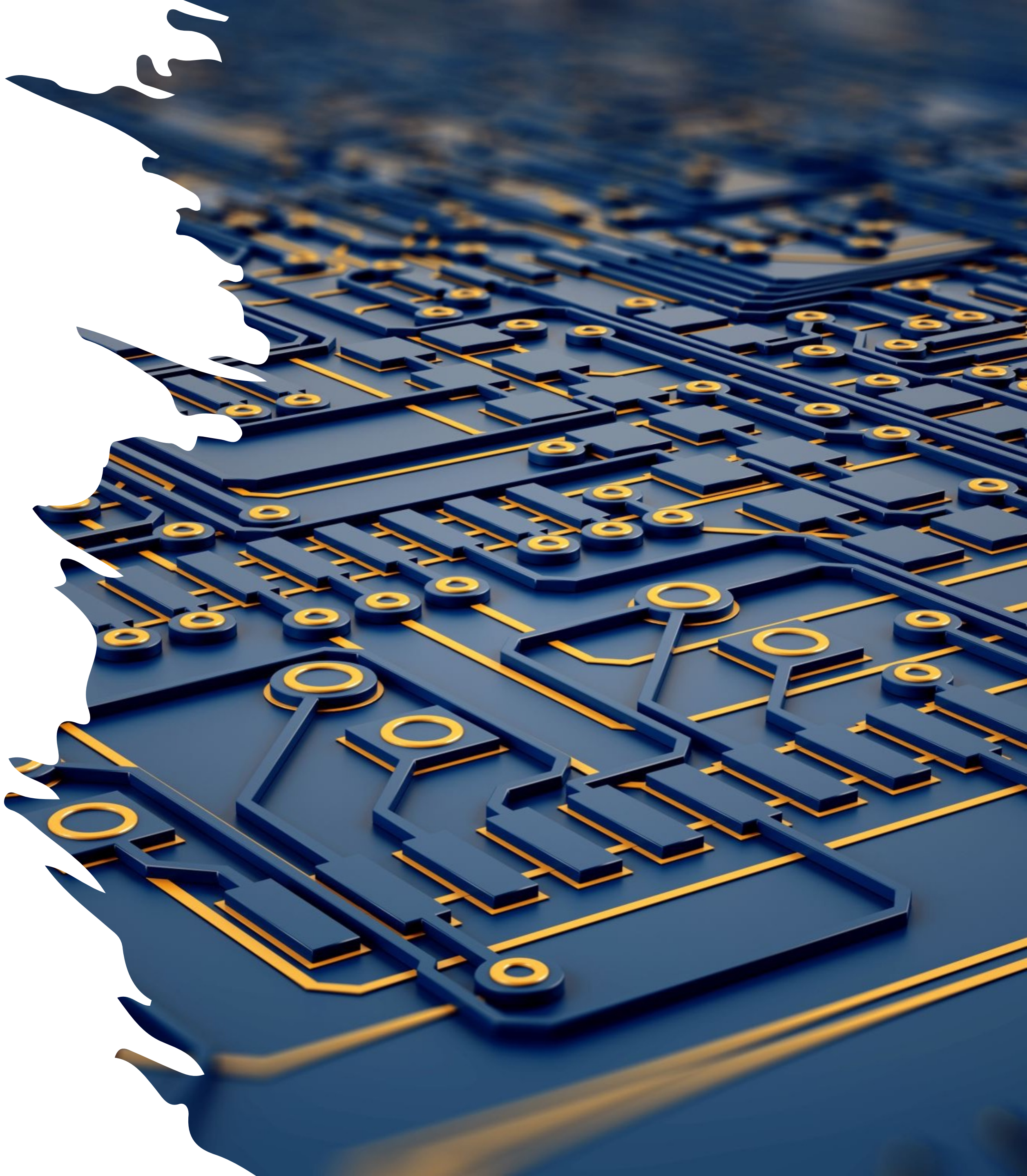
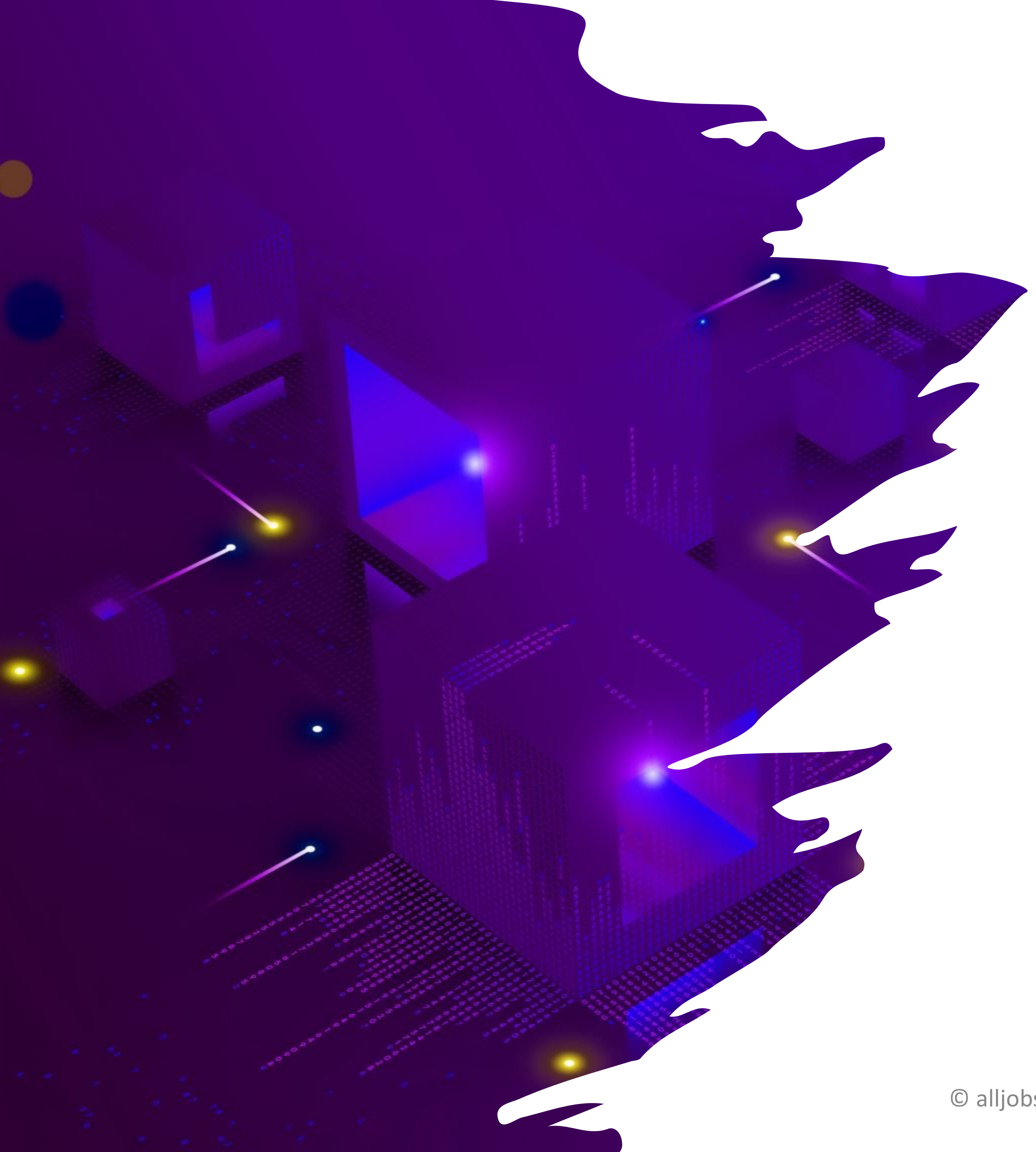
Embedded Processors





Contents

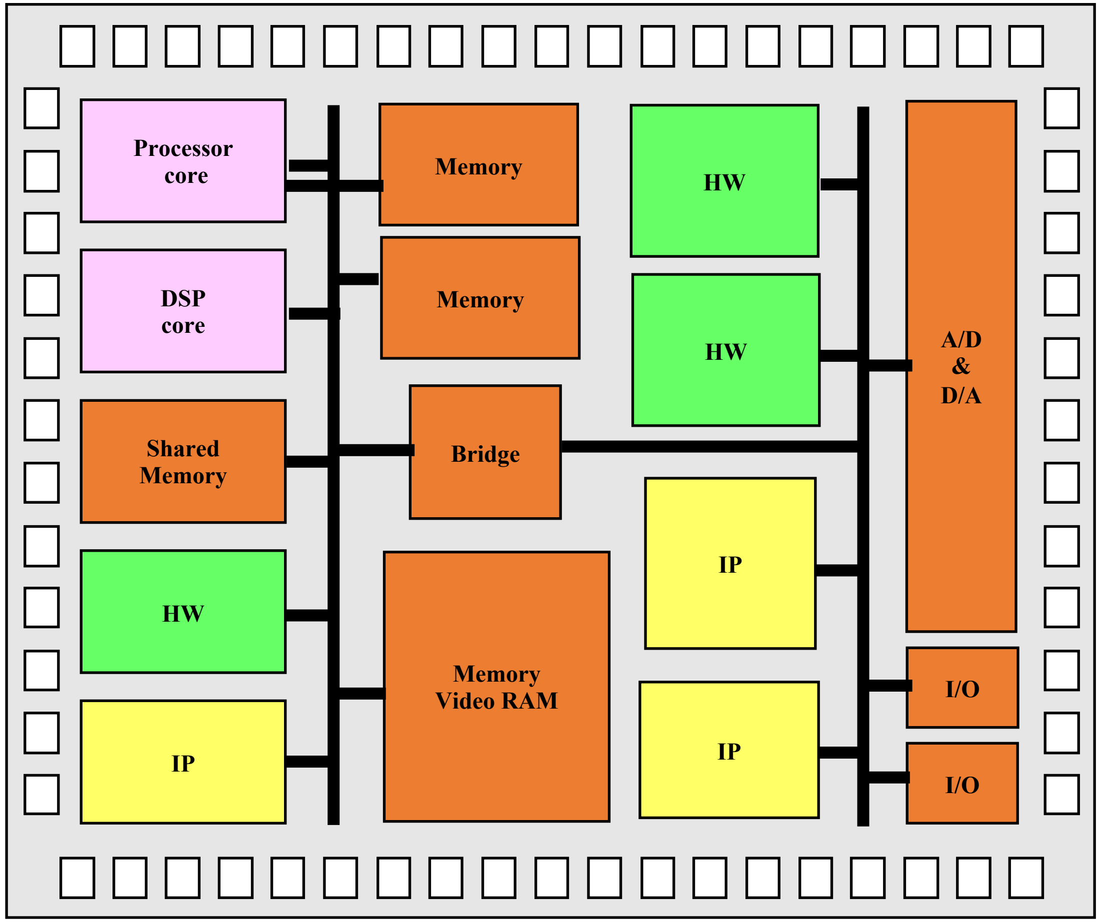
- Introduction.
- What is an Embedded Processor ?
- Types of Embedded Processor.
- Characteristic of Embedded Processor.
- Architecture.
- Configurability.
- Fixed processors.
- Fixed processor cores with reconfigurable logic.
- Configurable Processor.
- Examples of Embedded Processor.

Introduction

The system functionality is partitioned into Hardware, Software, and the Interface.

Software part runs on programmable processors (embedded processors).

Hardware part runs on IP blocks or custom designed Hardware blocks.



What is an embedded processor?

A programmable processor ‘embedded’ into an embedded system (on a chip).

An embedded processor can be a general-purpose processor, DSP, microcontroller, or a processor optimized to a specific application.

Programming self-contained computers : End-user, application developer, system integrator, and component manufacturer are all separated.

Programming embedded processors : Most software is provided by system integrator.

Types of Embedded Processor

- Computational microprocessors.
- Embedded general purpose microprocessors.
- Microcontrollers
- Domain-specific processors

General Purpose Processors (GPPs)

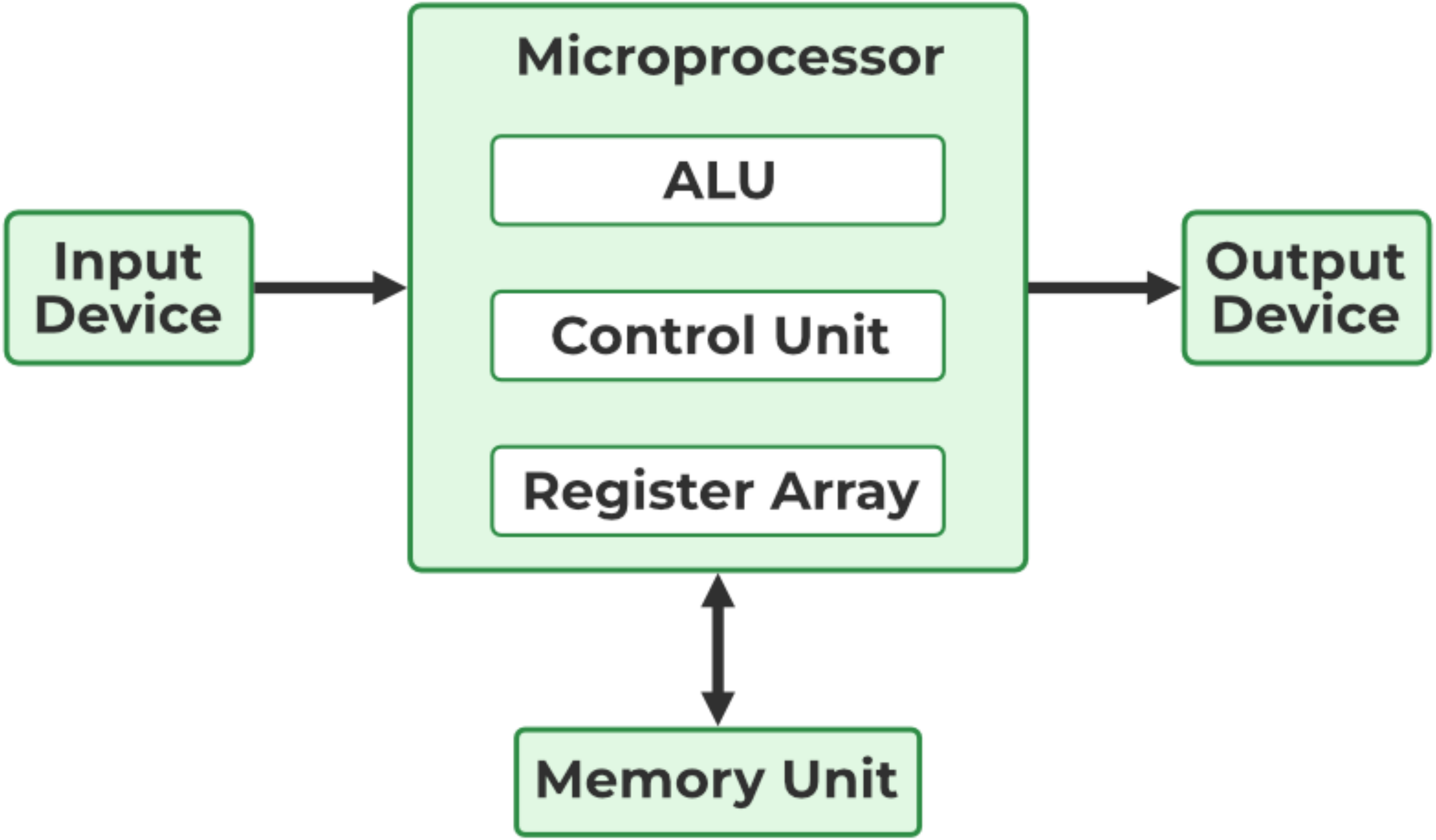
Capable of executing a wide range of tasks. They are used in computers and other devices that require high-performance processing capabilities. Some features of general-purpose processors include:

