Parallel Programming

ACSE-6: Lecture OpenMP-1

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What is Parallel Programming?

- Using more than one processor or computer to complete a task
- Each processor works on its section of the problem (functional parallelism)
- Each processor works on its section of the data (data parallelism)
- Processors can exchange information

Why Parallel Computing?

- This is a legitime question! Parallel computing is complex and will make debugging much more complex.

- The primary reasons for using parallel computing:
  - Save time - wall clock time
  - Solve larger problems
  - Provide concurrency (do multiple things at the same time)

Why Parallel Computing?

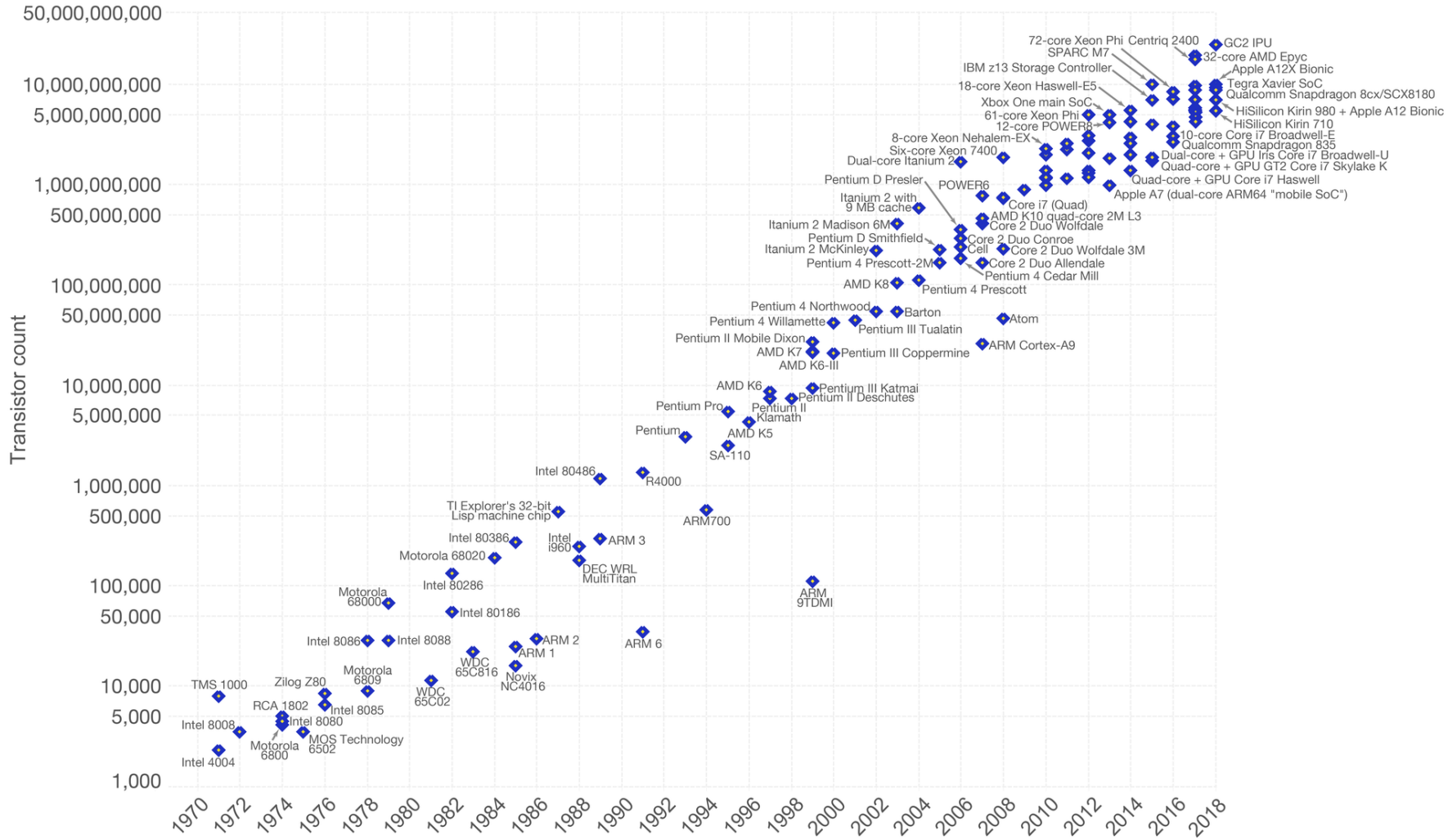
- Other reasons might include:
  - Taking advantage of non-local resources - using available compute resources on a wide area network, or even the Internet when local compute resources are scarce.
  - Cost savings - using multiple "cheap" computing resources instead of paying for time on a supercomputer.
  - Overcoming memory constraints - single computers have very finite memory resources. For large problems, using the memories of multiple computers may overcome this obstacle.

Moore’s Law

Moore’s Law – The number of transistors on integrated circuit chips (1971-2018)

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.

