SISTEMAS DIGITALES

ET-210

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Sistemas digitales
Estructura de evaluación

	Puntos	Descripción
Parcial Teórico 1	20	Cuestionario y ejercicios
Parcial Teórico 2	20	Cuestionario y ejercicios
Laboratorios	20	Simulación y construcción de sistemas
Proyecto	20	Diseño, montaje y pruebas de sistema
Final	20	Cuestionario y ejercicios
	100	

Tecnologías de información

Google Classroom

Google Drive

Google Meet

Google docs

UPSA Virtual

COMPUTER ORGANIZATION AND ARCHITECTURE

Designing for Performance

Tenth Edition

WILLIAM STALLINGS


Hello world in Python
Hello world in C
Hello world in Assembly

UNIDAD 1 - CONCEPTOS BASICOS DEL COMPUTADOR
Por qué estudiar la organización y arquitectura de los computadores?

«El computador está en el corazón de la informática. Sin él la mayoría de las asignaturas de informática serían hoy una rama de la matemática teórica. Para ser hoy un profesional en cualquier campo de la informática uno no debe ver al computador como una caja negra que ejecuta programas mágicamente. Todos los estudiantes de informática deben, en cierta medida, comprender y valorar los componentes funcionales de un computador, sus características, su funcionamiento y sus interacciones. También sus implicaciones prácticas. Los estudiantes necesitan comprender la arquitectura del computador para estructurar un programa de forma que este sea más eficiente en una máquina real. Seleccionando el sistema que se va a usar, debe ser capaz de comprender el compromiso entre varios componentes, como la velocidad del reloj de la CPU frente al tamaño de la memoria».

UNIDAD 1 - CONCEPTOS BASICOS DEL COMPUTADOR
Por qué estudiar la organización y arquitectura de los computadores?

razones para estudiar arquitectura de computadores:

1. Supóngase que un licenciado trabaja en la industria y se le pide seleccionar el computador con la mejor relación calidad precio para utilizarlo en una gran empresa. Comprender las implicaciones de gastar más en distintas alternativas, como una caché grande o una velocidad de reloj mayor, es esencial para tomar esta decisión.
2. Hay muchos procesadores que no forman pare de equipos PC o servidores, pero sí en sistemas embebidos. Un diseñador debe ser capaz de programar un procesador en C que esté embebido en algún sistema en tiempo real o sistema complejo, como un controlador electrónico de un coche inteligente. Depurar el sistema puede requerir utilizar un analizador lógico que muestre la relación entre las peticiones de interrupción de los sensores del sistema y el código máquina.
3. Los conceptos utilizados en arquitectura de computadores tienen aplicación en otros cursos. En particular, la forma en la que el computador ofrece un soporte arquitectural a los lenguajes de programación y funciones en principio propias del sistema operativo, refuerza los conceptos de estas áreas.

Contenido

Introducción a los computadores

El computador

Según el autor del [Stallings, 2010] un computador es:
Máquina digital electrónica programable para el tratamiento automático de la información, capaz de recibirla, operar sobre ella mediante procesos determinados y suministrar los resultados de tales operaciones

Introducción a los computadores

Motivación

¿Por qué estudiar arquitectura de computadores?

- Diseñar mejores programas de base
- Optimizar programas
- Construir computadoras
- Evaluar desempeño
- Entender la relación entre poder de cómputo, espacio y costos

Introducción a los computadores

Definiciones

- **Arquitectura del computador:** Se refiere a todos los atributos visibles por un programador del sistema
- **Organización del computador:** Se refiere a las unidades operacionales y las interconexiones para realizar operaciones de la arquitectura

Introducción a los computadores

For example, it is an architectural design issue whether a computer will have a multiply instruction. It is an organizational issue whether that instruction will be implemented by a special multiply unit or by a mechanism that makes repeated use of the add unit of the system. The organizational decision may be based on the anticipated frequency of use of the multiply instruction, the relative speed of the two approaches, and the cost and physical size of a special multiply unit.

Historically, and still today, the distinction between architecture and organization has been an important one. Many computer manufacturers offer a family of computer models, all with the same architecture but with differences in organization. Consequently, the different models in the family have different price and performance characteristics. Furthermore, a particular architecture may span many years and encompass a number of different computer models, its organization changing with changing technology.

	This item 2020 Newest Lenovo Thinkpad E490 14 Inch FHD 1080P Business Laptop (Intel 4-Core i7-8565U up to 4.6GHz, 32GB DDR4 RAM, 256GB SSD, Intel UHD 620, WiFi, Bluetooth, HDMI, Windows 10 Pro)	2020 Newest Lenovo Thinkpad E490 14 Inch FHD 1080P Business Laptop (Intel 4-Core i7-8565U up to 4.6GHz, 32GB DDR4 RAM, 512GB SSD, Intel UHD 620, WiFi, Bluetooth, HDMI, Windows 10 Pro)	2020 Newest Lenovo Thinkpad E490 14 Inch FHD 1080P Business Laptop (Intel 4-Core i7-8565U up to 4.6GHz, 1TB DDR4 RAM, 512GB SSD, Intel UHD 620, WiFi, Bluetooth, HDMI, Windows 10 Pro)	Lenovo Thinkpad E590 15.6" HD Business Laptop (Intel Quad Core i5-8265U, 16GB DDR4 Memory, 512GB PCIe 3.0(x4) NVMe SSD M.2 SSD) Type-C, HDMI, Ethernet, Webcam, Windows 10 Professional
	Add to Cart	Add to Cart	Add to Cart	Add to Cart
Customer Rating	(0)	(0)	(0)	(108)
Price	$970.52	$1,013.44	$1,218.20	$749.00
Shipping	FREE Shipping on orders over $25	FREE Shipping on orders over $25	FREE Shipping on orders over $25	prime
Sold By	NEXiPC	NEXiPC	NEXiPC	GAMMA Deals(SN Recorded)
computer memory size	32 GB	32 GB	32 GB	16 GB
Processor (CPU) Manufacturer	Intel	Intel	Intel	Intel
Processor (CPU) Speed	1.8 GHz	1.8 GHz	1.8 GHz	1.6 GHz
Display Resolution Max	1920 x 1080	1920 x 1080	1920 x 1080	1366 x 768
Display Size	14 in	14 in	14 in	15.6 in
Hard Disk Size	256 GB	512 GB	1 TB	512 GB
Item Dimensions	13 x 9.6 x 0.8 in	13 x 9.6 x 0.8 in	13 x 9.6 x 0.8 in	9.92 x 14.53 x 0.78 in
Item Weight	3.87 lbs	3.87 lbs	3.97 lbs	4.7 lbs
Operating System	Windows 10 Pro	Windows 10 Pro	Windows 10 Pro	None
Processor Count	4	4	4	4
System RAM Type	DDR4 SDRAM	DDR4 SDRAM	DDR4 SDRAM	DDR4 SDRAM
Wireless Compatibility	Bluetooth	Bluetooth	Bluetooth	802.11ac, Bluetooth

cpuboss

Intel Core i7 6700K vs i3 3220

Released July, 2015 OLDER

Intel Core i7 6700K

4 GHz | Quad core | Unlocked

intel inside CORE i

8.2 Out of 10

VS

Intel Core i3 3220

3.3 GHz | Dual core

Released September, 2012 OLDER

intel inside CORE i3

6.4 Out of 10

CybertronPC, 16 GB RAM, 15" screen

Intel Core i7 6700K

Buy now **B$14.504**

HP, 4 GB RAM

Intel Core i3 3220

Buy now **B$1.077**

cpuboss

Differences

What are the advantages of each

Much better 3DMark06 CPU score	80.5 vs 47.7	Around 70% better 3DMark06 CPU score
Much better CompuBench 1.5 bitcoin mining score	35.02 mHash/s vs 4.07 mHash/s	More than 8.5x better CompuBench 1.5 bitcoin mining score
Is unlocked	Yes vs No	Somewhat common; An unlocked multiplier allows for easier overclocking
Higher clock speed	4 GHz vs 3.3 GHz	More than 20% higher clock speed
More l2 cache	1 MB vs 0.5 MB	2x more l2 cache; more data can be stored in the l2 cache for quick access later
Significantly newer manufacturing process	14 nm vs 22 nm	A newer manufacturing process allows for a more powerful, yet cooler running processor
More l3 cache	8 MB vs 3 MB	Around 2.8x more l3 cache; more data can be stored in the l3 cache for quick access later
Significantly better PassMark score	11,109 vs 4,229	Around 2.8x better PassMark score
Better PassMark (Single core) score	2,349 vs 1,764	Around 35% better PassMark (Single core) score
Better turbo clock speed	1,150 MHz vs 1,050 MHz	Around 10% better turbo clock speed
Significantly better overclocked clock speed (Air)	4.61 GHz vs 3.43 GHz	Around 35% better overclocked clock speed (Air)
More cores	4 vs 2	Twice as many cores; run more applications at once
More threads	8 vs 4	Twice as many threads
More l3 cache per core	2 MB/core vs 1.5 MB/core	Around 35% more l3 cache per core
Newer	Jul, 2015 vs Sep, 2012	Release date over 2 years later
Significantly better overclocked clock speed (Water)	4.77 GHz vs 3.46 GHz	Around 40% better overclocked clock speed (Water)
Better performance per watt	3.49 pt/W vs 2.69 pt/W	Around 30% better performance per watt

Specifications

Full list of technical specs

Summary

	Core i7 6700K	i3 3220
Clock speed	4 GHz	3.3 GHz
Cores	Quad core	Dual core
Is unlocked	Yes	No

Features

	Core i7 6700K	i3 3220
Has a NX bit	Yes	Yes
Supports trusted computing	No	No
Has virtualization support	Yes	Yes
Instruction set extensions		
SSE2	✔	✔
MMX	✔	✔
SSE4	✔	✔
AVX	✔	✔
SSE3	✔	✔
SSE	✔	✔
SSE4.1	✔	✔
SSE4.2	✔	✔
Supplemental SSE3	✔	✔
AES	✔	✔
AVX 2.0	✔	✖
Supports dynamic frequency scaling	Yes	Yes

Power Consumption

	Core i7 6700K	i3 3220
TDP	91W	55W
Annual home	21.92 $/year	13.25 $/year

Details

	Core i7 6700K	i3 3220
Architecture	x86-64	x86-64
Threads	8	4
L2 cache	1 MB	0.5 MB
L2 cache per core	0.25 MB/core	0.25 MB/core
L3 cache	8 MB	3 MB
L3 cache per core	2 MB/core	1.5 MB/core
Manufacture process	14 nm	22 nm
Max CPUs	1	1
Operating temperature	Unknown - 64°C	Unknown - 65.3°C

Overclocking

	Core i7 6700K	i3 3220
Overclocked clock speed	4.61 GHz	3.43 GHz
Overclocked clock speed (Water)	4.77 GHz	3.46 GHz
Overclocked clock speed (Air)	4.61 GHz	3.43 GHz

Integrated Graphics

	Core i7 6700K	i3 3220
GPU	GPU	GPU
Label	Intel® HD Graphics 530	Intel® HD Graphics 2500
Number of displays supported	3	3
GPU clock speed	350 MHz	650 MHz
Turbo clock speed	1,150 MHz	1,050 MHz

Introducción a los computadores

Motivación

Algunos términos:

- **Hertz**: Ciclos de reloj por segundo.
- **Byte**: Unidad de almacenamiento.
- **Word**: Palabra (cantidad de bits que se pueden mover dentro de una CPU)

Introducción a los computadores

Motivación

Medidas de capacidad y velocidad

- **Kilo (K)**: 10^3 y 2^{10}
- **Mega (M)**: 10^6 y 2^{20}
- **Giga (G)**: 10^9 y 2^{30}
- **Tera (T)**: 10^{12} y 2^{40}
- **Peta (P)**: 10^{15} y 2^{50}

Si hablamos de velocidad estamos en unidades de 10 y de capacidad en unidades de 2.

