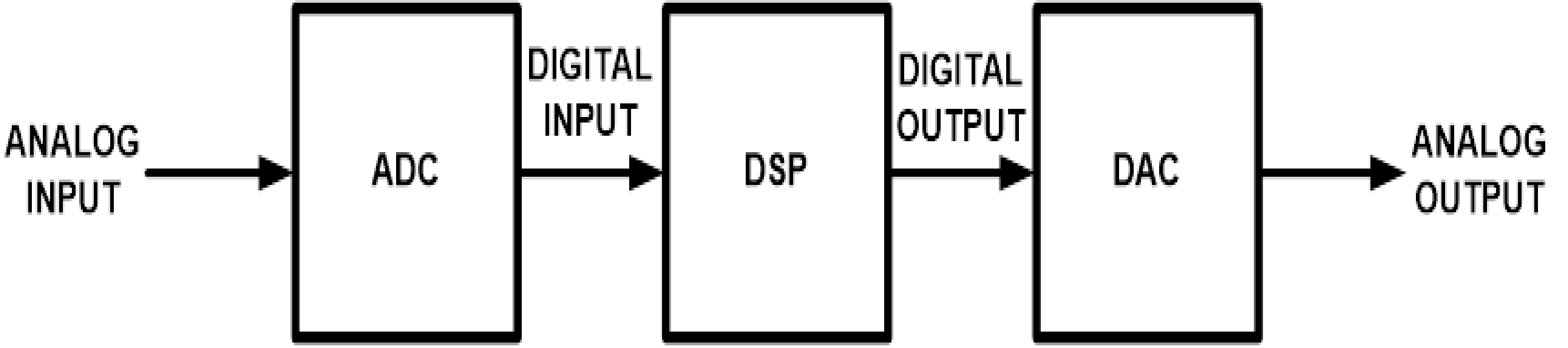
Module 6

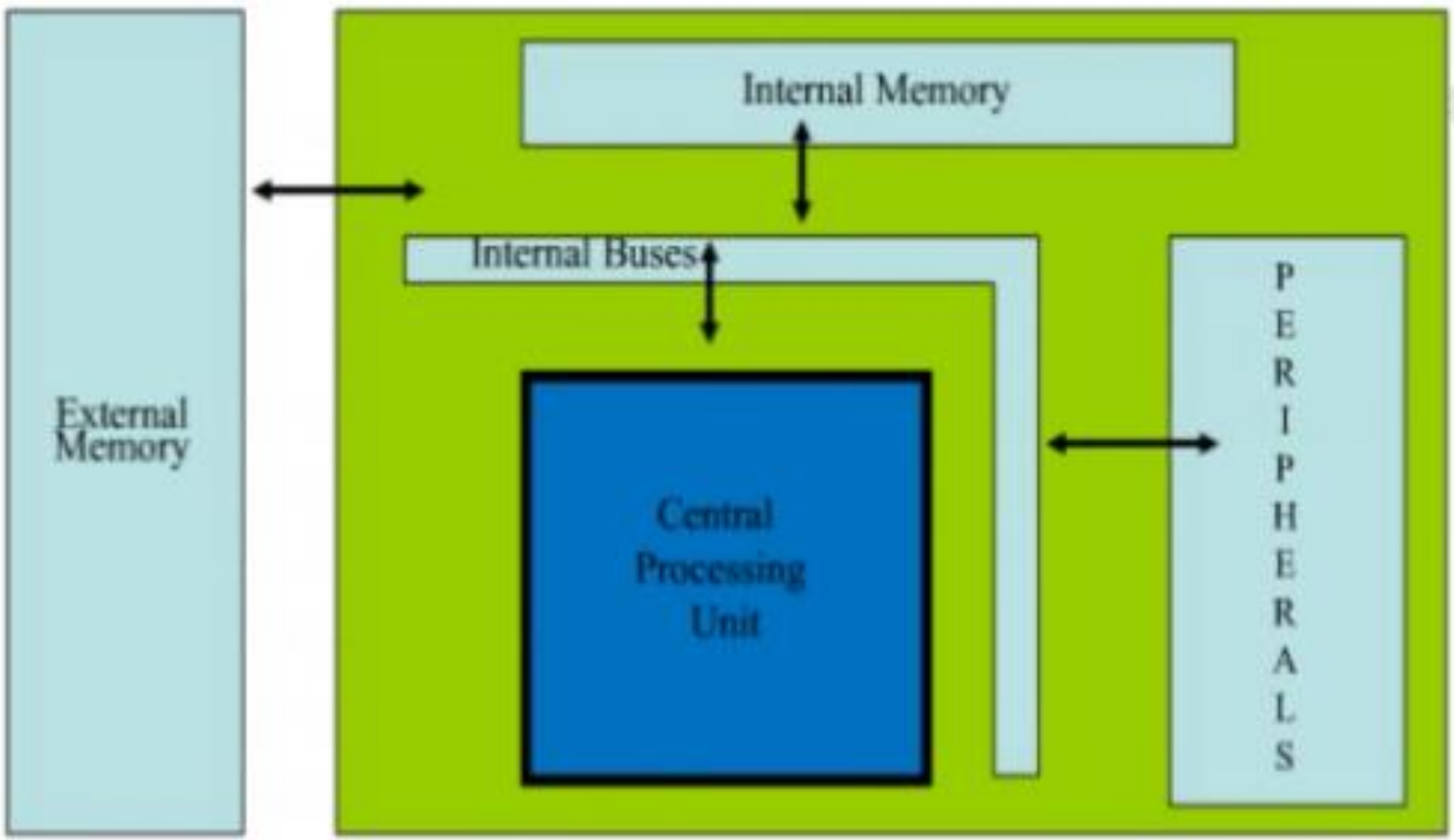
DSP processor and Applications of DSP

What is DSP?

- A specialized microprocessor for real-time DSP applications
  - Digital filtering (FIR and IIR)
  - FFT
  - Convolution, Matrix Multiplication etc



