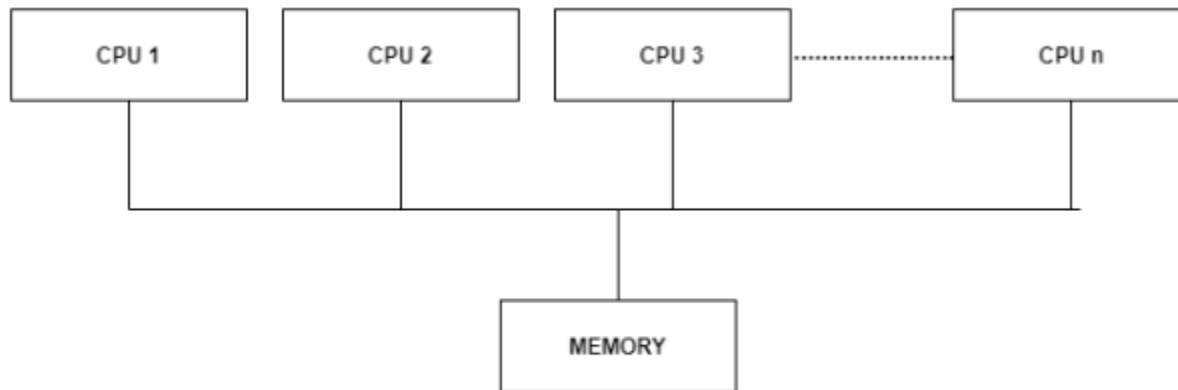


Unit-6

- **Introduction to Parallel Processing** : Pipelining, Characteristics of multiprocessors, Interconnection Structures, parallel processing
- **Latest technology and trends in computer architecture** : multi-cores processor, next generation processors architecture, micro-architecture, latest processor for smart phone or tablet and desktop
- **Multiprocessors** : Categorization of multiprocessors (SISD,MIMD,SIMD.SPMD), Introduction to GPU

Multiprocessors

A shared-memory multiprocessor (or just multiprocessor henceforth) is a computer system in which two or more CPUs share full access to a common RAM. A program running on any of the CPUs sees a normal (usually paged) virtual address space. The only unusual property this system has is that the CPU can write some value into a memory word and then read the word back and get a different value (because another CPU has changed it).



Multiprocessing Architecture

Types of Multiprocessors

There are mainly two types of multiprocessors i.e. symmetric and asymmetric multiprocessors. Details about them are as follows:

•Symmetric Multiprocessors

➤In these types of systems, each processor contains a similar copy of the operating system and they all communicate with each other. All the processors are in a peer to peer relationship i.e. no master - slave relationship exists between them.

➤An example of the symmetric multiprocessing system is the Encore version of Unix for the Multimax Computer.

•Asymmetric Multiprocessors

➤In asymmetric systems, each processor is given a predefined task. There is a master processor that gives instruction to all the other processors. Asymmetric multiprocessor system contains a master slave relationship.

➤Asymmetric multiprocessor was the only type of multiprocessor available before symmetric multiprocessors were created. Now also, this is the cheaper option.

Advantages of Multiprocessor Systems

There are multiple advantages to multiprocessor systems. Some of these are:

❑ **More reliable Systems** In a multiprocessor system, even if one processor fails, the system will not halt. This ability to continue working despite hardware failure is known as graceful degradation. For example: If there are 5 processors in a multiprocessor system and one of them fails, then also 4 processors are still working. So the system only becomes slower and does not ground to a halt.

❑ **Enhanced Throughput** If multiple processors are working in tandem, then the throughput of the system increases i.e. number of processes getting executed per unit of time increase. If there are N processors then the throughput increases by an amount just under N .

❑ **More Economic Systems** Multiprocessor systems are cheaper than single processor systems in the long run because they share the data storage, peripheral devices, power supplies etc. If there are multiple processes that share data, it is better to schedule them on multiprocessor systems with shared data than have different computer systems with multiple copies of the data.

Disadvantages of Multiprocessor Systems

There are some disadvantages as well to multiprocessor systems. Some of these are:

❑ **Increased Expense** Even though multiprocessor systems are cheaper in the long run than using multiple computer systems, still they are quite expensive. It is much cheaper to buy a simple single processor system than a multiprocessor system.

❑ **Complicated Operating System Required** There are multiple processors in a multiprocessor system that share peripherals, memory etc. So, it is much more complicated to schedule processes and impart resources to processes, than in single processor systems. Hence, a more complex and complicated operating system is required in multiprocessor systems.

❑ **Large Main Memory Required** All the processors in the multiprocessor system share the memory. So a much larger pool of memory is required as compared to single processor systems.

Coupling of Processors

Tightly Coupled System

- **Tasks and/or processors communicate in a highly synchronized fashion**
- **Communicates through a common shared memory**
- **Shared memory system**

Loosely Coupled System

- **Tasks or processors do not communicate in a synchronized fashion**
- **Communicates by message passing packets**
- **Overhead for data exchange is high**
- **Distributed memory system**

Interconnection Structure

The components that form a multiprocessor system are CPUs, IOPs connected to input-output devices, and a memory unit.

The interconnection between the components can have different physical configurations, depending on the number of transfer paths that are available

- o Between the processors and memory in a shared memory system
- o Among the processing elements in a loosely coupled system

There are several physical forms available for establishing an interconnection network.

- o Time-shared common bus
- o Multiport memory
- o Crossbar switch
- o Multistage switching network
- o Hypercube system

Time Shared Common Bus

A common-bus multiprocessor system consists of a number of processors connected through a common path to a memory unit.

- o Only one processor can communicate with the memory or another processor at any given time.

- o As a consequence, the total overall transfer rate within the system is limited by the speed of the single path

A more economical implementation of a dual bus structure is depicted in Fig. below.

Part of the local memory may be designed as a *cache memory attached to the CPU*.

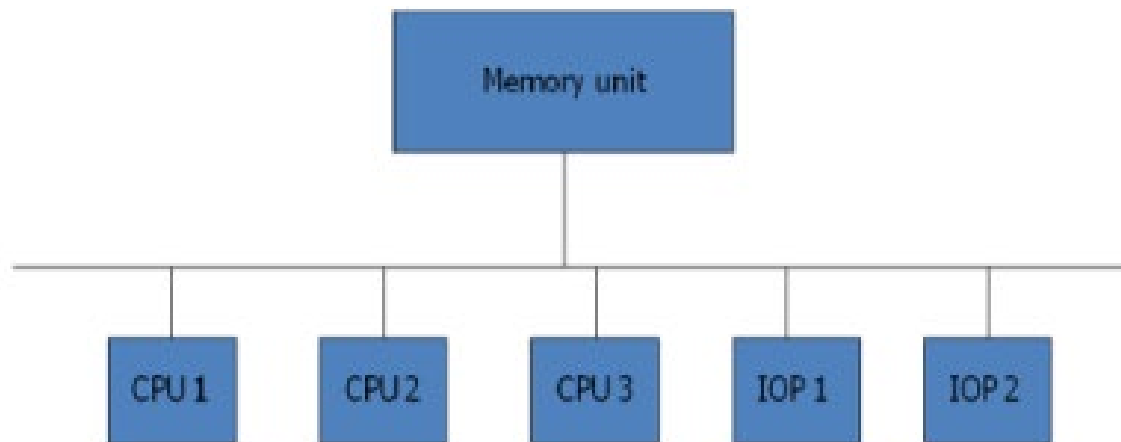


Fig: Time shared common bus organization

Multiport Memory

A multiport memory system employs separate buses between each memory module and each CPU.

The module must have internal control logic to determine which port will have access to memory at any given time.

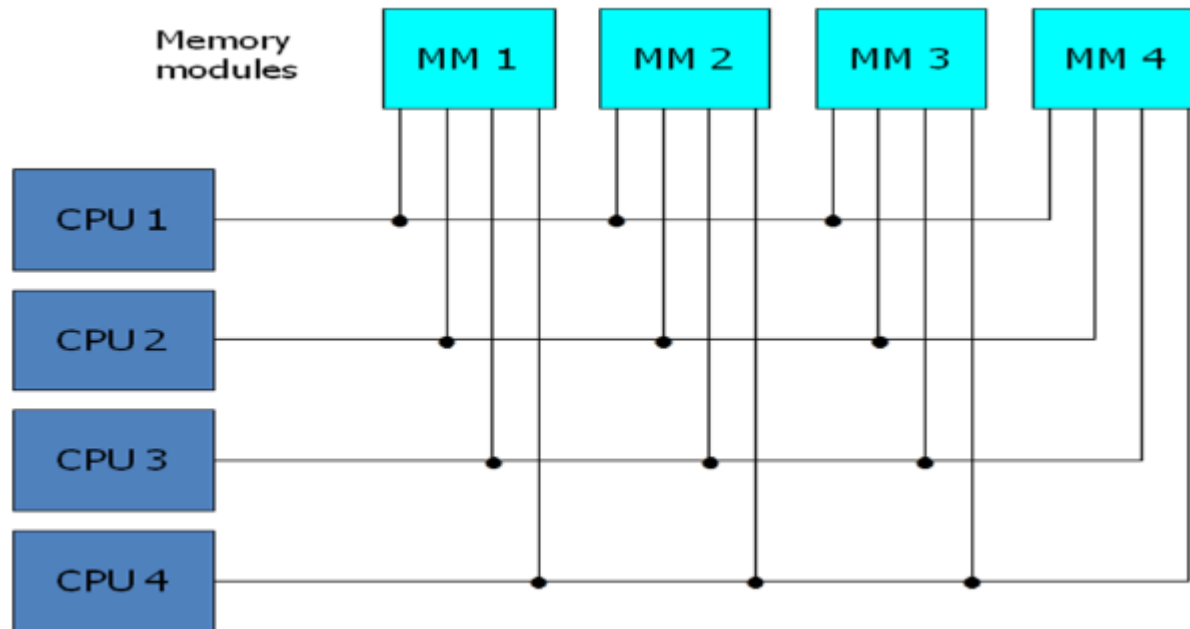
Memory access conflicts are resolved by assigning fixed priorities to each memory port.