1. **Instruction set:** General purpose processors have a large and complex instruction set, which allows them to perform a wide range of tasks.
2. **Multi-core:** Many general-purpose processors are multi-core, which means they have multiple processors on a single chip. This allows them to perform multiple tasks concurrently, improving performance.
3. **Clock speed:** The clock speed of a processor determines how fast it can execute instructions. General-purpose processors typically have high clock speeds, which allows them to perform tasks quickly.
4. **Cache:** General-purpose processors have one or more levels of cache, which is a small amount of high-speed memory that is used to store frequently accessed data. This helps to improve the performance of the processor.
5. **Compatibility:** General-purpose processors are typically compatible with a wide range of operating systems and software applications.
6. **Virtualization:** Many general-purpose processors support virtualization, which allows them to run multiple virtual machines on a single physical machine.
7. **Power consumption:** General-purpose processors can have high power consumption, which can be a concern in devices where power is limited

2. Microprocessors

A microprocessor is a processor that is contained on a microchip, or integrated circuit (IC). executes the instructions of a computer program. Some features of microprocessors include:

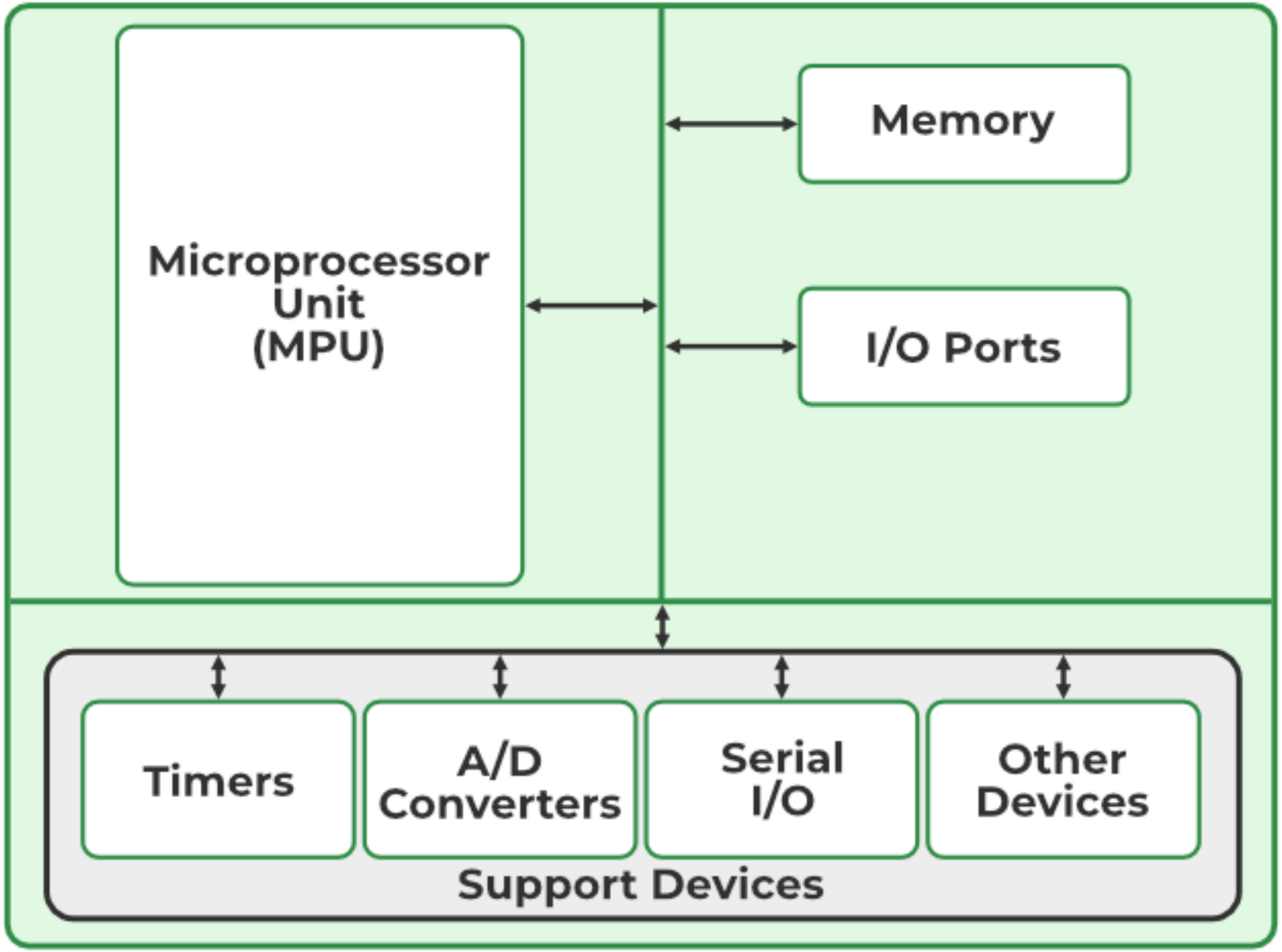
1. **Instruction set:** Microprocessors have a specific instruction set that defines the operations that they can perform.
2. **Clock speed:** The clock speed of a microprocessor determines how fast it can execute instructions. Microprocessors typically have high clock speeds, which allows them to perform tasks quickly.
3. **Data bus:** The data bus is a communication pathway that is used to transfer data between the microprocessor and other components in a system.
4. **Address bus:** The address bus is a communication pathway that is used to transfer the address of a memory location between the microprocessor and other components in a system.
5. **Cache:** Many microprocessors have one or more levels of cache, which is a small amount of high-speed memory that is used to store frequently accessed data. This helps to improve the performance of the microprocessor.
6. **Power consumption:** Microprocessors can have relatively high power consumption, which can be a concern in devices where power is limited.
7. **Size:** Microprocessors are designed to be small, as they are typically used in devices where space is at a premium.
8. **Cost:** Microprocessors can vary in cost depending on their capabilities and features.


Microprocessor
ALU
Control Unit
Register Array
Input Device
Output Device
Memory Unit

3. Microcontrollers

A microcontroller is a small, low-power computer that is contained in a single integrated circuit (IC). It is a type of embedded processor that is used in a wide range of devices, including consumer electronics, industrial control systems, and automotive systems. Some features of microcontrollers include:

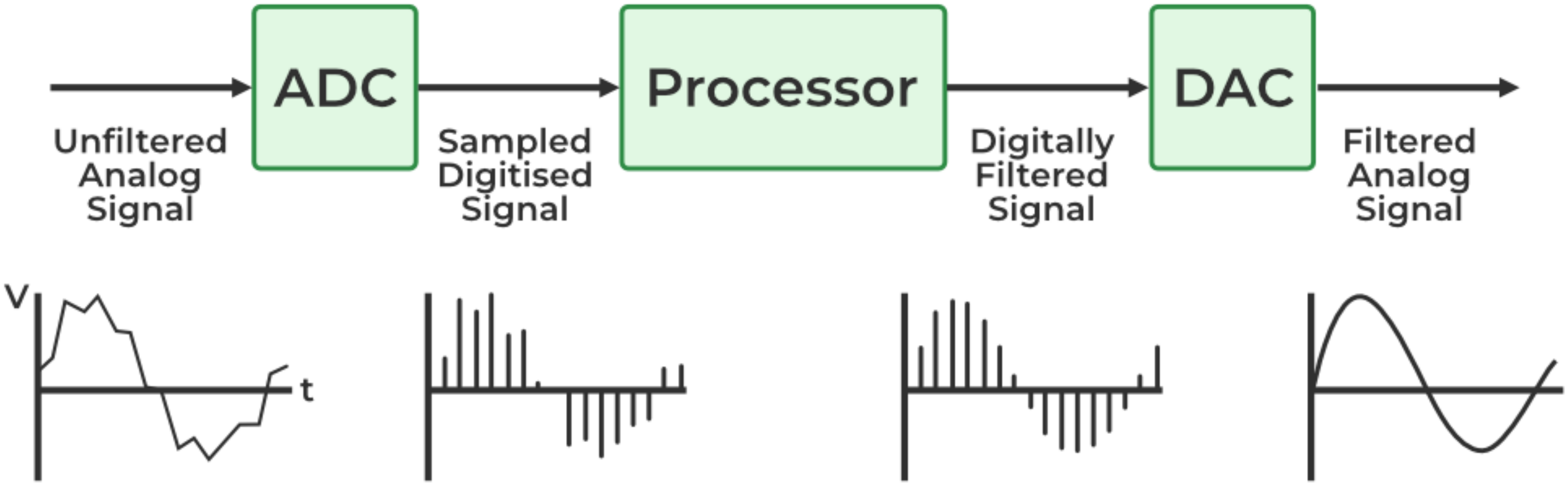
1. **On-chip peripherals:** Many microcontrollers have a variety of on-chip peripherals, such as timers, serial ports, and analog-to-digital converters, which allow them to interface with external devices.
2. **Memory:** Microcontrollers have both program memory, which stores the instructions that are executed by the processor, and data memory, which is used to store variables and other data.
3. **Input/output (I/O) pins:** Microcontrollers have a set of I/O pins that can be used to interface with external devices, such as sensors or actuators.
4. **Low power consumption:** Microcontrollers are designed to be low-power, which makes them suitable for use in battery-powered devices.
5. **Cost:** Microcontrollers are typically less expensive than general-purpose processors, as they are designed for specific tasks and do not have as many capabilities.
6. **Size:** Microcontrollers are small, which makes them suitable for use in compact devices.
7. **Flexibility:** Microcontrollers are highly flexible and can be programmed to perform a wide range of tasks.


Microprocessor Unit (MPU)
Memory
I/O Ports
Timers
A/D Converters
Serial I/O
Other Devices
Support Devices

4. Digital Signal Processor (DSP)

Digital signal processors (DSPs) are specialized microprocessors that are designed to process digital signals. They are used in a wide range of applications, including audio and video processing, telecommunications, and control systems. Some key features of DSPs include:

1. **High-speed processing:** DSPs are designed to process large amounts of data quickly, making them well-suited for real-time applications.
2. **Parallel processing:** Many DSPs are designed to perform multiple operations simultaneously, which can increase their processing speed and efficiency.
3. **Hardware support for common operations:** DSPs often include specialized hardware to support common operations, such as filtering and FFTs (Fast Fourier Transforms), which can reduce the processing overhead and improve performance.
4. **Low power consumption:** DSPs are often designed to be energy-efficient, making them well-suited for battery-powered applications.
5. **Programmability:** Most DSPs are programmable, which means that they can be customized to perform specific tasks. This allows them to be used in a wide range of applications.


ADC
Processor
DAC
Unfiltered Analog Signal
Sampled Digitised Signal
Digitally Filtered Signal
Filtered Analog Signal
V
t

5. Single-Purpose Embedded Processor

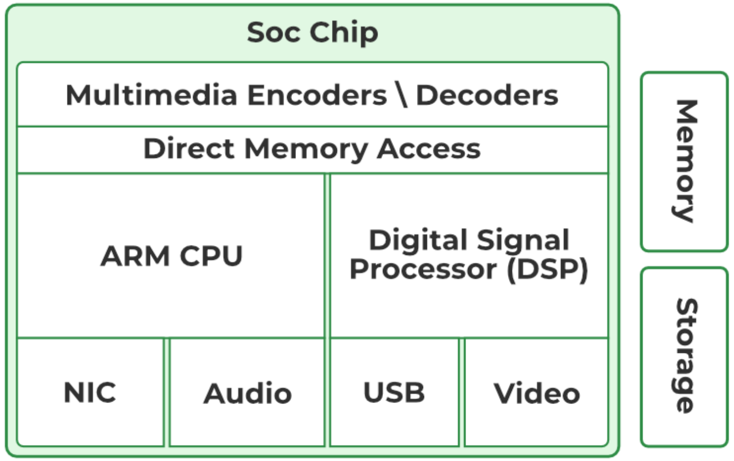
Single-purpose embedded processors, also known as application-specific embedded processors, are microprocessors that are designed to perform a specific task or set of tasks. They are used in a wide range of applications, including automotive systems, industrial control systems, and consumer electronics. Some key features of single-purpose embedded processors include:

1. **Specialized functionality:** Single-purpose embedded processors are designed to perform a specific task or set of tasks, making them well-suited for applications that require highly specialized functionality.
2. **Low power consumption:** Single-purpose embedded processors are often designed to be energy-efficient, making them well-suited for battery-powered applications.
3. **Compact size:** Single-purpose embedded processors are often designed to be small and lightweight, making them well-suited for applications where space is limited.
4. **High reliability:** Single-purpose embedded processors are often designed to be highly reliable, as they are typically used in mission-critical applications where downtime is not an option.
5. **Low cost:** Single-purpose embedded processors are often less expensive than general-purpose processors, as they are designed to perform a specific set of tasks and do not require the same level of flexibility and programmability.

6. System-on-Chip (SoC)

System-on-Chip (SoC) is an integrated circuit that integrates all components of a computer or other electronic system onto a single chip. Some key features of SoCs include:

1. **Integration:** SoCs integrate all or most of the components of a system onto a single chip, which can reduce the size and complexity of the system.
2. **Low power consumption:** SoCs can be designed to be highly power efficient, which can be useful in battery-powered or energy-sensitive applications.
3. **High performance:** SoCs can be designed for high performance, making them suitable for applications that require a lot of processing power.
4. **Customization:** SoCs can be customized for specific applications, allowing them to be optimized for the specific requirements of those applications.
5. **Reduced component count:** Because many components are integrated onto a single chip, SoCs can reduce the component count of a system, which can make the system simpler and easier to manufacture.