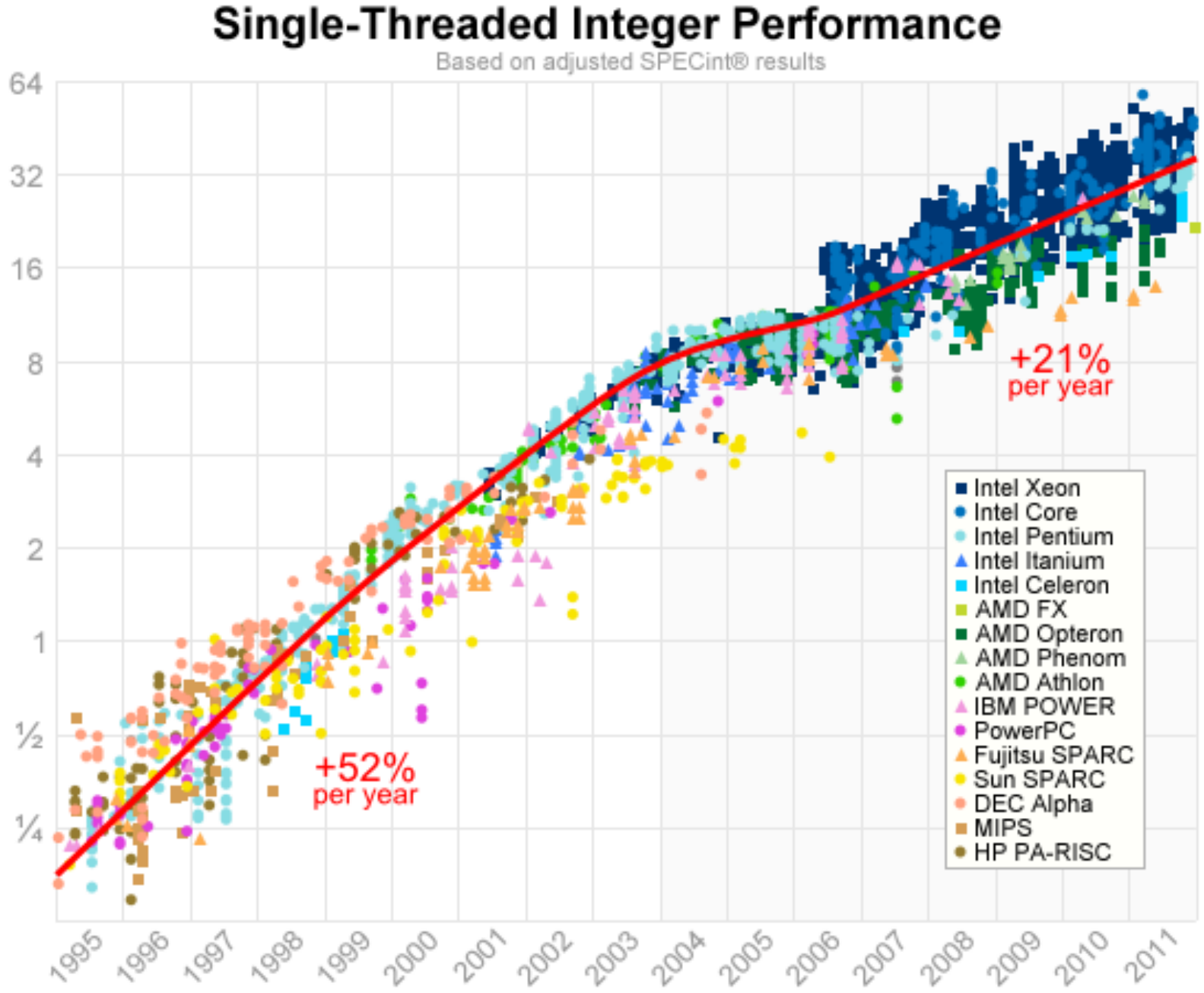
Our World in Data



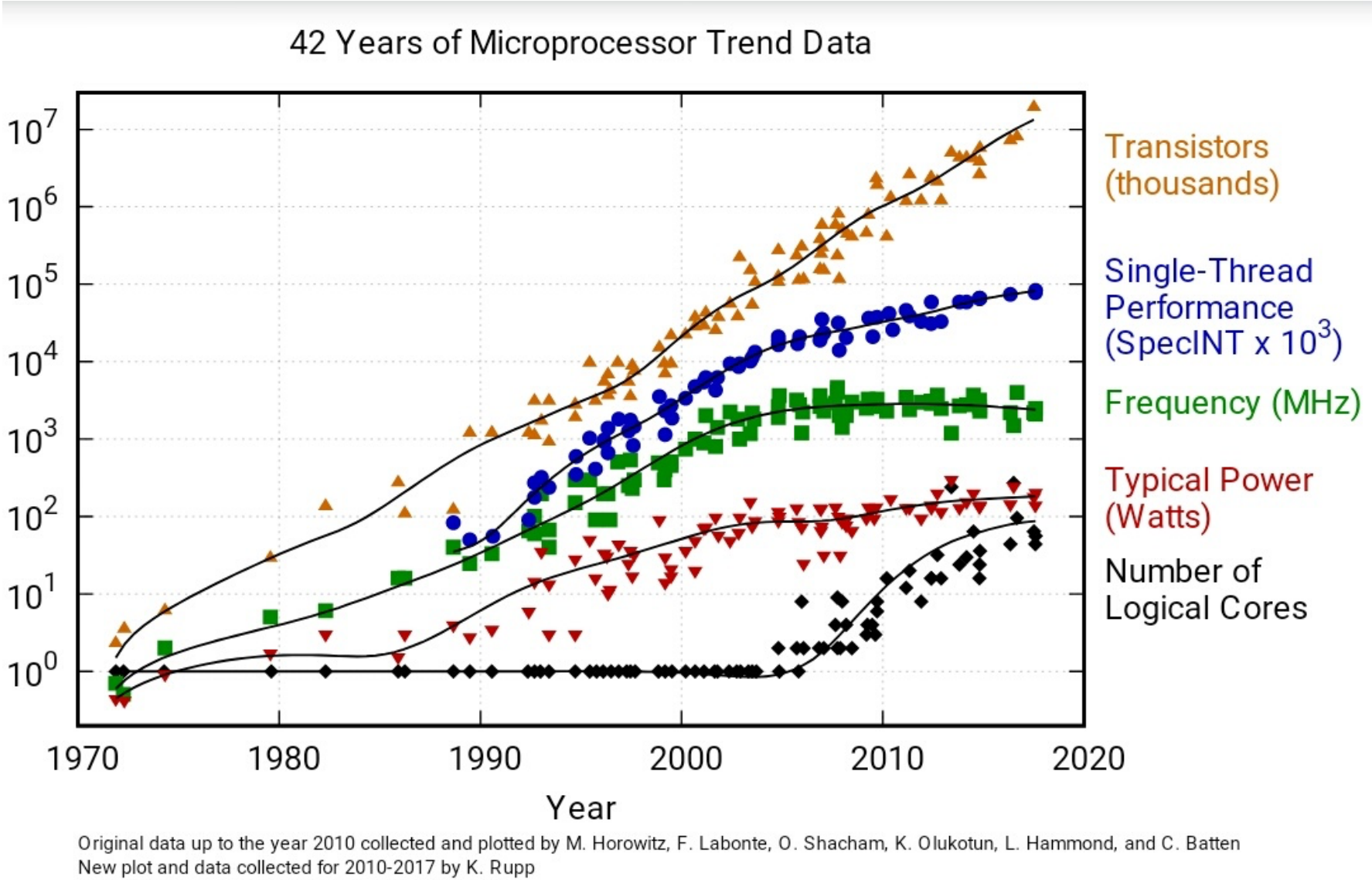
Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

Limitations of Serial Computing

- Transmission speeds
- Limits to miniaturization
- Economic limitations



Trend not what we expected?



Terminology

- **serial**: code is a single thread of execution working on a single data item at any one time
- **parallel**: code has more than one thing happening at a time. This could be
  - A single thread of execution operating on multiple data items simultaneously
  - Multiple threads of execution in a single executable
  - Multiple executables all working on the same problem
  - Any combination of the above
- **task**: is the name we use for an instance of an executable. Each task has its own virtual address space and may have multiple threads.