Adv.:

- o The high transfer rate can be achieved because of the multiple paths.

Disadv.:

- o It requires expensive memory control logic and a large number of cables and connections



Cross Bar Switch

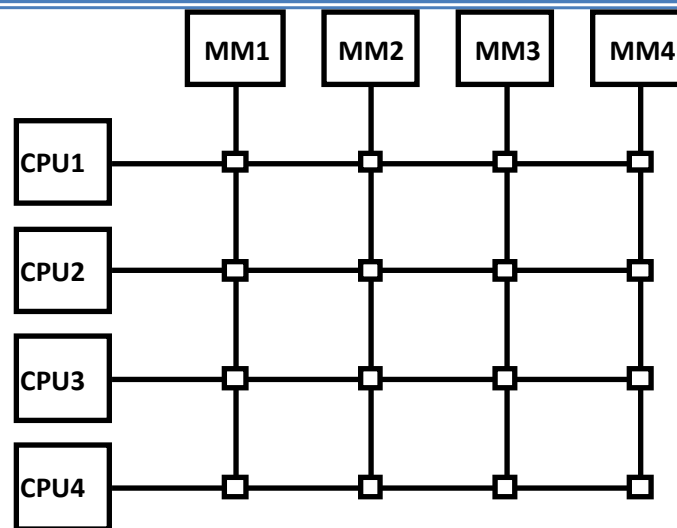


fig. shows the functional design of a crossbar switch connected to one memory module.

Consists of a number of *crosspoints that are placed at intersections between processor buses and memory module paths.*

The small square in each crosspoint is a *switch that determines the path from a processor to a memory module.*

Adv.:

- o Supports simultaneous transfers from all memory modules

Disadv.:

- o The hardware required to implement the switch can become quite large and complex.

Multiprocessor architectures

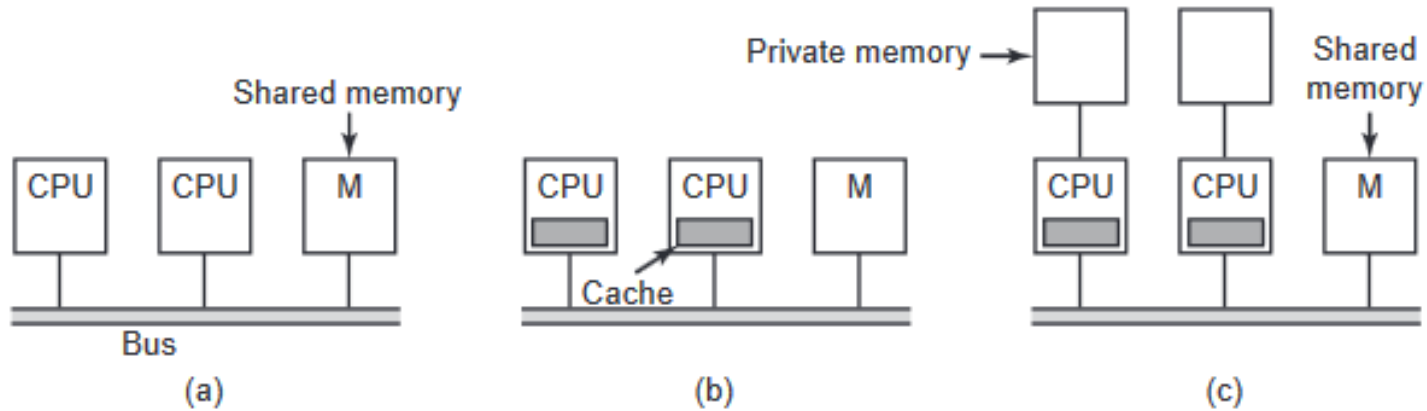


Figure 8-1. Three bus-based multiprocessors. (a) Without caching. (b) With caching. (c) With caching and private memories.

- (a) Two or more CPUs and one or more memory modules all use the same bus for communication. When a CPU wants to read a memory word, it first checks to see if the bus is busy. If the bus is idle, the CPU puts the address of the word it wants on the bus, asserts a few control signals, and waits until the memory puts the desired word on the bus.
- (b) Problem to previous approach, If the bus is busy when a CPU wants to read or write memory, the CPU just waits until the bus becomes idle. The cache can be inside the CPU chip, next to the CPU chip, on the processor board, or some combination of all three. Since many reads can now be satisfied out of the local cache, there will be much less bus traffic, and the system can support more CPUs.

(c) in this each CPU has not only a cache, but also a local, private memory which it accesses over a dedicated (private) bus. To use this configuration optimally, the compiler should place all the program text, strings, constants and other read-only data, stacks, and local variables in the private memories. The shared memory is then only used for writable shared variables.

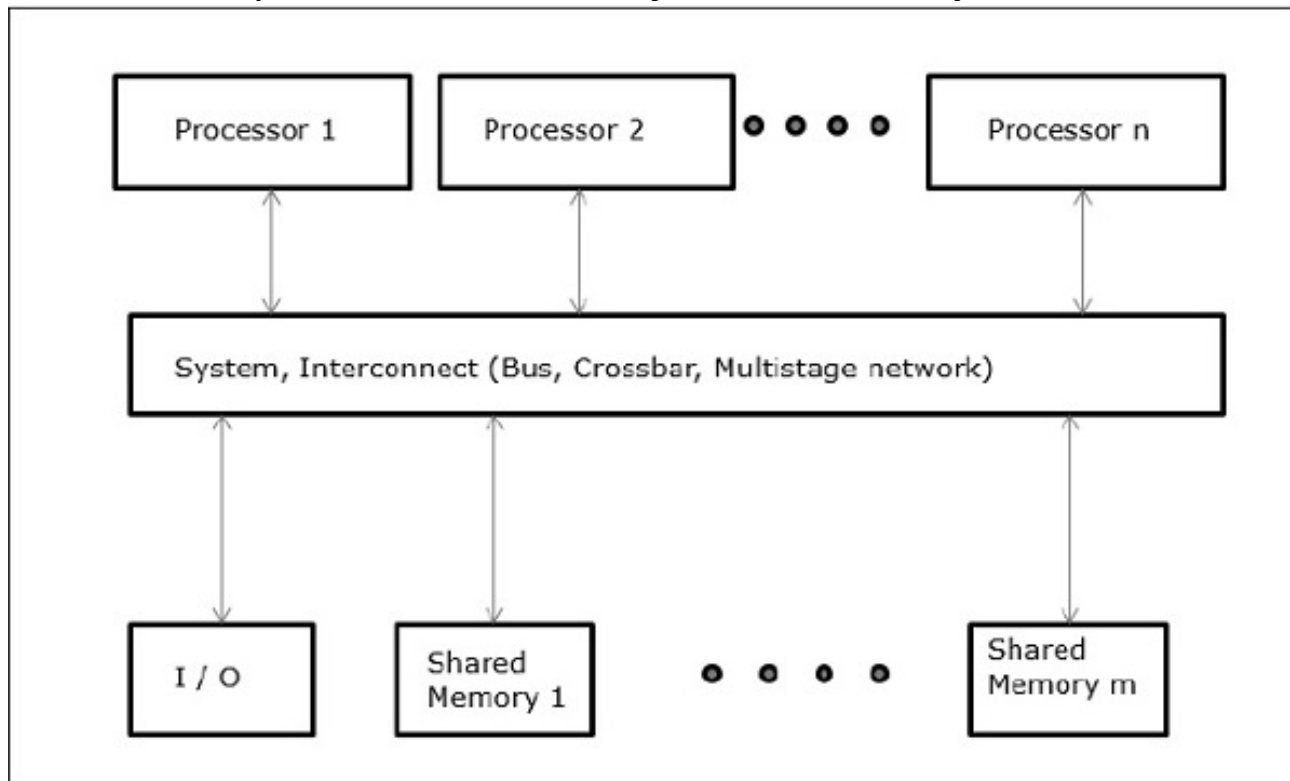
Shared-Memory Multicomputers

Three most common shared memory multiprocessors models are –

Uniform Memory Access (UMA)