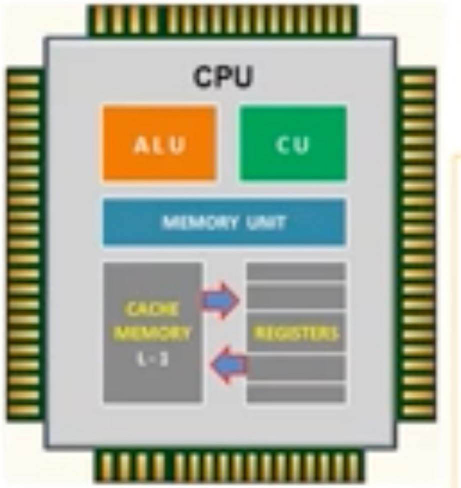


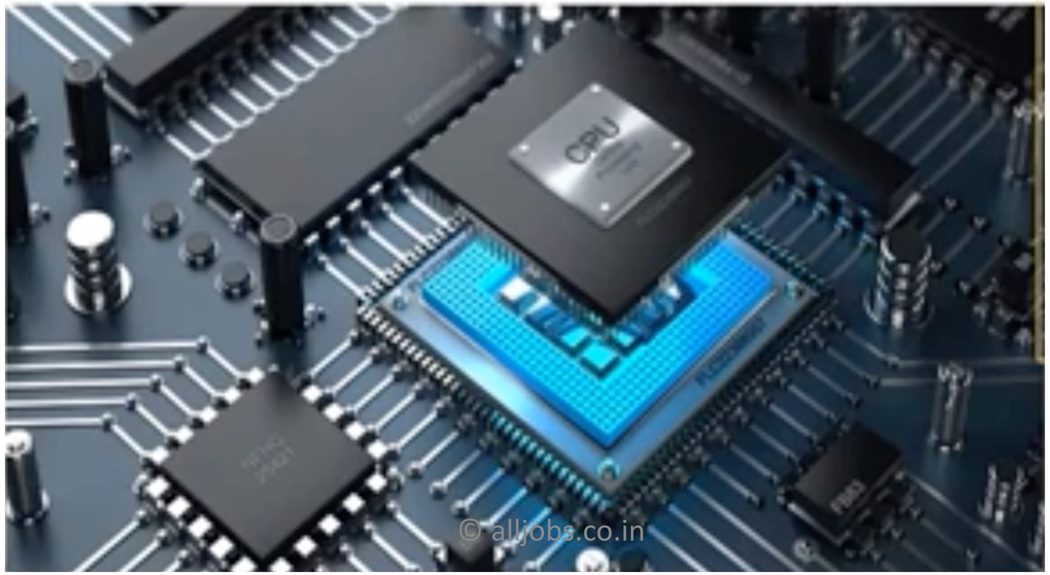

intel
CORE

Multi-Core Computer

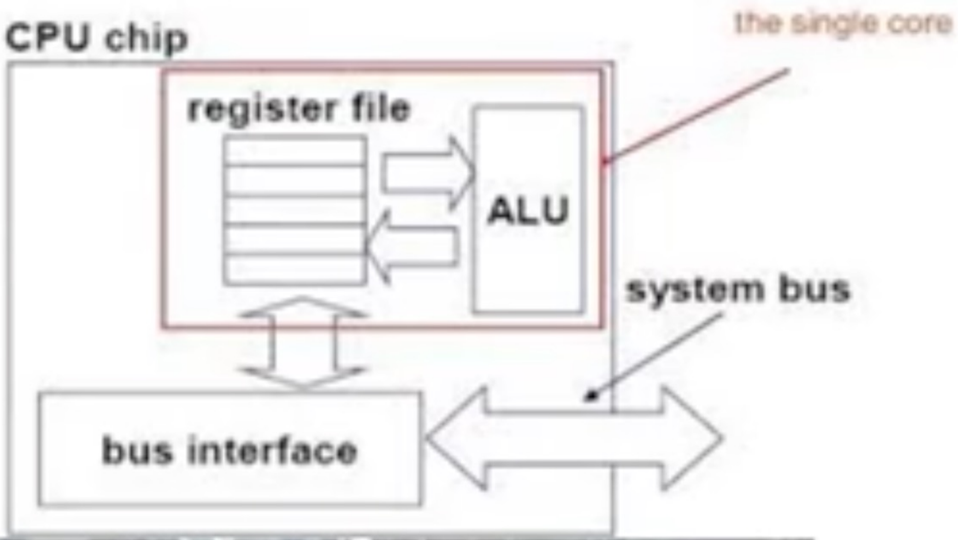
- A **multi-core** microprocessor is one that combines two or more independent processors into a single package, often a single integrated circuit (IC).
- A **dual-core** device contains two independent microprocessors.
- In general, multi-core microprocessors allow a computing device to exhibit some form of thread-level parallelism (**TLP**) without including multiple microprocessors in separate physical packages.

Dual Core/Quad Core/Octa Core/ Hexa Core

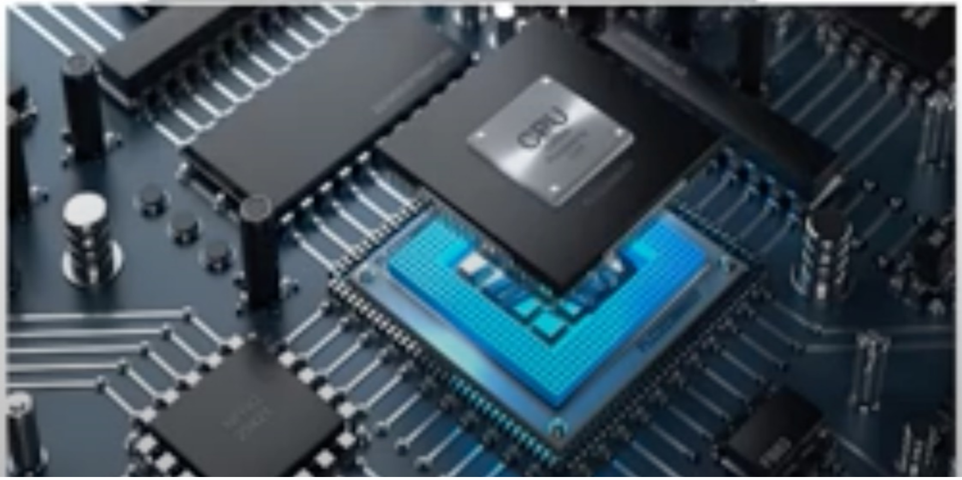


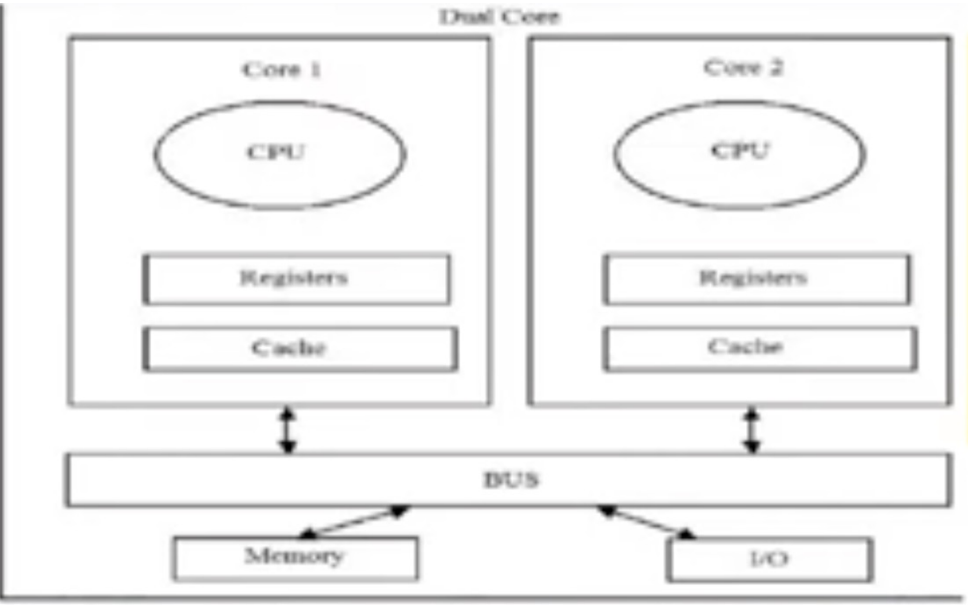


Single-core CPU chip



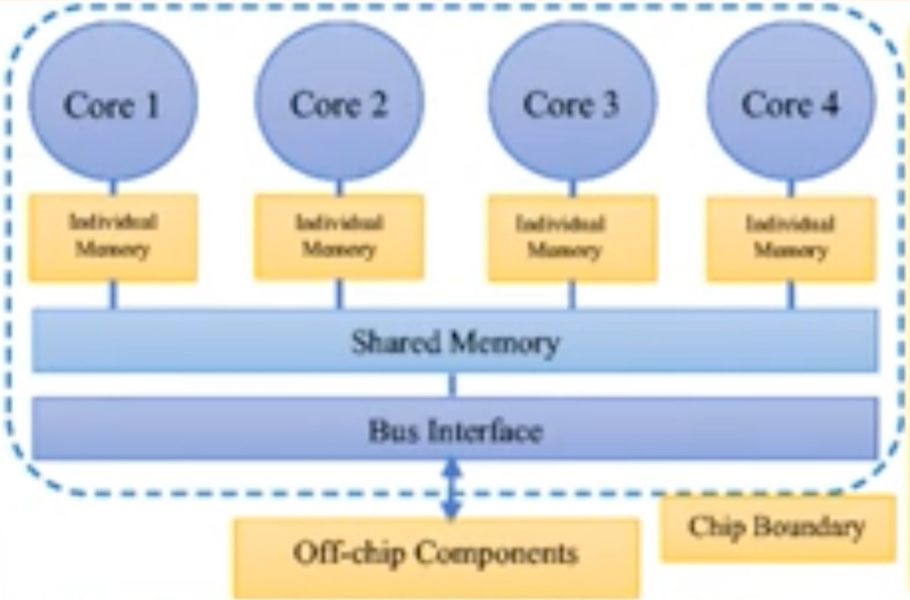
- Oldest CPU
- Execute only one command at a time
- Not efficient for multi-tasking.
- Work on FIFO(First Come First Serve)



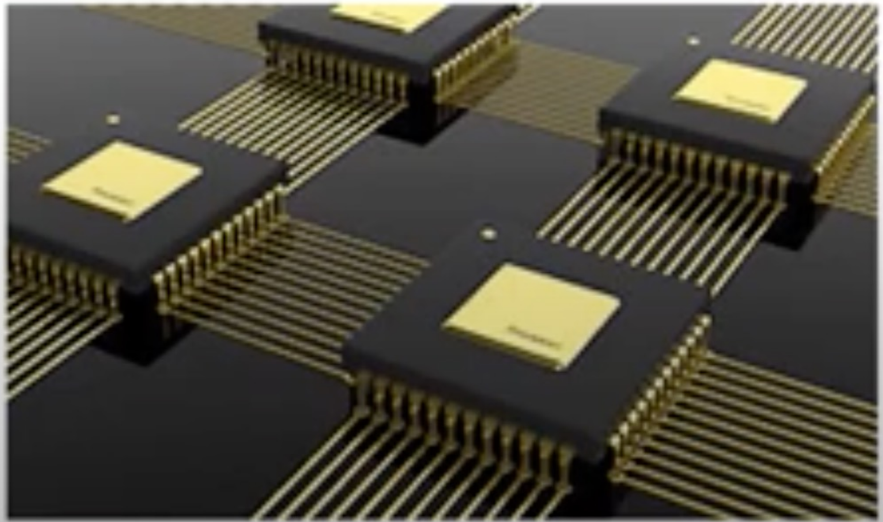


- Two processors are linked together into single IC
- Caches & controllers are combined into one chip.
- Capable to perform different operations quickly
- Capable of multitasking.

For example, if you are doing two tasks same time such as listen music and playing game then one processor can handle one task music and other second processor can handle game.



- High power CPU,
- Four processors Combined into one processor.
- Can execute massive instructions at a time.
- Enhance the processing power of computer
- Capable to execute multiple tasks

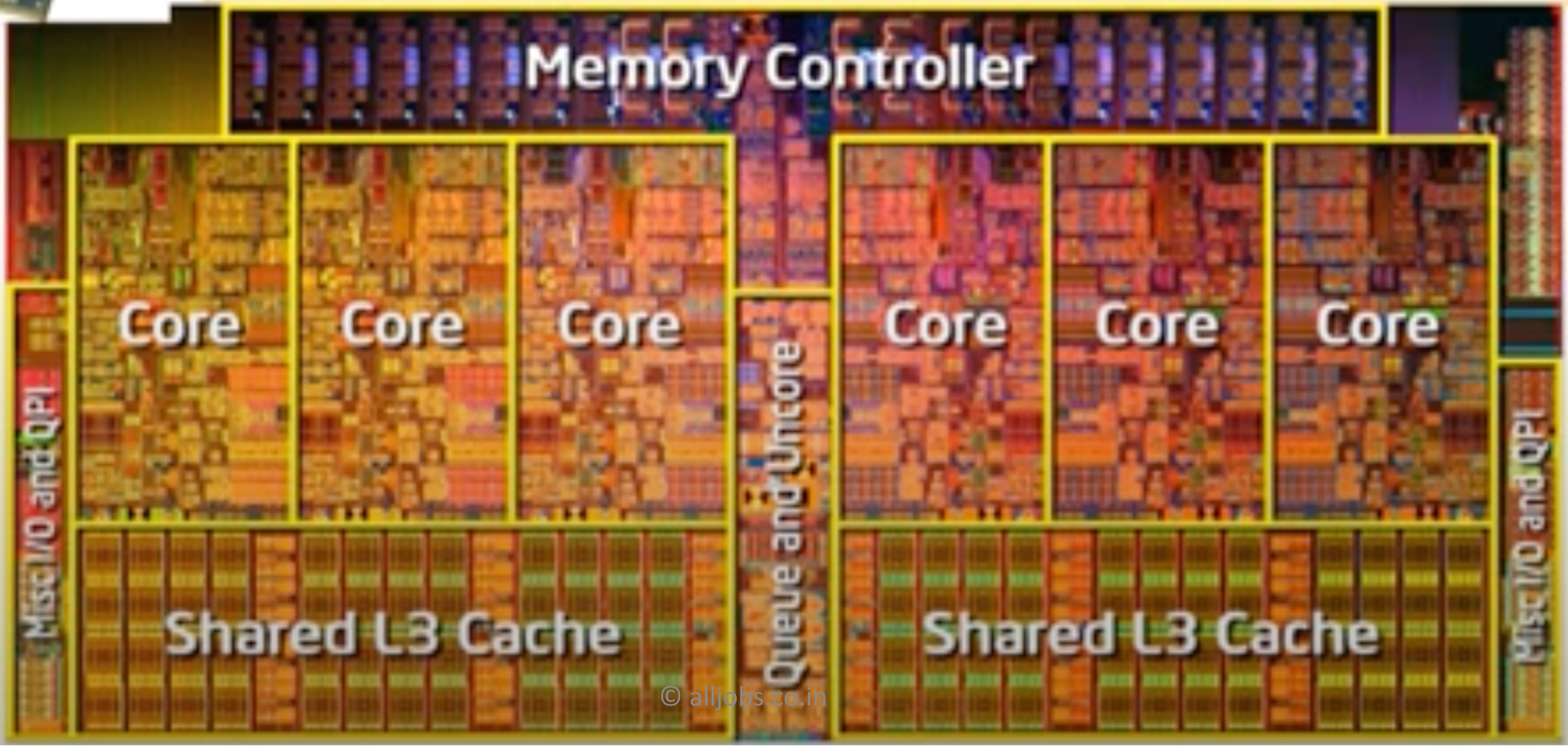


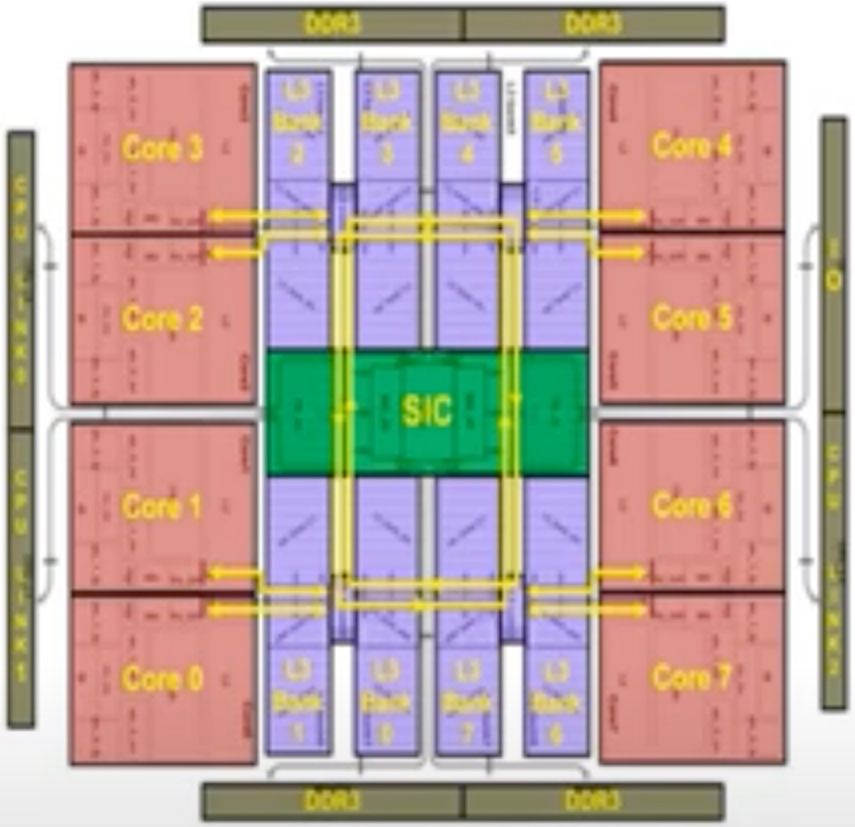
Multi-core processor with 6 cores

Perform faster than Dual-core & Quad-core processors.