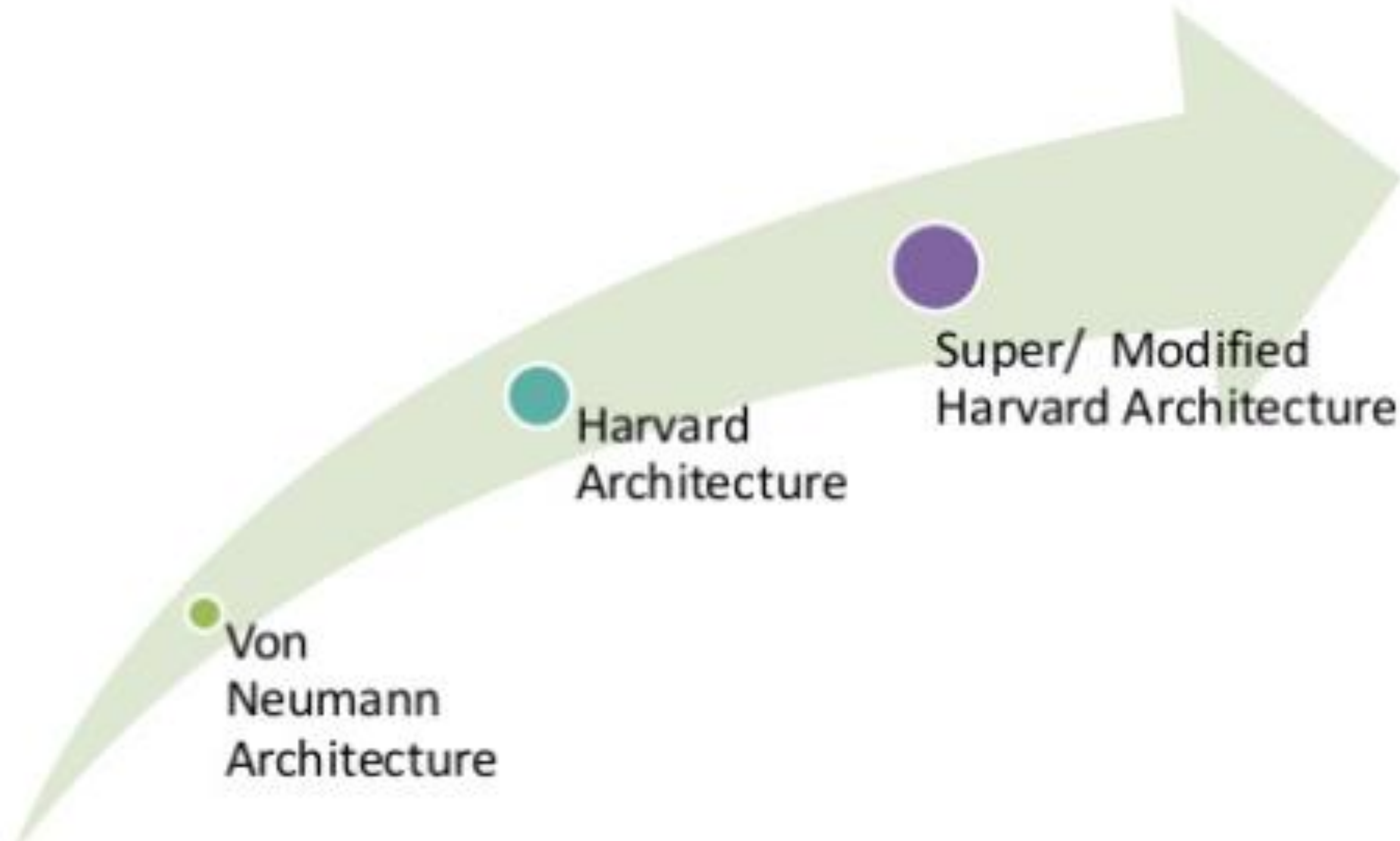
What is there inside DSP?



What is there inside DSP?

- Program Memory:
  - Stores the programs the DSP will use to process data
- Data Memory:
  - Stores the information to be processed
- Compute Engine:
  - Performs the math processing, accessing the program from the Program Memory and the data from the Data Memory
- Input / Output:
  - Serves a range of functions to connect to the outside world

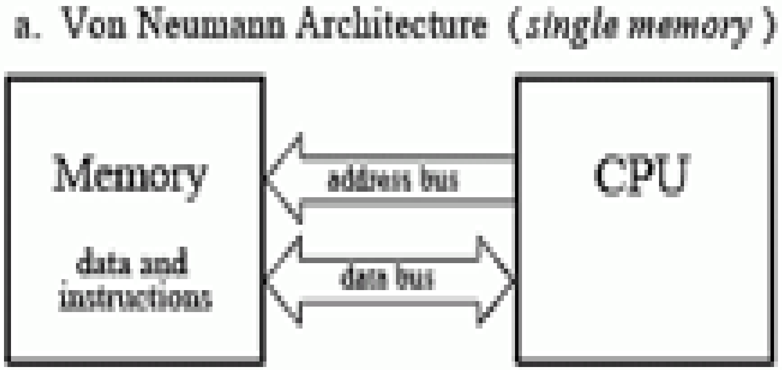
Types of architecture



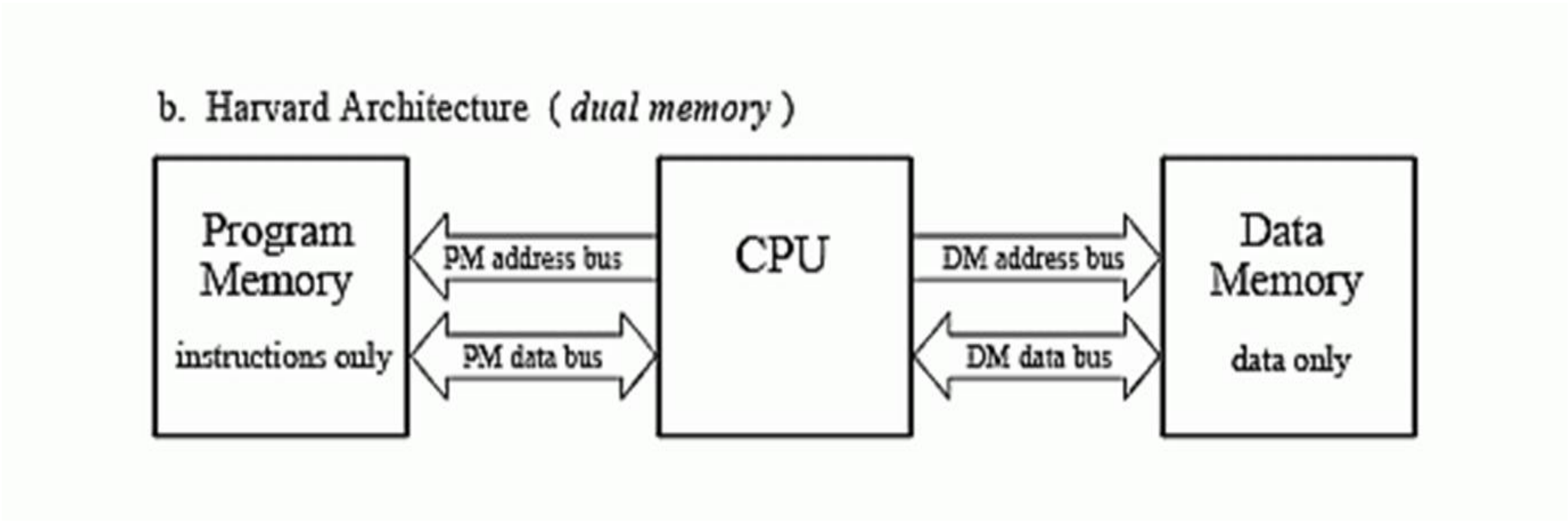
von Neumann architecture

- The term "von Neumann architecture" has evolved to mean any stored-program computer in which an instruction fetch and a data operation cannot occur at the same time because they share a common bus.

von Neumann architecture



Harvard architecture



Harvard architecture

- a Harvard architecture machine—which is also a stored-program system but has one dedicated set of address and data buses for reading and writing to memory, and another set of address and data buses to fetch instructions.

