Parallel Programming

GPU Architecture

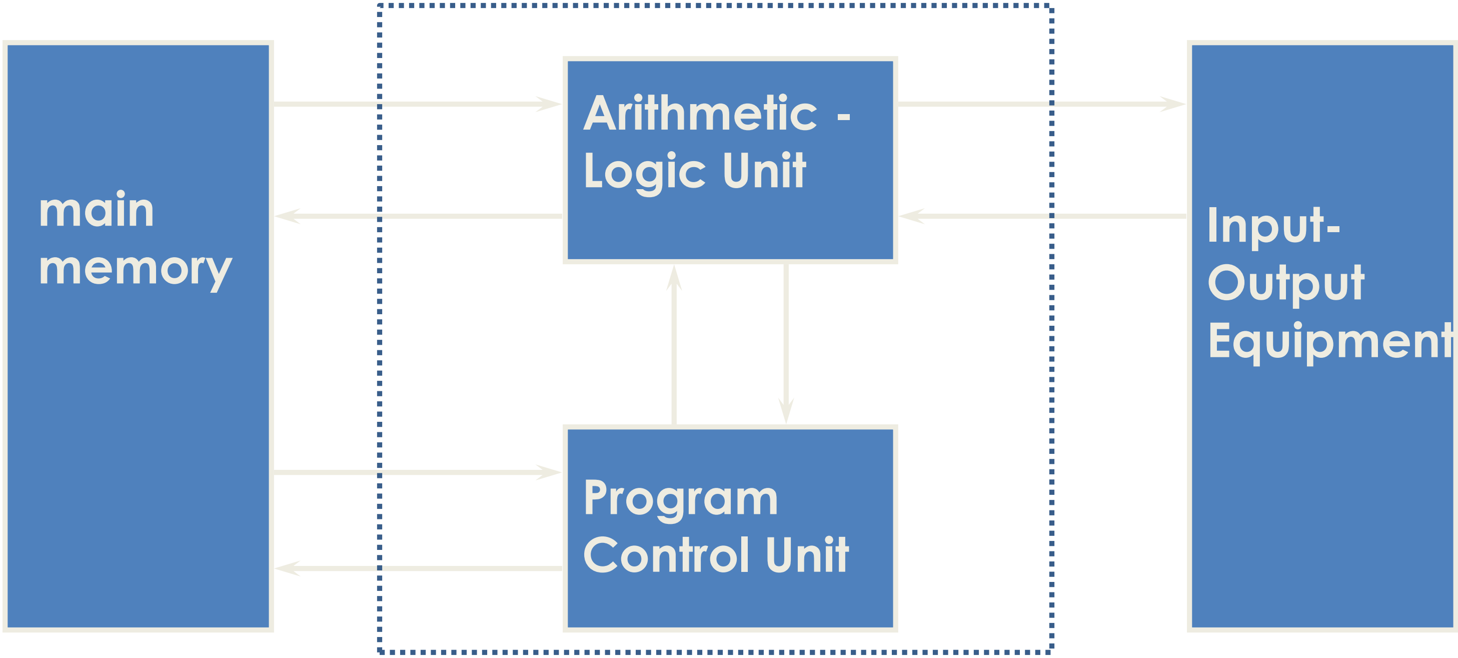
Acknowledgement: Some graphics and examples are taken from various online resources, including NVIDIA web sites and lecture slides of Prof. Wen-mei Hwu.

