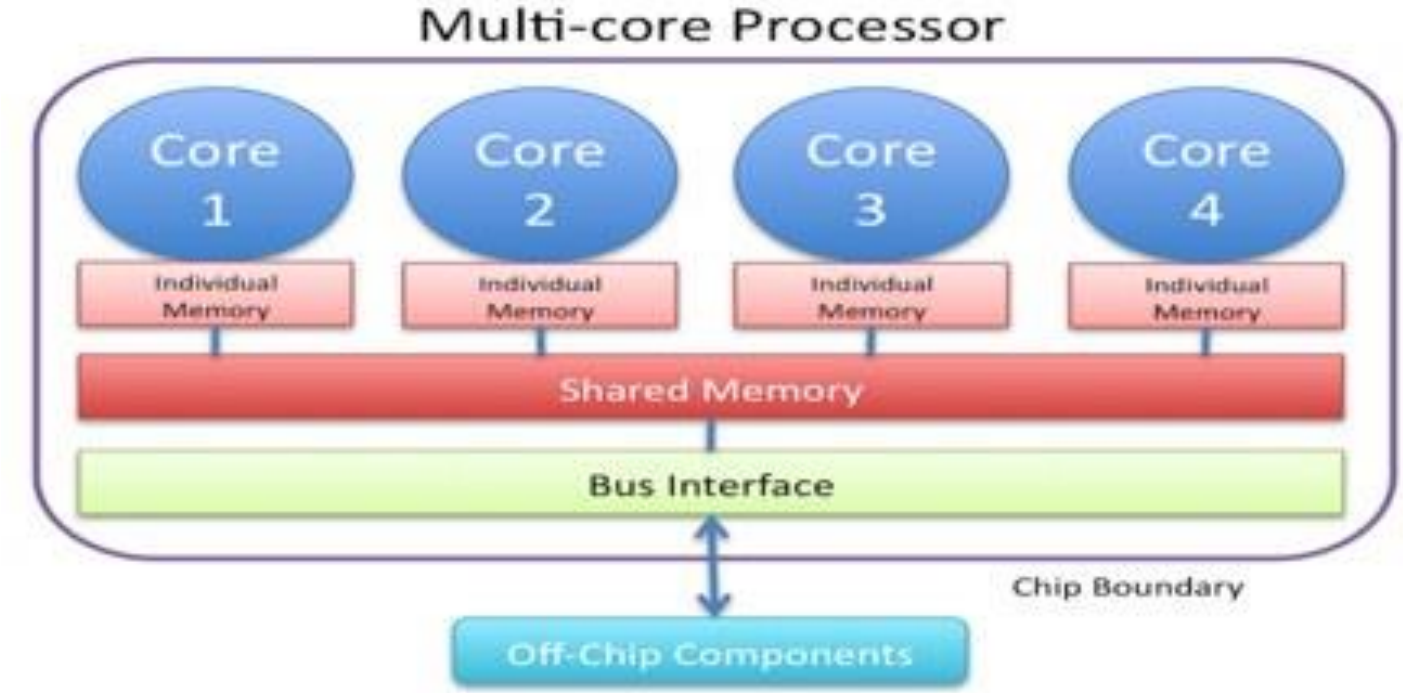
Wireless Technology

- Wireless communications is the transfer of information between two or more points that are not physically connected
- Distances can be short, such as a few meters for television remote control, or as far as thousands or even millions of kilometers for deep-space radio communications.



Multi Core processor

- A multi-core processor is a single computing component with two or more independent processing units called cores, which read and execute program instructions.



Open source Technology

- The open-source model is a decentralized software-development model that encourages open collaboration. A main principle of open-source software development is peer production, with products such as source code, blueprints, and documentation freely available to the public.
- Examples:

  OpenRISC: open-source microprocessor family, with architecture specification licensed under GNU GPL

  Arduino: a microcontroller platform for hobbyists, artists and designers.

  Linux: an operating system platform . . .

  and many more

Internet of things

- The Internet of things (IoT) is the network of physical devices, vehicles, home appliances and other items embedded with electronics, software, sensors, actuators, and connectivity which enables these objects to connect and exchange data.

Research in Embedded Systems

- Hardware – to improve performance (sensors and actuators), verification, etc.
- Software – reusability, testing, verification, OS, etc.
- Network – higher connectivity between systems (e.g. smart homes link many systems together, standardised protocols, etc.
- Security – protection against attacks
- Design – improved methodology, more automation, formal verification

Group Activity

- Propose 3 project ideas related to embedded systems
- Make a presentation on 3 ideas in the class out of which one will be selected
- You need to complete the prototype development by the end of this semester