von Neumann architecture

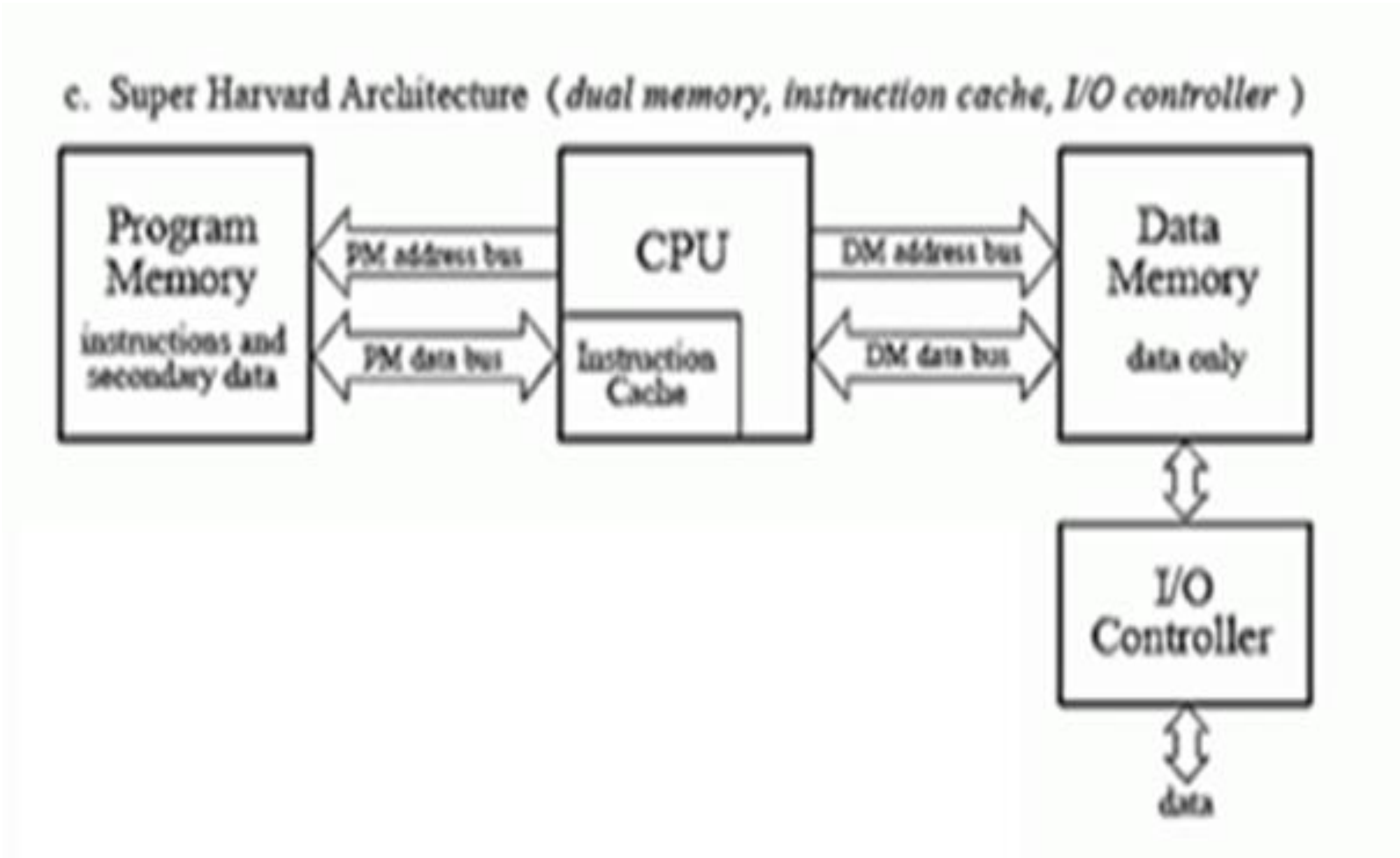
- digital computer with these components:
- A processing unit that contains an arithmetic logic unit and processor registers
- A control unit that contains an instruction register and program counter
- Memory that stores data and instructions
- External mass storage
- Input and output mechanisms[1][2]
- This is referred to as the von Neumann bottleneck and often limits the performance of the system.

Super Harvard Architecture

- **Super Harvard Architecture**. are called **SHARC®** DSPs, a contraction of the longer term, Super Harvard ARChitecture.

- The idea is to build upon the **Harvard architecture by adding features to improve the throughput.**
- E.g.an *instruction cache*, and an *I/O controller*.

Super Harvard Architecture



Super Harvard Architecture

- an instruction cache, and an I/O controller.

comparision

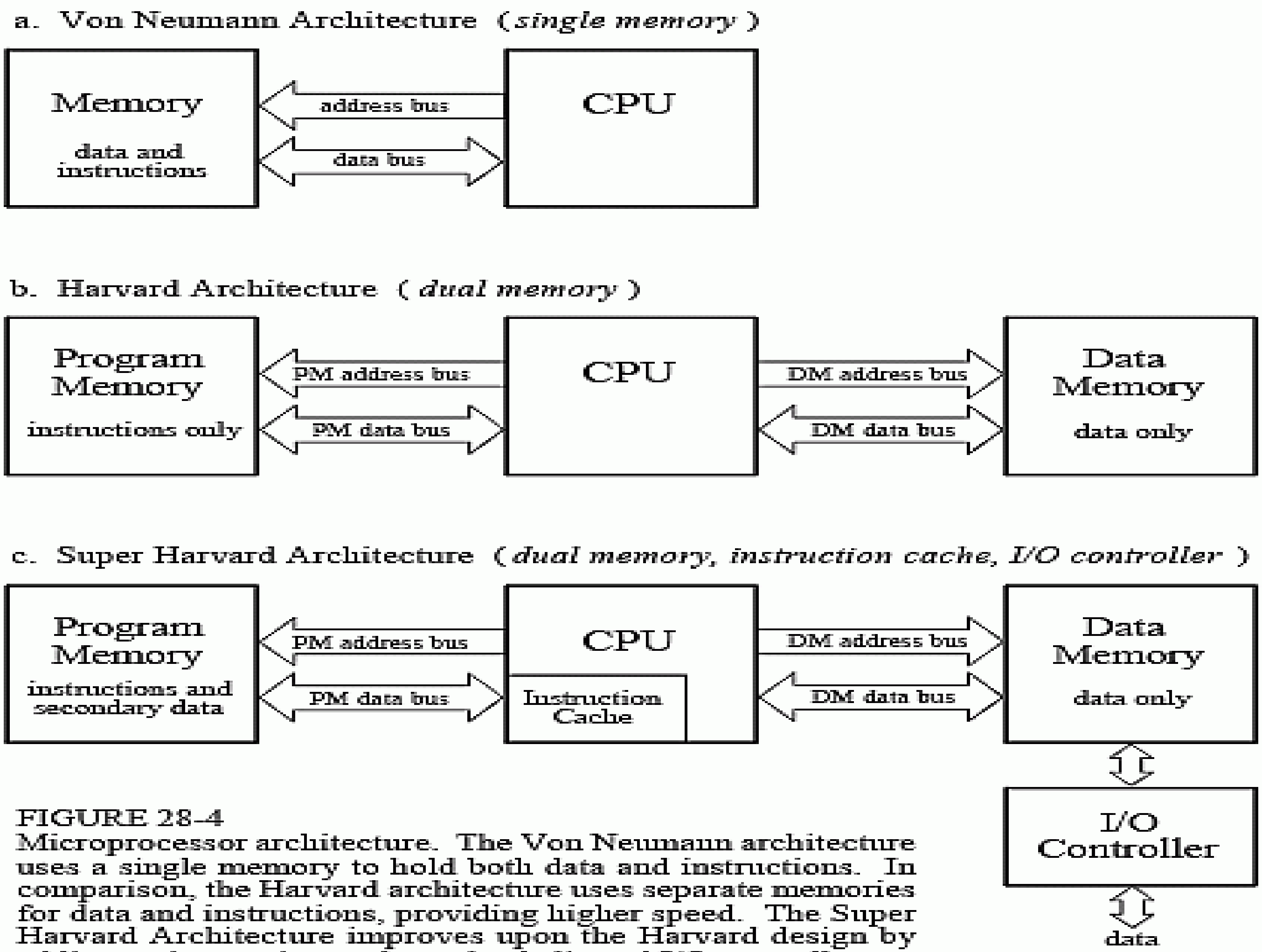


FIGURE 28-4
Microprocessor architecture. The Von Neumann architecture uses a single memory to hold both data and instructions. In comparison, the Harvard architecture uses separate memories for data and instructions, providing higher speed. The Super Harvard Architecture improves upon the Harvard design by adding an instruction cache and a dedicated I/O controller.