Introducción a los computadores

Motivación

Medidas de capacidad y velocidad

- **1KHz**: 1000Hz
- **1MHz**: 1000000Hz o 1000KHz
- **1KB**: 2^{10}Bytes = 1024 bytes
- **1GB**: 2^{30}Bytes = 1024 MB
- Las palabras (Word) suelen ser unidades de transferencia fija: 8 bits, 16 bits, etc.

Unidades de medida de memoria

$1\,B \longrightarrow 8\text{ bits}$

$1\,kB \longrightarrow 1024\,B$

$1\,MB \longrightarrow 1024\,kB$

$1\,GB \longrightarrow 1024\,MB$

$1\,TB \longrightarrow 1024\,GB$

Byte → Megabyte (Byte → MB)

$1\,kB = 1024\,B$

$1\,MB = 1024\,kB$

$\boxed{4720091\,B \longrightarrow MB}$

$$\frac{4720091\ B}{} \Bigg| \frac{1\,kB}{1024\ B} \Bigg| \frac{1\,MB}{1024\,kB} = \frac{(4720091\,[\cancel{B}])(1\,[\cancel{kB}])(1\,[MB])}{(1024\,[\cancel{B}])(1024\,[\cancel{kB}])}$$

$$= \frac{4720091}{1048576}\,[MB] = \underline{4.5014\,[MB]}$$

$\boxed{9900000\,B \longrightarrow MB}$

$$\frac{9900000\ B}{} \Bigg| \frac{1\,kB}{1024\ B} \Bigg| \frac{1\,MB}{1024\,kB} = \frac{(9900000[\cancel{B}])(1[\cancel{kB}])(1[MB])}{(1024\,[\cancel{B}])(1024\,[\cancel{kB}])}$$

$$= \frac{9900000}{1048576}\,[MB] = 9.4413\,[MB]$$

PASOS POR INGENIERÍA

Prefijo	Símbolo	Valor	Equivalencia en Unidades
exa	E	1×10^{18}	trillón
peta	P	1×10^{15}	mil billones
tera	T	1×10^{12}	billón
giga	G	1×10^{9}	mil millones
mega	M	1×10^{6}	millón
kilo	K	1×10^{3}	mil
hecto	h	1×10^{2}	cien
deca	da	1×10	diez
unidad	1	1	uno
deci	d	1×10^{-1}	décima
centi	c	1×10^{-2}	centésima
mili	m	1×10^{-3}	milésima
micro	µ	1×10^{-6}	millonésima
nano	n	1×10^{-9}	mil millonésimas
pico	p	1×10^{-12}	billonésima
femto	f	1×10^{-15}	mil billonésimas
atto	a	1×10^{-18}	trillonésima

Introducción a los computadores

Motivación

En el caso de la velocidad del procesador F en Hertz, podemos conocer el tiempo de ciclo de reloj T con esta formula:

$$T = \frac{1}{F}$$

Ejemplo, un procesador que trabaja a 133MHz, tiene un tiempo de ciclo de reloj de 7.52 nanosegundos

Contenido

Estructura y función

A computer is a complex system; contemporary computers contain millions of elementary electronic components. How, then, can one clearly describe them? The key is to recognize the hierarchical nature of most complex systems, including the computer [SIMO96]. A hierarchical system is a set of interrelated subsystems, each of the latter, in turn, hierarchical in structure until we reach some lowest level of elementary subsystem.

Definiciones

- **Estructura:** Como están interrelacionados los componentes
- **Función:** La operación de cada uno de los componentes como parte de una estructura

Function

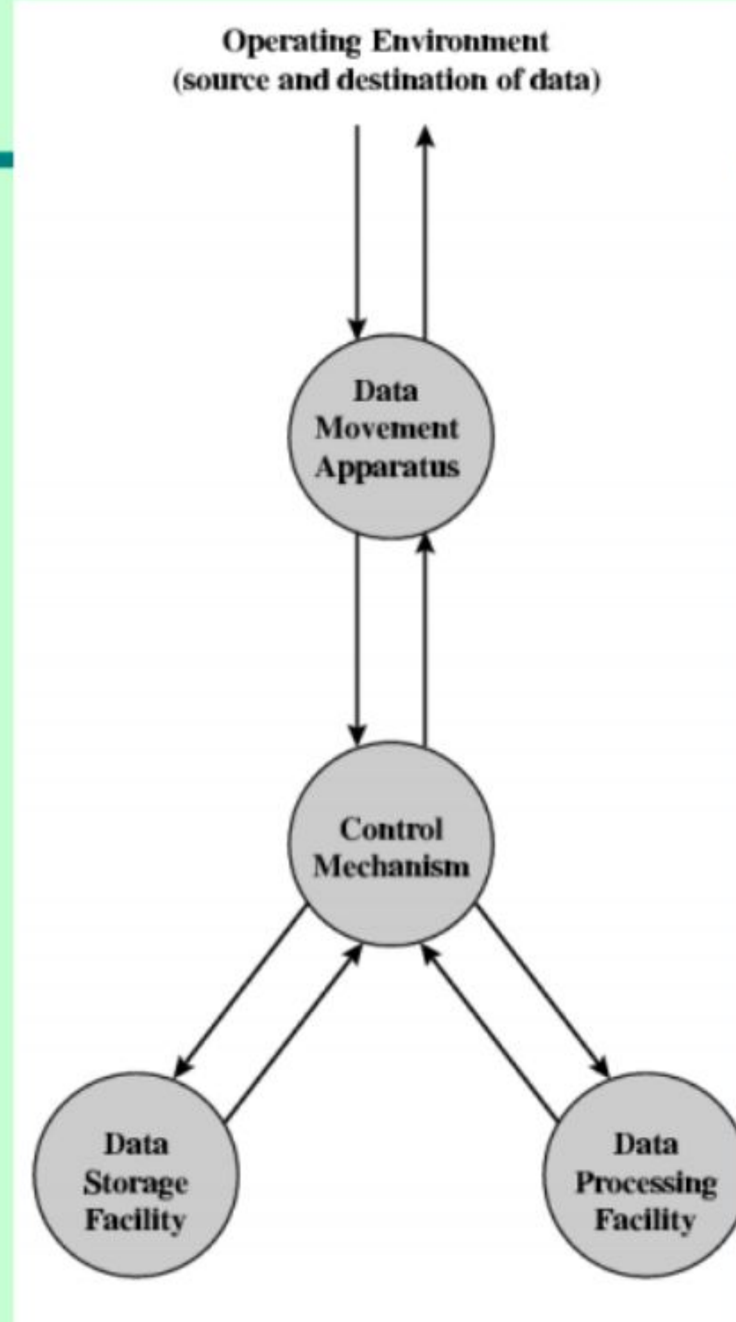
Both the structure and functioning of a computer are, in essence, simple. In general terms, there are only four basic functions that a computer can perform:

- **Data processing:** Data may take a wide variety of forms, and the range of processing requirements is broad. However, we shall see that there are only a few fundamental methods or types of data processing.
- **Data storage:** Even if the computer is processing data on the fly (i.e., data come in and get processed, and the results go out immediately), the computer must temporarily store at least those pieces of data that are being worked on at any given moment. Thus, there is at least a short-term data storage function. Equally important, the computer performs a long-term data storage function. Files of data are stored on the computer for subsequent retrieval and update.
- **Data movement:** The computer's operating environment consists of devices that serve as either sources or destinations of data. When data are received from or delivered to a device that is directly connected to the computer, the process is known as *input–output* (*I/O*), and the device is referred to as a *peripheral*. When data are moved over longer distances, to or from a remote device, the process is known as *data communications*.
- **Control:** Within the computer, a control unit manages the computer's resources and orchestrates the performance of its functional parts in response to instructions.

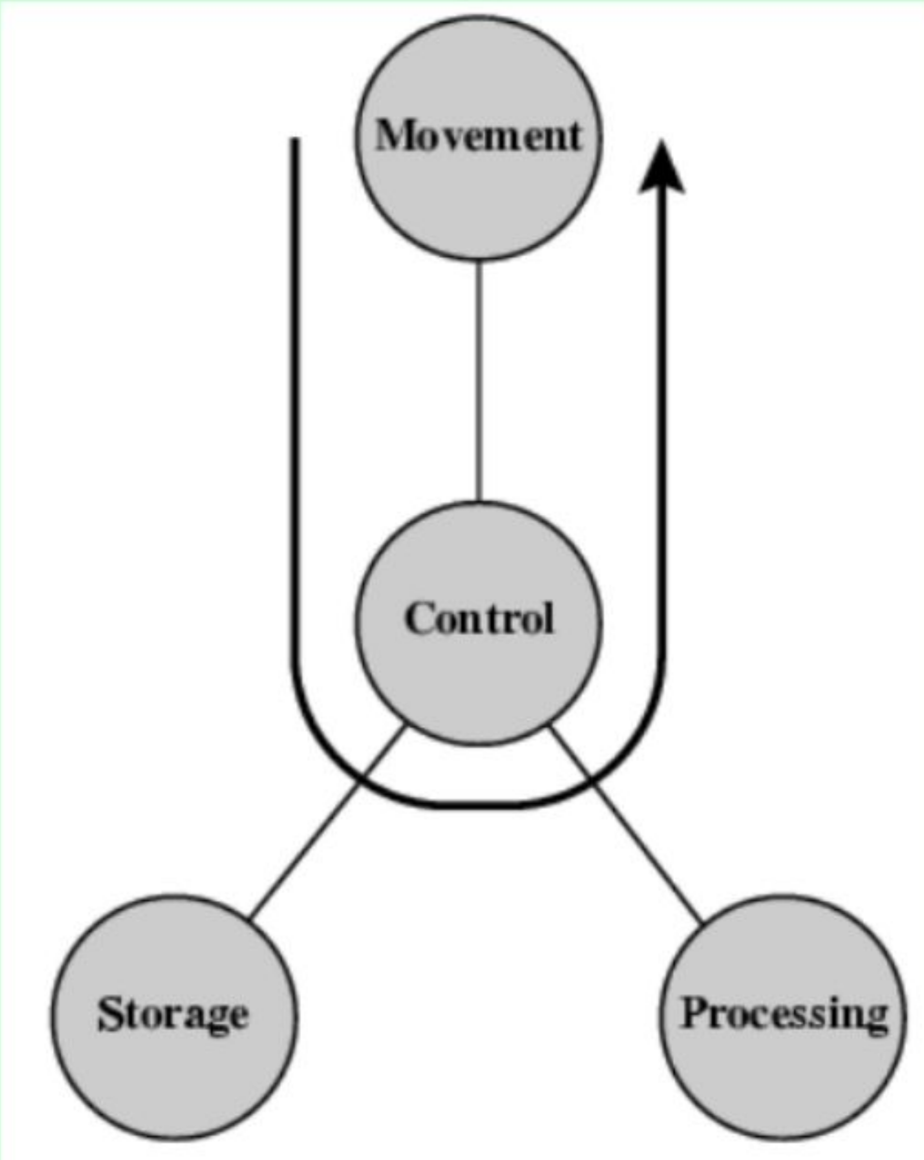
Function

General computer functions:

- Data processing
- Data storage
- Data movement
- Control



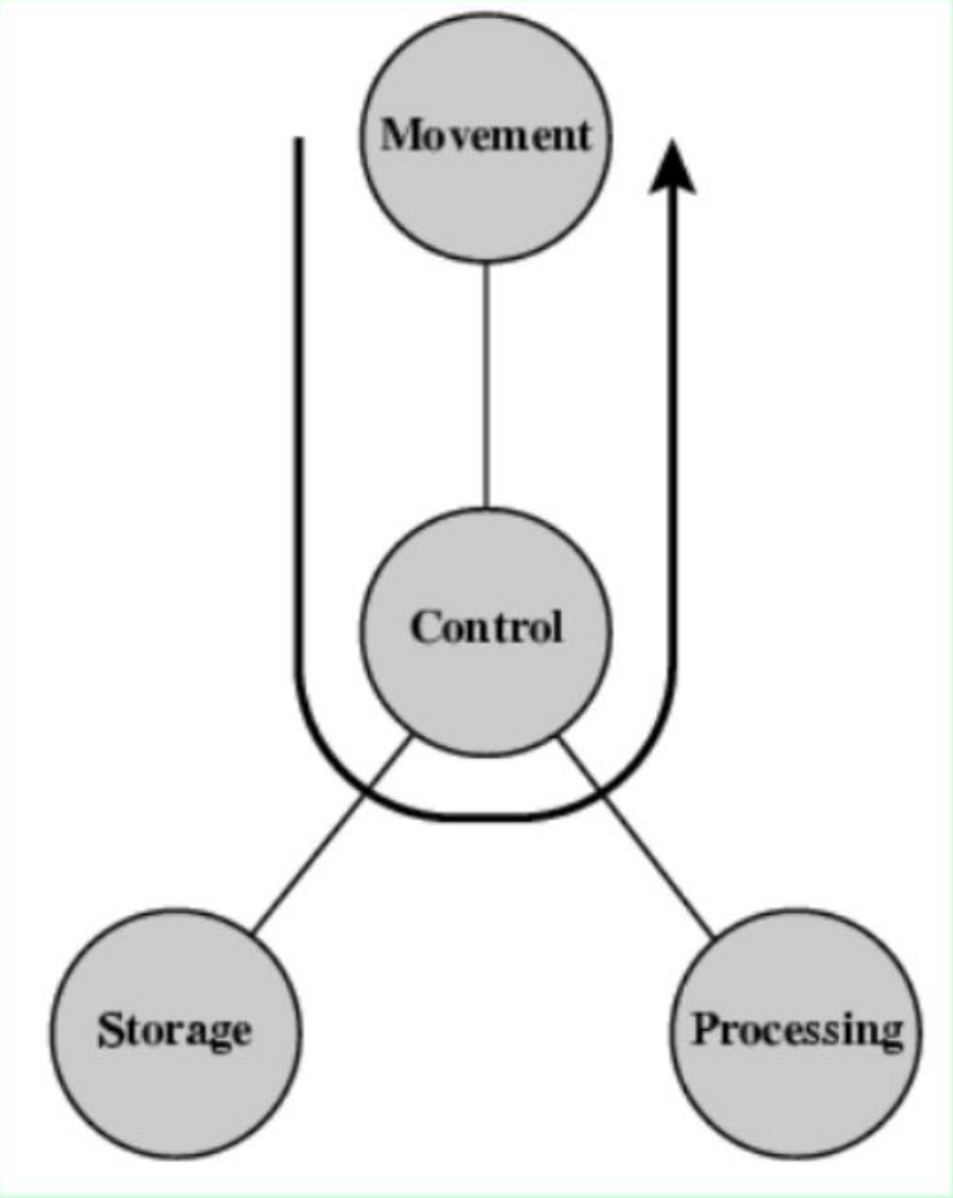
Operations (a) Data movement



I/O (peripherals directly attached)
Communications/Networking (communication lines)

Example application?

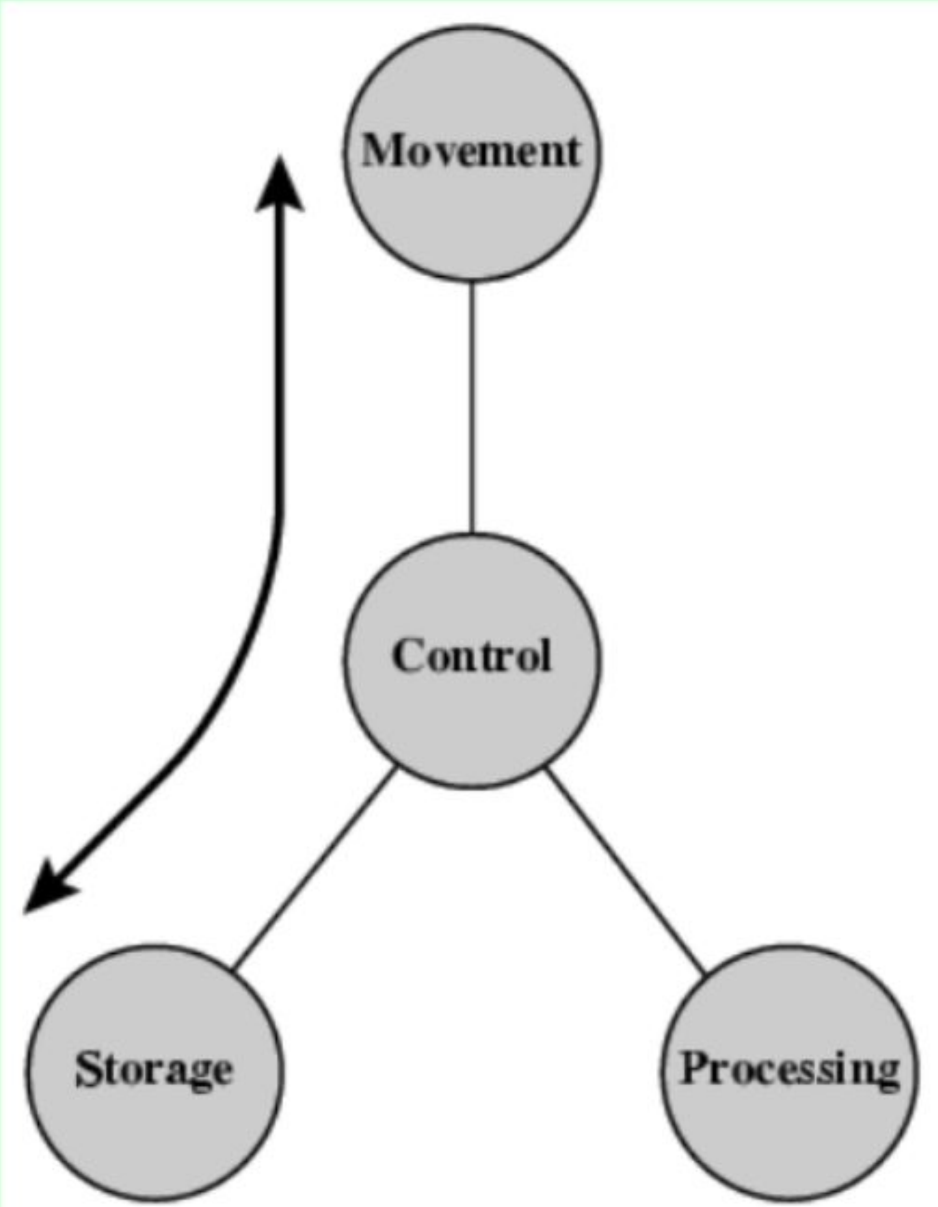
Operations (a) Data movement



I/O (peripherals directly attached)
Communications/Networking (communication lines)

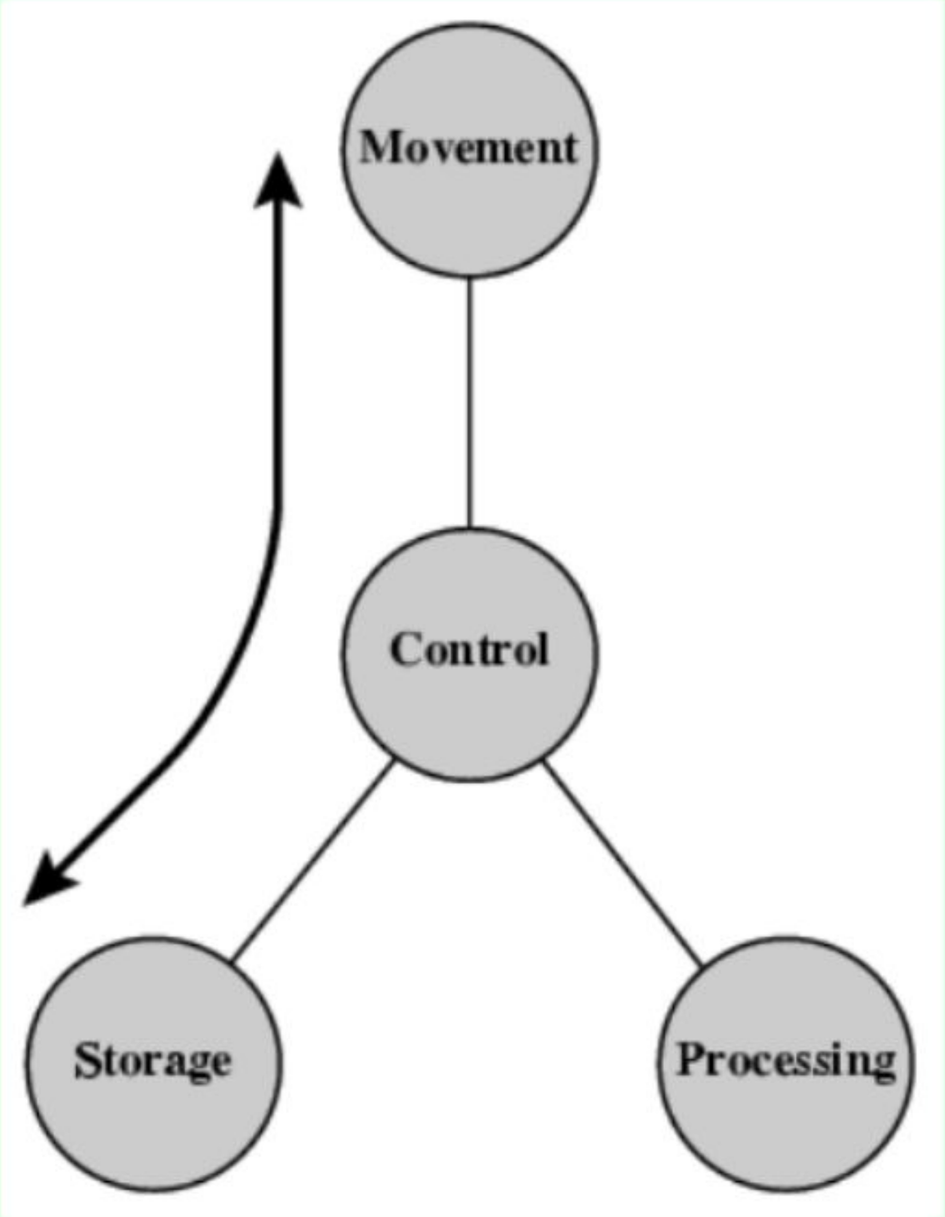
Camera attached to a PC, sending the frames to a window on the screen of the same PC.