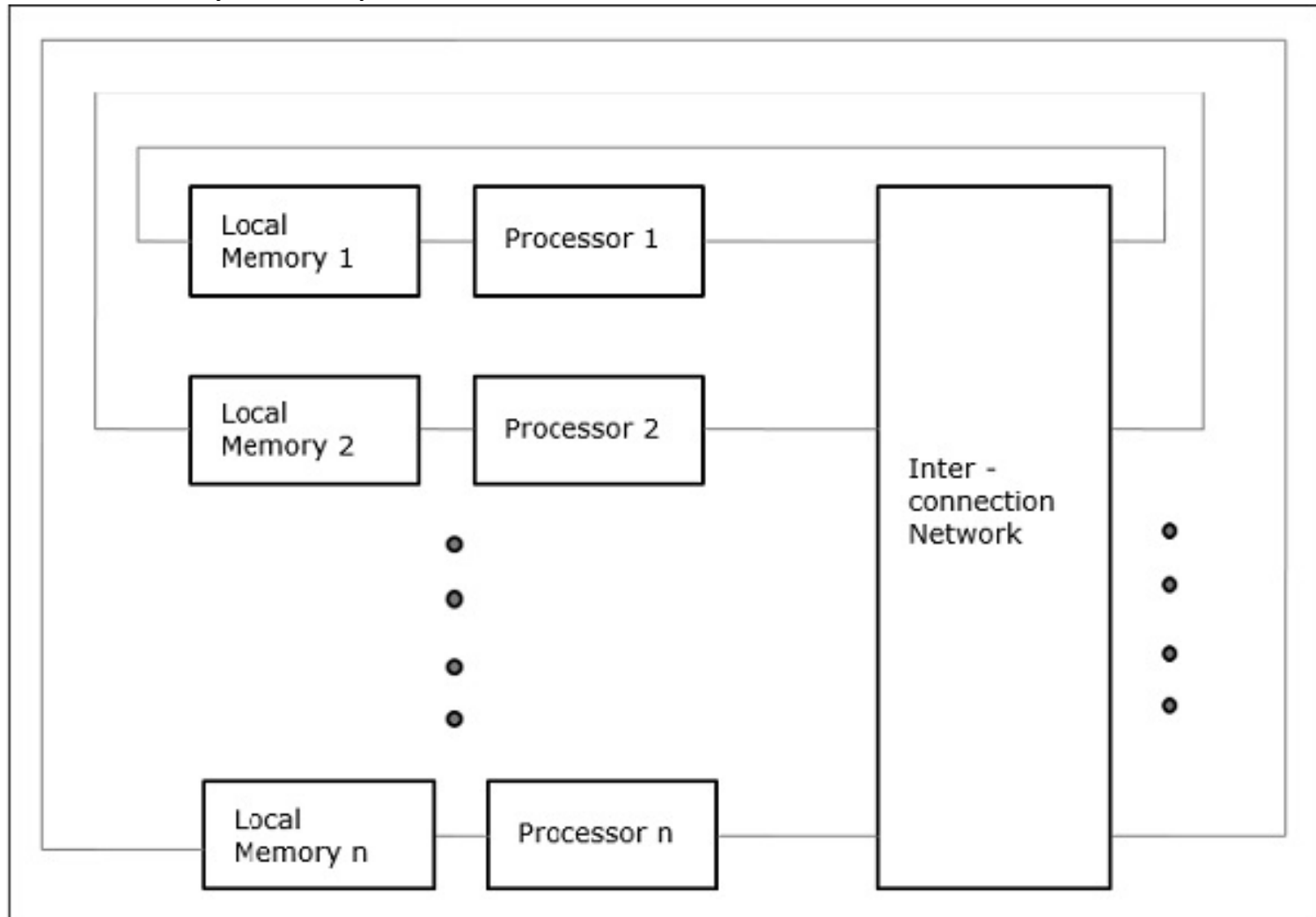
In this model, all the processors share the physical memory uniformly. All the processors have equal access time to all the memory words. Each processor may have a private cache memory. Same rule is followed for peripheral devices.

When all the processors have equal access to all the peripheral devices, the system is called a **symmetric multiprocessor**. When only one or a few processors can access the peripheral devices, the system is called an **asymmetric multiprocessor**.



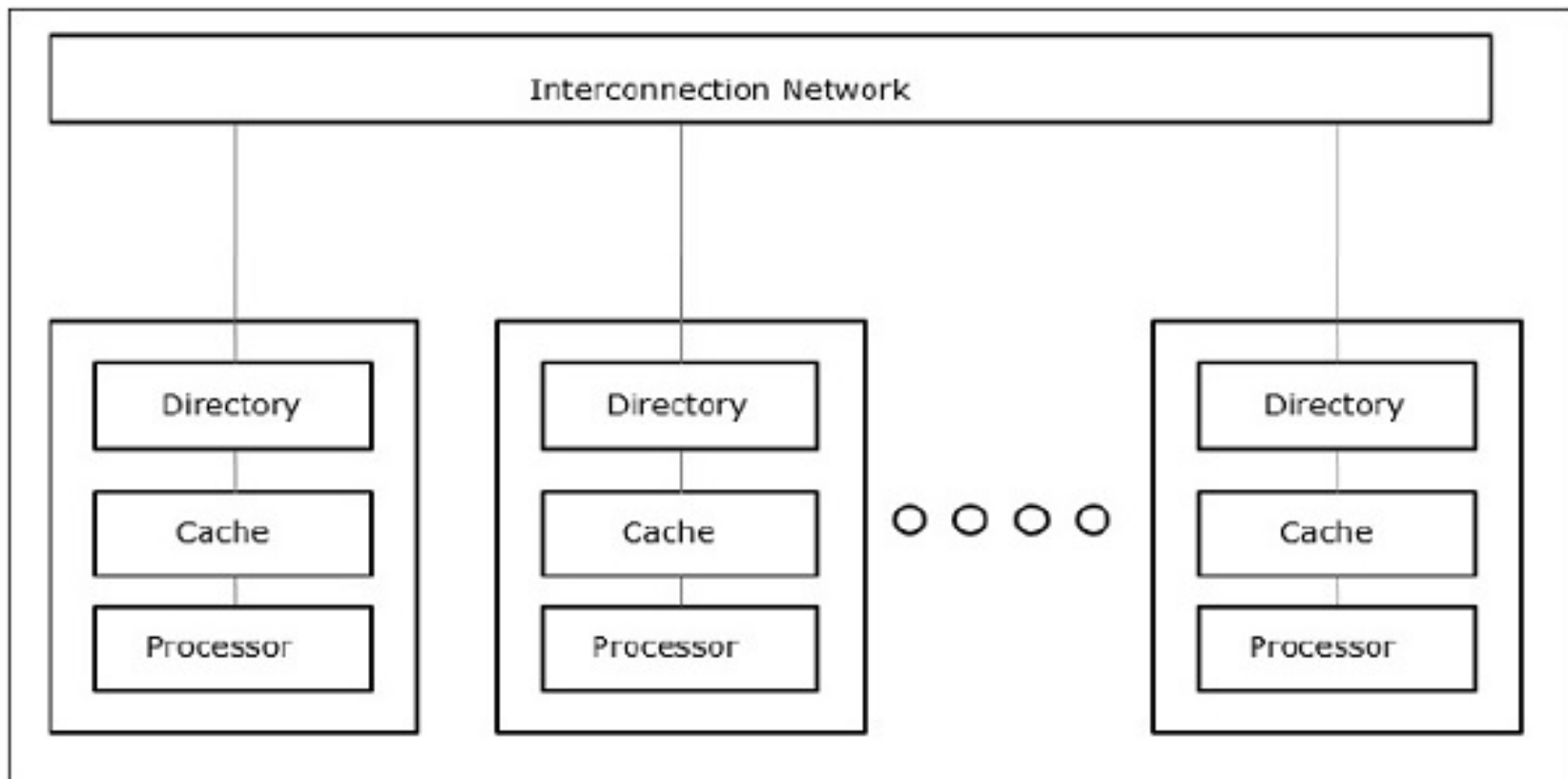
Non-uniform Memory Access (NUMA)

In NUMA multiprocessor model, the access time varies with the location of the memory word. Here, the shared memory is physically distributed among all the processors, called local memories. The collection of all local memories forms a global address space which can be accessed by all the processors.



Cache Only Memory Architecture (COMA)

The COMA model is a special case of the NUMA model. Here, all the distributed main memories are converted to cache memories.



Comparison Chart

Basis for comparison	UMA	NUMA
Basic	Uses a single memory controller	Multiple memory controller
Type of buses used	Single, multiple and crossbar.	Tree and hierarchical
Memory accessing time	Equal	Changes according to the distance of microprocessor.
Suitable for	General purpose and time-sharing applications	Real-time and time-critical applications
Speed	Slower	Faster
Bandwidth	Limited	More than UMA.

Parallel processing

Serial processing deals with following:

- In this, a problem statement is broken into discrete instructions.
- Then the instructions are executed one by one.
- Only one instruction is executed at any moment of time.

Why Parallel Architecture?

Parallel computer architecture adds a new dimension in the development of computer system by using more and more number of processors. In principle, performance achieved by utilizing large number of processors is higher than the performance of a single processor at a given point of time.