Super Harvard Architecture example : SHARC

- e.g SHARC architecture, showing the **I/O controller** connected to data memory. (next slide)
- **Extremely high speed connections**.
- . For instance, the SHARC DSPs provides both serial and parallel communications ports
- For example, at a 40 MHz clock speed, there are two serial ports that operate at 40 Mbits/second each, while six parallel ports each provide a 40 Mbytes/second data transfer. When all six parallel ports are used together, the data transfer rate is an **incredible 240 Mbytes/second.** This is fast enough to transfer the entire text of this book in only 2 milliseconds!

Super Harvard Architecture example : SHARC

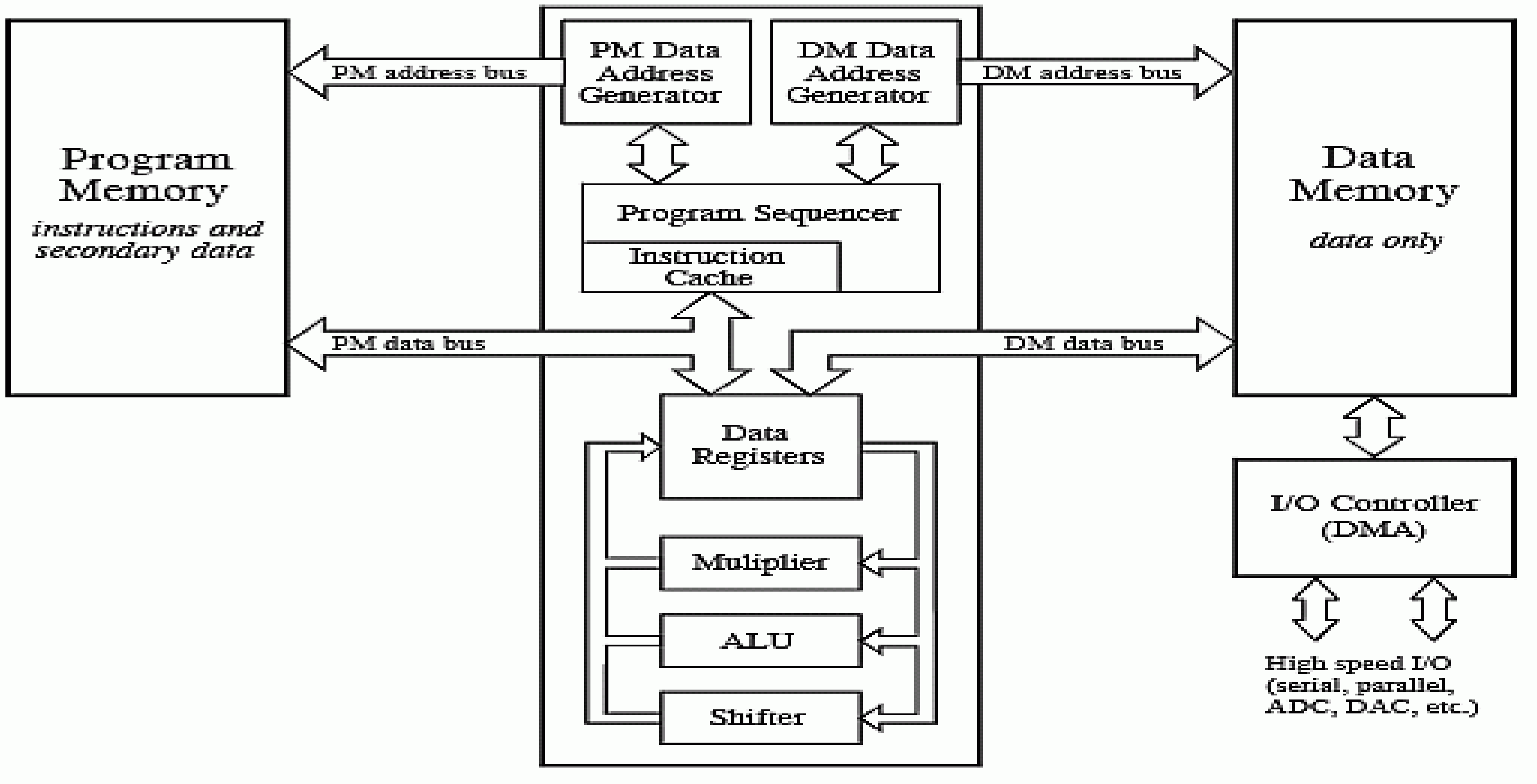


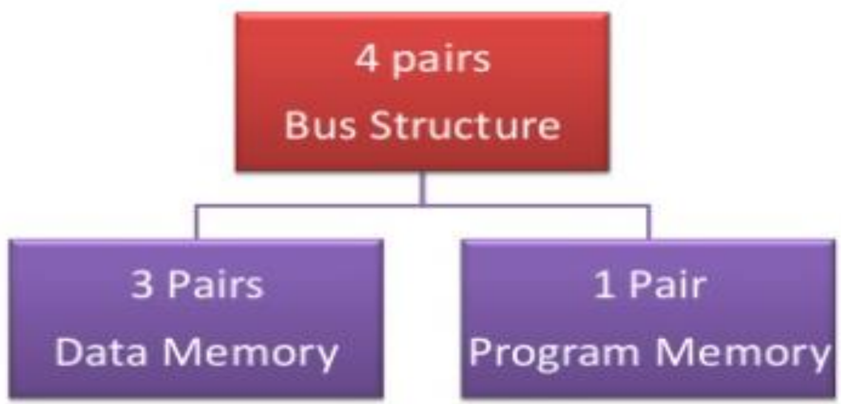
FIGURE 28-5
Typical DSP architecture. Digital Signal Processors are designed to implement tasks in parallel. This simplified diagram is of the Analog Devices SHARC DSP. Compare this architecture with the tasks needed to implement an FIR filter, as listed in Table 28-1. All of the steps within the loop can be executed in a single clock cycle.

- Ref https://www.dspguide.com/ch28/3.htm

Super Harvard Architecture example

TMS32054XX

- Uses an advanced , Modified Harvard architecture
- Maximizes processing power by providing



What architecture is best suited for DSP?

1. Common general-purpose personal computers use processors designed with the von Neuman architecture while the Harvard architecture is more commonly used in specialized microprocessors for real-time and embedded applications.

2. DSPs typically use Harvard architecture, although von Neuman DSPs also exist.

3. Many signal and image processing applications require fast, real-time machines.

4. The drawback to using a true Harvard architecture is that since it uses separate program and data memories, it needs twice as many address and data pins on the chip and twice as much external memory. Unfortunately, as the number of pins or chips increases, so does the price.