Operations (b) Storage



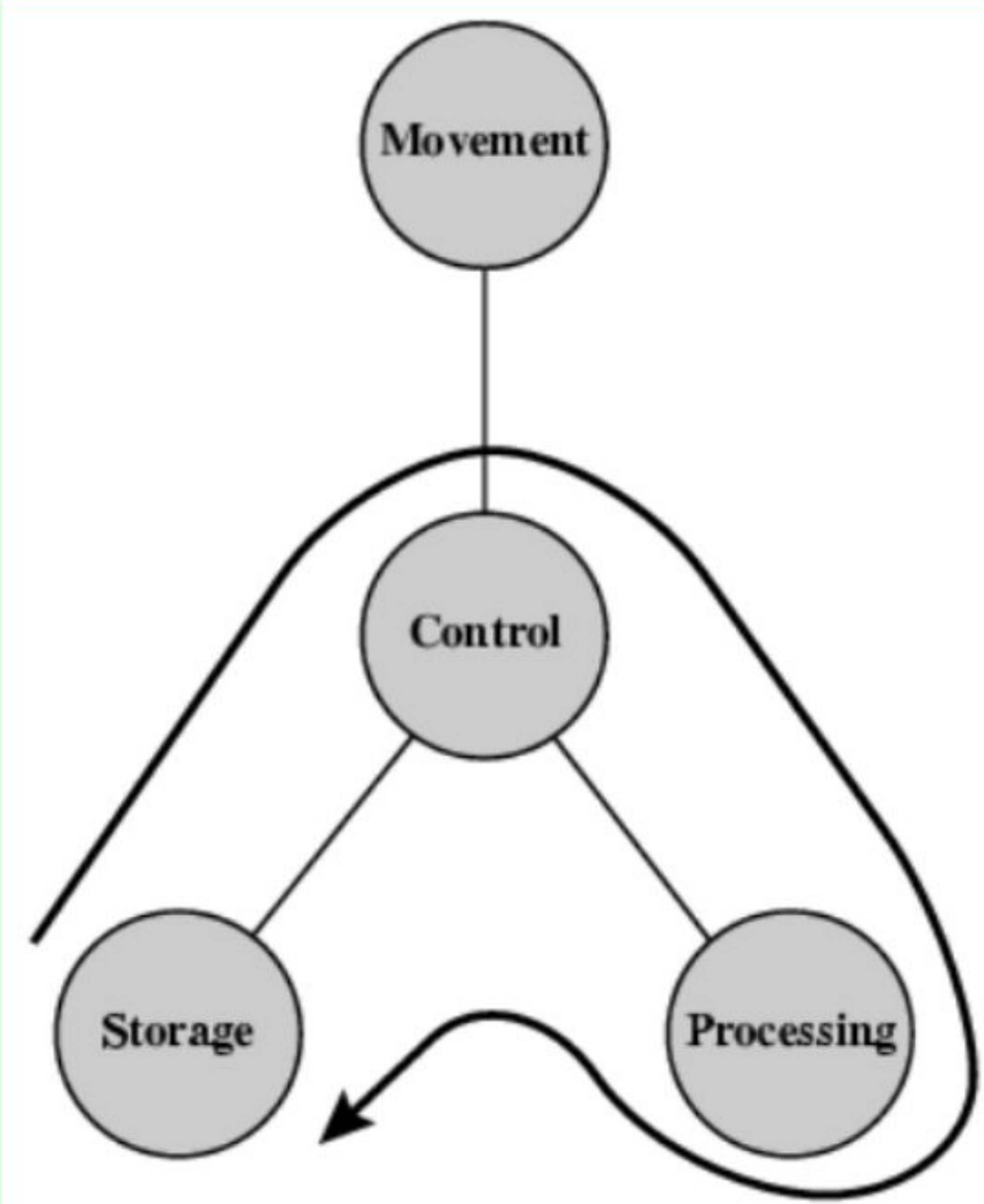
Example application?

Operations (b) Storage



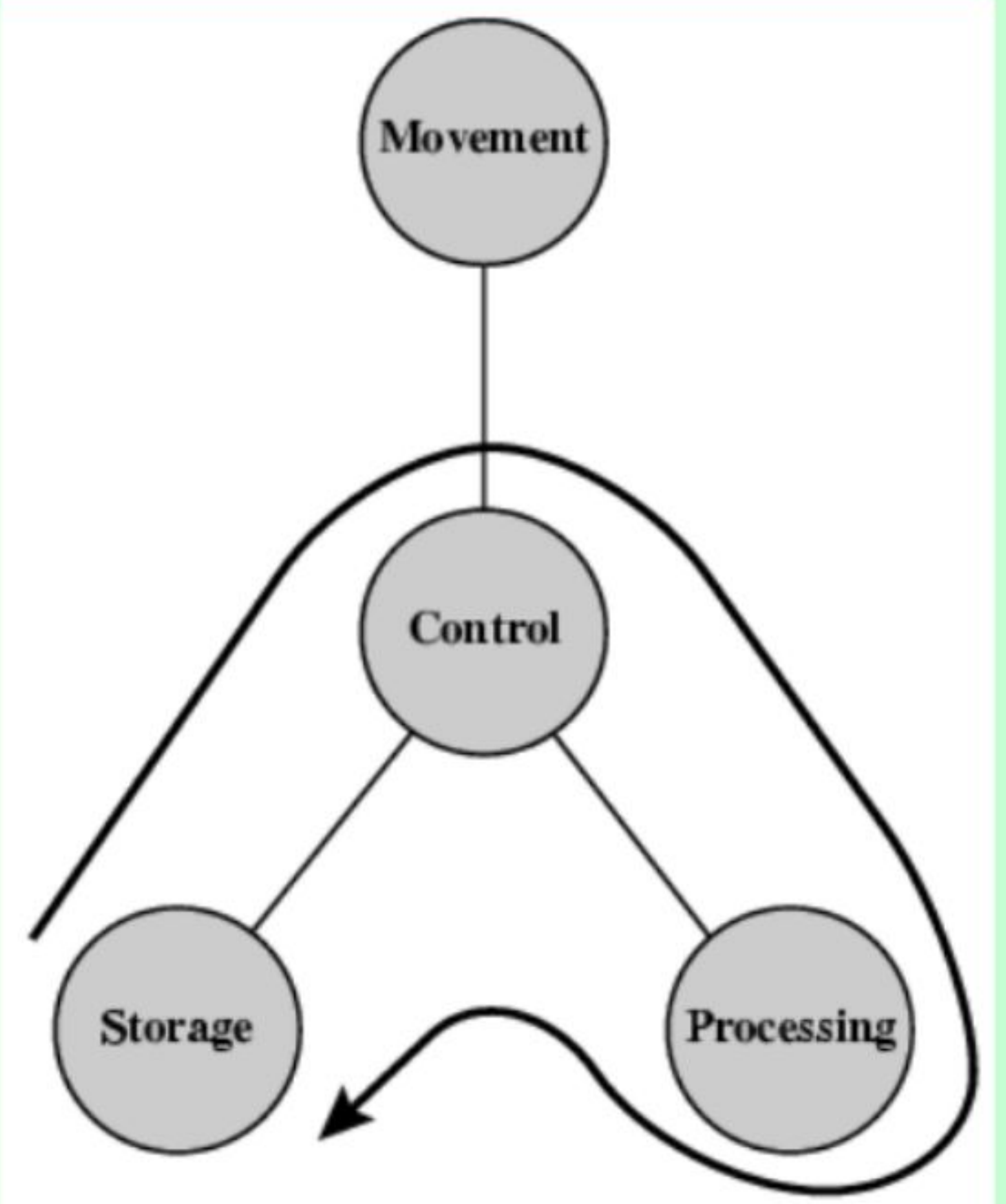
Playing an mp3 file stored in memory to earphones attached to the same PC.

Operation (c) Processing from/to storage



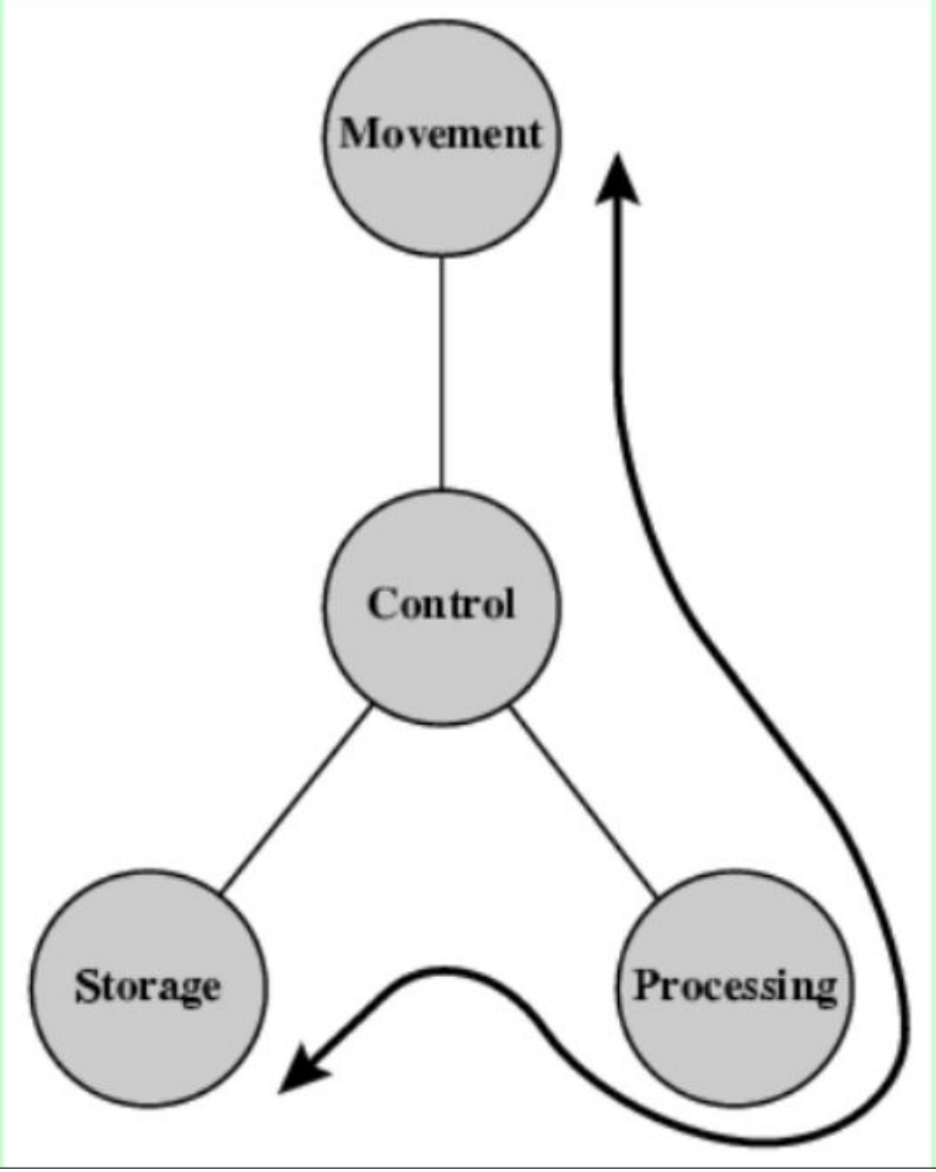
Example application?

Operation (c) Processing from/to storage



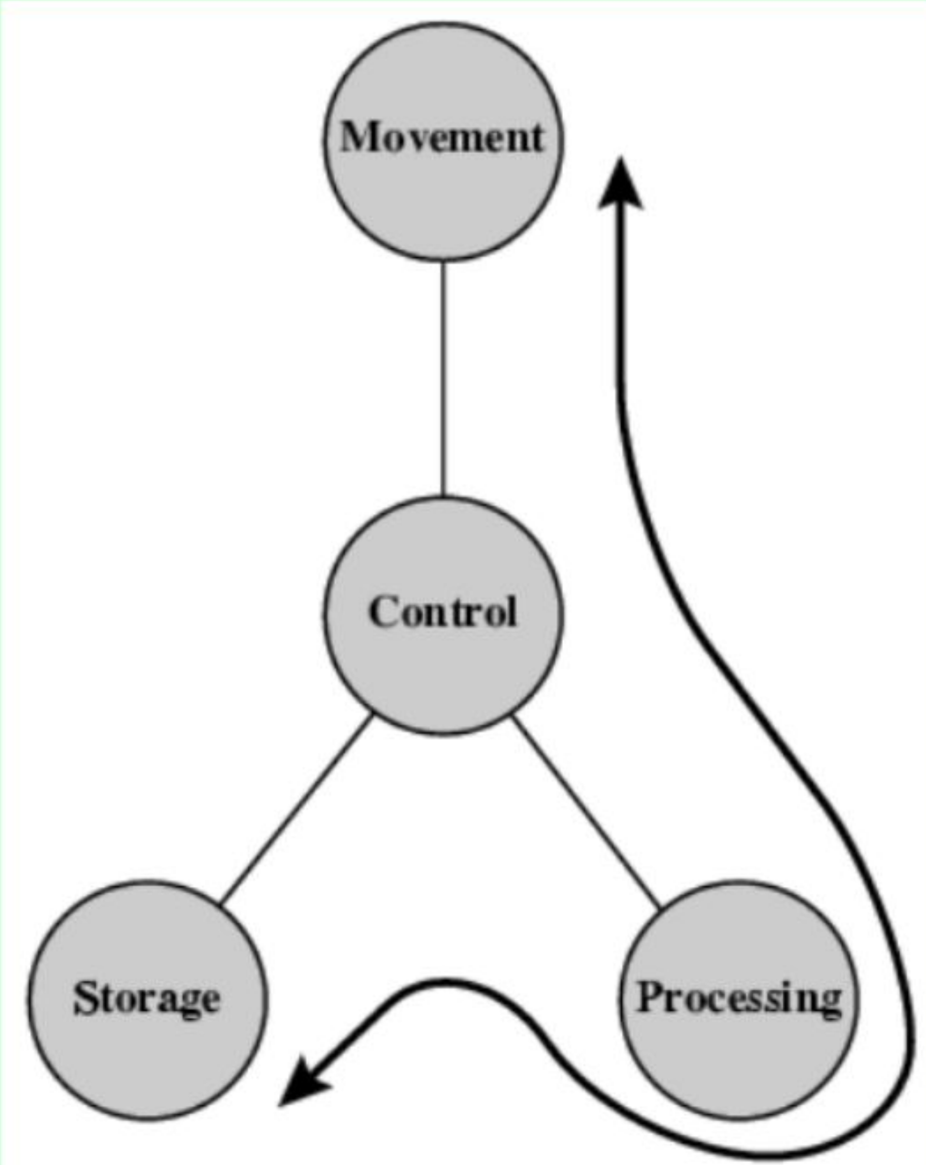
Any number-crunching application that takes data from memory and stores the result back in memory.