Intel launched i7 Hexa-Core in 2010.

New for Smartphones





- Developed with eight independent cores
- More efficient and rapid than quad-core and hexacore processors.
- Comprises of a dual set of quad-core processors .
- Best ability to perform multi tasking and to boost up efficiency of your CPU.
- These processor mostly used in smart phones

Types of Processors

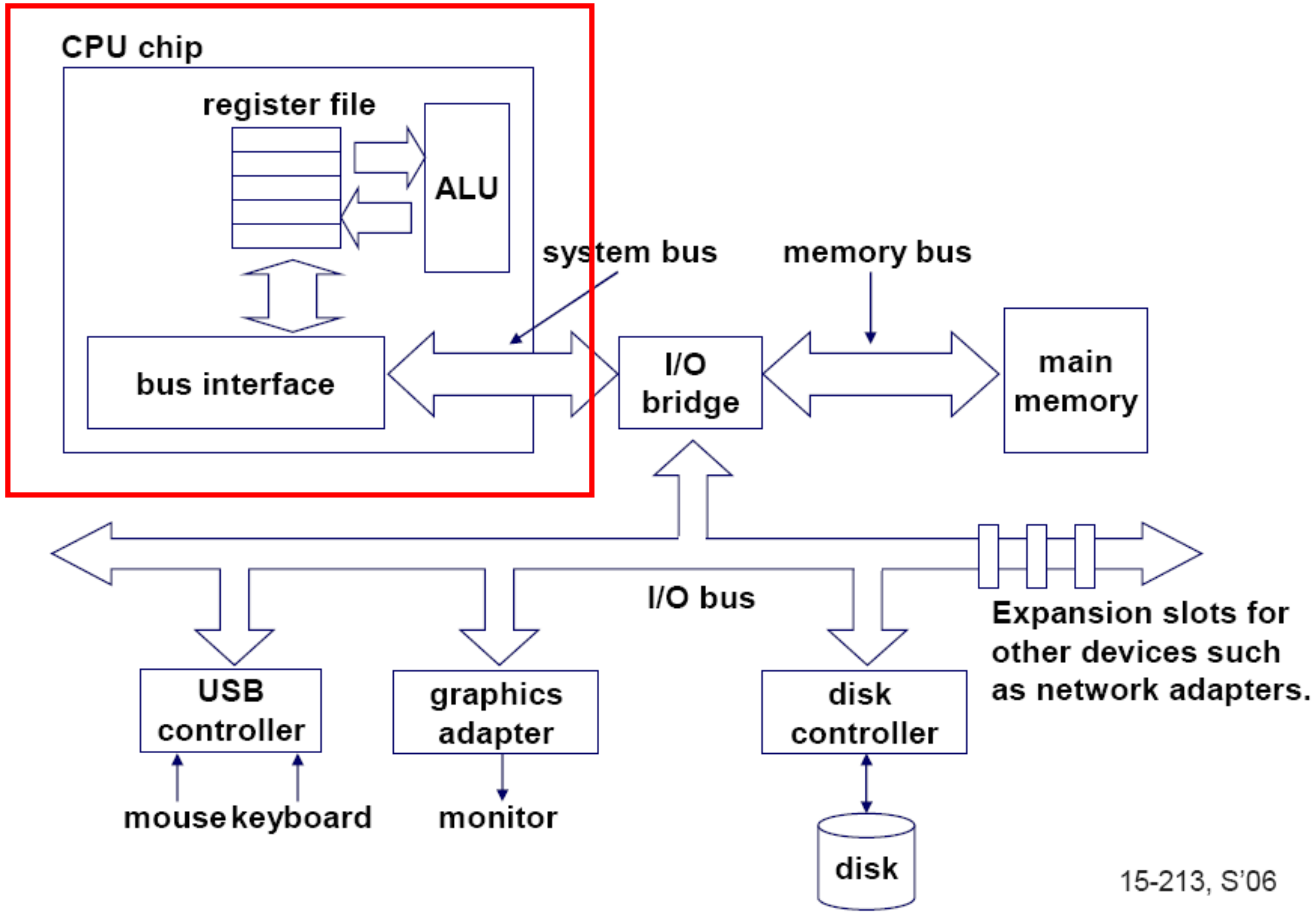
- **Followings are the types of Intel processors**
- **Intel Pentium 1**
- **Intel Pentium 2**
- **Intel Pentium 3**
- **Intel Pentium 4**
- **Intel core**
- **Intel Core solo**
- Core 2 Solo
- Core 2 Duo
- Core 2 Quad
- Core i3
- Core i5
- Core i7

Major Technology Providers

- The latest versions of many architectures use **multi-core**, including PA-RISC (PA-8800), IBM POWER (POWER7), SPARC (UltraSPARC IV), and various processors from Intel and AMD.
- There is some controversy as to whether multiple cores on a chip is the same thing as multiple processors. Major technology providers are divided on this issue.
- IBM considers its dual-core POWER4 and POWER5 to be two processors, just packaged together.
- Sun Microsystems, in contrast, considers its UltraSPARC IV to be a multi-threaded rather than multi-processor chip.
- Intel considers their multi-core designs to be a single processor.
- This is not an idle debate, because software is often more expensive when licensed for more processors.

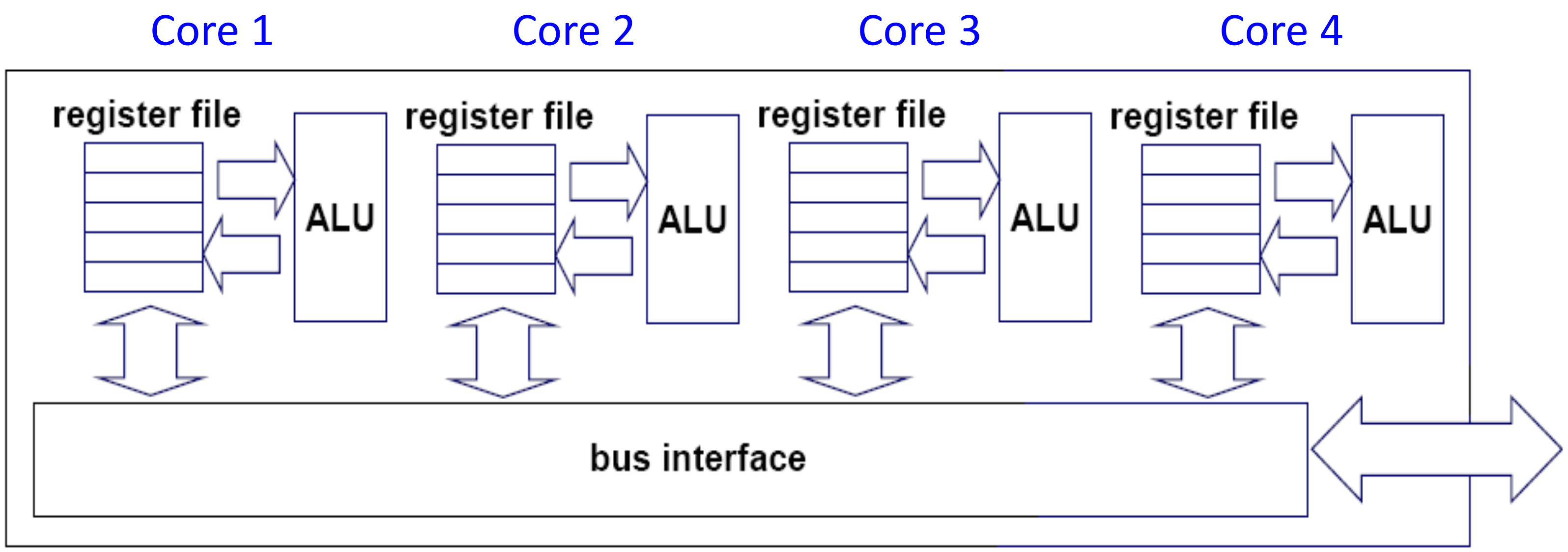
Microsoft, Red Hat Linux, Suse Linux will license their OS per chip, not per core

Single-core computer



Multi-core architectures

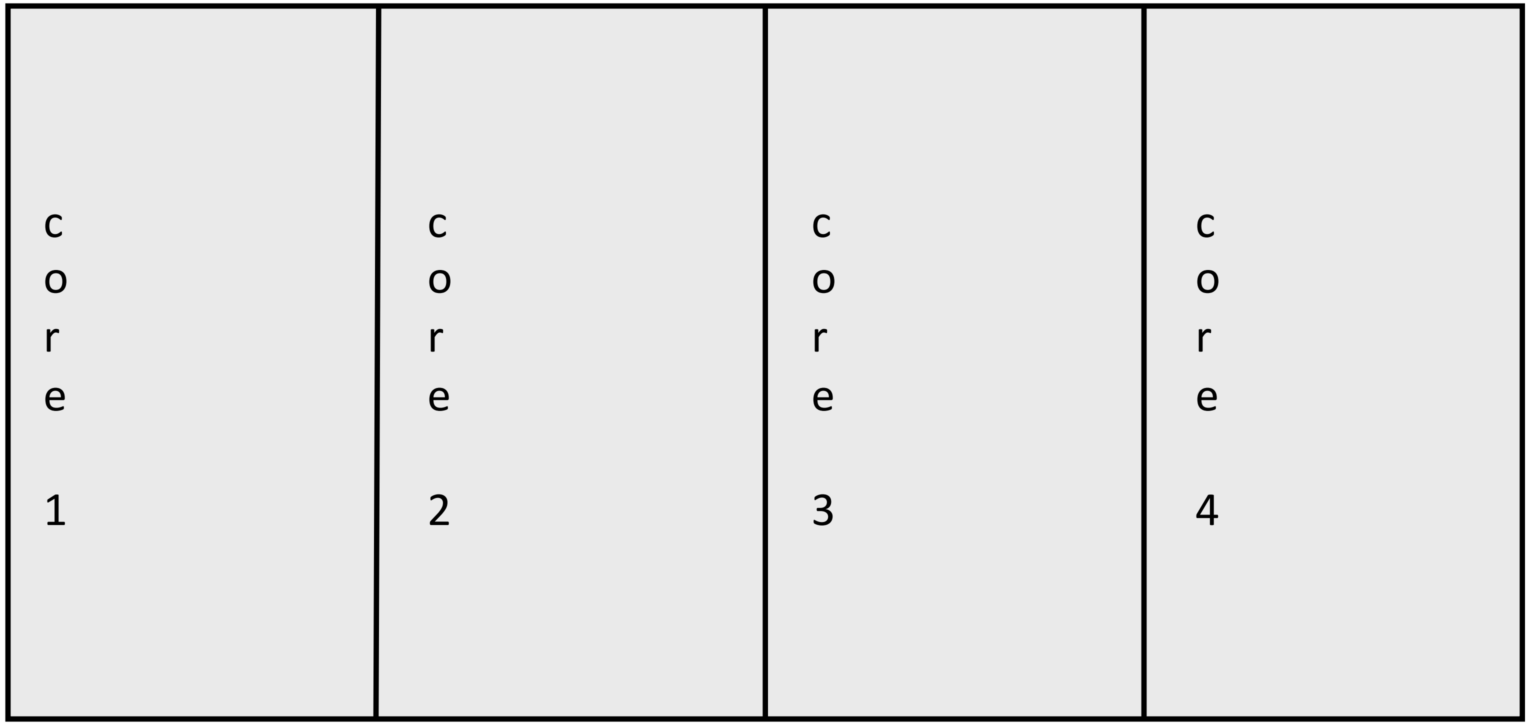
- Replicate multiple processor cores on a single die.