Overview

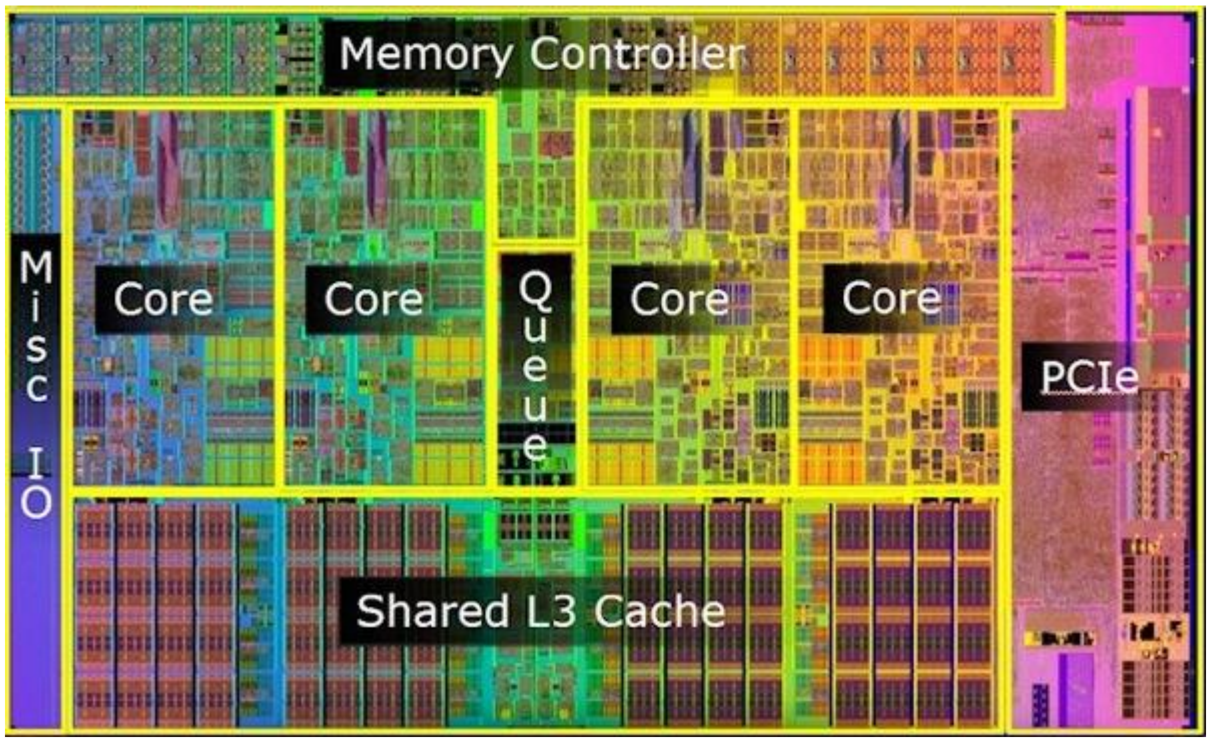
- Modern GPUs have a massively parallel architecture.
  - We use NVIDIA CUDA-enabled GPU as example.
- How are they different from CPUs?
- Where do GPUs fit in parallel architectures?

Von Neumann Machine (1947)

- Fetch-and-Execute cycle on the CPU:
  - Fetch instructions and data from memory
  - Execute instructions on ALU