Terminology

- **node**: a discrete unit of a computer system that typically runs its own instance of the operating system
- **core**: a processing unit on a computer chip that is able to support a thread of execution; can refer either to a single core or to all of the cores on a particular chip
- **cluster**: a collection of machines or nodes that function in someway as a single resource.
- **grid**: the software stack designed to handle the technical and social challenges of sharing resources across networking and institutional boundaries. grid also applies to the groups that have reached agreements to share their resources.

Types of parallelism

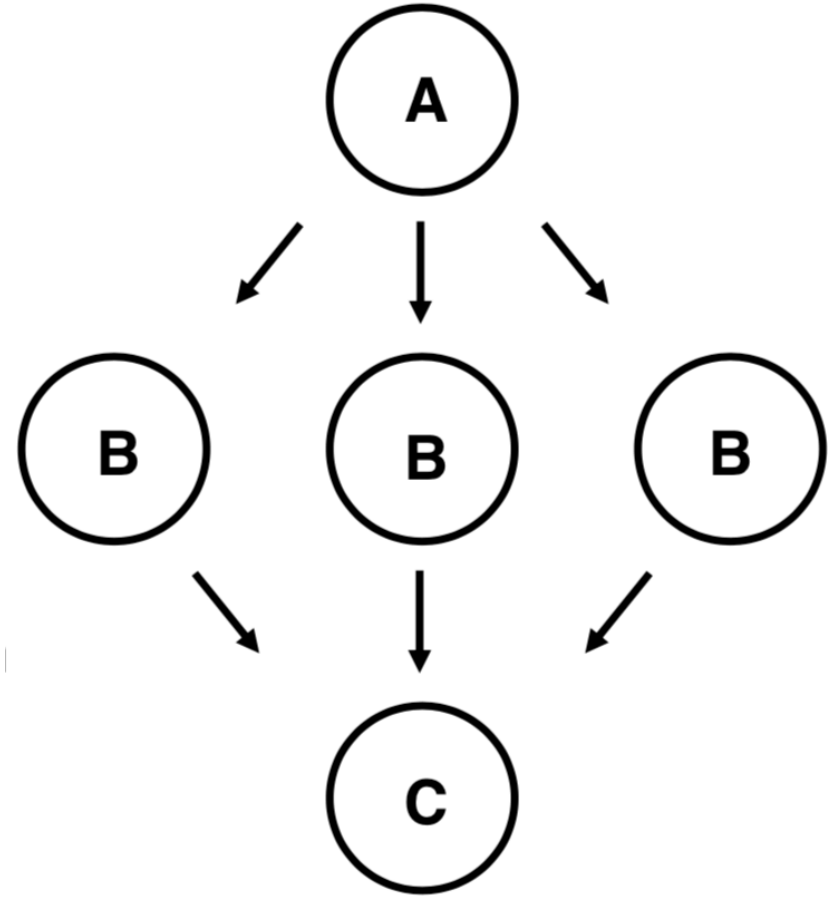
- Data parallelism
- Functional parallelism
- Task parallelism
- Pipeline parallelism

Data parallelism

- Definition: each process does the same work on unique and independent pieces of data

- Examples:
  - 2 brothers mow the lawn
  - 8 farmers paint a barn

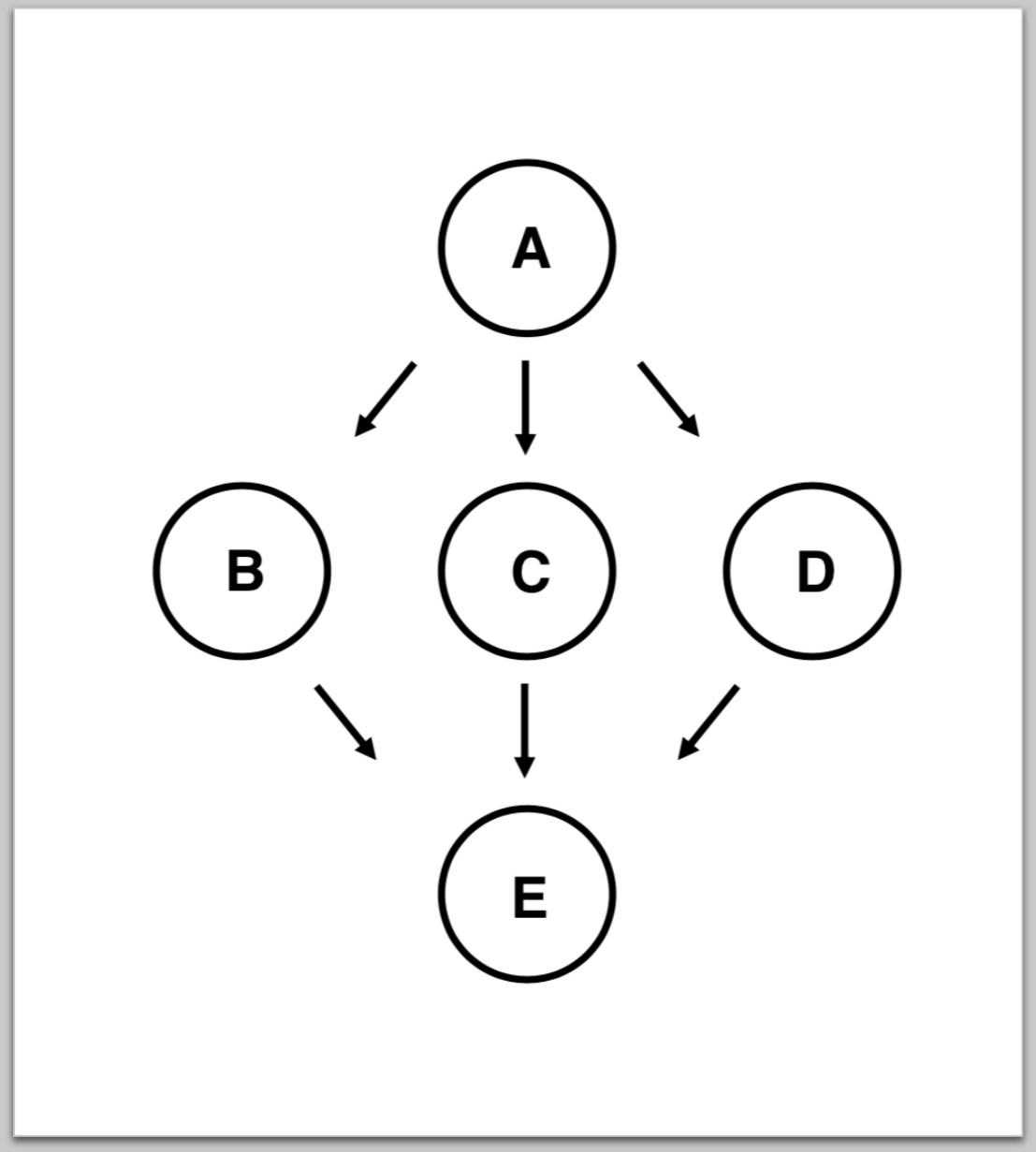
- Usually more scalable than functional parallelism
- Can be programmed at a high level with OpenMP, or at a lower level using a message-passing library like MPI.