Operation (d)
Processing from storage to I/O



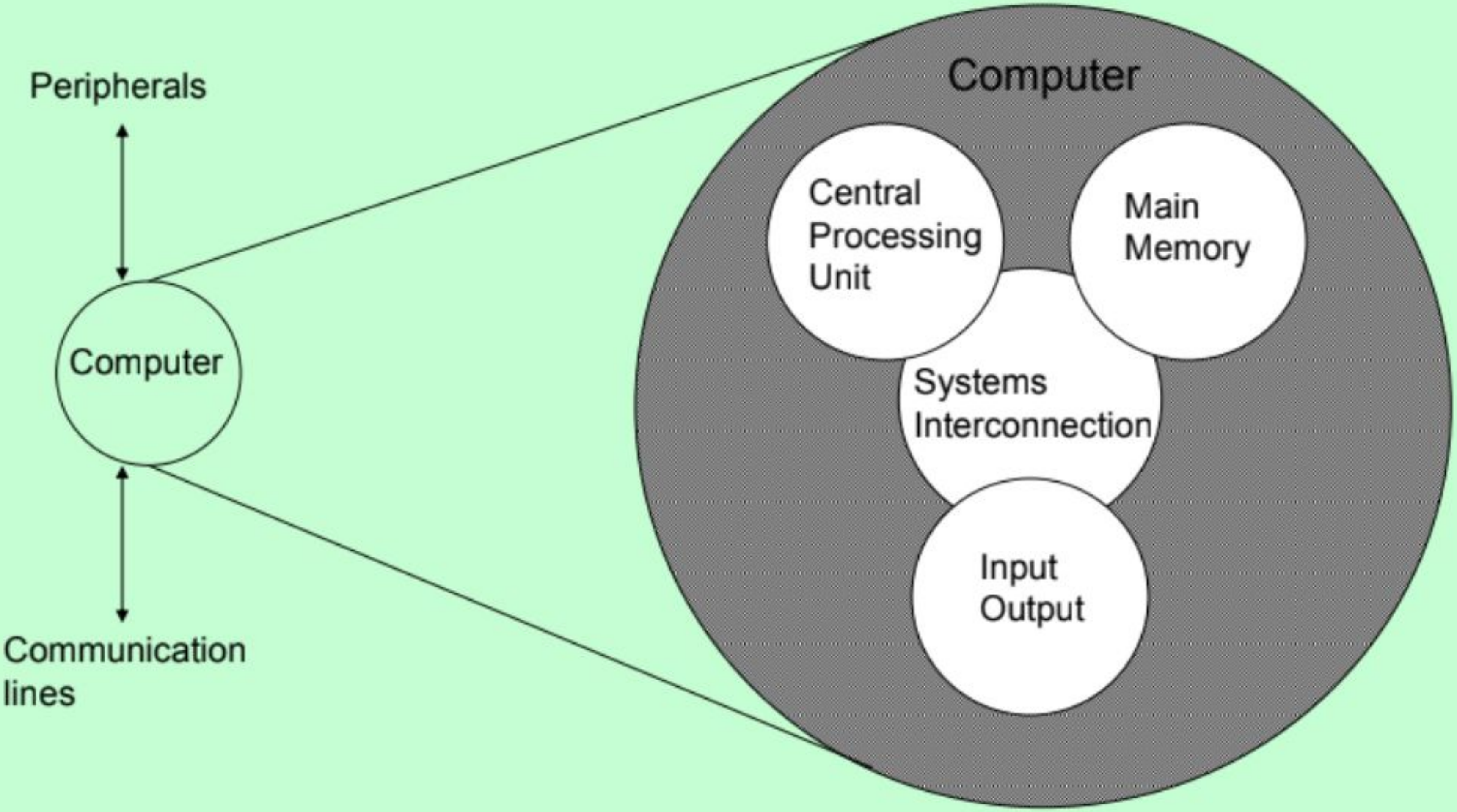
Example application?

Operation (d)
Processing from storage to I/O

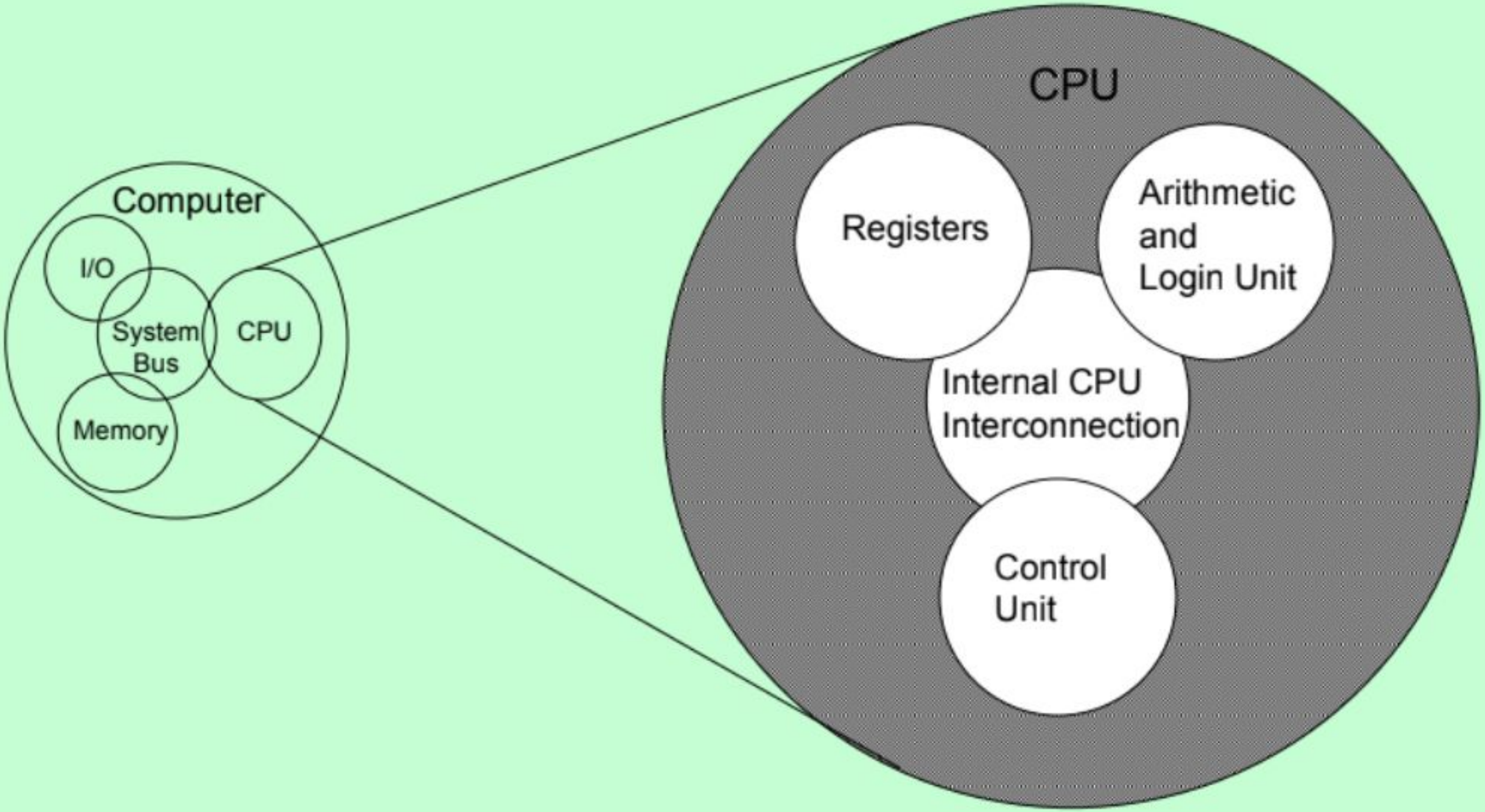


Receiving packets over a network interface, verifying their CRC, then storing them in memory.

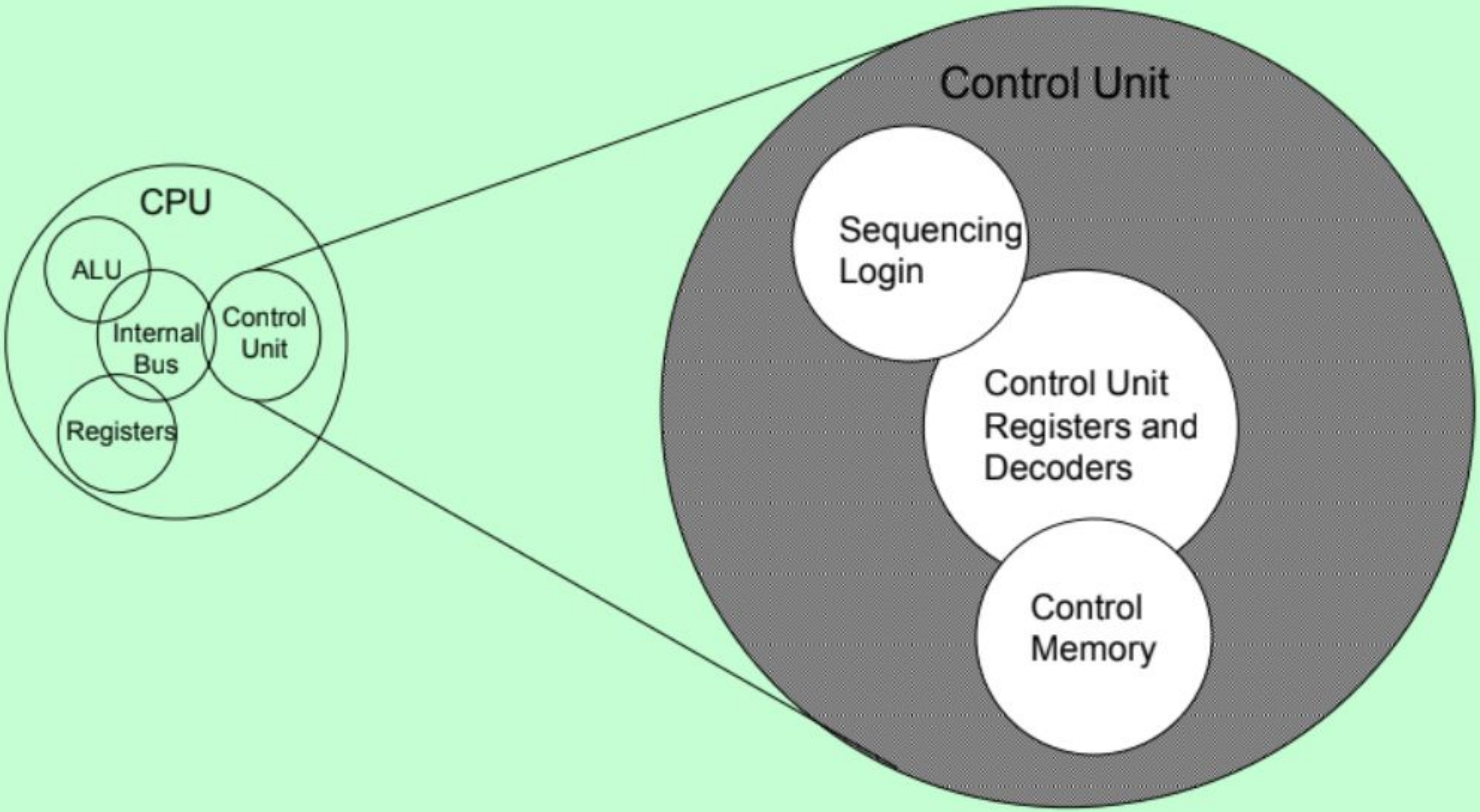
Structure - Top Level



Structure - The CPU



Structure - The Control Unit



Estructura y función

Structure

We now look in a general way at the internal structure of a computer. We begin with a traditional computer with a single processor that employs a microprogrammed control unit, then examine a typical multicore structure.