Modern CPU Architecture



Intel i5/i7. Source: Intel

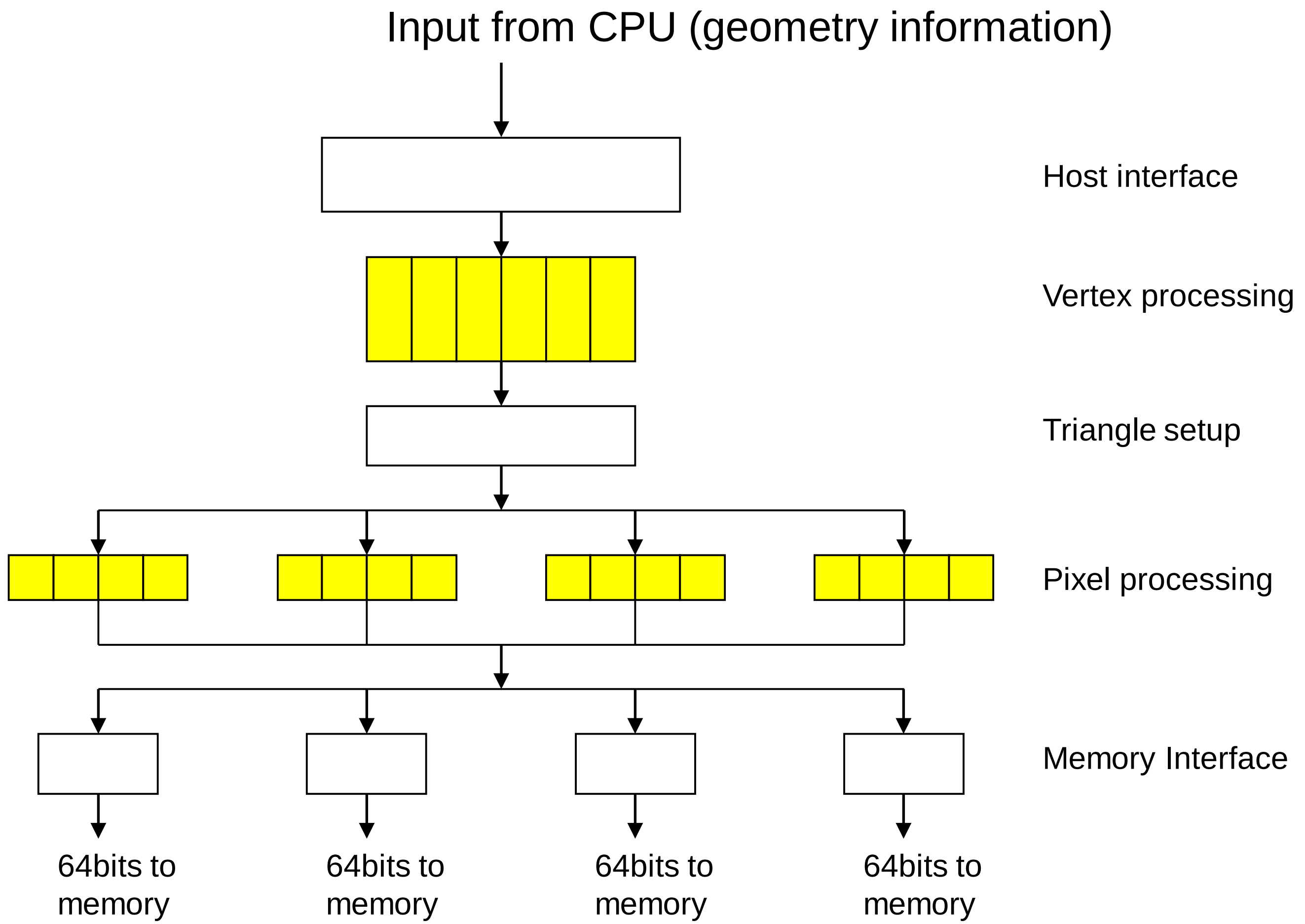
Parallelism in CPUs

- Multiple physical cores
- Hyper Threading (HT) or Simultaneous Multithreading (SMT)
  - Map each physical core to two logical processors
- Instructional level parallelism (ILP)
  - Divide each instruction into stages and pipeline multiple independent instructions by stages

Graphics Processing Unit (GPU)

- Traditionally used for game (3D rendering) applications
- Currently major accelerators for general-purpose computing applications that exhibit data parallelism
- Work as co-processors, i.e., rely on the CPU for task control, memory allocation, data transfer, etc.