Functional parallelism

- Definition: each process performs a different "function" or execute a different code sections that are independent.
- Commonly programmed with message passing libraries

- Examples:
  - 2 brothers do yard work (1 edges & 1 mows)
  - 8 farmers build a barn

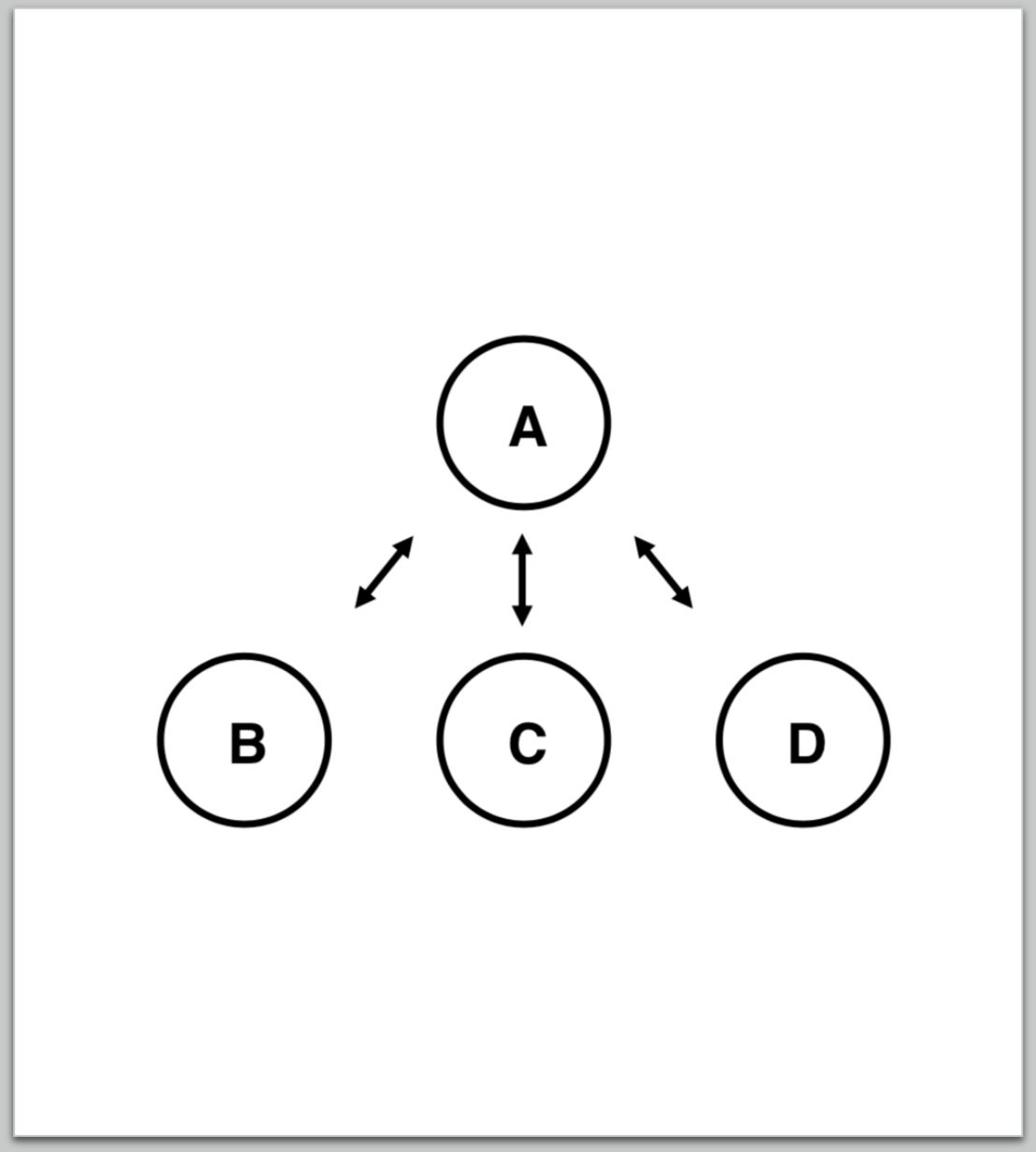


Task parallelism

- Definition: each process perform the same functions but do not communicate with each other, only with a "Master" Process. are often called "Embarrassingly Parallel".
- Examples:

  - Independent Monte Carlo Simulations

  - ATM Transactions

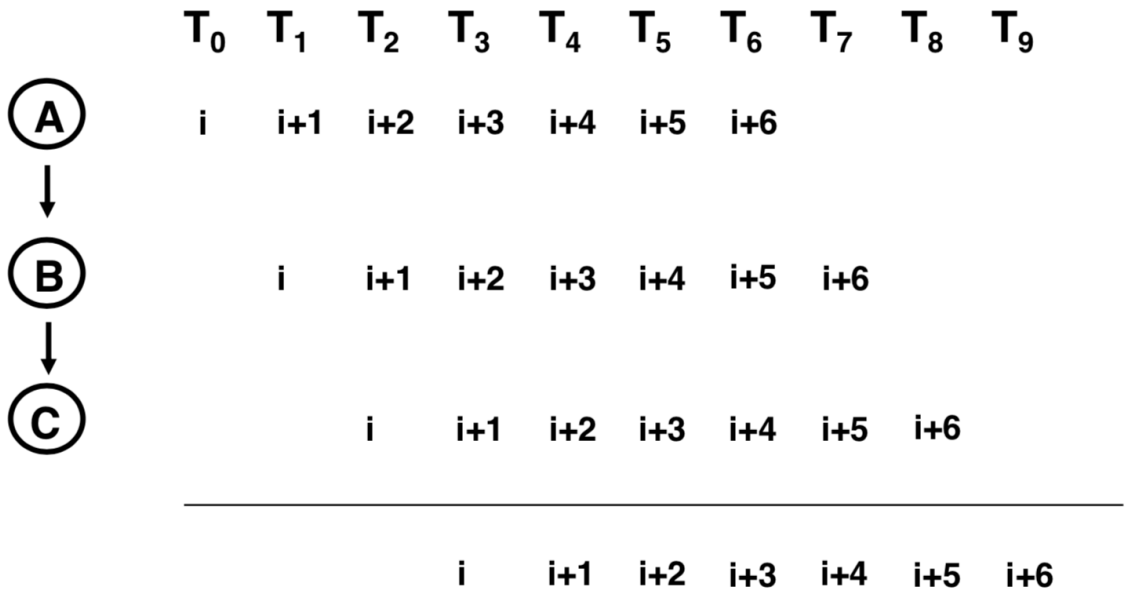


Pipeline parallelism

- **Definition**: each Stage works on a part of a solution. The output of one stage is the input of the next.