SIMPLE SINGLE-PROCESSOR COMPUTER Figure 1.1 provides a hierarchical view of the internal structure of a traditional single-processor computer. There are four main structural components:

Estructura

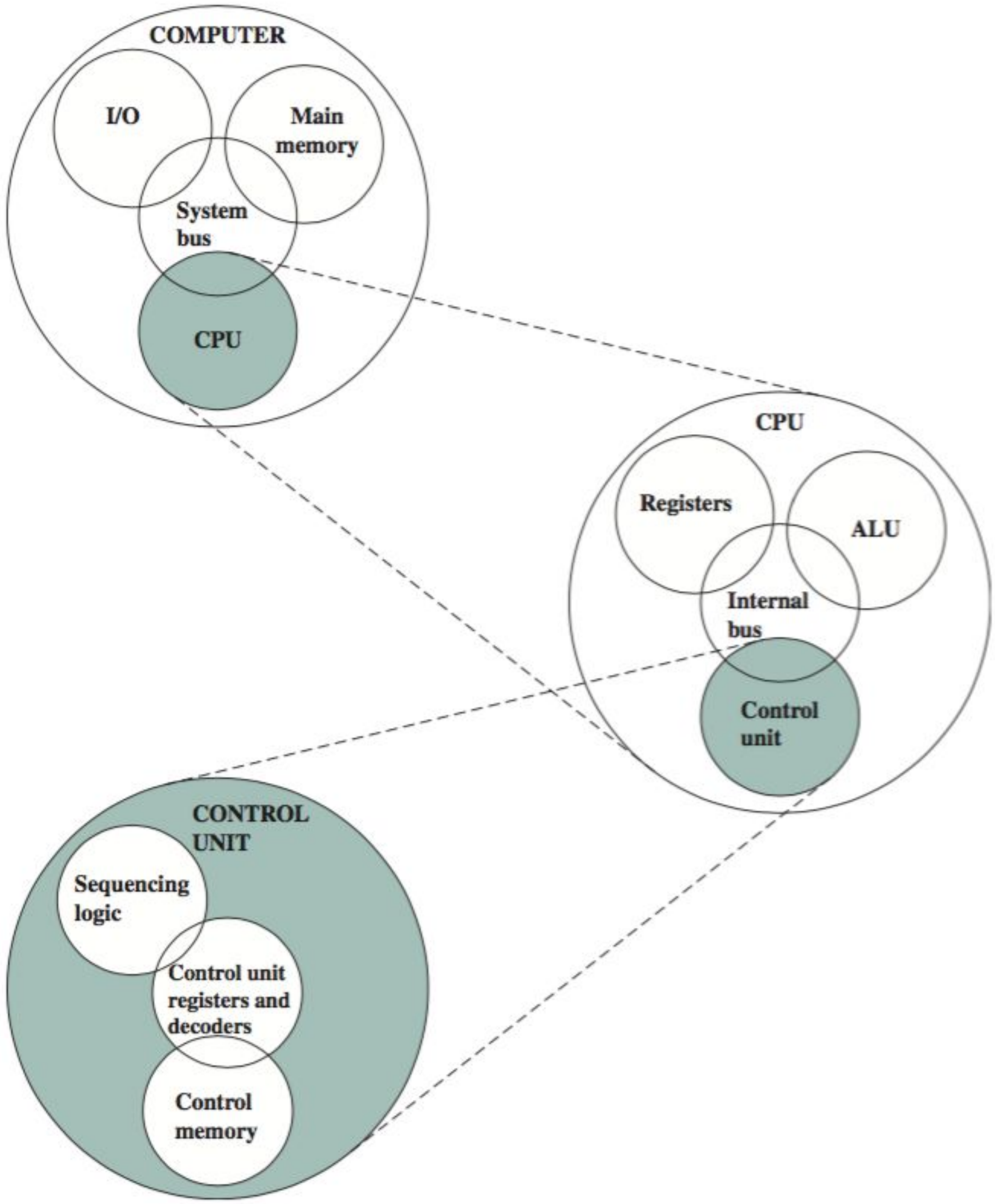
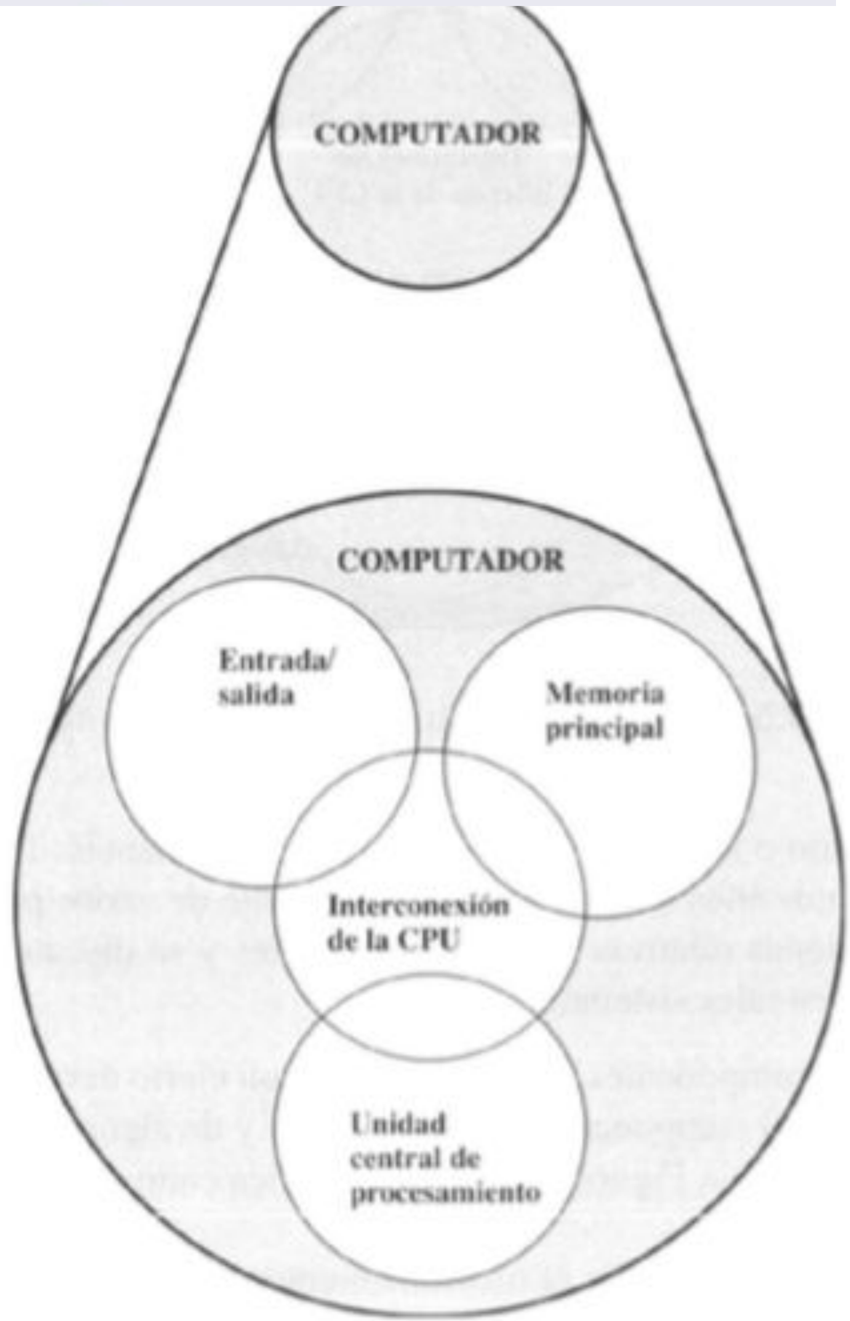


Figure 1.1 The Computer: Top-Level Structure

Estructura y función

Figura: El computado nivel superior.



Estructura y función

- **Unidad Central de Procesamiento (CPU, *Central Processing Unit*)**: controla el funcionamiento del computador y lleva a cabo sus funciones de procesamiento de datos. Frecuentemente se le llama simplemente **procesador**.
- **Memoria principal:** almacena datos.
- **E/S:** transfiere datos entre el computador y el entorno externo.
- **Sistema de interconexión:** es un mecanismo que proporciona la comunicación entre la CPU, la memoria principal y la E/S.

Estructura y función

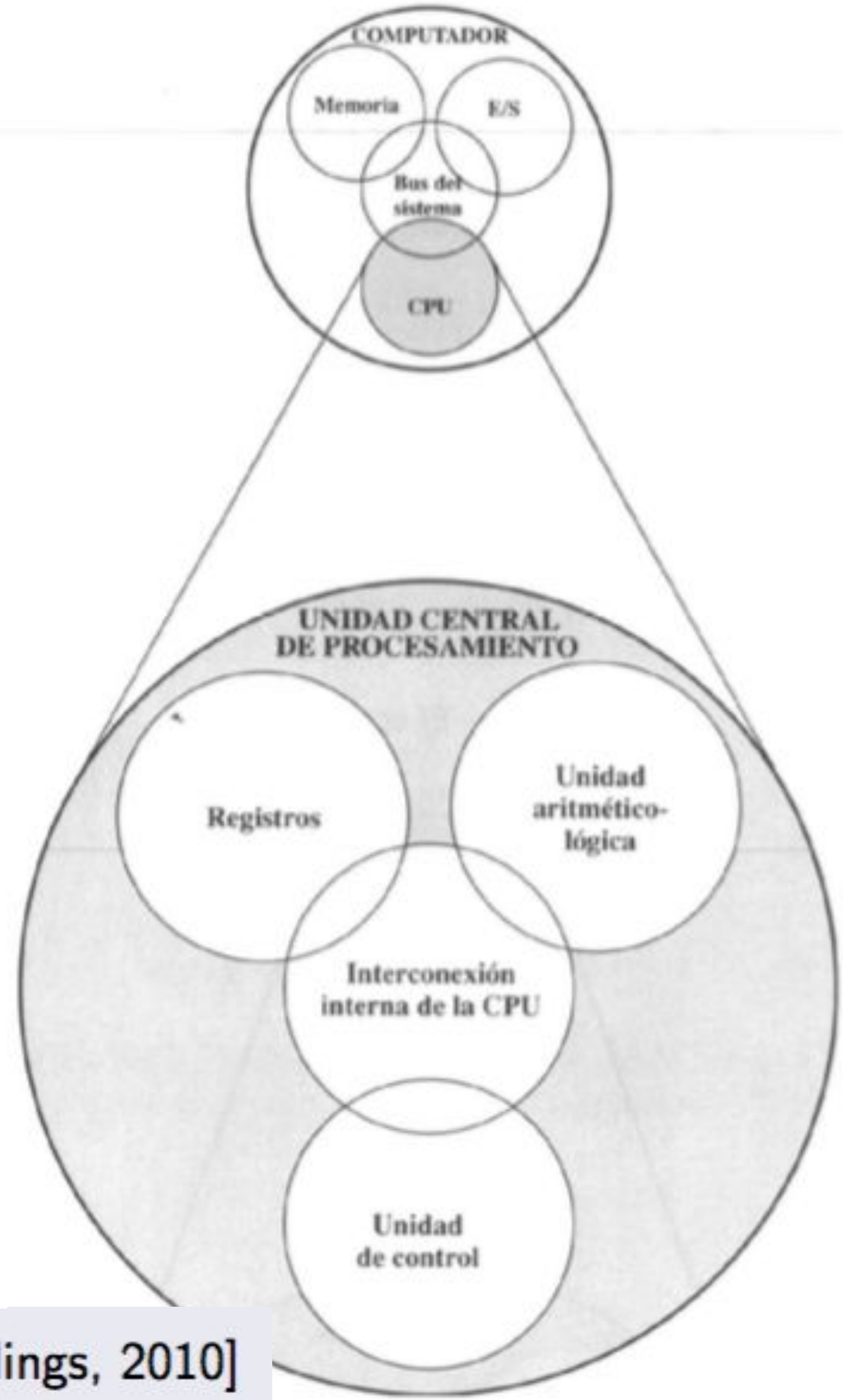


Figura: La CPU. Tomado de [Stallings, 2010]

Estructura y función

Estructura

- **Unidad de control:** controla el funcionamiento de la CPU y por tanto del computador.
- **Unidad aritmético-lógica (ALU, *Arithmetic Logic Unit*):** lleva a cabo las funciones de procesamiento de datos del computador.
- **Registros:** proporcionan almacenamiento interno a la CPU.
- **Interconexiones CPU:** son mecanismos que proporcionan comunicación entre la unidad de control, la ALU y los registros.