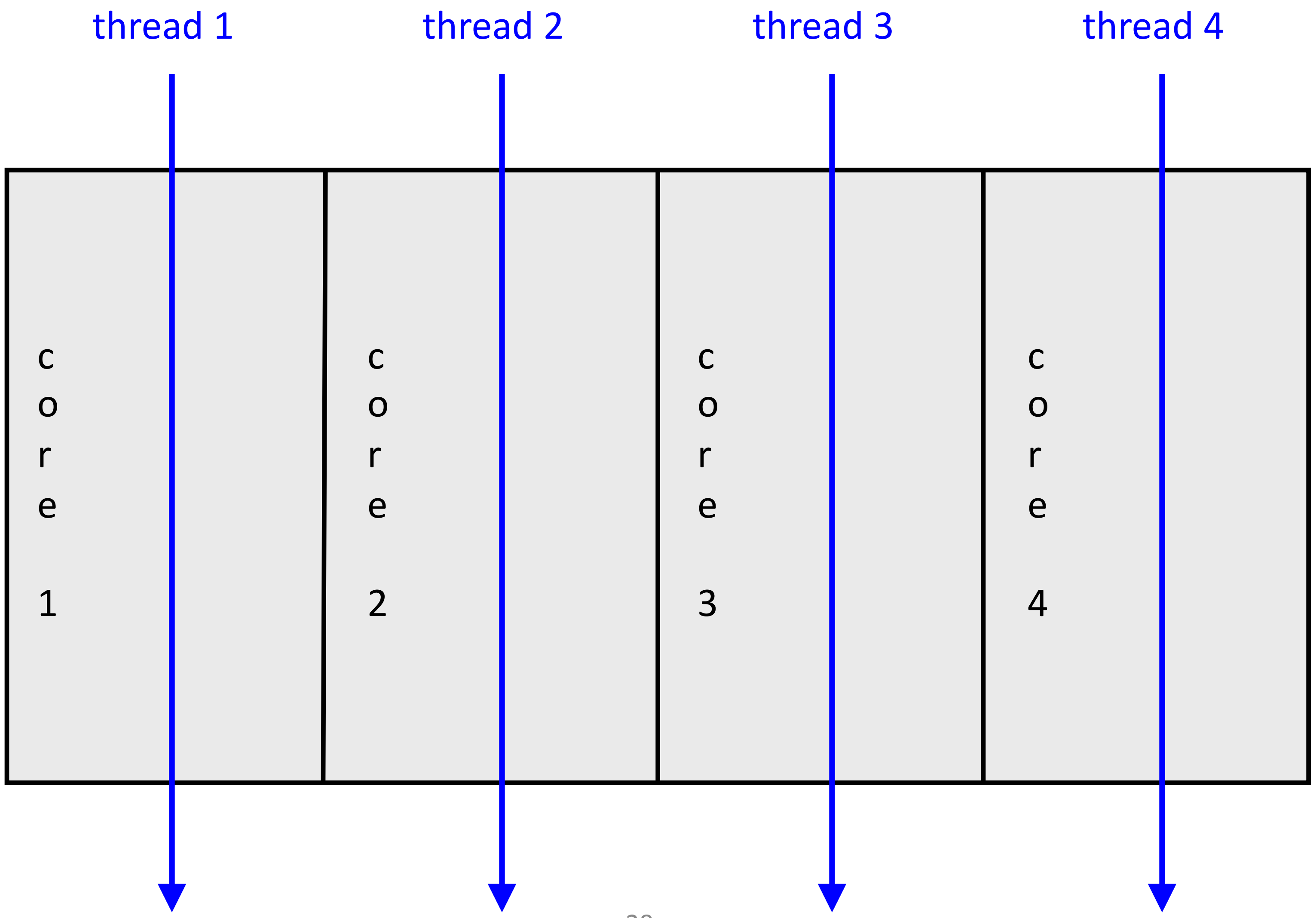
Multi-core CPU chip

Multi-core CPU chip

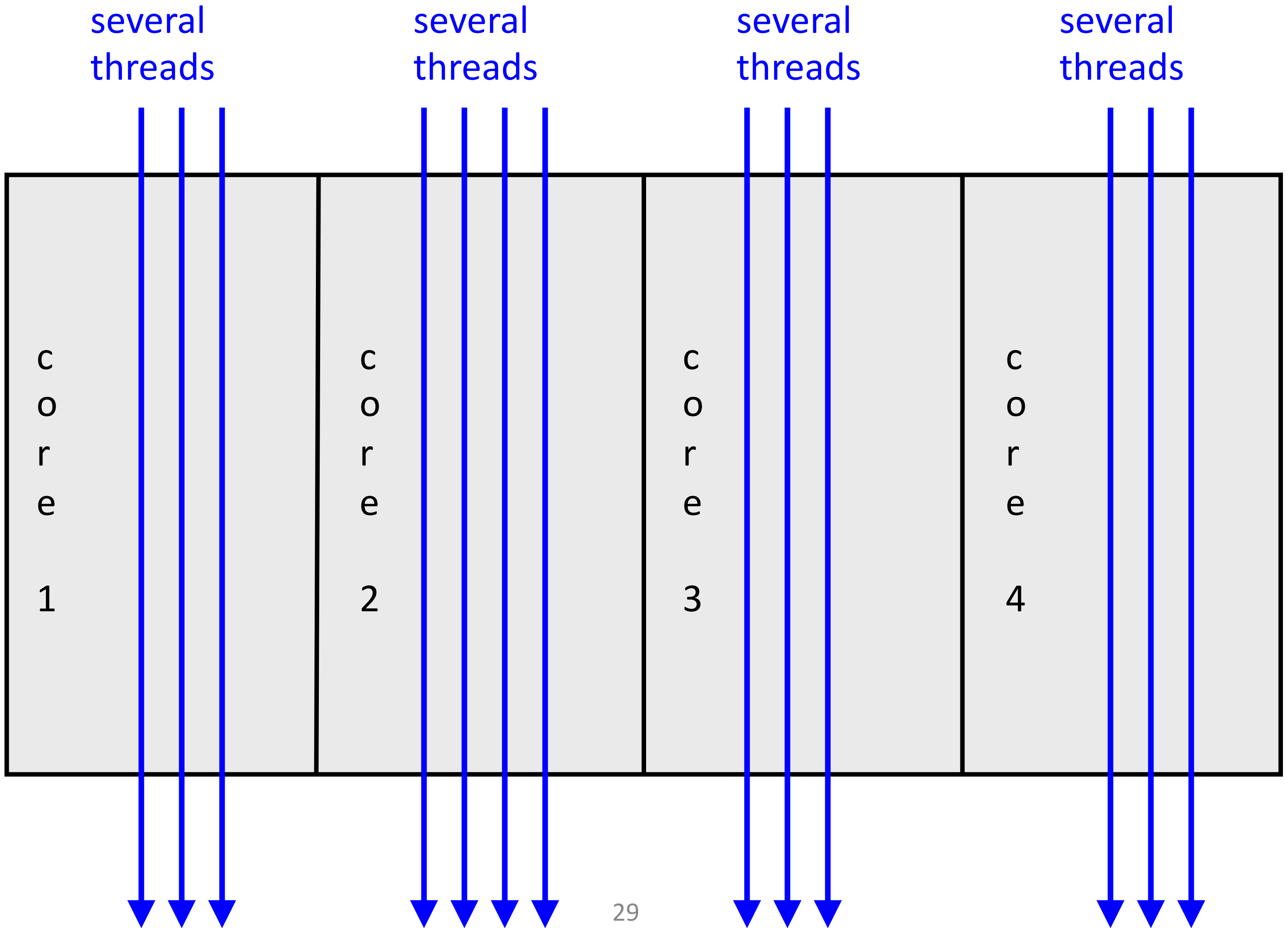
- The cores fit on a single processor socket
- Also called CMP (Chip Multi-Processor)



The cores run in parallel



Within each core, threads are time-sliced (just like on a uniprocessor)



Interaction with OS

- OS perceives each core as a separate processor
- OS scheduler maps threads/processes
  to different cores
- Most major OS support multi-core today

Why multi-core ?

- Difficult to make single-core clock frequencies even higher
- Many new applications are multithreaded
- General trend in computer architecture (shift towards more parallelism)

Instruction-level parallelism

- Parallelism at the machine-instruction level
- The processor can re-order, pipeline instructions, split them into microinstructions, do aggressive branch prediction, etc.
- Instruction-level parallelism enabled rapid increases in processor speeds over the last 15 years

Thread-level parallelism (TLP)

- This is parallelism on a more coarser scale
- Server can serve each client in a separate thread (Web server, database server)
- A computer game can do AI, graphics, and physics in three separate threads
- Single-core superscalar processors cannot fully exploit TLP
- Multi-core architectures are the next step in processor evolution: explicitly exploiting TLP

General context: Multiprocessors

- Multiprocessor is any computer with several processors

- SIMD
  - Single instruction, multiple data
  - Modern graphics cards
- MIMD
  - Multiple instructions, multiple data

Lemieux cluster, Pittsburgh supercomputing center

Multiprocessor memory types

- Shared memory:
  In this model, there is one (large) common shared memory for all processors

- Distributed memory:
  In this model, each processor has its own (small) local memory, and its content is not replicated anywhere else

Multi-core processor is a special kind of a multiprocessor:

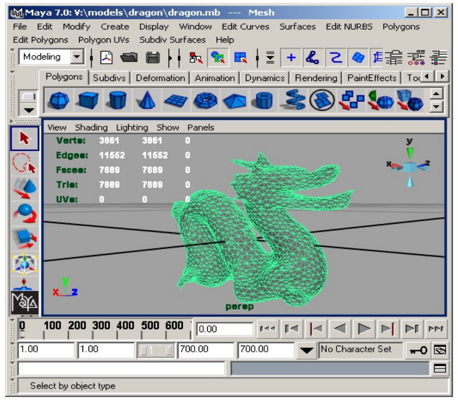
All processors are on the same chip

- Multi-core processors are MIMD:
  Different cores execute different threads (Multiple Instructions), operating on different parts of memory (Multiple Data).

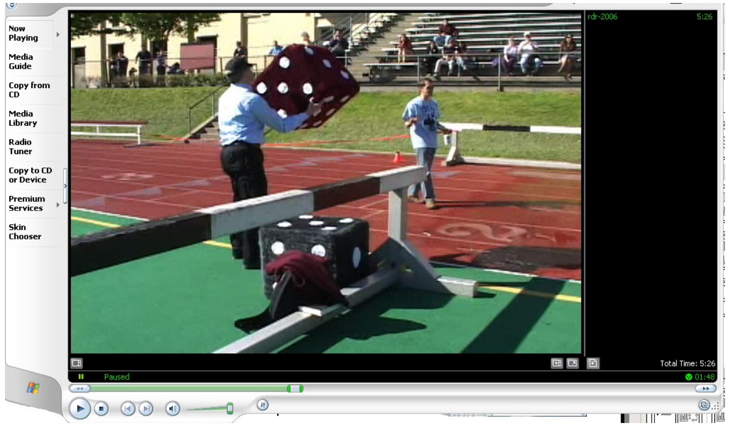
- Multi-core is a shared memory multiprocessor:
  All cores share the same memory

What applications benefit from multi-core?

- Database servers
- Web servers (Web commerce)
- Telecommuncation markets: 6WINDGate (datapath and control plane)
- Multimedia applications
- Scientific applications, CAD/CAM
- In general, applications with *Thread-level parallelism* (as opposed to instruction-level parallelism)



Each can run on its own core



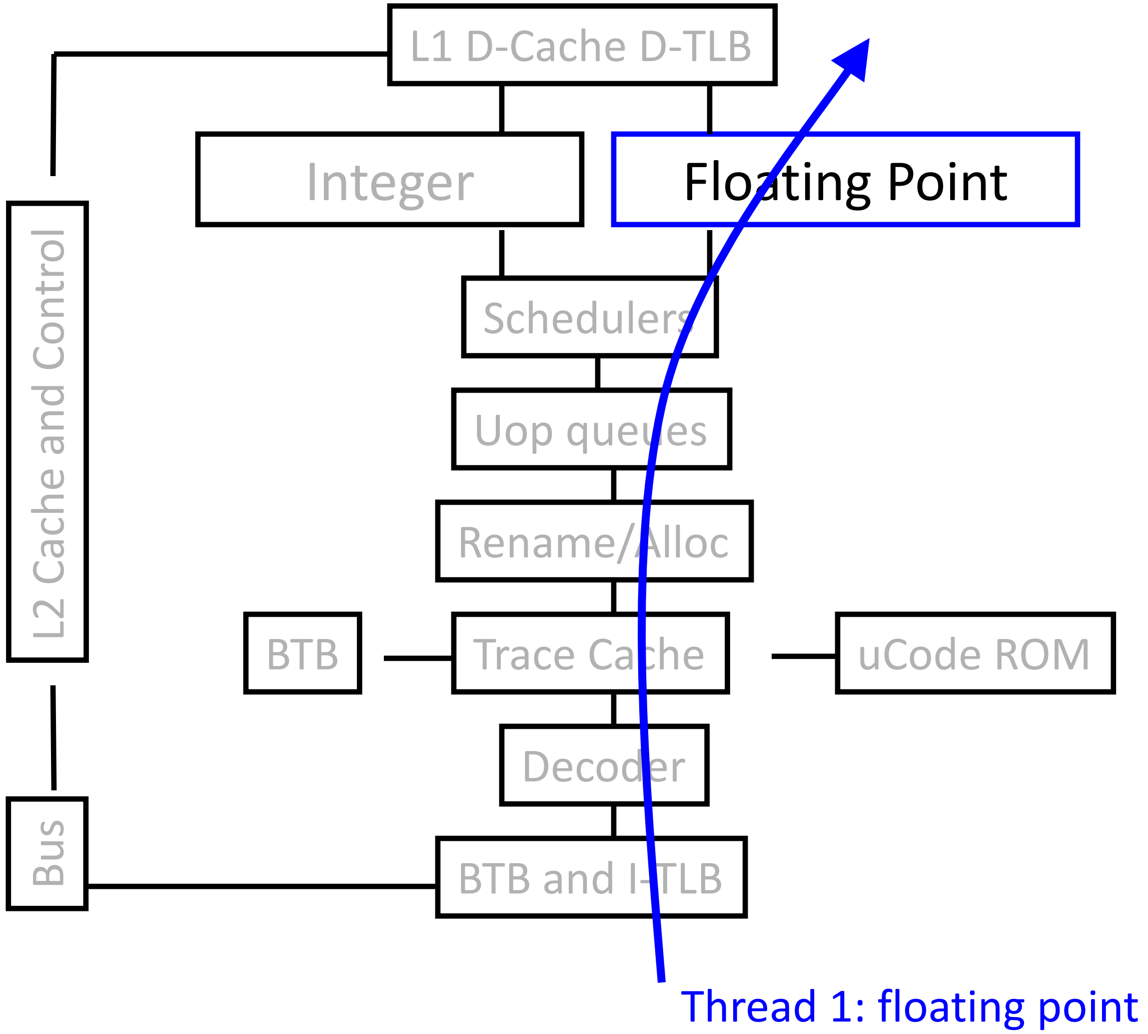
More examples

- Editing a photo while recording a TV show through a digital video recorder
- Downloading software while running an anti-virus program
- “Anything that can be threaded today will map efficiently to multi-core”
- BUT: some applications difficult to parallelize

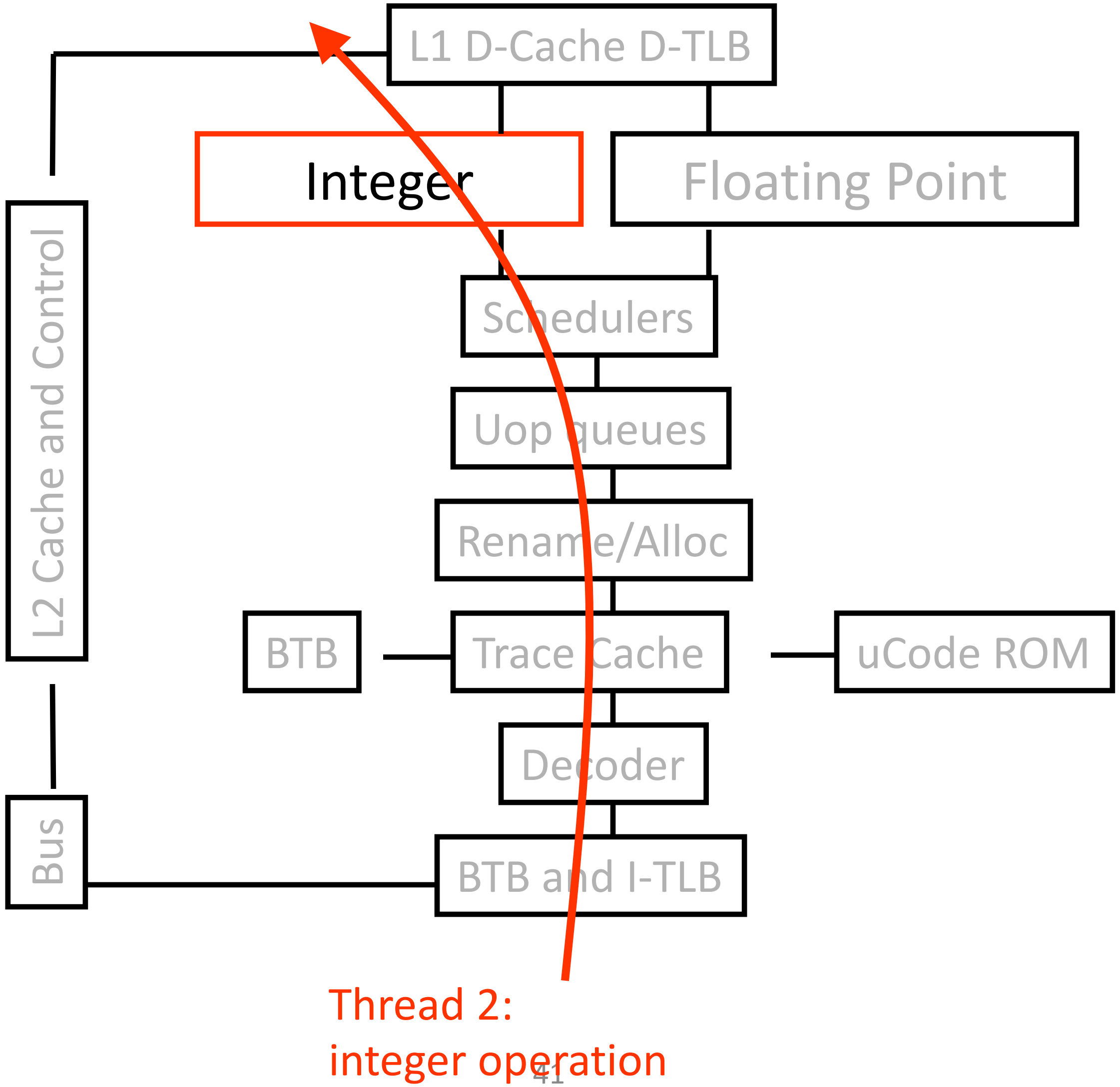
Simultaneous multithreading (SMT)