(Note: This works best when each stage takes the same amount of time to complete)

- **Examples**: Assembly lines, Computing partial sums



Is it really worth it to go Parallel?

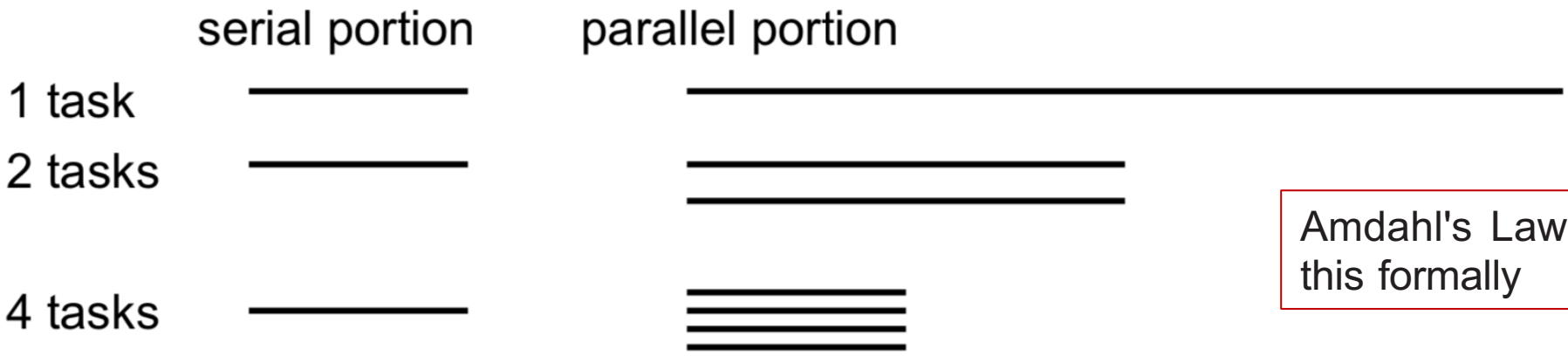
- Writing effective parallel applications is difficult!!
  - Load balance is important
  - Communication can limit parallel efficiency
  - Serial time can dominate

- Is it worth your time to rewrite your application?
  - Do the CPU requirements justify parallelization? Is your problem really 'large'?
  - Is there a library that does what you need (parallel FFT, linear system solving)
  - Will the code be used more than once?

Theoretical Upper Limits to Performance

- All parallel programs contain:
  - parallel sections (we hope!)
  - serial sections (unfortunately)

- Serial sections limit the parallel effectiveness



Amdahl's Law states this formally

Amdahl's Law

- Amdahl's Law places a strict limit on the speedup that can be realized by using multiple processors.
- Effect of multiple processors on run time

$$t_n = (f_p / N + f_s) t_1$$

where

f_s = serial fraction of code

f_p = parallel fraction of code

N = number of processors

t_1 = time to run on one processor

Limit Cases of Amdahl's Law

- Speed up formula:
  - $S = 1 / (f_s + f_p/N)$

  where

  f_s = serial fraction of code

  f_p = parallel fraction of code

  N = number of processors

- Case:

  1. $f_s = 0$, $f_p = 1$, then $S = N$

  2. N -> infinity: $S = 1/f_s$; if 10% of the code is sequential, you will never speed up by more than 10, no matter the number of processors

More terminology

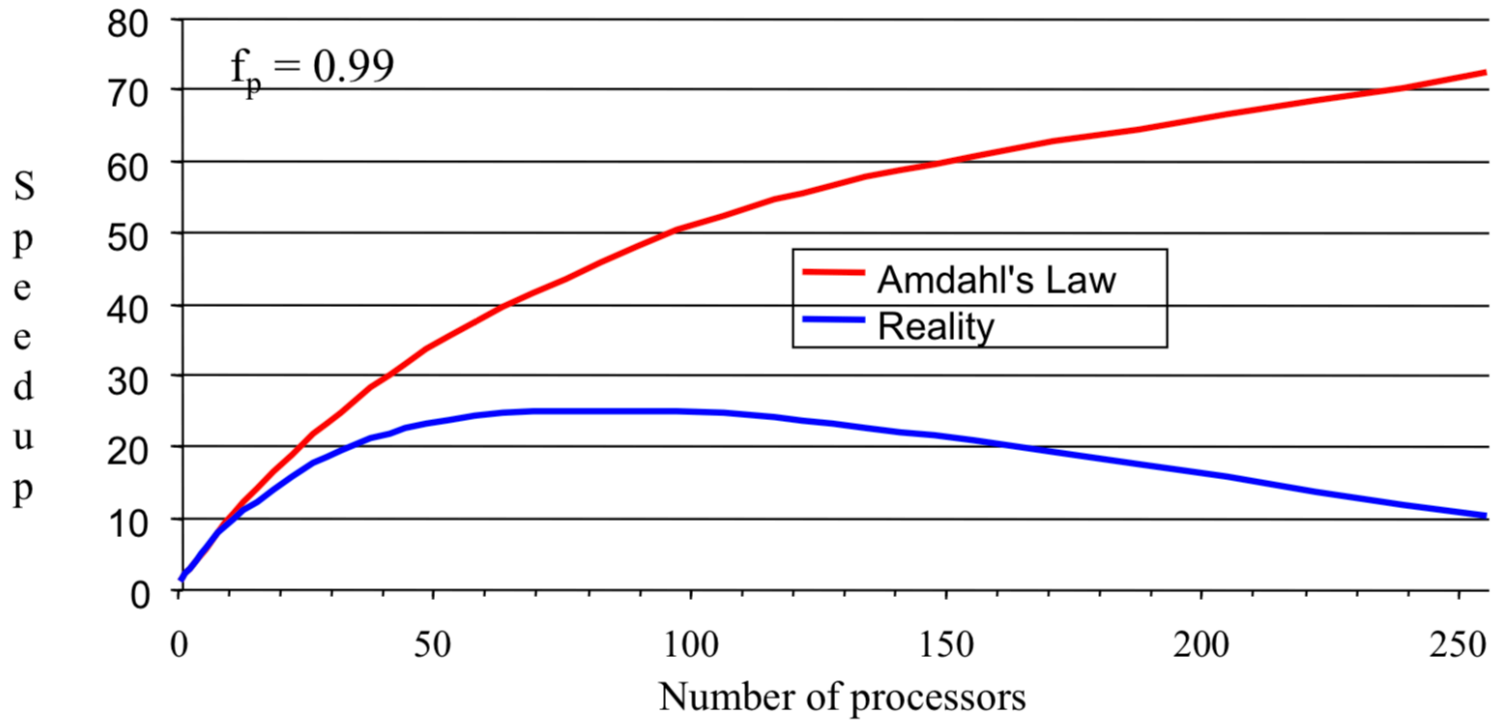
- **synchronization**: the temporal coordination of parallel tasks. It involves waiting until two or more tasks reach a specified point (a sync point) before continuing any of the tasks.