Estructura y función

El computador

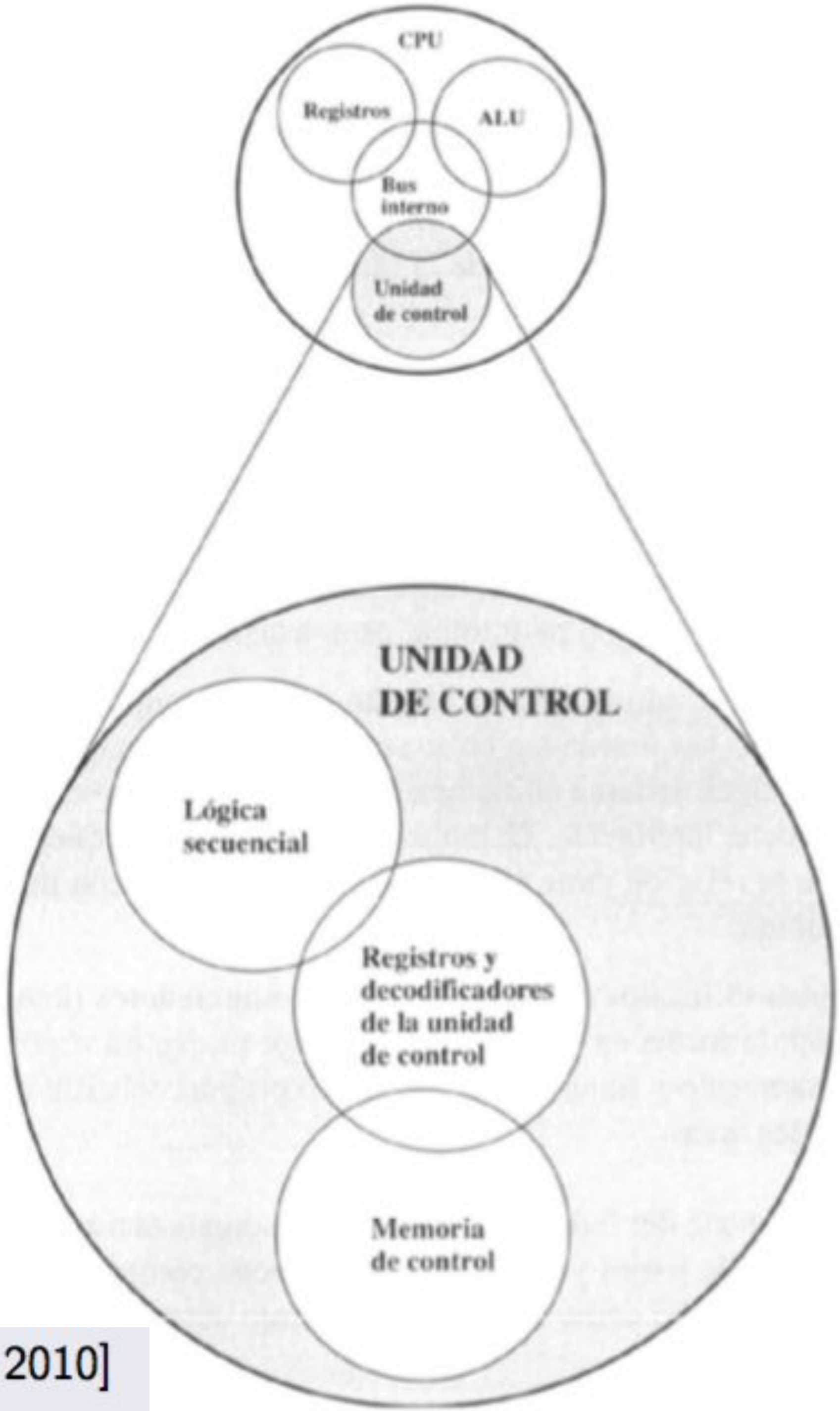


Figura: La unidad de control. Tomado de [Stallings, 2010]

MULTICORE COMPUTER STRUCTURE As was mentioned, contemporary computers generally have multiple processors. When these processors all reside on a single chip, the term *multicore computer* is used, and each processing unit (consisting of a control unit, ALU, registers, and perhaps cache) is called a *core*. To clarify the terminology, this text will use the following definitions.

- **Central processing unit (CPU):** That portion of a computer that fetches and executes instructions. It consists of an ALU, a control unit, and registers. In a system with a single processing unit, it is often simply referred to as a *processor*.
- **Core:** An individual processing unit on a processor chip. A core may be equivalent in functionality to a CPU on a single-CPU system. Other specialized processing units, such as one optimized for vector and matrix operations, are also referred to as cores.
- **Processor:** A physical piece of silicon containing one or more cores. The processor is the computer component that interprets and executes instructions. If a processor contains multiple cores, it is referred to as a **multicore processor**.

MULTICORE COMPUTER STRUCTURE

The most prominent elements on the motherboard are the chips. A **chip** is a single piece of semiconducting material, typically silicon, upon which electronic circuits and logic gates are fabricated. The resulting product is referred to as an **integrated circuit**.

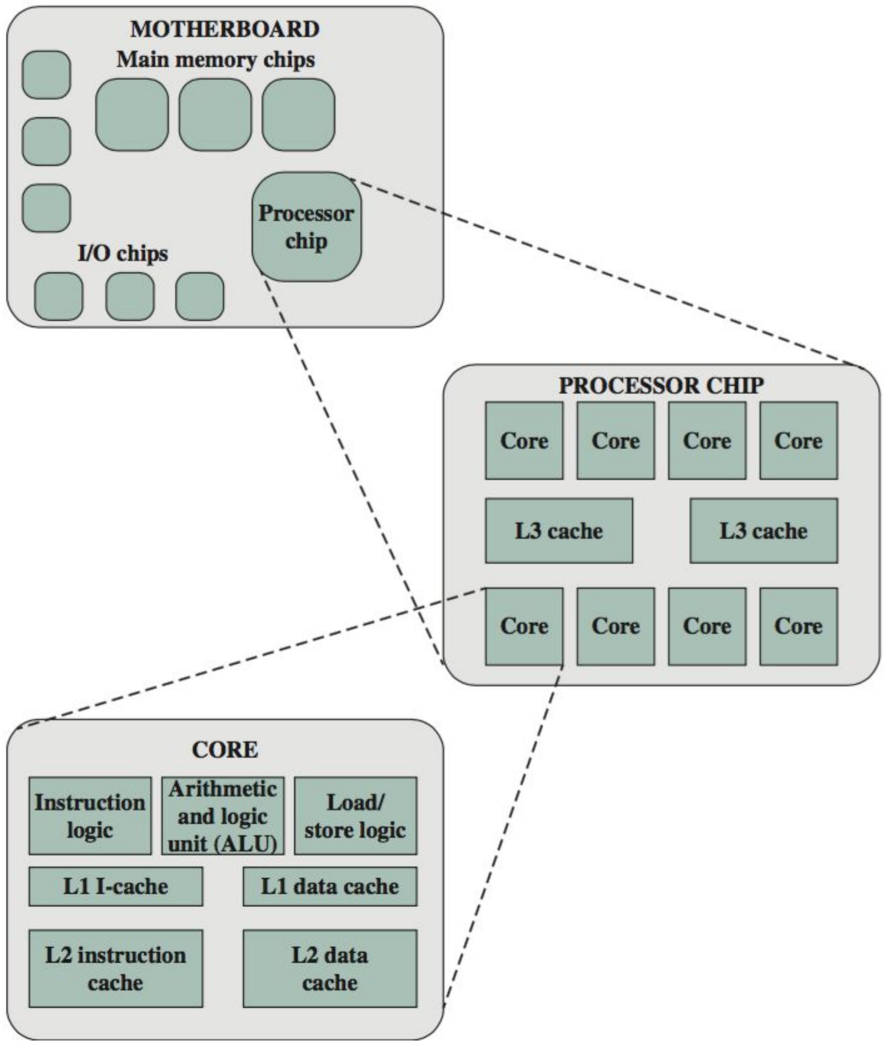


Figure 1.2 Simplified View of Major Elements of a Multicore Computer

MULTICORE COMPUTER STRUCTURE

Figure 1.2 shows a processor chip that contains eight cores and an L3 cache. Not shown is the logic required to control operations between the cores and the cache and between the cores and the external circuitry on the motherboard. The figure indicates that the L3 cache occupies two distinct portions of the chip surface. However, typically, all cores have access to the entire L3 cache via the aforementioned control circuits.

The core also contains an L1 cache, split between an instruction cache (I-cache) that is used for the transfer of instructions to and from main memory, and an L1 data cache, for the transfer of operands and results. Typically, today's processor chips also include an L2 cache as part of the core. In many cases, this cache is also split between instruction and data caches, although a combined, single L2 cache is also used

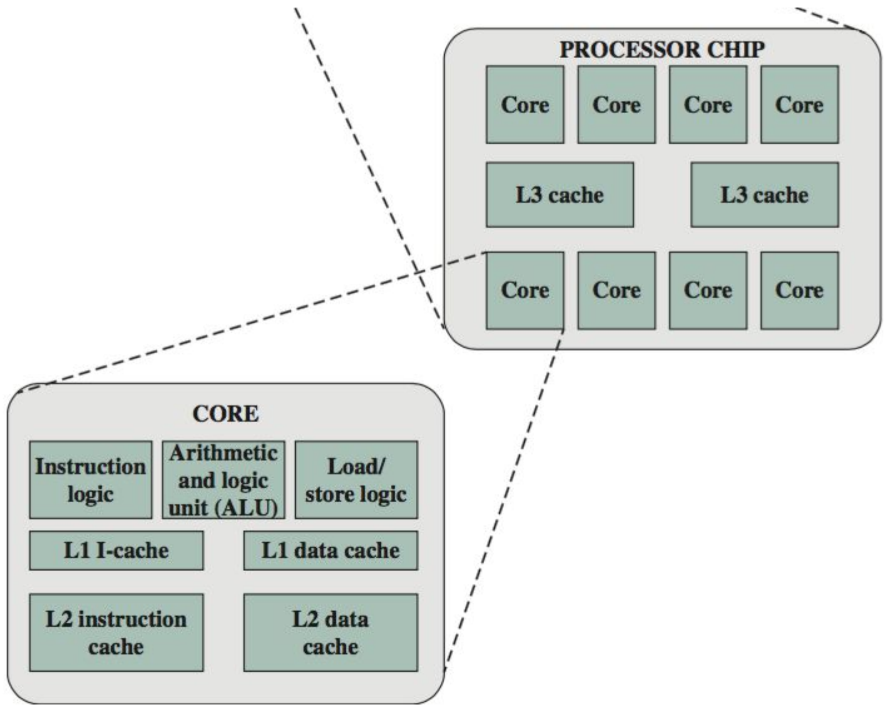


Figure 1.2 Simplified View of Major Elements of a Multicore Computer

MULTICORE COMPUTER STRUCTURE

Next, we zoom in on the structure of a single core, which occupies a portion of the processor chip. In general terms, the functional elements of a core are:

- **Instruction logic:** This includes the tasks involved in fetching instructions, and decoding each instruction to determine the instruction operation and the memory locations of any operands.
- **Arithmetic and logic unit (ALU):** Performs the operation specified by an instruction.
- **Load/store logic:** Manages the transfer of data to and from main memory via cache.