- Permits multiple independent threads to execute SIMULTANEOUSLY on the SAME core
- Weaving together multiple “threads” on the same core
- Example: if one thread is waiting for a floating point operation to complete, another thread can use the integer units

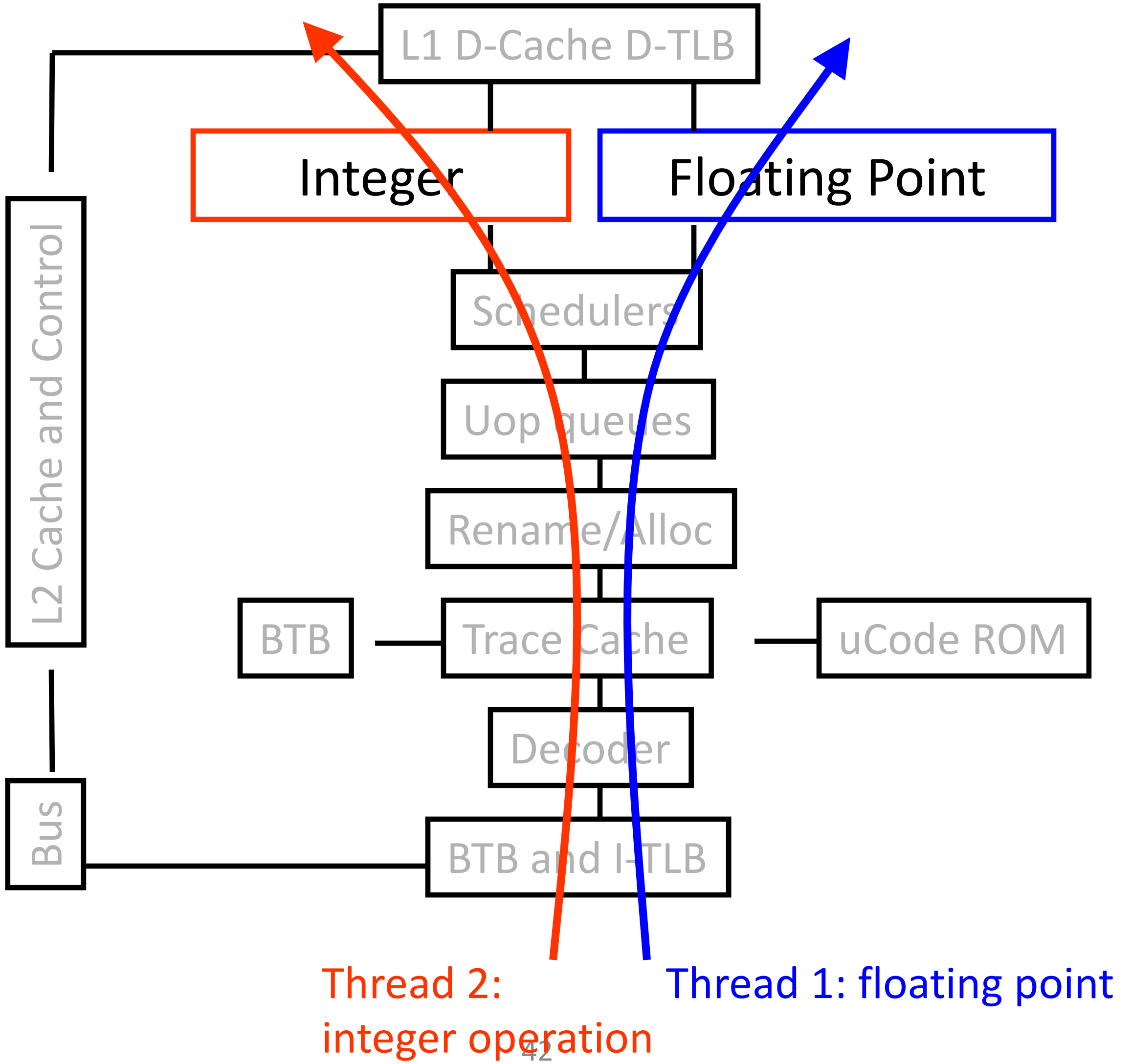
Without SMT, only a single thread can run at any given time



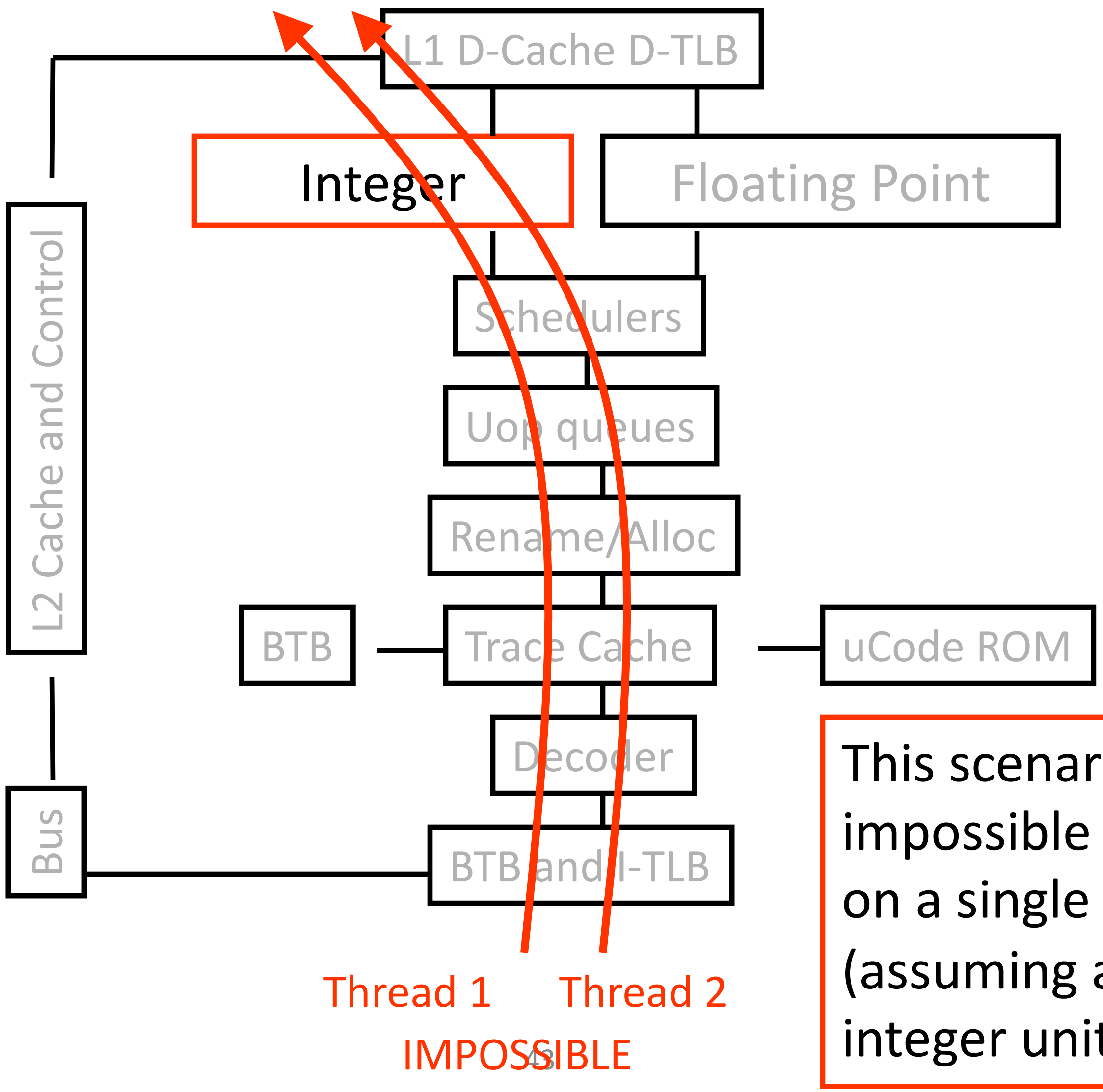
Without SMT, only a single thread can run at any given time



SMT processor: both threads can run concurrently



But: Can't simultaneously use the same functional unit

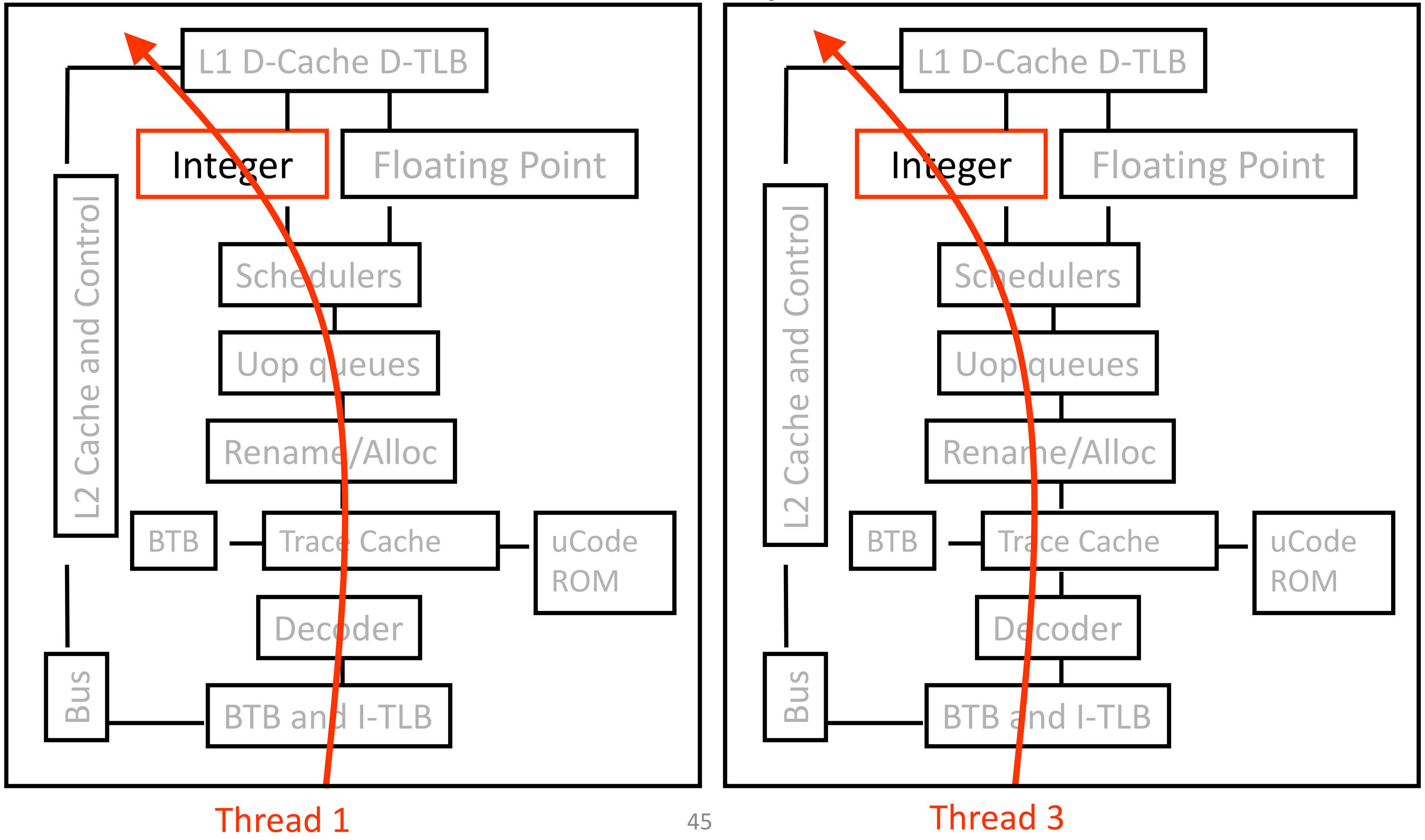


This scenario is impossible with SMT on a single core (assuming a single integer unit)

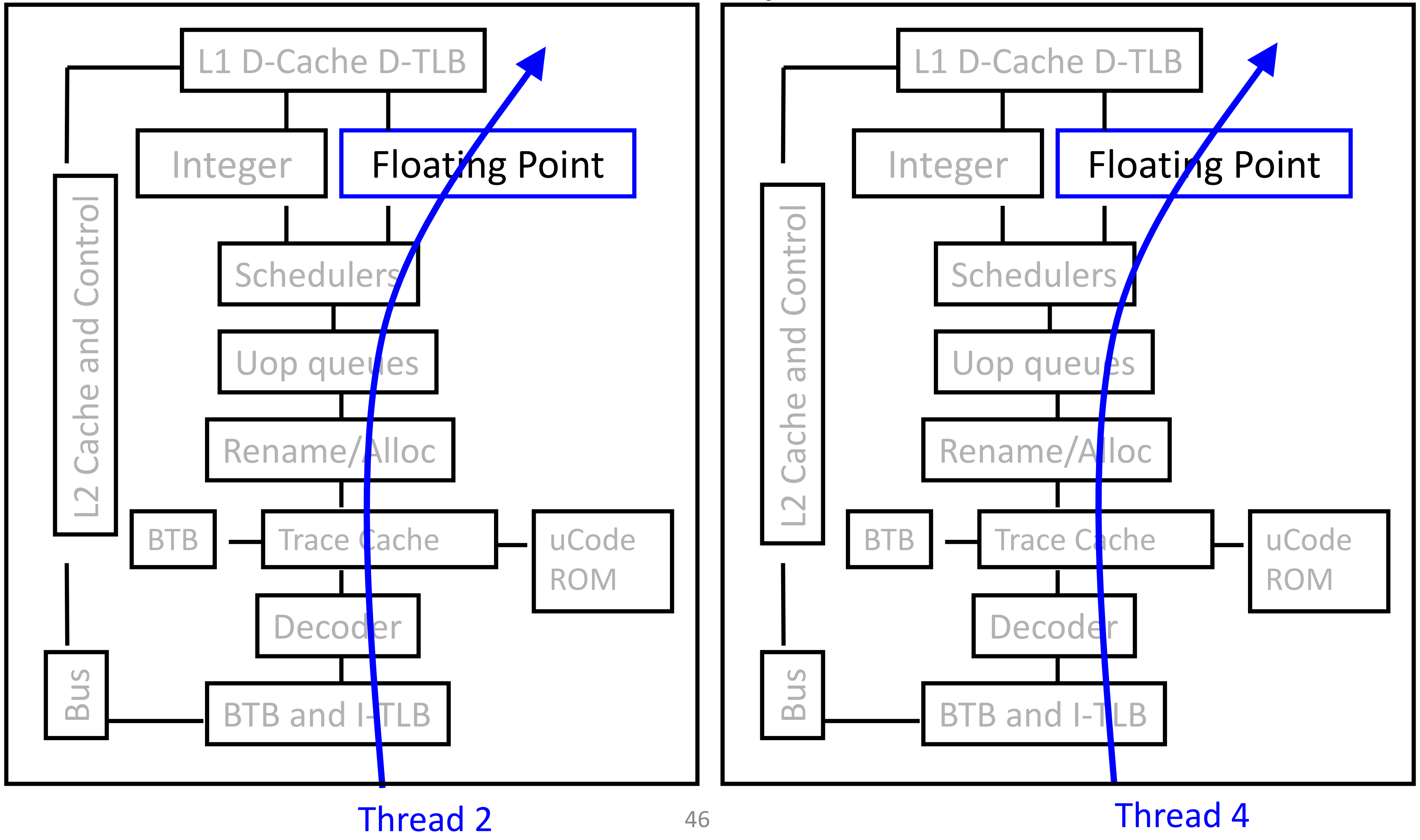
SMT not a “true” parallel processor

- Enables better threading (e.g. up to 30%)
- OS and applications perceive each simultaneous thread as a separate “virtual processor”
- The chip has only a single copy of each resource
- Compare to multi-core: each core has its own copy of resources