- **parallel overhead**: the amount of time required to coordinate parallel tasks, as opposed to doing useful work, including time to start and terminate tasks, communication, move data.

- **granularity**: a measure of the ratio of the amount of computation done in a parallel task to the amount of communication.
  - fine-grained (very little computation per communication-byte)
  - coarse-grained (extensive computation per communication-byte).

Practical Limits: Amdahl's Law vs. Reality

- Amdahl's Law shows a theoretical upper limit for speedup
- In reality, the situation is even worse than predicted by Amdahl's Law due to:
  - Load balancing (waiting)
  - Scheduling (shared processors or memory)
  - Communications
  - I/O



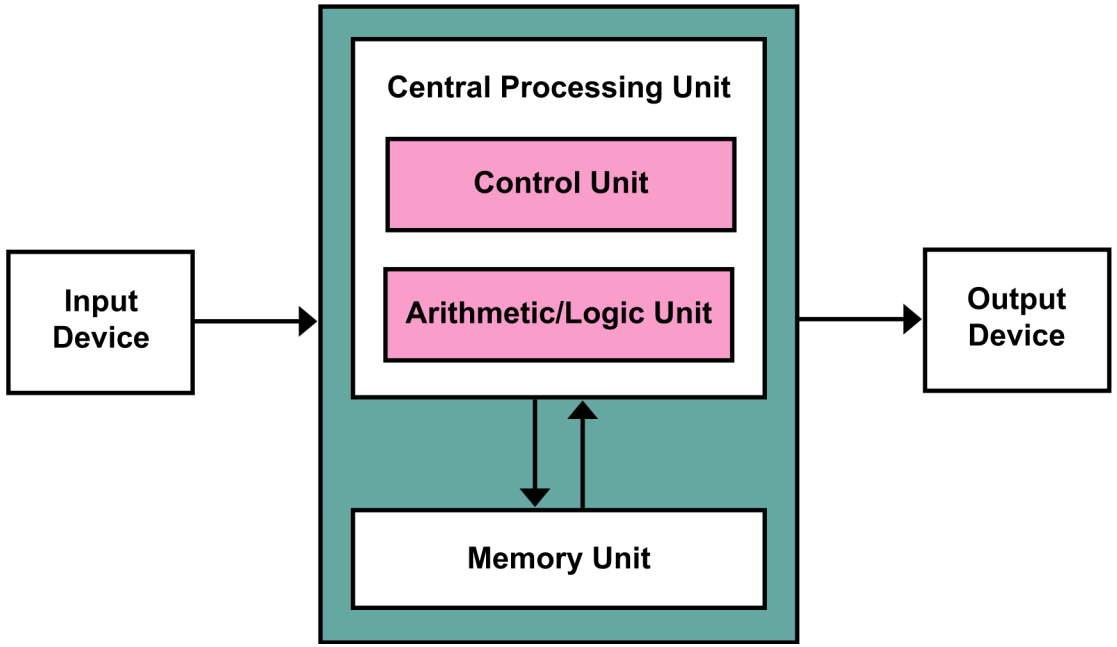
Von Neumann Architecture

- For over 40 years, virtually all computers have followed a common machine model known as the von Neumann computer. Named after the Hungarian mathematician John von Neumann.

- A von Neumann computer uses the stored-program concept. The CPU executes a stored program that specifies a sequence of read and write operations on the memory.

Basic Design

- Basic design
  - Memory is used to store both program and data instructions
  - Program instructions are coded data which tell the computer to do something
  - Data is simply information to be used by the program
- A central processing unit (CPU) gets instructions and/or data from memory, decodes the instructions and then ***sequentially*** performs them.