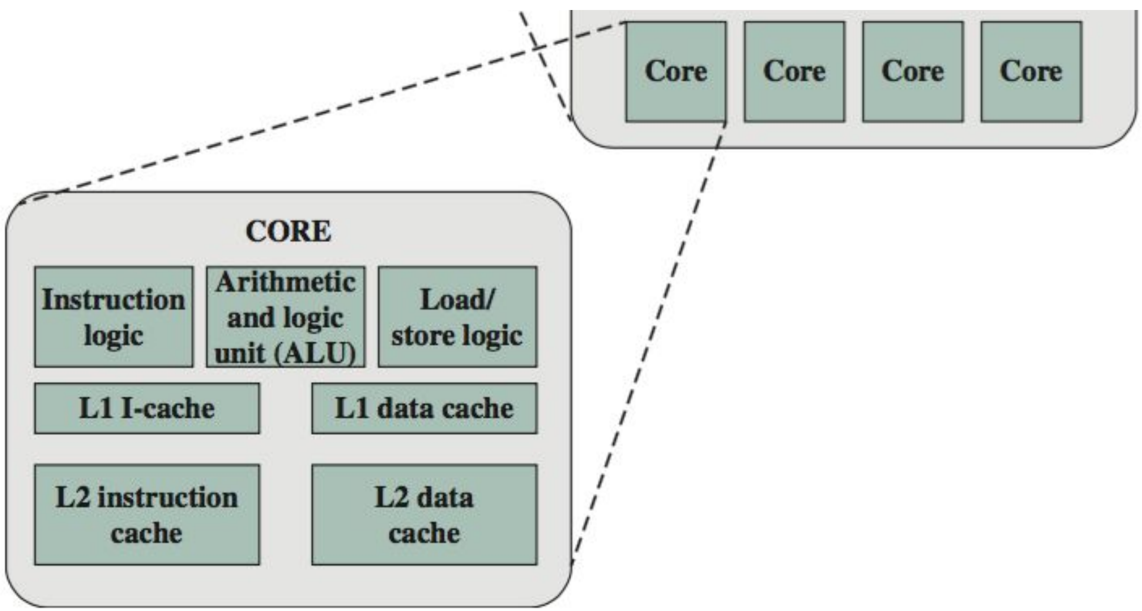


Figure 1.2 Simplified View of Major Elements of a Multicore Computer

MULTICORE COMPUTER STRUCTURE

Figure 1.4 is a photograph of the processor chip for the IBM zEnterprise EC12 mainframe computer. This chip has 2.75 billion transistors. The superimposed labels indicate how the silicon real estate of the chip is allocated

We see that this chip has six cores, or processors. In addition, there are two large areas labeled L3 cache, which are shared by all six processors. **The L3 control logic** controls traffic between the L3 cache and the cores and between the L3 cache and the external environment. Additionally, there is **storage control (SC) logic** between the cores and the L3 cache. The **memory controller (MC) function** controls access to memory external to the chip. The **GX I/O bus** controls the interface to the channel adapters accessing the I/O.

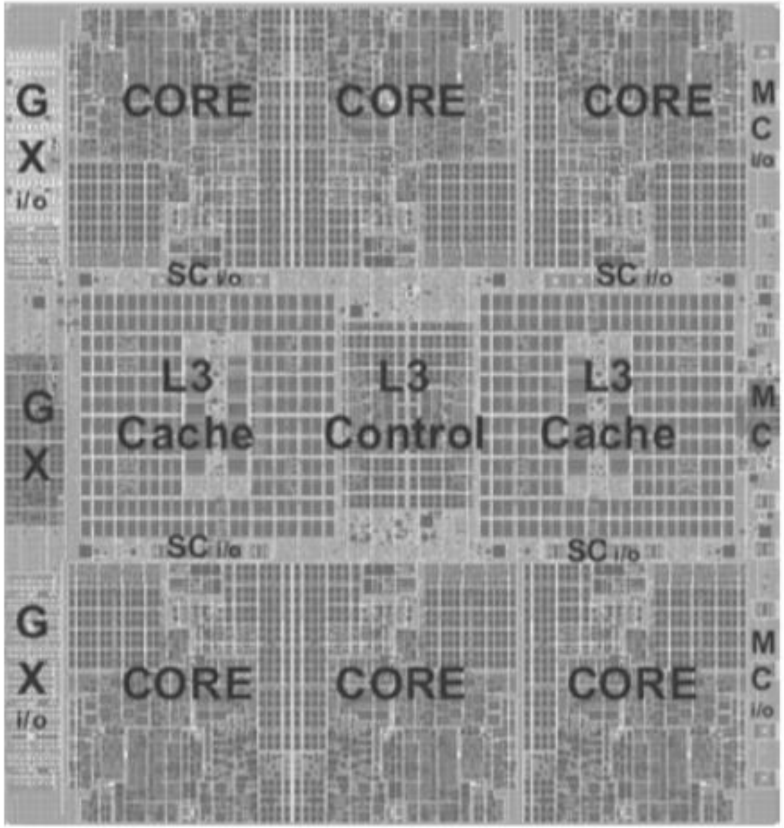


Figure 1.4 zEnterprise EC12 Processor Unit (PU) chip diagram
Source: IBM zEnterprise EC12 Technical Guide, December 2013, SG24-8049-01. IBM, Reprinted by Permission

MULTICORE COMPUTER STRUCTURE

Going down one level deeper, we examine the internal structure of a single core, as shown in the photograph of Figure 1.5. Keep in mind that this is a portion of the silicon surface area making up a single-processor chip. The main sub-areas within this core area are the following:

ISU (instruction sequence unit): Determines the sequence in which instructions are executed in what is referred to as a superscalar architecture

IFU (instruction fetch unit): Logic for fetching instructions.

- **IDU (instruction decode unit):** The IDU is fed from the IFU buffers, and is responsible for the parsing and decoding of all z/Architecture operation codes.
- **LSU (load-store unit):** The LSU contains the 96-kB L1 data cache,1 and manages data traffic between the L2 data cache and the functional execution units. It is responsible for handling all types of operand accesses of all lengths, modes, and formats as defined in the z/Architecture.

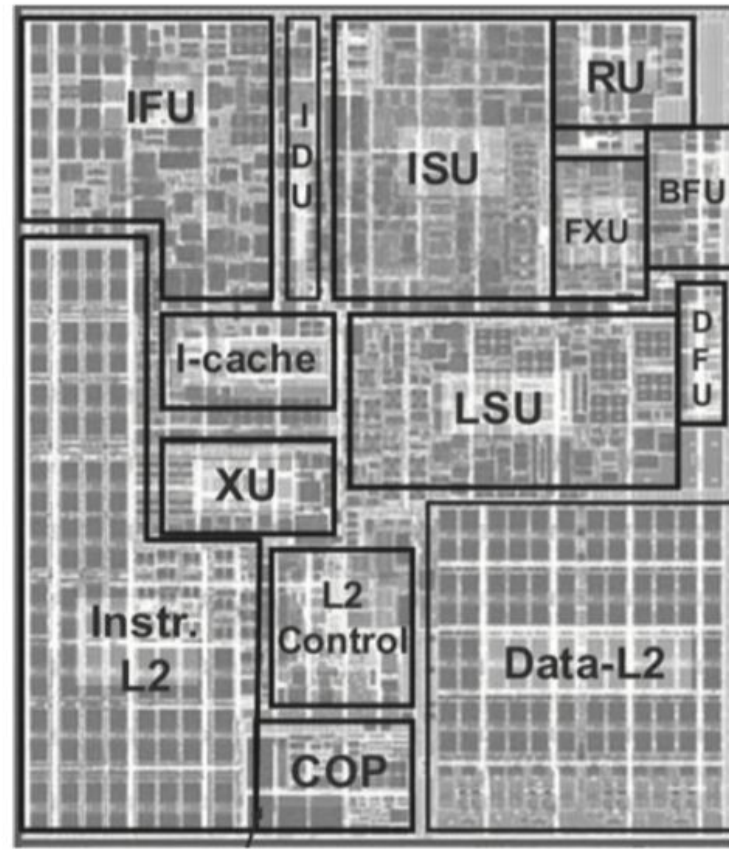


Figure 1.5 zEnterprise EC12 Core layout
Source: IBM zEnterprise EC12 Technical Guide, December 2013, SG24-8049-01. IBM, Reprinted by Permission

MULTICORE COMPUTER STRUCTURE

XU (translation unit): This unit translates logical addresses from instructions into physical addresses in main memory. The XU also contains a translation lookaside buffer (TLB) used to speed up memory access.
FXU (fixed-point unit): The FXU executes fixed-point arithmetic operations.

- **BFU (binary floating-point unit):** The BFU handles all binary and hexadecimal floating-point operations, as well as fixed-point multiplication operations.
- **DFU (decimal floating-point unit):** The DFU handles both fixed-point and floating-point operations on numbers that are stored as decimal digits.
- **RU (recovery unit):** The RU keeps a copy of the complete state of the system that includes all registers, collects hardware fault signals, and manages the hardware recovery actions.

- **COP (dedicated co-processor):** The COP is responsible for data compression and encryption functions for each core.
- **I-cache:** This is a 64-kB L1 instruction cache, allowing the IFU to prefetch instructions before they are needed.
- **L2 control:** This is the control logic that manages the traffic through the two L2 caches.
- **Data-L2:** A 1-MB L2 data cache for all memory traffic other than instructions.
- **Instr-L2:** A 1-MB L2 instruction cache.

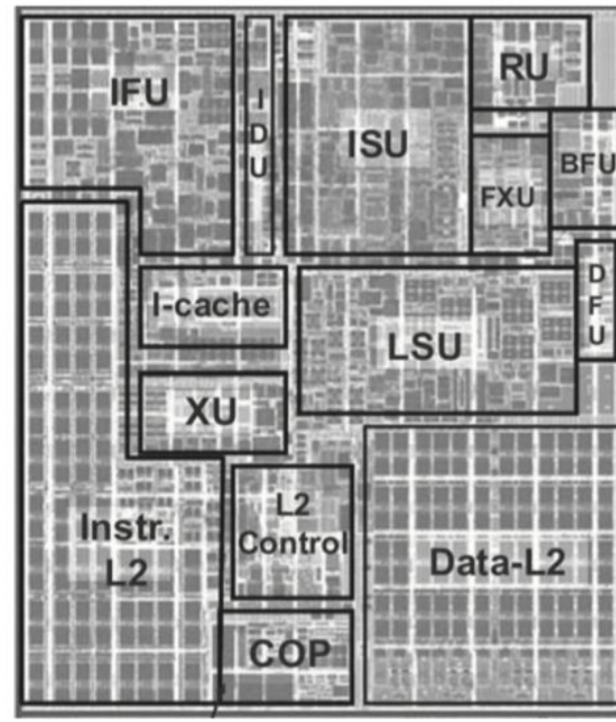


Figure 1.5 zEnterprise EC12 Core layout
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