Types of DSP

1. General Purpose DSP

Basically high speed MP with architecture and instruction sets optimized for DSP operations.

e.g: Fixed Point : TMS320C5x, C54x, DSP563x

Floating Point: TMS320C4x, C67xx, ADSP21xxx

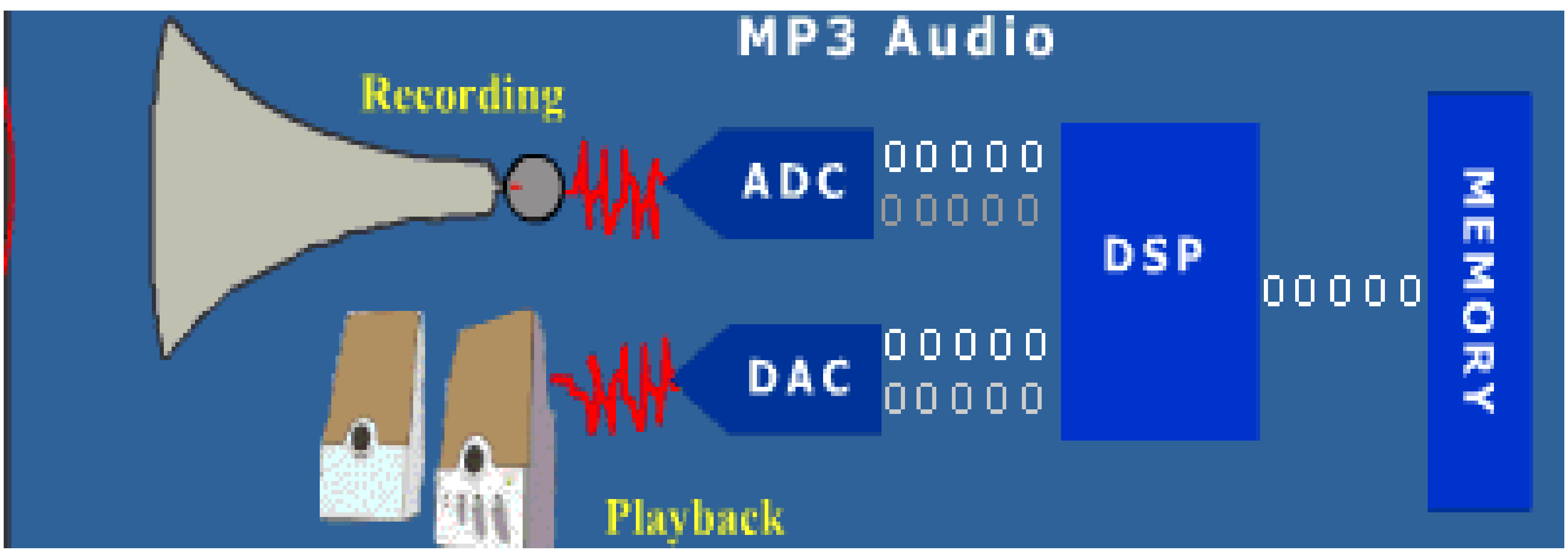
2. Special Purpose DSP

:: Hardware designed for,

1. Specific DSP algorithms such as FFT
2. Specific applications – PCM & Filtering.

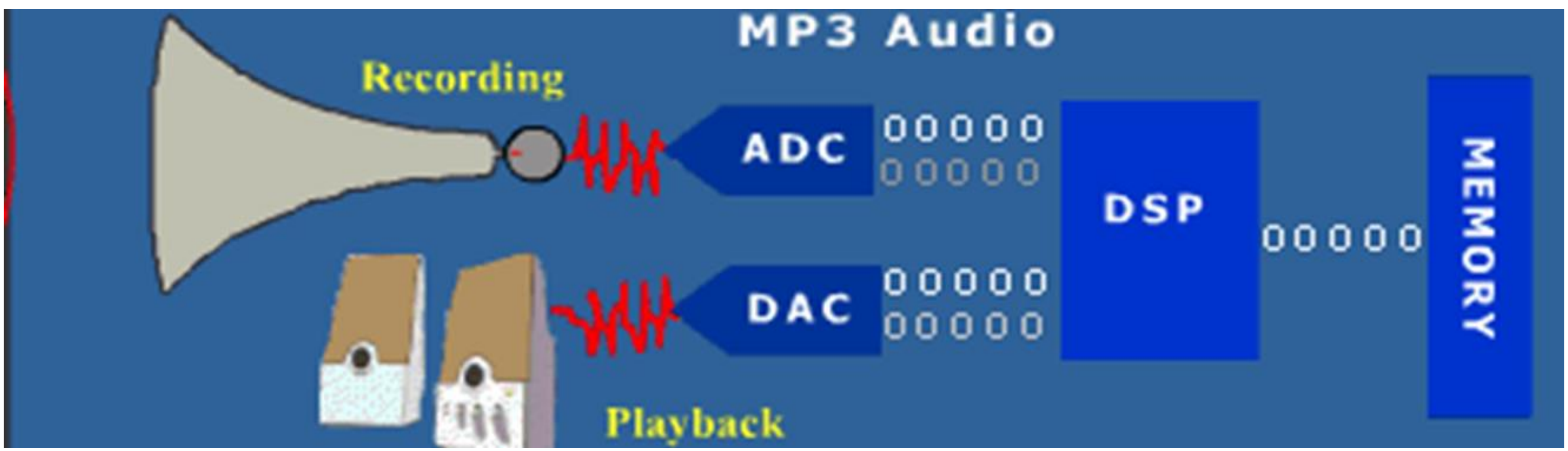
DSP in an MP3 audio player

- During the **recording phase**, analog audio is input through a receiver . This analog signal is then converted to a digital signal by **ADC a**nd passed to the DSP. The DSP performs the **MP3 encoding** and saves the file to memory.



DSP in an MP3 audio player

- During the **playback phase**, the file is taken from memory, **decoded by the DSP** and then converted back to an analog signal through **DAC** so it can be output through the speaker system.
- In a more complex example, the DSP would perform other functions such as **volume control, equalization and user interface.**



Goal of a DSP

- DSPs are fabricated on **MOS integrated circuit chips** The goal of a DSP is usually to **measure, filter** or **compress** continuous real-world analog signals

Selection of DSP

Type of arithmetic :

- Fixed point (Cell phone & Computer disk drives)
- Floating point (Wide & dynamic range of values)

Word length :

- Fixed point

16 - bit ::	TMS320C54x
	Telecommunications applications
24 - bit ::	DSP56300
	High quality audio applications

- Floating point

32 - bit ::	TMS320C3x, C4x
	Single - precision arithmetic

why are conventional processors not suitable for dsp?

Add and Subtract

Add and subtract operations are performed quite simply by general-purpose microprocessors in a single or very few clock cycles. Digital addition is similar to decimal add. Our example shows adding 1 plus 2. The result is the decimal 3.

Multiply and Divide

The multiply and divide operations are more complex. A digital multiply operation consists of a series of *shift and add operations. example shows a multiplication of 3 & 5*. General-purpose microprocessors are quite slow in performing multiply and divide operations. They will typically sequentially execute a series of shift, add, and subtract operations from their microcode i.e.

to perform a single multiply operation, it may consume many cycles to complete

The DSP performs multiplication in a single cycle by implementing all shift and add operations in parallel.

why are conventional processors not suitable for dsp?