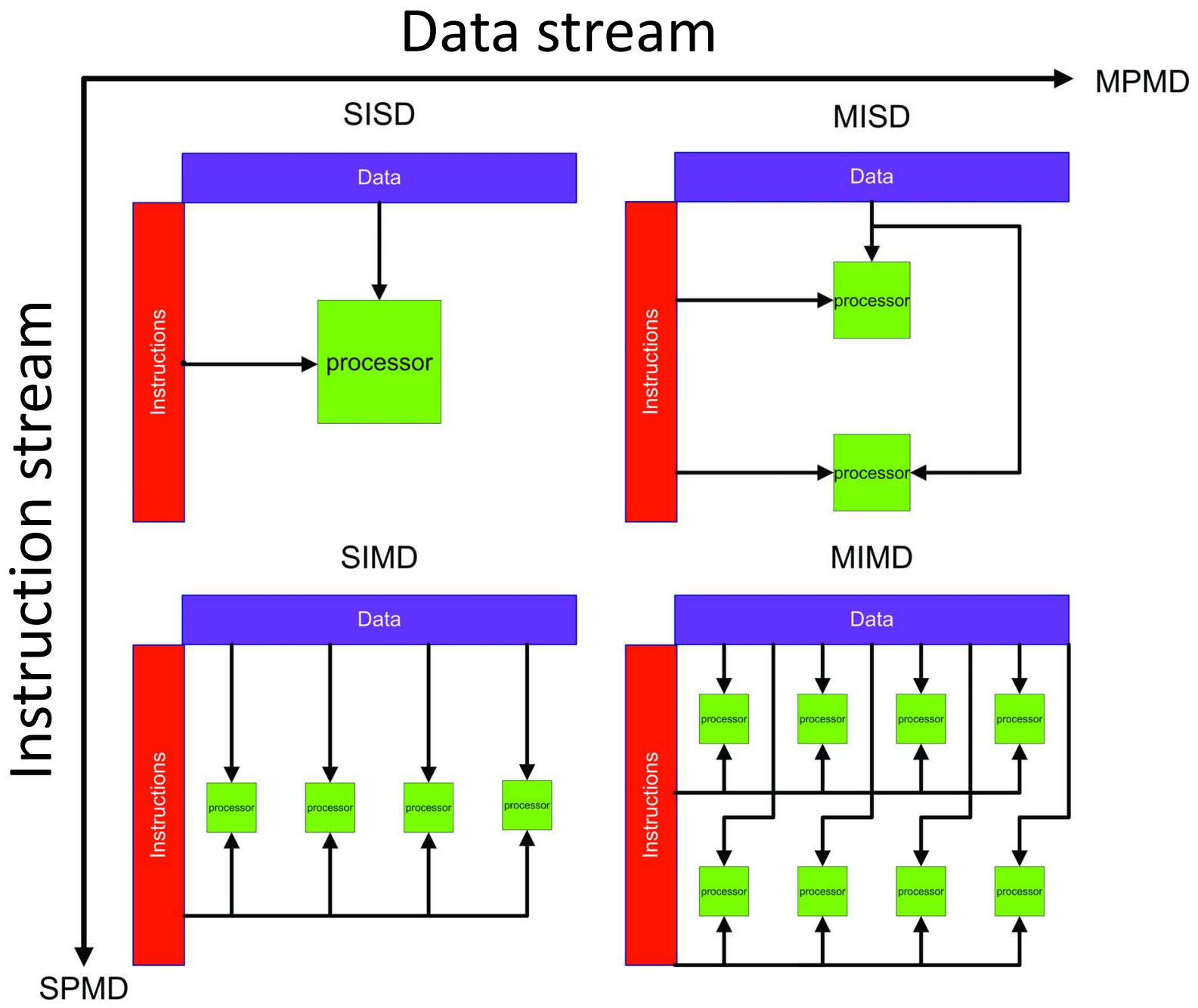


Flynn's Classical Taxonomy

- There are different ways to classify parallel computers. One of the more widely used classifications, in use since 1966, is called Flynn's Taxonomy.
- Flynn's taxonomy distinguishes multi-processor computer architectures according to how they can be classified along the two independent dimensions of ***Instruction*** and ***Data***. Each of these dimensions can have only one of two possible states: ***Single*** or ***Multiple***.

Flynn's Taxonomy

- Classification Scheme for Parallel Computers



Schmeisser *et al. 2009*

Volume 65 | **Part 7** | July 2009 | Pages 659–671 | 10.1107/S0907444909011433

Dell EMC PowerEdge Servers

- Next generation accelerators
  - Graphics Processing Unit (GPU) Market to Surpass **67.6 Million units by 2020***
  - **Field Programmable Gate Arrays (FPGA)** Market worth **$7.2 Billion by 2022***

CPU vs GPU vs FPGA

CPU - SISD

- Applicable to any programmable environment and language.
- Non-vectored integer applications

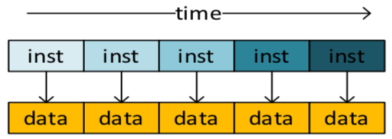
GPU - SIMD

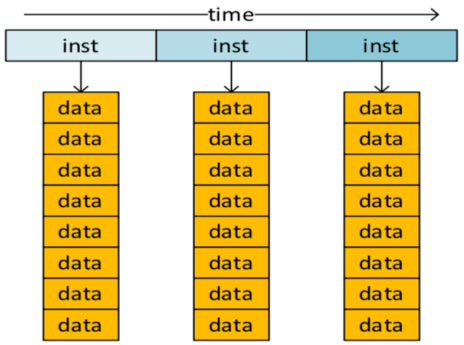
- Excels at vectored floating point
- Requires large data to be effective
- Hurt by branches or exceptions – "if" statements

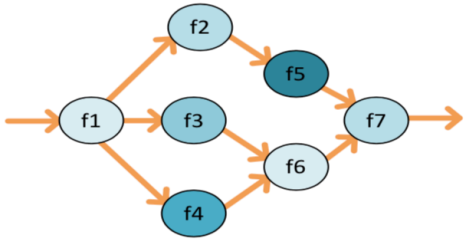
FPGA - MIMD

- Many independent instructions can operate in parallel and with either small amounts or large amounts of data
- Excellent streaming with IO devices

- Remains the core center of computation
- Remains focused on a subset of high-performance problems
- Not going away; limited breadth
- Greater breadth than GPUs
- Expect higher prevalence for enterprise applications than GPUs over time



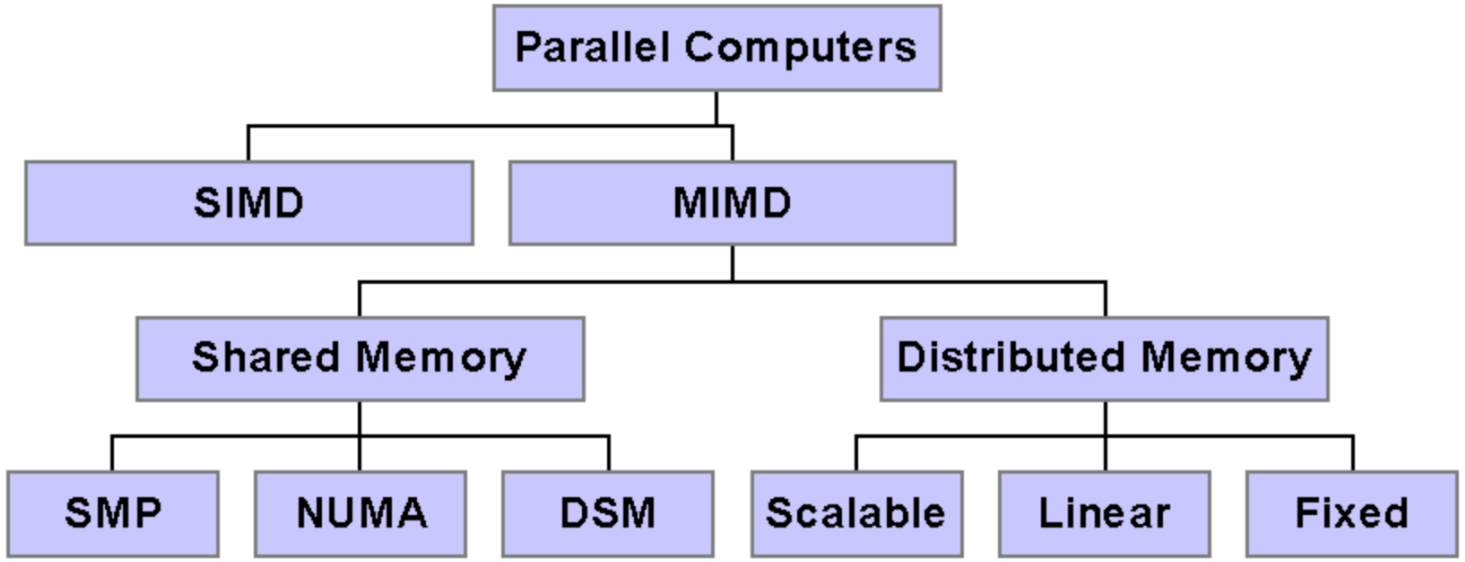




https://www.dellemc.com/en-gb/servers/index.htm

Types of Parallel Computers (Memory Model)