Advantages of Parallel Computing over Serial Computing are as follows:

- It saves time and money as many resources working together will reduce the time and cut potential costs.
- It can be impractical to solve larger problems on Serial Computing.
- It can take advantage of non-local resources when the local resources are finite.
- Serial Computing 'wastes' the potential computing power, thus Parallel Computing makes better work of hardware.

Parallel Processing

Execution of *Concurrent Events* in the computing process to achieve faster *Computational Speed*

- The purpose of parallel processing is to speed up the computer processing capability and increase its throughput, i.e. the amount of processing that can be accomplished during a given interval of time

Levels of Parallel Processing

- Job or Program level
- Task or Procedure level
- Inter-Instruction level
- Intra-Instruction level

Lowest level : shift register, register with parallel load

Higher level : multiplicity of functional unit that perform identical /different task

Types of Parallelism:

- Bit-level parallelism:** Consider a scenario where an 8-bit processor must compute the sum of two 16-bit integers. It must first sum up the 8 lower-order bits, then add the 8 higher-order bits, thus requiring two instructions to perform the operation. A 16-bit processor can perform the operation with just one instruction.
- Instruction-level parallelism:** A processor can only address less than one instruction for each clock cycle phase. These instructions can be re-ordered and grouped which are later on executed concurrently without affecting the result of the program. This is called instruction-level parallelism.
- Task Parallelism:** Task parallelism employs the decomposition of a task into subtasks and then allocating each of the subtasks for execution. The processors perform execution of sub tasks concurrently.

Parallel Computers

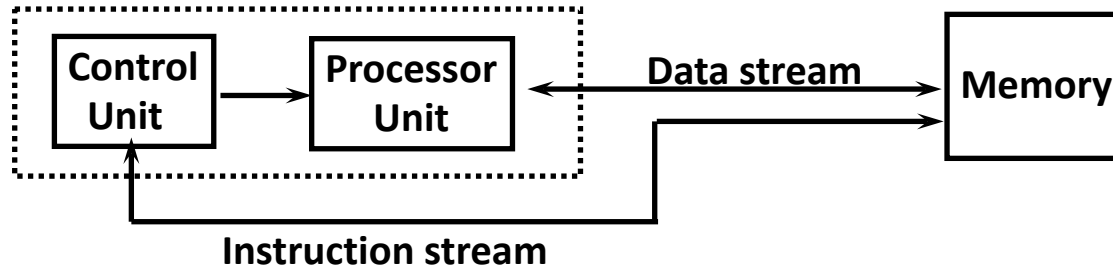
Architectural Classification

– Flynn's classification

- Based on the multiplicity of *Instruction Streams* and *Data Streams*
- Instruction Stream
 - Sequence of Instructions read from memory
- Data Stream
 - Operations performed on the data in the processor

		Number of <i>Data Streams</i>	
		Single	Multiple
Number of <i>Instruction Streams</i>	Single	SISD	SIMD
	Multiple	MISD	MIMD

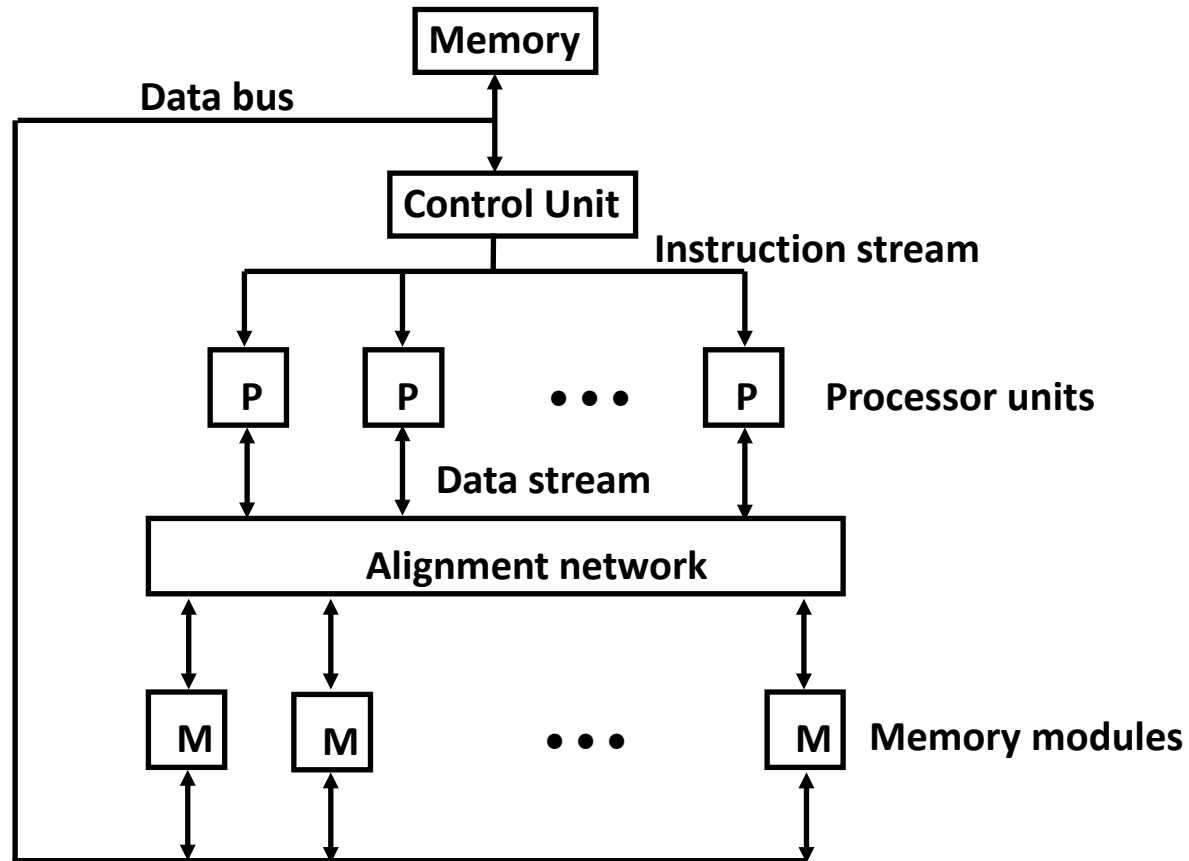
SISD



Characteristics

- Single computer containing a control unit, processor and memory unit
- Instructions and data are stored in memory and executed sequentially
- may or may not have parallel processing
- parallel processing can be achieved by pipelining

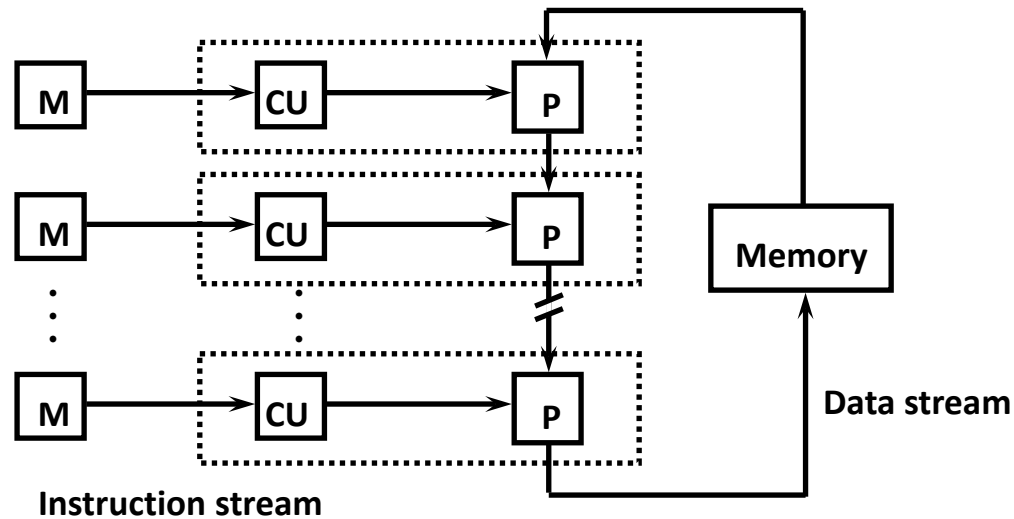
SIMD



Characteristics

- Only one copy of the program exists
- A single controller executes one instruction at a time

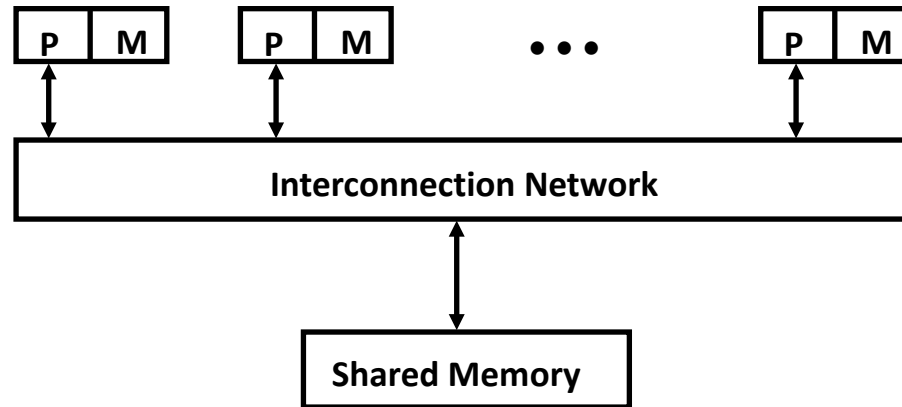
MISD



Characteristics

- There is no computer at present that can be classified as MISD

MIMD



Characteristics

- Multiple processing units
- Execution of multiple instructions on multiple data