- Most general-purpose microprocessors and operating systems can execute **DSP** algorithms successfully, but are **not suitable** for use in portable devices such as mobile phones **because of power efficiency constraints**.

DSP vs microprocessors

1. Most general-purpose microprocessors can also execute digital signal processing algorithms successfully, but may not be able to keep up with such processing continuously in real-time.
2. Also, dedicated DSPs usually have **better power efficiency**, thus they are more suitable in portable devices such as mobile phones because of power consumption constraints.[5]
3. DSPs often use special memory architectures that are able to fetch multiple data or instructions at the same time.

DSP vs microprocessors

Microprocessors are used for **data manipulation**, such as word processing and **database management**,

Data manipulation involves **storing and sorting information**.

For example, consider **a word processing program**.

The basic task is to

I. **store the information** (typed in by the operator),

II. **organize the information** (cut and paste, spell checking, page layout, etc.), and then

III. **retrieve the information** (such as saving the document on a floppy disk or printing it with a laser printer)

DSP vs microprocessors

whereas

DSP processors are designed specifically to **perform large numbers of complex arithmetic calculations** and as **quickly as possible**

such as image processing, speech recognition and telecommunications. These applications need to do Large number of mathematical operations on **a series of data samples**

DSP processors have Hardware implementation of Multiply/Accumulate function **Critical for FFT type applications**

DSP vs microprocessors

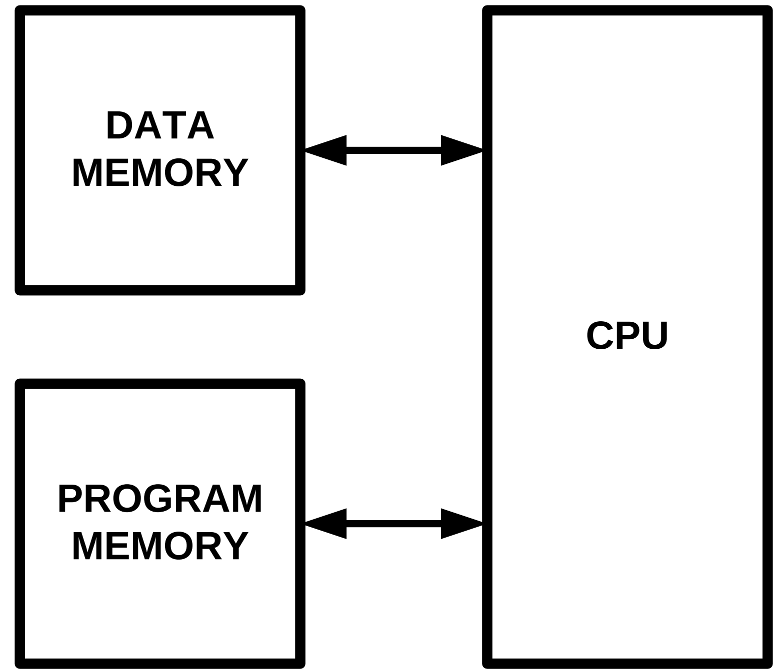
1. Most general purpose microprocessors **are present in personal computers**. They are often used for **computation, text editing, multimedia display**, and **communication over a network** whereas A DSP processor is a **specialized microprocessor** that has an architecture optimized for the **operational needs of digital signal processing**.

Common DSP features

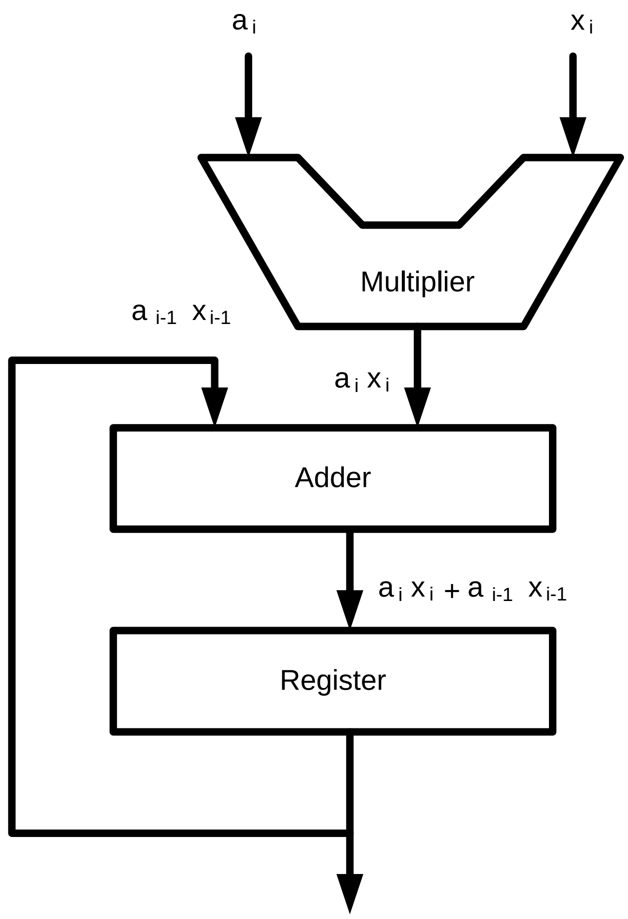
- Harvard architecture
- Dedicated single-cycle Multiply-Accumulate (MAC) instruction (hardware MAC units)
- Single-Instruction Multiple Data (SIMD) Very Large Instruction Word (VLIW) architecture
- Pipelining
- Saturation arithmetic
- Zero overhead looping
- Hardware circular addressing
- Cache
- DMA

Harvard Architecture

- Physically separate memories and paths for instruction and data



Single-Cycle MAC unit

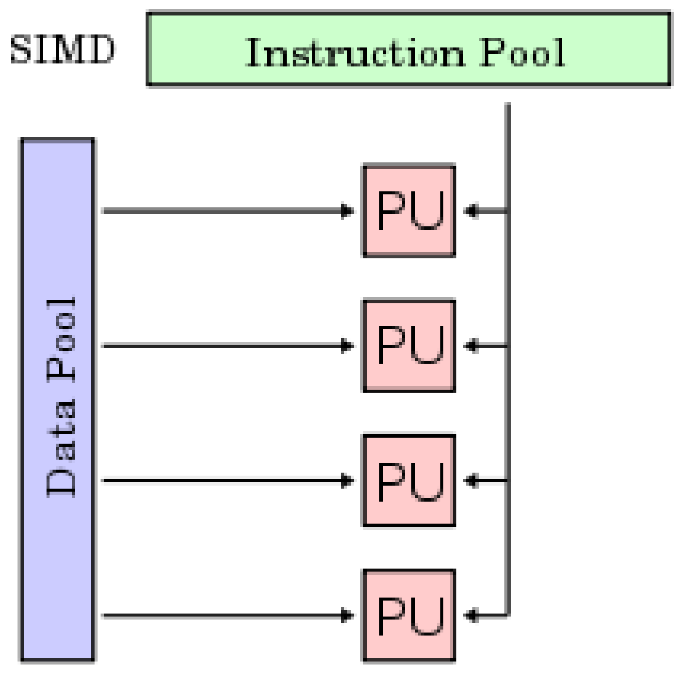


$$\sum_{i=0}^{n}(a_i x_i)$$

Can compute a sum of *n*-products in *n* cycles

Single Instruction - Multiple Data (SIMD)