Multi-core: threads can run on separate cores



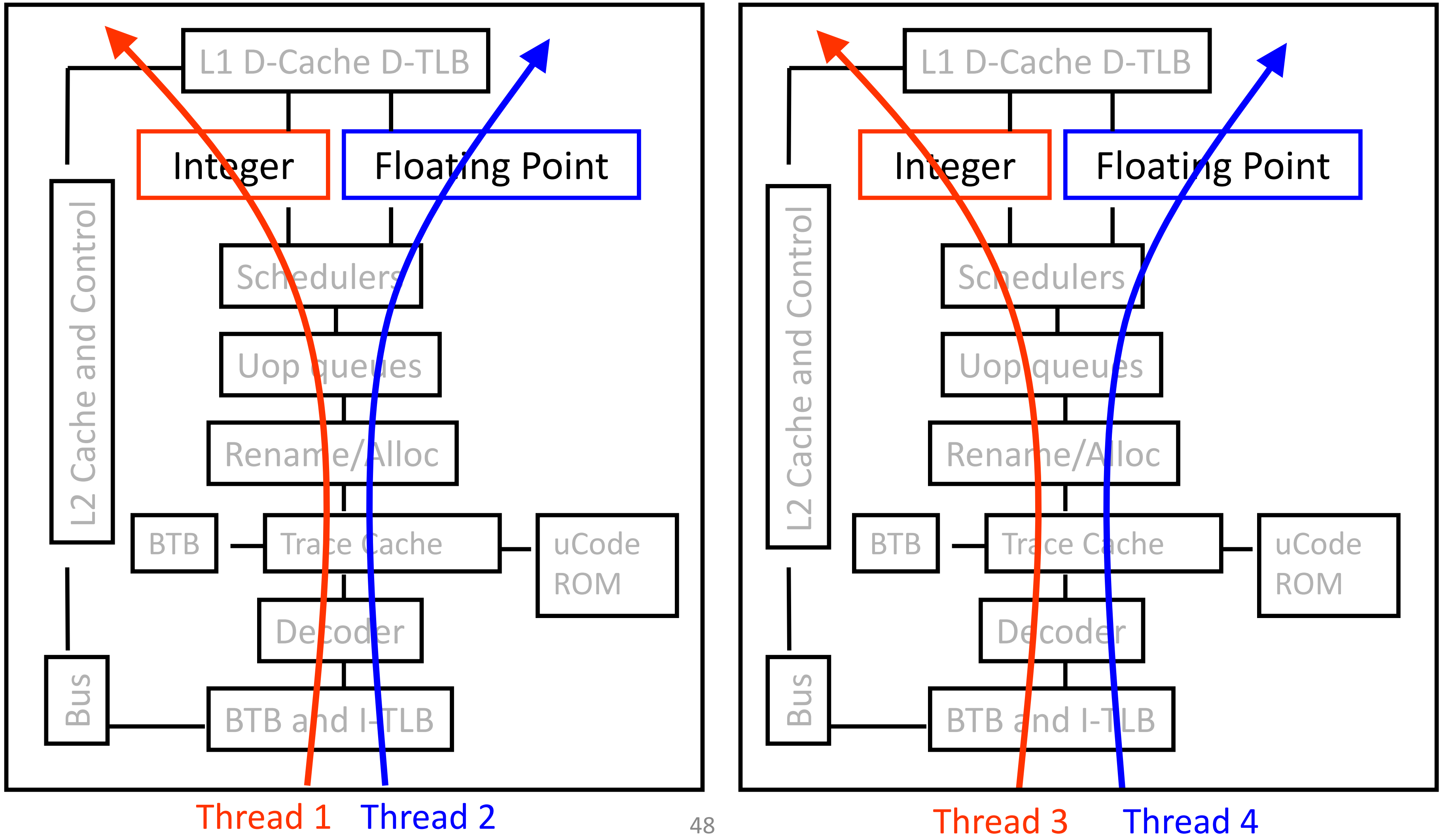
Multi-core: threads can run on separate cores



Combining Multi-core and SMT

- Cores can be SMT-enabled (or not)
- The different combinations:
  - Single-core, non-SMT: standard uniprocessor
  - Single-core, with SMT
  - Multi-core, non-SMT
  - Multi-core, with SMT:
- The number of SMT threads:
  2, 4, or sometimes 8 simultaneous threads
- Intel calls them “hyper-threads”

SMT Dual-core: all four threads can run concurrently



Comparison: multi-core vs SMT

- Multi-core:
  - Since there are several cores,
    each is smaller and not as powerful
    (but also easier to design and manufacture)
  - However, great with thread-level parallelism
- SMT
  - Can have one large and fast superscalar core
  - Great performance on a single thread
  - Mostly still only exploits instruction-level parallelism

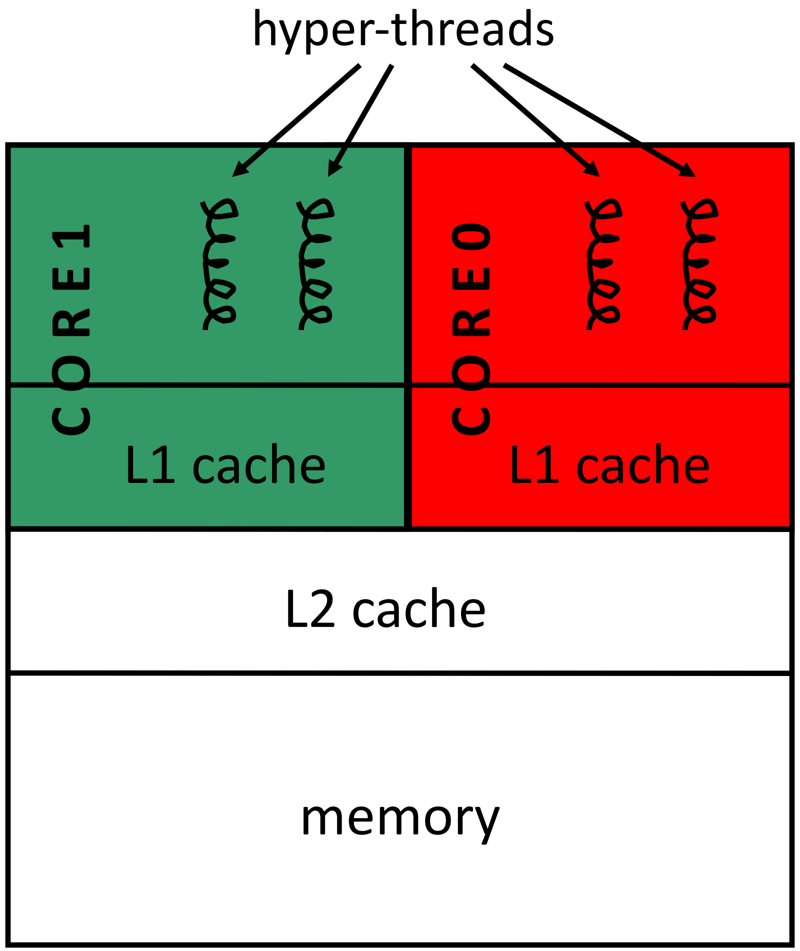
The memory hierarchy

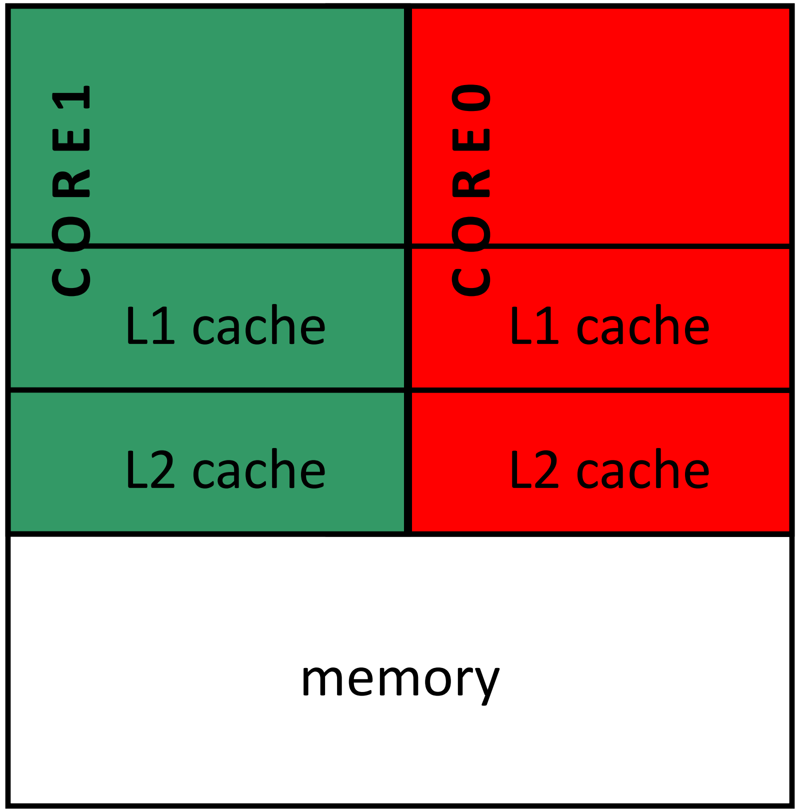
- If simultaneous multithreading only:
  - all caches shared
- Multi-core chips:
  - L1 caches private
  - L2 caches private in some architectures and shared in others
- Memory is always shared

- Dual-core
  Intel Xeon processors

- Each core is
  hyper-threaded

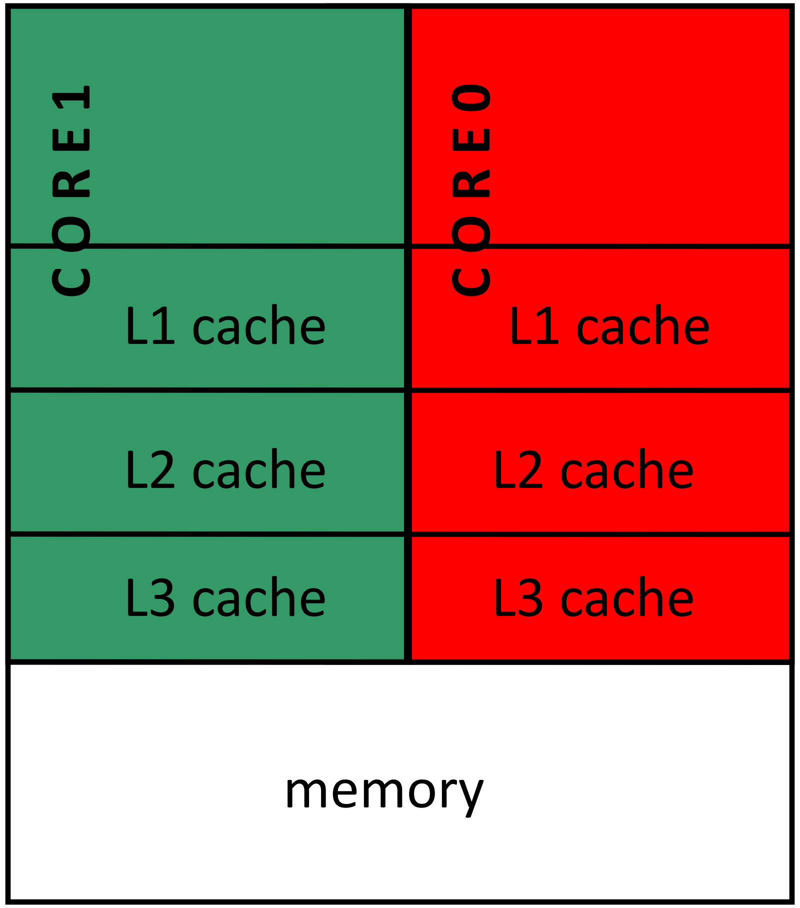
- Private L1 caches
- Shared L2 caches





Both L1 and L2 are private

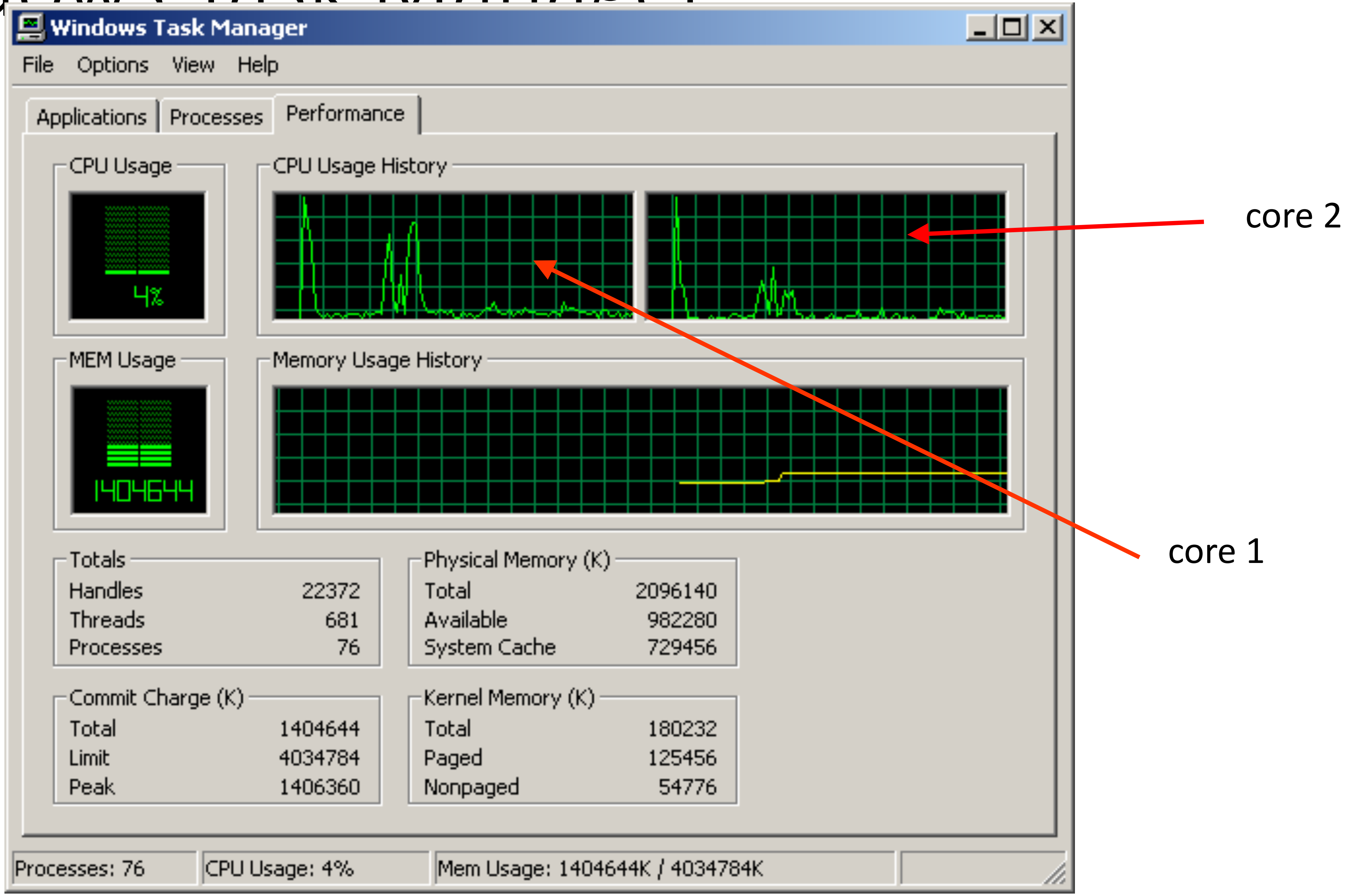
Examples: AMD Opteron,
AMD Athlon, Intel Pentium D