Types of MIMD computer systems

- Shared memory multiprocessors
- Message-passing multicomputers

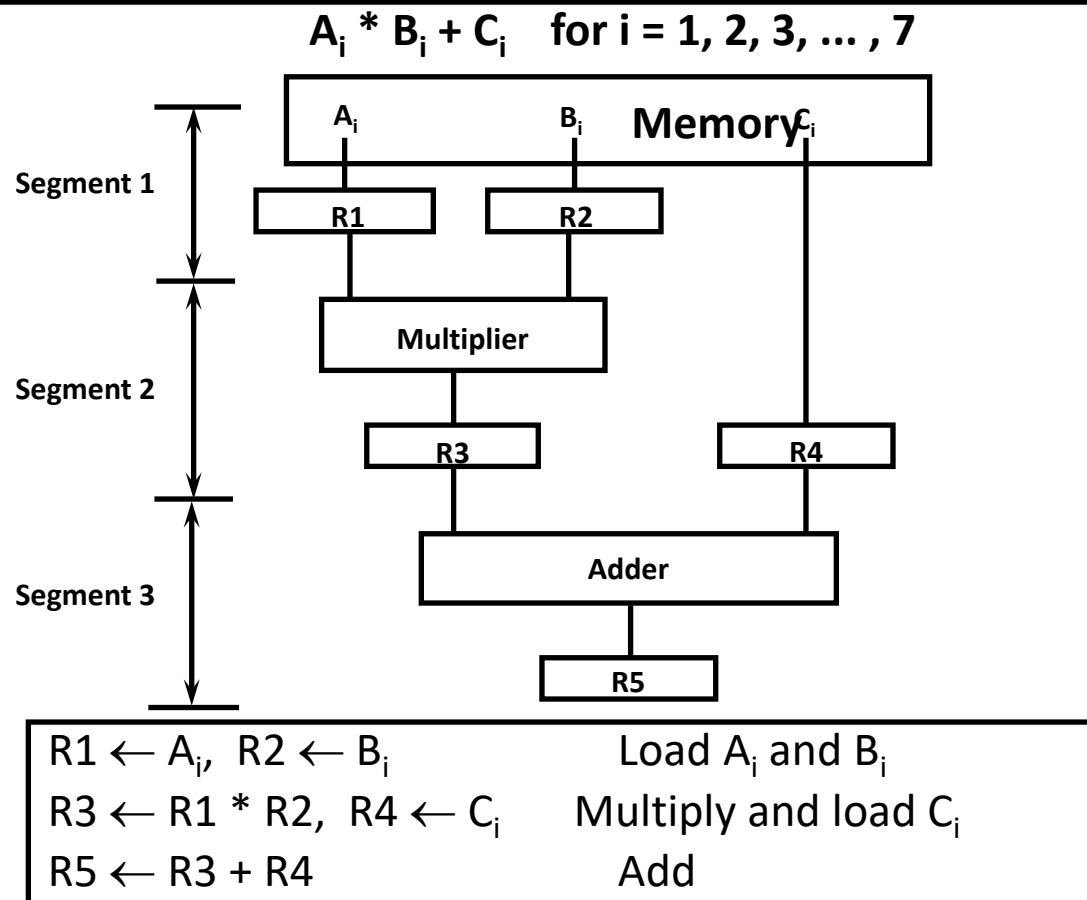
Pipelining

A technique of decomposing a sequential process into sub operations, with each sub process being executed in a special dedicated **segment** that operates concurrently with all other segments.

- It is the characteristic of pipelining that several computations can be in progress in distinct segments at the same time.
- Each segment performs partial processing dictated by the way the task is dictated
- The result obtained from computation in each segment is transferred to next segment in the pipeline
- The final result is obtained after data has been passed through all segment

Pipelining

Simplest way to understand pipelining is to imagine that each segment consist of input register followed by combinational circuit. The o/p of combinational circuit in a segment is applied to i/p register of next segment



Design of a basic pipeline

- In a pipelined processor, a pipeline has two ends, the input end and the output end. Between these ends, there are multiple stages/segments such that output of one stage is connected to input of next stage and each stage performs a specific operation.
- Interface registers are used to hold the intermediate output between two stages. These interface registers are also called latch or buffer.
- All the stages in the pipeline along with the interface registers are controlled by a common clock.

Pipeline Stages

RISC processor has 5 stage instruction pipeline to execute all the instructions in the RISC instruction set. Following are the 5 stages of RISC pipeline with their respective operations:

Stage 1 (Instruction Fetch)

In this stage the CPU reads instructions from the address in the memory whose value is present in the program counter.

Stage 2 (Instruction Decode)

In this stage, instruction is decoded and the register file is accessed to get the values from the registers used in the instruction.

Stage 3 (Instruction Execute)

In this stage, ALU operations are performed.

Stage 4 (Memory Access)

In this stage, memory operands are read and written from/to the memory that is present in the instruction.

Stage 5 (Write Back)

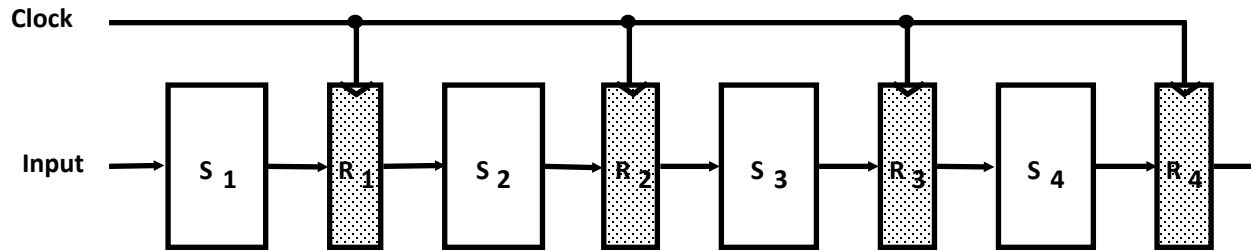
In this stage, computed/fetched value is written back to the register present in the instruction.

Operations in each Pipeline Stage

Clock Pulse Number	Segment 1		Segment 2		Segment 3
	R1	R2	R3	R4	R5
1	A1	B1			
2	A2	B2		A1 * B1	C1
3	A3	B3		A2 * B2	C2
4	A4	B4		A3 * B3	C3
5	A5	B5		A4 * B4	C4
6	A6	B6		A5 * B5	C5
7	A7	B7		A6 * B6	C6
8				A7 * B7	C7
9					A7 * B7 + C7

General Pipeline

General Structure of a 4-Segment Pipeline



Space-Time Diagram

		1	2	3	4	5	6	7	8	9	Clock cycles
Segment	1	T1	T2	T3	T4	T5	T6				
	2		T1	T2	T3	T4	T5	T6			
	3			T1	T2	T3	T4	T5	T6		
	4				T1	T2	T3	T4	T5	T6	

Pipeline SpeedUp

n: Number of tasks to be performed

Conventional Machine (Non-Pipelined)

t_n : Clock cycle (time to complete each task)

τ_1 : Time required to complete the n tasks

$$\tau_1 = n * t_n$$

Pipelined Machine (k stages)

t_p : Clock cycle (time to complete each suboperation)

τ_k : Time required to complete the n tasks

$$\tau_k = (k + n - 1) * t_p$$

Speedup

S_k : Speedup

$$S_k = n * t_n / (k + n - 1) * t_p$$

Pipeline SpeedUp

As n becomes very larger than $k-1$ then $k+n-1$ approaches to n

Then : $S = t_n/t_p$

If we consider time taken to complete a task is same in both circuits then $t_n = kt_p$ and speedup reduces to

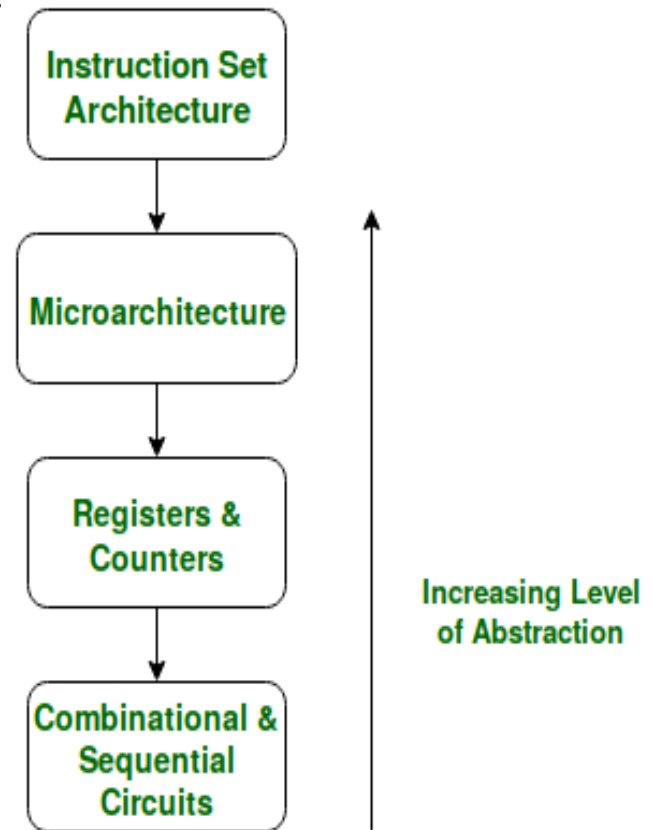
$$S = kt_p/t_n = k$$

i.e. maximum theoretical speedup pipeline can provide is k .