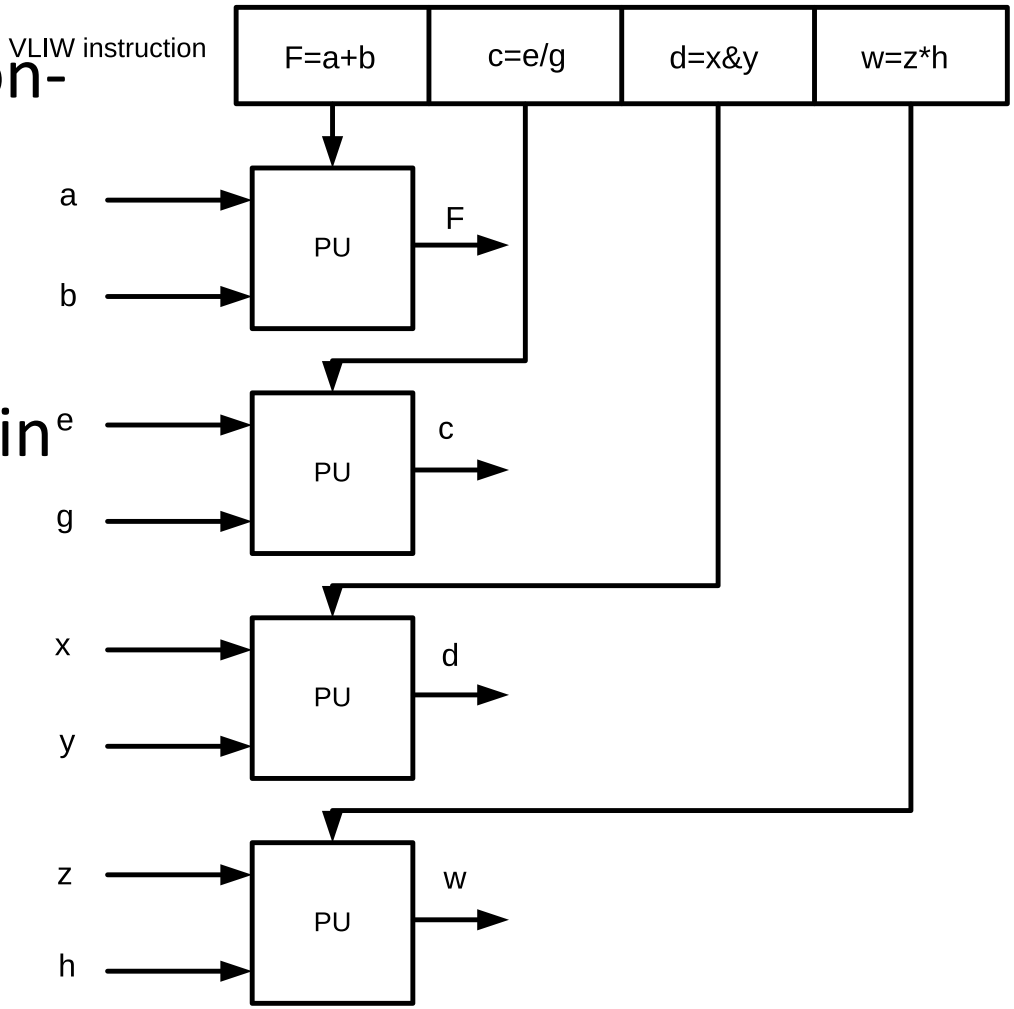
- A technique for data-level parallelism by employing a number of processing elements working in parallel



Very Long Instruction Word (VLIW)

- A technique for instruction-level parallelism by executing instructions without dependencies (known at compile-time) in parallel
- Example of a single VLIW instruction:

F=a+b; c=e/g; d=x&y; w=z*h;



Pipelining

- DSPs commonly feature deep pipelines
- TMS320C6x processors have 3 pipeline stages with a number of phases (cycles):
  - Fetch
  - Decode
  - Execute

barrel shifter

- A **barrel shifter** is a digital **circuit** that can shift a data word by a specified number of bits using pure combinational logic.
- The amount of shifting is selected via the control inputs. Several microprocessors include barrel-shifters as part of their ALUs to provide fast shift (and rotate) operations.

Saturation Arithmetic

- **Saturation arithmetic** is a version of **arithmetic** in which all operations such as addition and multiplication are limited to a fixed range between a minimum and maximum value.

Zero Overhead Looping

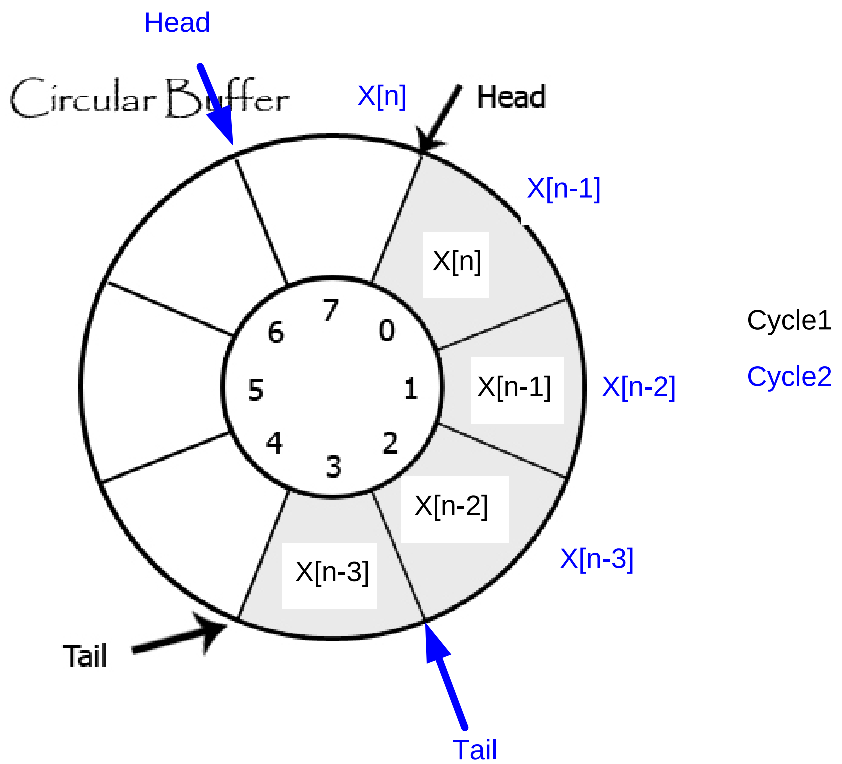
- Hardware support for loops with a constant number of iterations using hardware.
- A zero overhead loop is a loop whose endpoints are determined by hardware so that no software is required to determine when the loop has ended and must return to the beginning.

Zero Overhead Looping

- The most fundamental mathematical operation in DSP is shown in Equation :
- the sum of products (dot product). Zero overhead looping is required by the repetitive nature of the kernel equation.
- The multiply-accumulate function and the data fetches required are repeated N times every time the kernel function is calculated.
    - $y[n]=\sum k=0N-1h[k]*x[n-k]$
-

Hardware Circular Addressing

- A data structure implementing a fixed length queue of fixed size objects where **objects are added to the head of the queue** while items are r**emoved from the tail of the queue.**
- Requires at least 2 pointers (head and tail)
- Extensively used in digital filtering



y[n] = a0x[n]+a1x[n-1]+…+akx[n-k]

Direct Memory Access (DMA)

- The feature that allows peripherals to access main memory **without the intervention of the CPU**
- Typically, the CPU initiates DMA transfer, does other operations while the transfer is in progress, and receives an interrupt from the DMA controller once the operation is complete.