A design with L3 caches

Example: Intel Itanium 2

Windows Task Manager



Advantages /Disadvantages

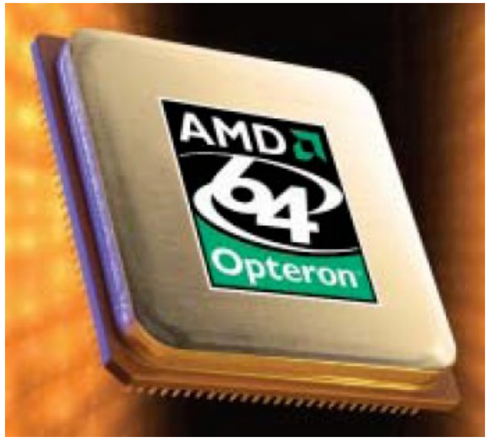
Advantages

- Cache coherency circuitry can operate at a much higher clock rate than is possible if the signals have to travel off-chip
- Signals between different CPUs travel shorter distances, those signals degrade less
- These higher quality signals allow more data to be sent in a given time period since individual signals can be shorter and do not need to be repeated as often
- A dual-core processor uses slightly less power than two coupled single-core processors

Disadvantages

- Ability of multi-core processors to increase application performance depends on the use of multiple threads within applications.
- Most Current video games will run faster on a 3 GHz single-core processor than on a 2GHz dual-core processor (of the same core architecture
- Two processing cores sharing the same system bus and memory bandwidth limits the real-world performance advantage.
- If a single core is close to being memory bandwidth limited, going to dual-core might only give 30% to 70% improvement
- If memory bandwidth is not a problem, a 90% improvement can be expected

Conclusion



- Multi-core chips an important new trend in computer architecture
- Several new multi-core chips in design phases

- Parallel programming techniques likely to gain importance

References

- http://en.wikipedia.org/wiki/Multi-core_(computing)
- www.princeton.edu/~jdonald/research/hyperthreading/garg_report.pdf

- www.cs.cmu.edu/~**barbic/multi-core**.ppt

Characteristic of Embedded Processor

APPLICATION-SPECIFIC FUNCTIONALITY – SPECIALIZED FOR ONE OR ONE CLASS OF APPLICATIONS

DEADLINE CONSTRAINED OPERATION – SYSTEM MAY HAVE TO PERFORM ITS FUNCTION(S) WITHIN SPECIFIC TIME PERIODS TO ACHIEVE SUCCESSFUL RESULTS

RESOURCE CHALLENGED – SYSTEMS TYPICALLY ARE CONFIGURED WITH A MODEST SET OF RESOURCES TO MEET THE PERFORMANCE OBJECTIVES

Characteristic of Embedded Processor (cntd)

Power efficient : Many systems are battery-powered and must conserve power to maximize the usable life of the system.

Form factor : Many systems are light weight and low volume to be used as components in host systems

Manufactural : Usually small and inexpensive to manufacture based on the size and low complexity of the hardware.

Architecture

Single-issue RISC architecture : ARM, SH3-DSP, Xtensa, ARCtangent

Superscalar architecture : MIPS, PowerPC

VLIW architecture : TMS320C6x, ADSP-TS0xx, Saturn, Jazz

- ST100 and Carmel provide instruction sets that support all these architectural features in one processor.
- ST100: 16, 32, 128-bit instruction formats
- Carmel: 24, 48, 144-bit instruction formats

Configurability

FIXED PROCESSORS

FIXED PROCESSOR CORES WITH RECONFIGURABLE LOGIC

FIXED PROCESSOR CORES GIVEN AS SOFT CORES

CONFIGURABLE PROCESSORS

Fixed processors

- 8051, ARM, MIPS, PowerPC, SH3-DSP, TMS320x, Saturn, Carmel, ST100
- Hard cores with fixed layouts or soft cores with synthesizable HDL descriptions
- Instruction sets are fixed and are not supposed to be configured for application specific optimization.
- Coprocessors can accompany fixed processor cores to improve the overall system performance.
- The coprocessors can be synthesized for specific applications as in HP PICO project.

Fixed processor cores with reconfigurable logic

Virtex II Pro (Xilinx), Excalibur (Altera), E5 and A7 (Triscend), QuickMIPS (Quicklogic), RCP (Chameleon), FPSLIC (Atmel).

RCP has an ARC configurable processor embedded in it, but it is a pre-configured one.

Fixed processor cores given as soft cores

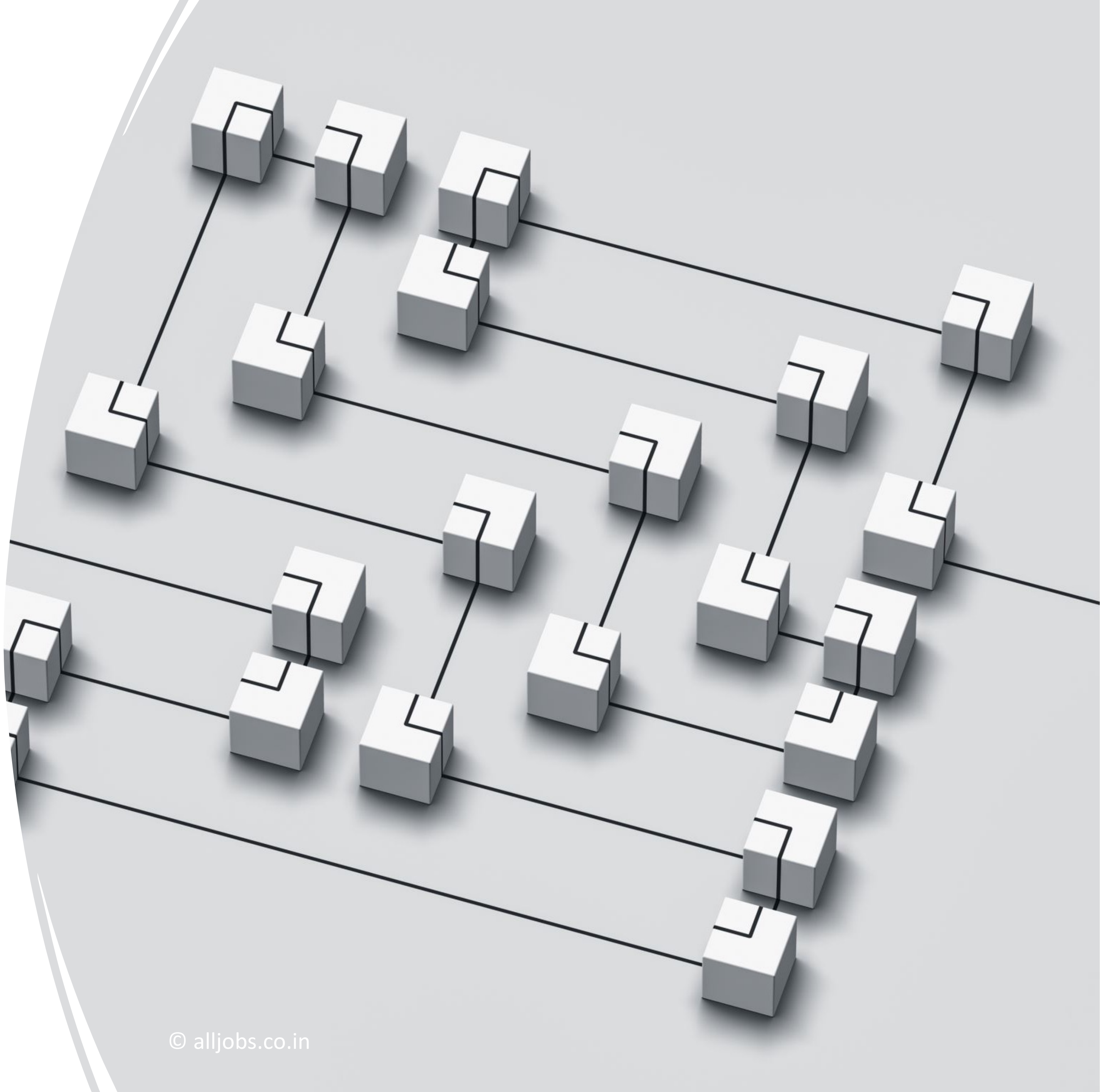
MicroBlaze (Xilinx)

Need to be synthesized to be programmed on a reconfigurable logic.

Limited configuration can be done on peripherals and bus interfaces, but the instruction set is fixed.

Configurable processors

- Processors that can be configured according to the application
- Especially processors whose instruction set architectures can be configured according to the application are called ASIPs (Application Specific Instruction set Processors)
- Xtensa, ARCtangent, and Jazz provide basic cores and instruction sets. They can be configured or extended for the target application.



Configurable processors (cntd).

NIOS (Altera) is a configurable processor that can be programmed on a reconfigurable logic.

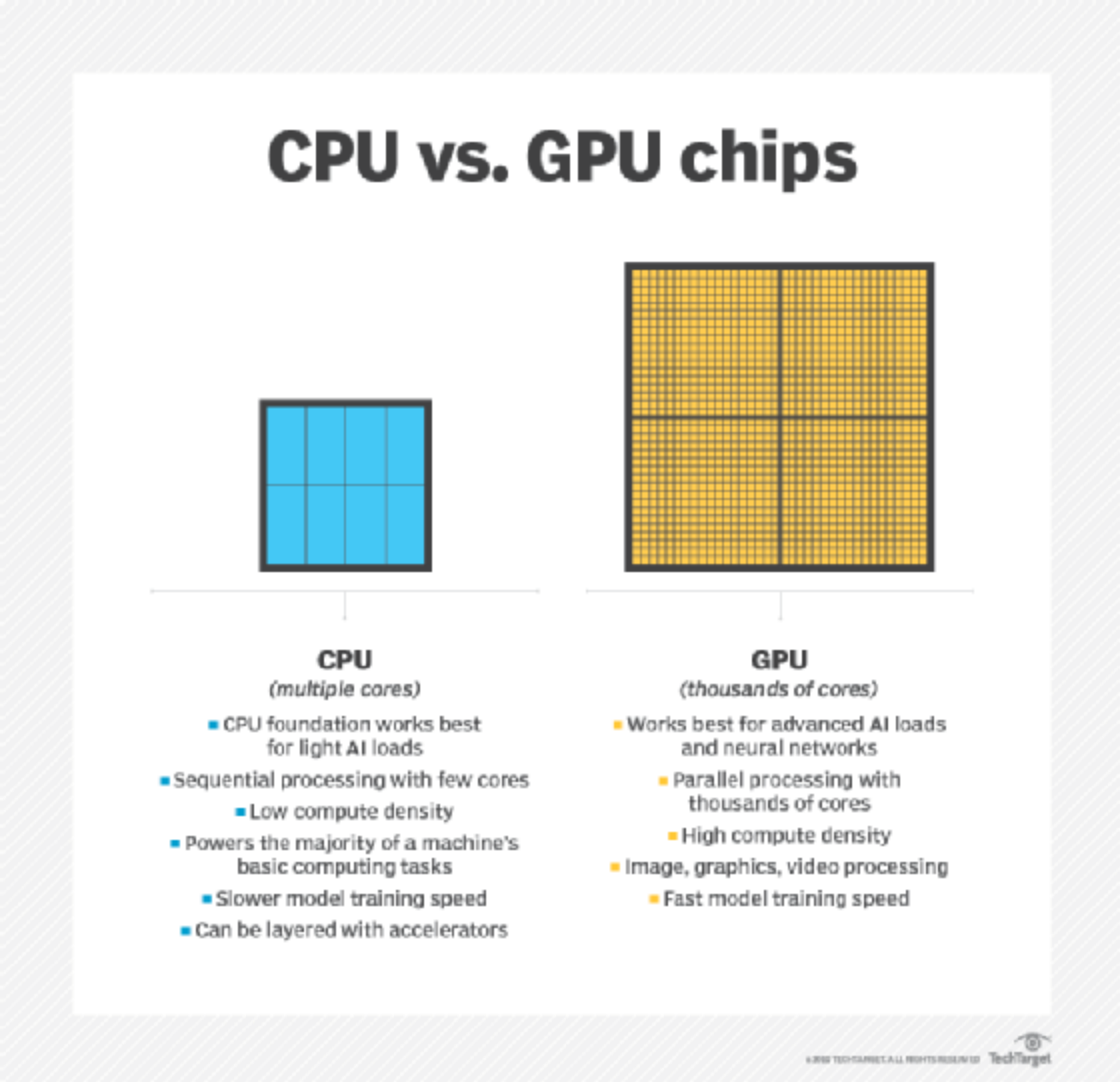
However, only five opcodes (256 for NIOS II) can be used for user customizable instructions.

LISATek (merged to CoWare) and Target Compiler Technologies do not provide basic cores but start from scratch.

From an architecture description in a specific ADL (Architecture Description Language: LISA, nML), they generate a compiler, a simulator, and a synthesizable HDL.

Examples of Embedded Processor

- 8051
- ARM
- ARM7TDMI
- ARM922T
- ARM1022E
- ARM11
- XScale


CPU vs. GPU chips
CPU
(multiple cores)
CPU foundation works best for light AI loads
Sequential processing with few cores
Low compute density
Powers the majority of a machine's basic computing tasks
Slower model training speed
Can be layered with accelerators
GPU
(thousands of cores)
Works best for advanced AI loads and neural networks
Parallel processing with thousands of cores
High compute density
Image, graphics, video processing
Fast model training speed