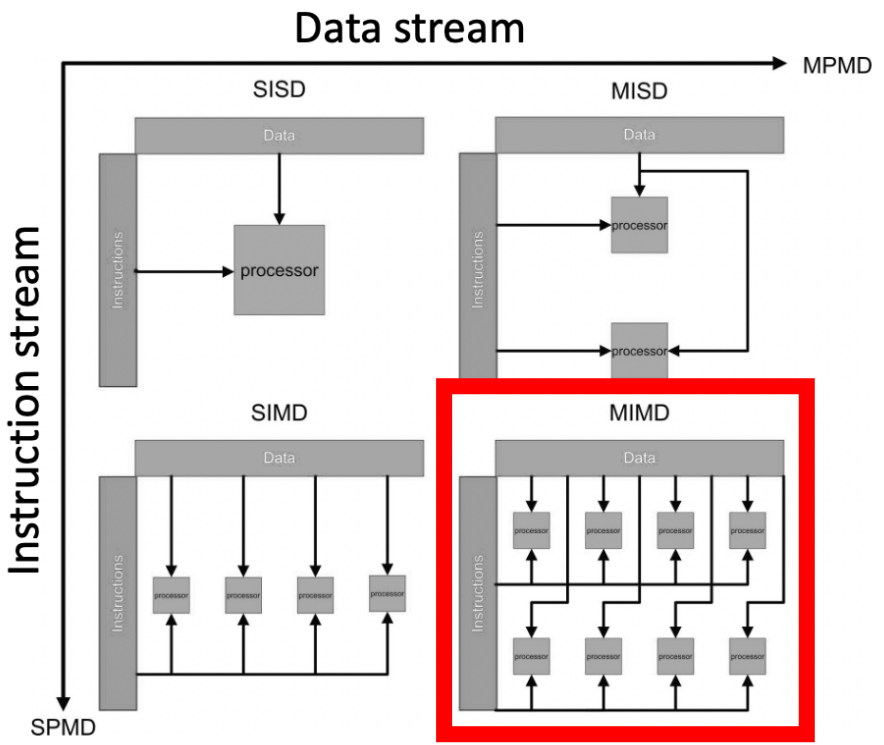
- Nearly all parallel machines these days are multiple instruction, multiple data (MIMD)
- A much more useful way to classify modern parallel computers is by their memory model
  - shared memory
  - distributed memory



https://www.cise.ufl.edu/research/ParallelPatterns/PatternLanguage/Background/ParallelHardware.htm

MPI

- Implementation of the “Message Passing Interface” standard
  - Focuses on message passing
  - Ideal for writing distributed computing applications (multiple cores that do not share memory)
  - MPI is a library for message-passing between “shared-nothing” processes.

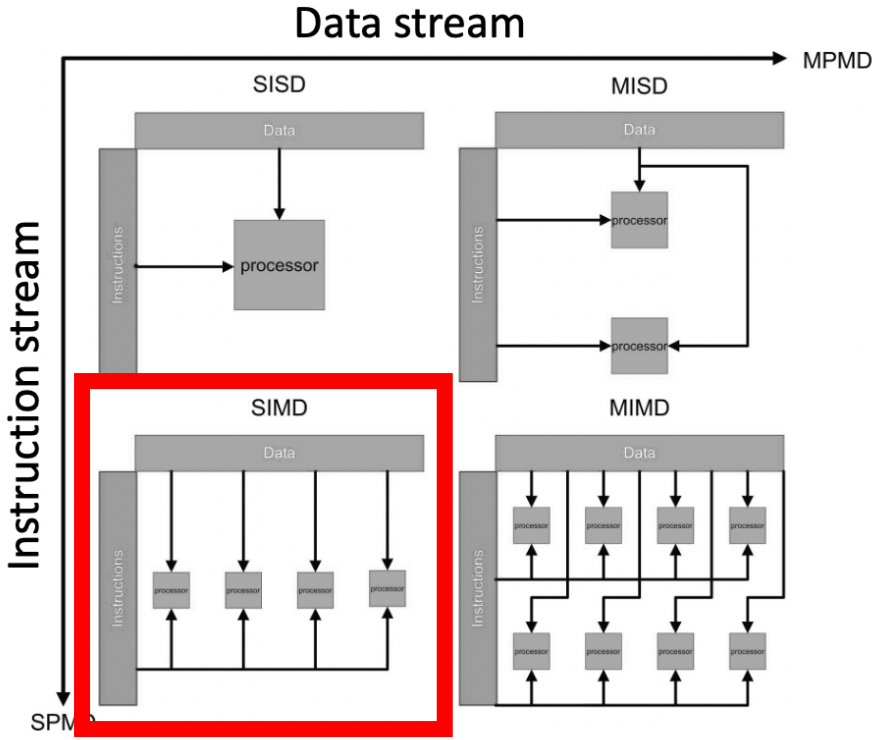


MIMD is has a wide variety of associated architectures, most commonly HPC

OpenMP

- Implementation of the “Multi-Processing” interface
  - OpenMP is a language-extension for expressing data-parallel operations
  - Focuses on shared memory
  - Ideal for writing shared memory multi-process applications.

OpenMP is a higher-level of abstraction, since its purpose is to expose the program's concurrency and dataflow to the compiler. By contrast, MPI concurrency is implicit (all processes are parallel), and the *messages* establish the dataflow structure of the computation.



- Share single memory
- Shared bus to access memory
- Memory access to each area of memory is approx. the same for each processor

Intel® oneAPI Toolkits (Beta)

Deliver uncompromised performance for diverse workloads across multiple architectures.

A Unified, Standards-Based Programming Model

Modern workload diversity necessitates the need for architectural diversity; no single architecture is best for every workload. A mix of scalar, vector, matrix, and spatial (SVMS) architectures deployed in CPU, GPU, AI, FPGA, and other accelerators is required to extract high performance.

Intel® oneAPI products will deliver the tools needed to deploy applications and solutions across SVMS architectures. Its set of complementary toolkits—a base kit and specialty add-ons—simplify programming and help developers improve efficiency and innovation.

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