Cache memory

- Separate instruction and data L1 caches

DSP vs. Microcontroller

- DSP
  - Harvard Architecture
  - VLIW/SIMD (parallel execution units)
  - No bit level operations
  - Hardware MACs
  - DSP applications
- Microcontroller
  - Mostly von Neumann Architecture
  - Single execution unit
  - Flexible bit-level operations
  - No hardware MACs
  - Control applications

Fixed versus Floating Point DSP

- Digital Signal Processing can be divided into two categories, **fixed point** and **floating point**.
- These refer to the format used to store and manipulate numbers within the devices.
- Fixed point DSPs usually represent each number **with a minimum of 16 bits**, although a different length can be used.
- For instance, **Motorola** manufactures a family of fixed point DSPs that use 24 bits. There are four common ways that these $2^{16} = 65536$ possible bit patterns can represent a number.

Fixed versus Floating Point DSP

- In comparison, floating point DSPs typically use a minimum of **32 bits** to store each value.
- This results in many more bit patterns than for fixed point, **2^{32} = 4,294,967,296** to be exact.
- A key feature of floating point notation is that the represented numbers are ***not* uniformly spaced**.
- In the most common format (**ANSI/IEEE Std. 754**), the largest is $\pm 3.4 \times 10^{38}$.
- The represented values are **unequally spaced between these two extremes**, such that the gap between any two numbers is about ten-million times smaller than the value of the numbers.
- This is important because it places large gaps between large numbers, but **small gaps between small numbers**

Fixed versus Floating Point DSP

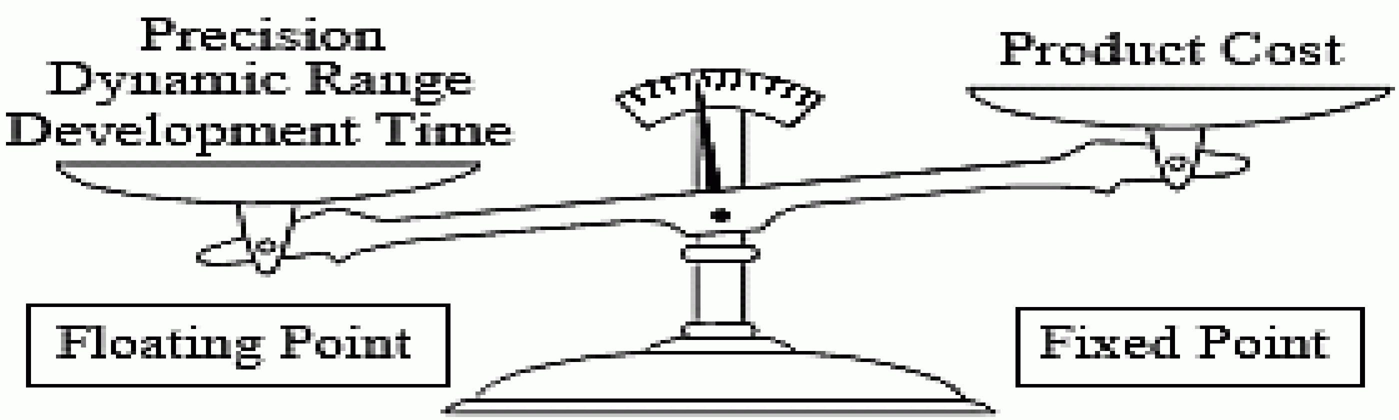
- All floating point DSPs **can also handle fixed point numbers,** a necessity to implement counters, loops, and signals coming from the ADC and going to the DAC.
- However, this doesn't mean that fixed point math will be carried out as quickly as the floating point operations; it depends on the internal architecture.
- For instance, the SHARC DSPs are optimized for **both floating point and fixed point operations**, and executes them with equal efficiency. For this reason, the SHARC devices are often referred to as "**32-bit DSPs**," rather than just "Floating Point."

Fixed versus Floating Point DSP

- The internal architecture of a floating point DSP is more complicated than for a fixed point device. All the registers and data buses must be 32 bits wide instead of only 16

Fixed versus Floating Point DSP

- Floating point (32 bit) has **better precision and a higher dynamic range than fixed point** (16 bit)
- . In addition, floating point programs often have a **shorter development cycle**, since the programmer doesn't generally need to worry about issues such as overflow, underflow, and round-off error.



Fixed versus Floating Point DSP

- ; the multiplier and ALU must be able to quickly perform floating point arithmetic, the instruction set must be larger (so that they **can handle both floating and fixed point numbers**), and so on.
-

Applications of DSP

1. **audio signal processing,**
2. **telecommunications,**
3. **digital image processing,**
4. **radar, sonar and**
5. **speech recognition systems, and**
6. **consumer electronic devices such as mobile phones, disk drives and high-definition television (HDTV) products**

Speech recognition

- It is used to communicate between humans

and machines. Rather than using your hands and eyes, you use your mouth and ears. This is very **convenient when your hands and eyes should be doing something else**,

such as: driving a car, performing surgery, or (unfortunately) firing your weapons at the enemy

Digital Signal Processors (DSPs) are microprocessors with the following characteristics:

a) **Real-time** digital signal processing **capabilities.** DSPs typically have to process data in real time

b) **High throughput**. DSPs can sustain processing of high-speed streaming data, such as audio and multimedia data processing.

.

Digital Signal Processors (DSPs) are microprocessors with the following characteristics:

c) **Deterministic operation**. The execution time of DSP programs can be foreseen accurately, thus guaranteeing a repeatable, desired performance.

d) Re-programmability by software. Different system behaviour might be obtained by

re-coding the algorithm executed by the DSP instead of by hardware modifications.

Applications of DSP

- Speech processing
- Radar signal Procesing

DSP of speech signals

- **Speech** recognition are used to communicate between humans and machines. Rather than using your hands and eyes, you use your mouth and ears.
- This is very convenient when your hands and eyes should be doing something else, such as: driving a car, performing surgery, or (unfortunately)

DSP of speech signals

Speech Coding is the process of transforming a speech signal into a representation for efficient transmission and storage of speech

- narrowband and broadband wired telephony
- cellular communications
- Voice over IP (VoIP) to utilize the Internet as a real-time communications medium
- secure voice for privacy and encryption for national security applications
- extremely narrowband communications channels, e.g., battlefield applications using HF radio
- storage of speech for telephone answering machines, IVR systems, prerecorded messages

DSP of speech signals

Synthesis of Speech is the process of generating a speech signal using computational means for effective human-machine interactions

– machine reading of text or email messages

DSP of speech signals

- ***Speaker Verification*** for secure access to premises, information, virtual spaces
- ***Speaker Recognition*** for legal and forensic purposes—national security; also for personalized services
- ***Speech Enhancement*** for use in noisy environments, to eliminate echo, to align voices with video segments, to change voice qualities, to speed-up or slow-down prerecorded speech (e.g., talking books, rapid review of material, careful scrutinizing of spoken material, etc) => potentially to improve intelligibility and naturalness of speech
- ***Language Translation*** to convert spoken words in one language to another to facilitate natural language dialogues between people speaking different languages, i.e., tourists, business people