Micro-architecture

A microarchitecture is a hardware implementation of an ISA (instruction set architecture). An ISA is a structure of commands and operations used by software to communicate with hardware. A microarchitecture is the hardware circuitry that implements one particular ISA.

For example, x86-64 is the ISA used by most modern laptop and desktop computers. It is implemented by various microarchitectures, including those designed by Intel and AMD. Software that is compiled for the x86-64 ISA can run on any microarchitecture designed to use the x86-64 instruction set.



The ISA defines the **types of instructions** to be supported by the processor. Based on the type of operations they perform MIPS Instructions are classified into 3 types:

➤ **Arithmetic/Logic Instructions:**

These Instructions perform various Arithmetic & Logical operations on one or more operands.

➤ **Data Transfer Instructions:**

These instructions are responsible for the transfer of instructions from memory to the processor registers and vice versa.

➤ **Branch and Jump Instructions:**

These instructions are responsible for breaking the sequential flow of instructions and jumping to instructions at various other locations, this is necessary for the implementation of *functions* and *conditional statements*.

The ISA defines the **maximum length** of each type of instruction. Since the MIPS is a 32 bit ISA, each instruction must be accommodated within 32 bits.

The ISA defines the **Instruction Format** of each type of instruction.

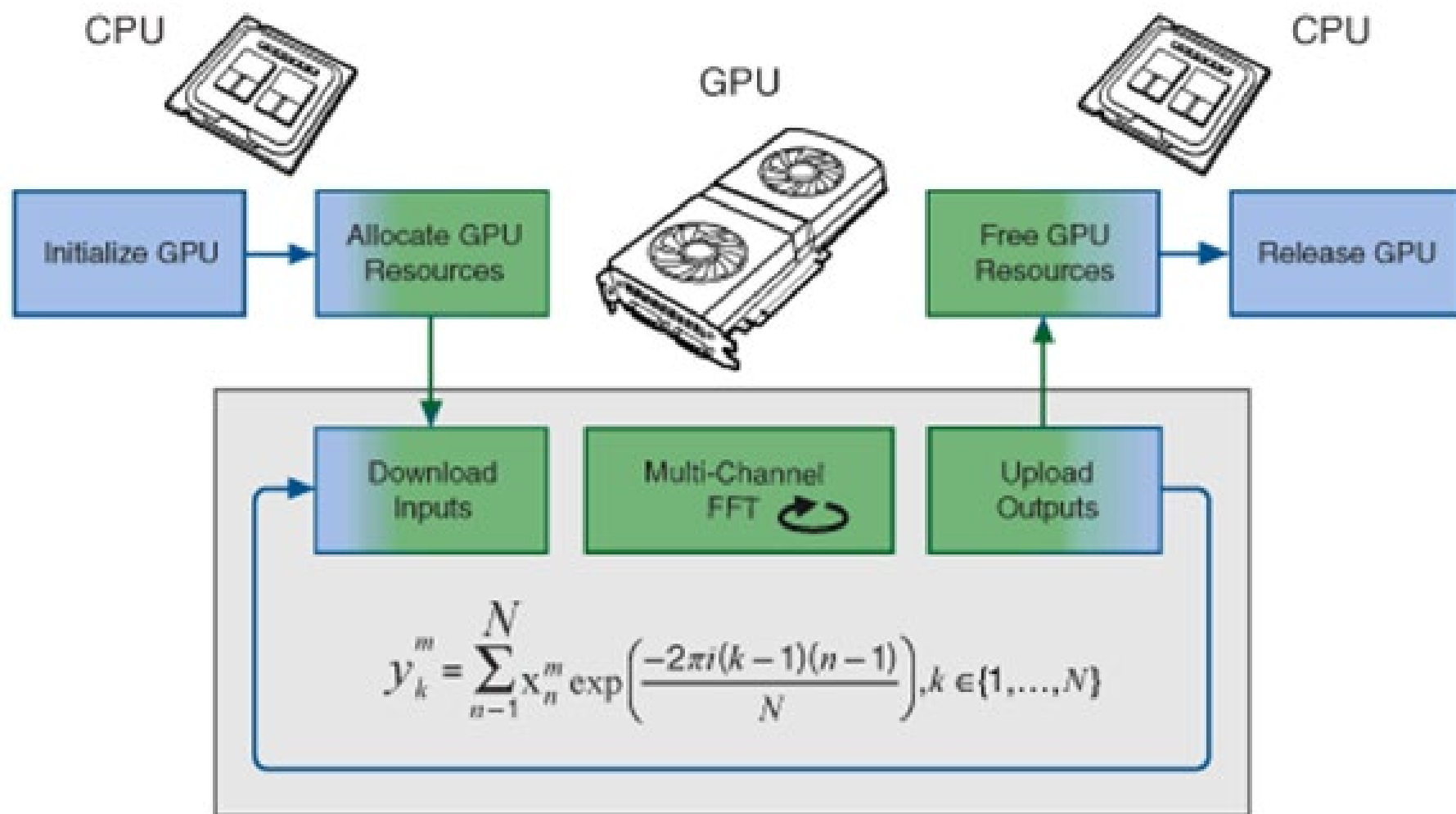
The **Instruction Format** determines how the entire instruction is encoded within 32 bits. Each Instruction Format has different instruction encoding schemes, and hence need to be interpreted differently by the processor.

Terminologies associated with Processors :

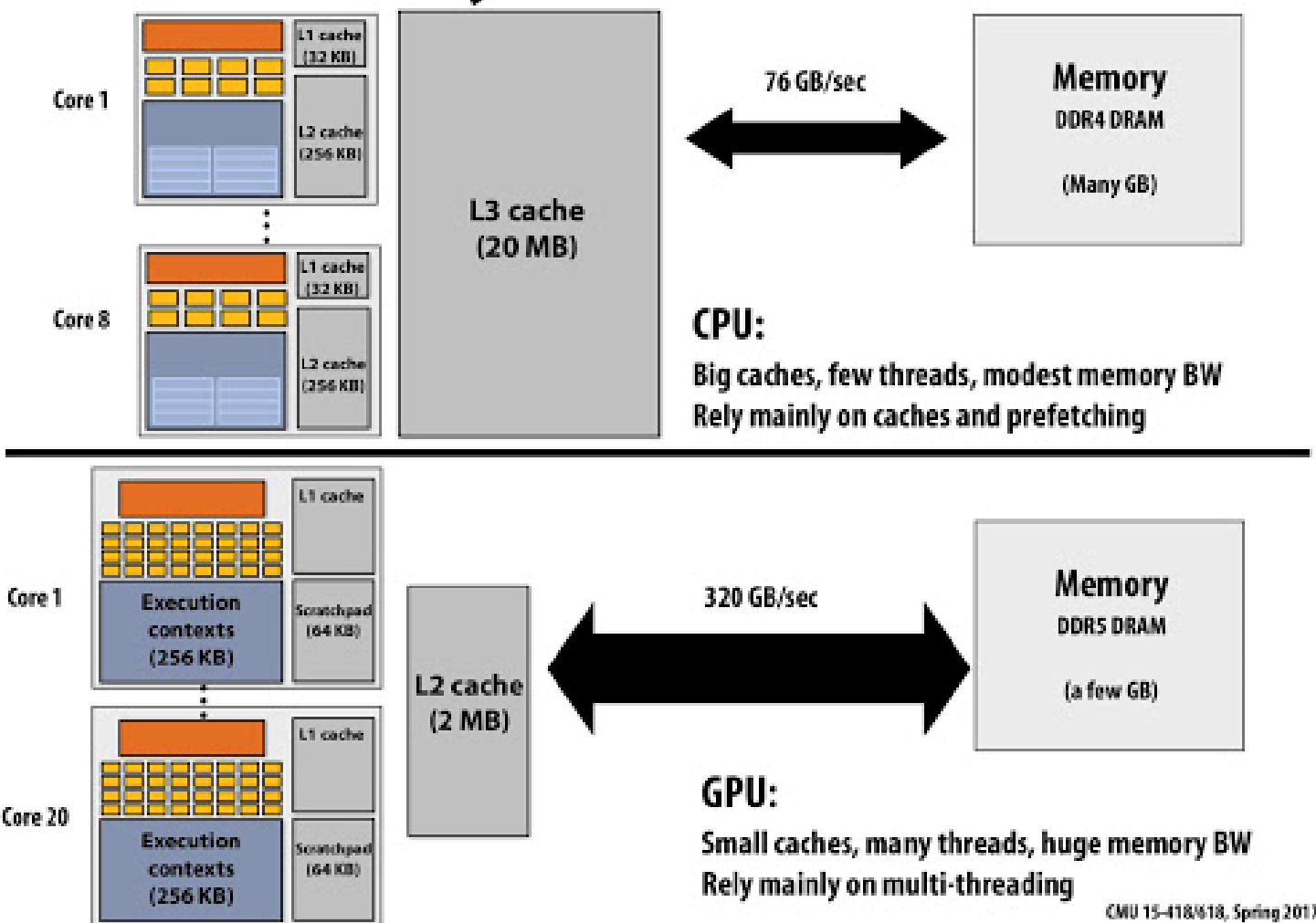
- **Multithreading** is a form of parallelization or dividing up work for simultaneous processing. Instead of giving a large workload to a single core, threaded programs split the work into multiple software threads. These threads are processed in parallel by different CPU cores to save time.
- **X86 architecture** The x86 is developed based on the Intel 8086 microprocessor and its 8088 variant where it started out as a 16-bit instruction set for 16-bit processors where many additions and extensions have been added to the x86 where it grew to 32-bit instruction sets over the years with almost entirely full backward compatibility.

Graphics Processing Unit

- Like a motherboard, a graphics card is a printed circuit board that houses a processor and RAM. It also has an input/output system (BIOS) chip, which stores the card's settings and performs diagnostics on the memory, input and output at startup.
- A graphics card's processor, called a graphics processing unit (GPU), is similar to a computer's CPU. A GPU, however, is designed specifically for performing the complex mathematical and geometric calculations that are necessary for graphics rendering. Some of the fastest GPUs have more transistors than the average CPU. A GPU produces a lot of heat, so it is usually located under a heat sink or a fan.
- A GPU however is more dedicated in function. It takes that same function that a CPU was processing and completes it all at once.
- The specified function requested of a GPU enters the GPU's hundred's of cores, and processes all at a single point in time, where it handles each process parallel to the next.
- The GPU has become the most powerful processing unit of the system, especially since organizations are beginning to rely more on the processing power of a GPU rather than a CPU for the single fact that it can process more at a single point in time faster than a CPU.

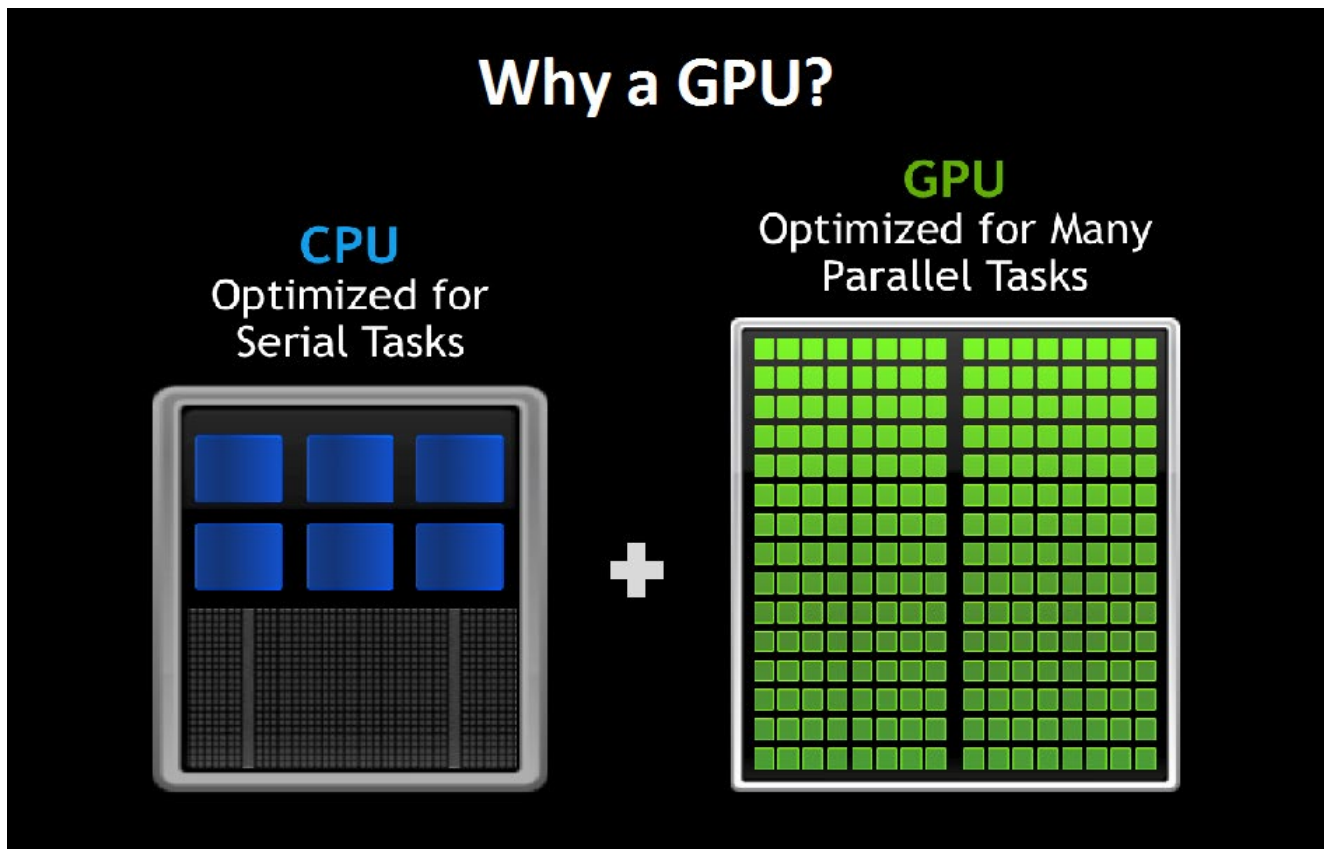


CPU vs. GPU memory hierarchies



There are two different types of GPUs:

- **Integrated GPUs** are located on a PC's CPU and share memory with the CPU processor.
- **Discrete GPUs** live on their own card and have their own video memory (VRAM), so that the PC doesn't have to use its RAM for graphics.



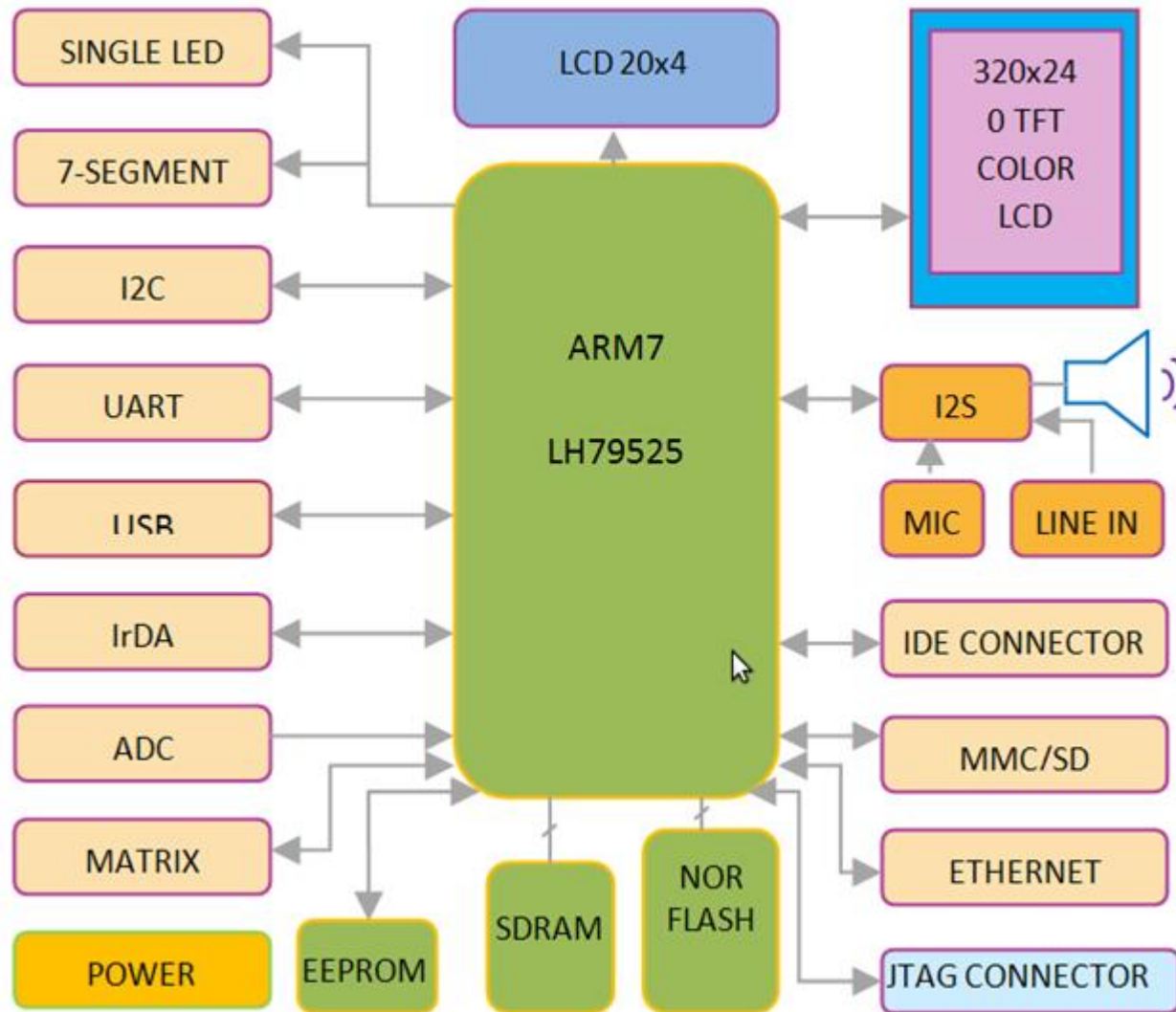
ARM processors

Advanced RISC Machine (ARM) Processor is considered to be family of Central Processing Units that is used in music players, smart phones, wearables, tablets and other consumer electronic devices.

The architecture of **ARM processor** is created by **Advanced RISC Machines**, hence name ARM. This needs very few instruction sets and transistors. It has very small size. This is reason that it is perfect fit for small size devices. It has less power consumption along with reduced complexity in its circuits.

They can be applied to various designs such as 32-bit devices and embedded systems. They can even be upgraded according to user needs.

A sample setup for a basic ARM processor



The main features of ARM Processor are mentioned below :

- **Multiprocessing Systems** –ARM processors are designed so that they can be used in cases of multiprocessing systems where more than one processors are used to process information. First AMP processor introduced by name of ARMv6K had ability to support 4 CPUs along with its hardware.
- **Tightly Coupled Memory** –Memory of ARM processors is tightly coupled. This has very fast response time. It has low latency (quick response) that can also be used in cases of cache memory being unpredictable.
- **Memory Management** –ARM processor has management section. This includes Memory Management Unit and Memory Protection Unit. These management systems become very important in managing memory efficiently.

- One cycle execution time** –ARM processor is optimised for each instruction on CPU. Each instruction is of fixed length that allows time for fetching future instructions before executing present instruction. ARM has CPI (Clock Per Instruction) of one cycle.

- Pipelining**–Processing of instructions is done in parallel using pipelines. Instructions are broken down and decoded in one pipeline stage. The pipeline advances one step at a time to increase throughput (rate of processing).

- Large number of registers** –Large number of registers are used in ARM processor to prevent large amount of memory interactions. Registers contain data and addresses. These act as local memory store for all operations.

Advantages of ARM Processor :

- Affordable to create
- Low Power Consumption
- Work Faster
- Multiprocessing feature
- Better Battery Life
- Load store architecture
- Simple Circuits

Disadvantages of ARM Processor :

- It is not compatible with X86 hence it cannot be used in Windows.
- The speeds are limited in some processors which might create problems.
- Scheduling instructions is difficult in case of ARM processors.
- There must be proper execution of instructions by programmer. This is because entire performance of ARM processors depend upon their execution.

Multi-core Processors

A **multicore processor** is a single integrated circuit (a.k.a., chip multiprocessor or CMP) that contains multiple core processing units, more commonly known as *cores*. There are many different multicore processor architectures, which vary in terms of

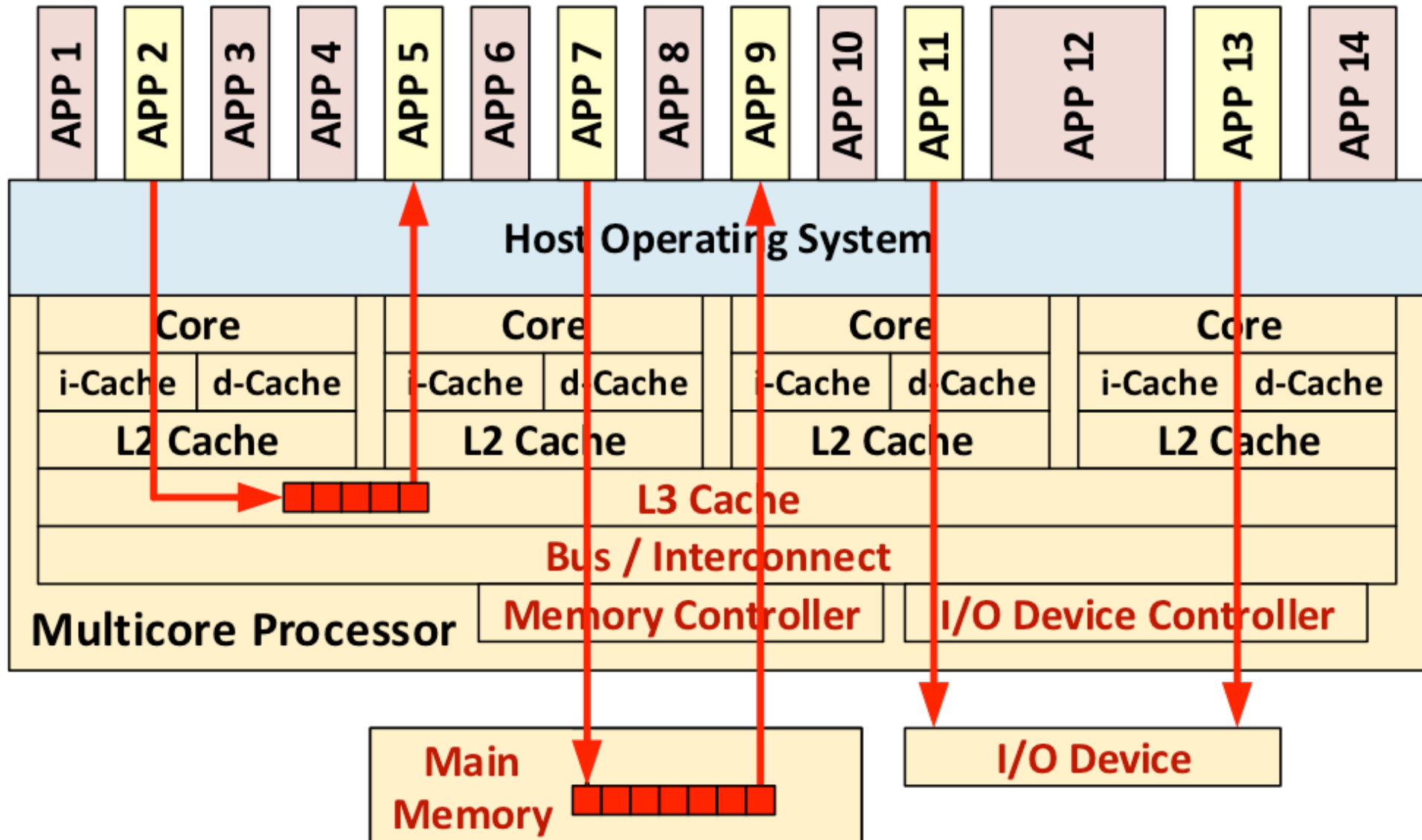
Number of cores. Different multicore processors often have different numbers of cores. For example, a quad-core processor has four cores. The number of cores is usually a power of two.

Number of core types.

- **Homogeneous (symmetric) cores.** All of the cores in a homogeneous multicore processor are of the same type; typically the core processing units are general-purpose central processing units that run a single multicore operating system.

- **Heterogeneous (asymmetric) cores.** Heterogeneous multicore processors have a mix of core types that often run different operating systems and include graphics processing units.

Sample work flow process for multi-core processors



Processors on Handheld devices

ARM processor

- An ARM processor is one of a family of CPUs based on the RISC (reduced instruction set computer) architecture developed by Advanced RISC Machines (ARM).
- ARM makes 32-bit and 64-bit RISC multi-core processors. RISC processors are designed to perform a smaller number of types of computer instructions so that they can operate at a higher speed, performing more millions of instructions per second (MIPS).
- By stripping out unneeded instructions and optimizing pathways, RISC processors provide outstanding performance at a fraction of the power demand of CISC (complex instruction set computing) devices.
- ARM processors are extensively used in consumer electronic devices such as smartphones, tablets, multimedia players and other mobile devices, such as wearables. Because of their reduced instruction set, they require fewer transistors, which enables a smaller die size for the integrated circuitry (IC).
- The ARM processor's smaller size, reduced complexity and lower power consumption makes them suitable for increasingly miniaturized devices.

System on Chip (SoC)based architectures

- Mobile device processor architecture became simple with SOC designs. Real time responsiveness in mobile devices can be managed by using an enhanced DSP hybrid chip. Lowering the voltage of the chip enables low power operation in mobile devices.
- Qualcomm Snapdragon Processors Snapdragon is a family of mobile system on a chip (SoC) processor architecture provided by Qualcomm. Scorpion, the original snapdragon CPU had many features similar to ARM Cortex-A8 core based on ARMv7 instruction set, but with an added advantage of higher performance utilizing SIMD operations.

Smartphone Hardware Architecture

Every modern smartphone today uses a System on a Chip (SoC) Architecture with the following 3 primary components:

- Application processor executing the user's application software with instructions from the middleware and the operating system (OS)
- A baseband (or modem) processor with its own OS components performing baseband radio transmission and reception of audio, video and data
- Various peripheral devices for the user interface

Basic Smartphone architecture