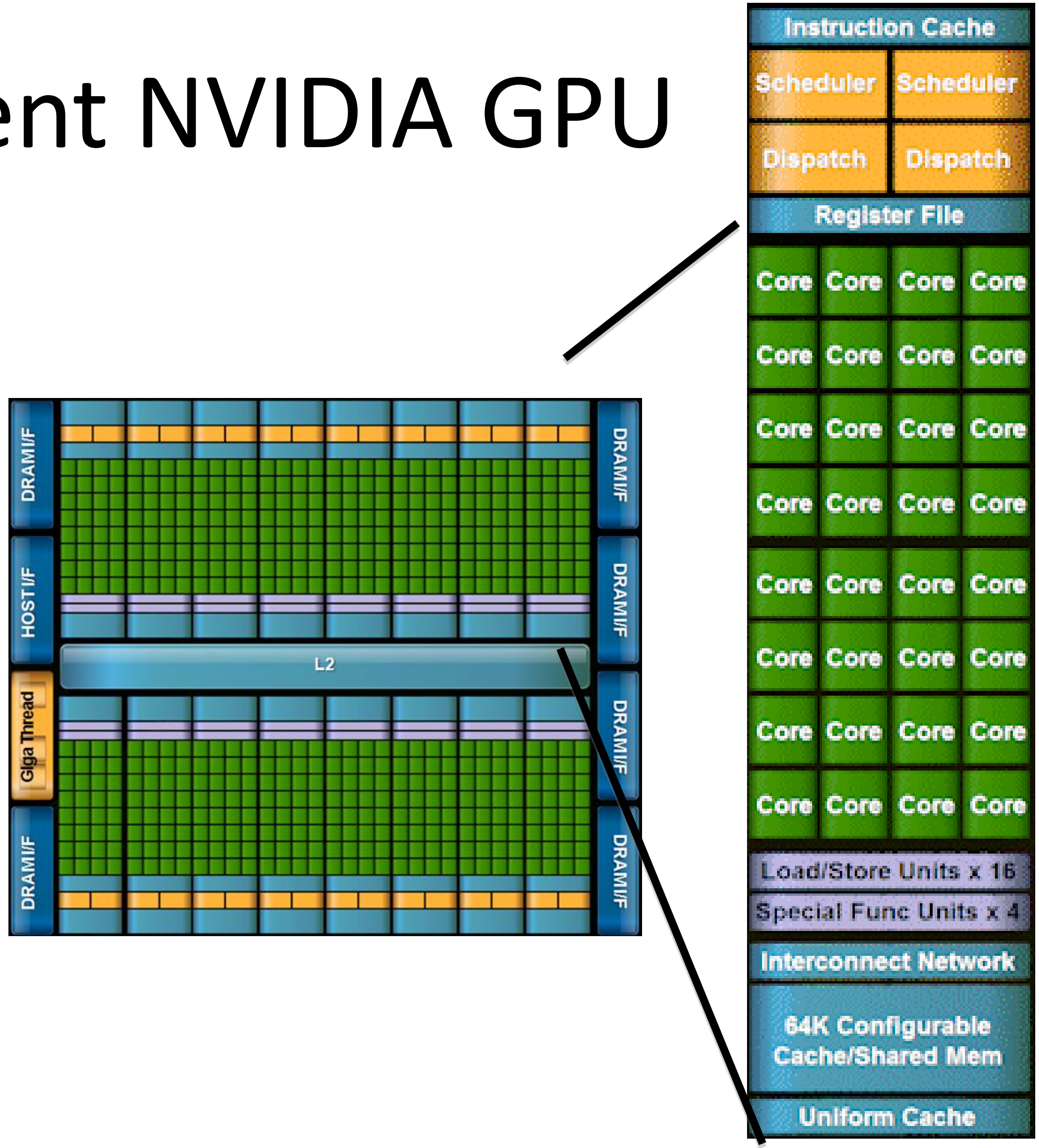
Traditional GPU Pipeline



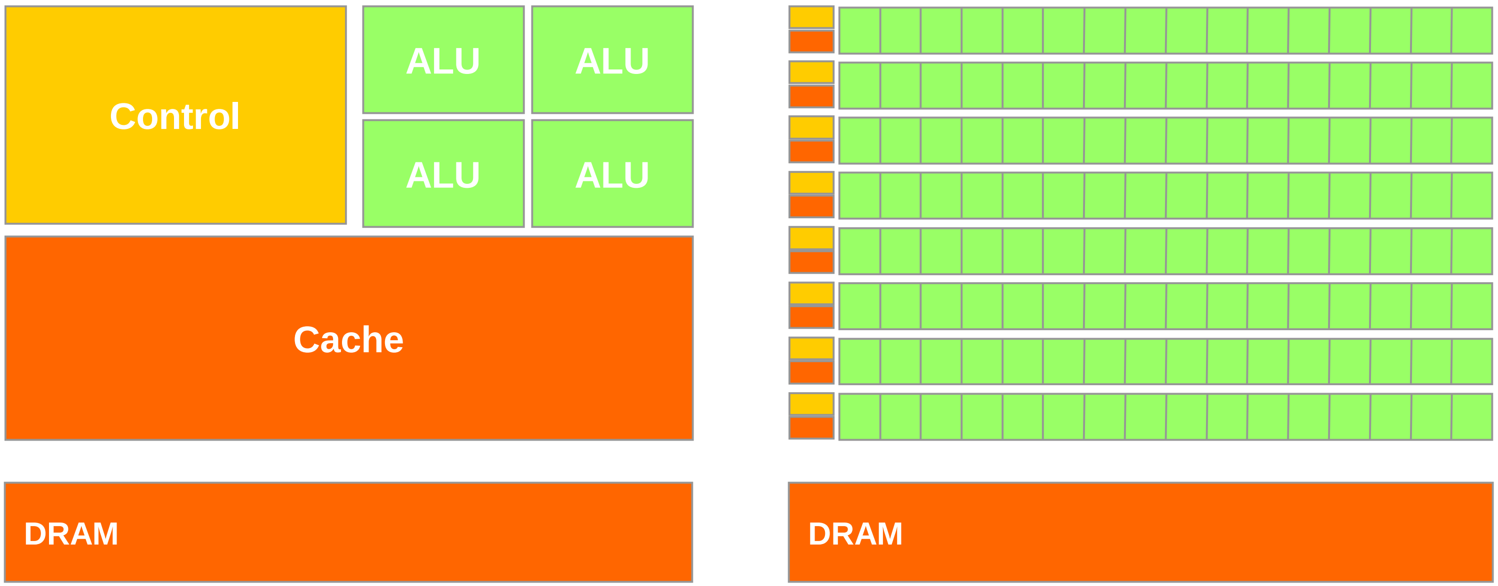
Traditional graphics hardware abstraction
Limited programmability (only highlighted stages programmable)

Current NVIDIA GPU

- General-purpose
- Fully programmable
- Massively parallel



Comparison of CPU and GPU



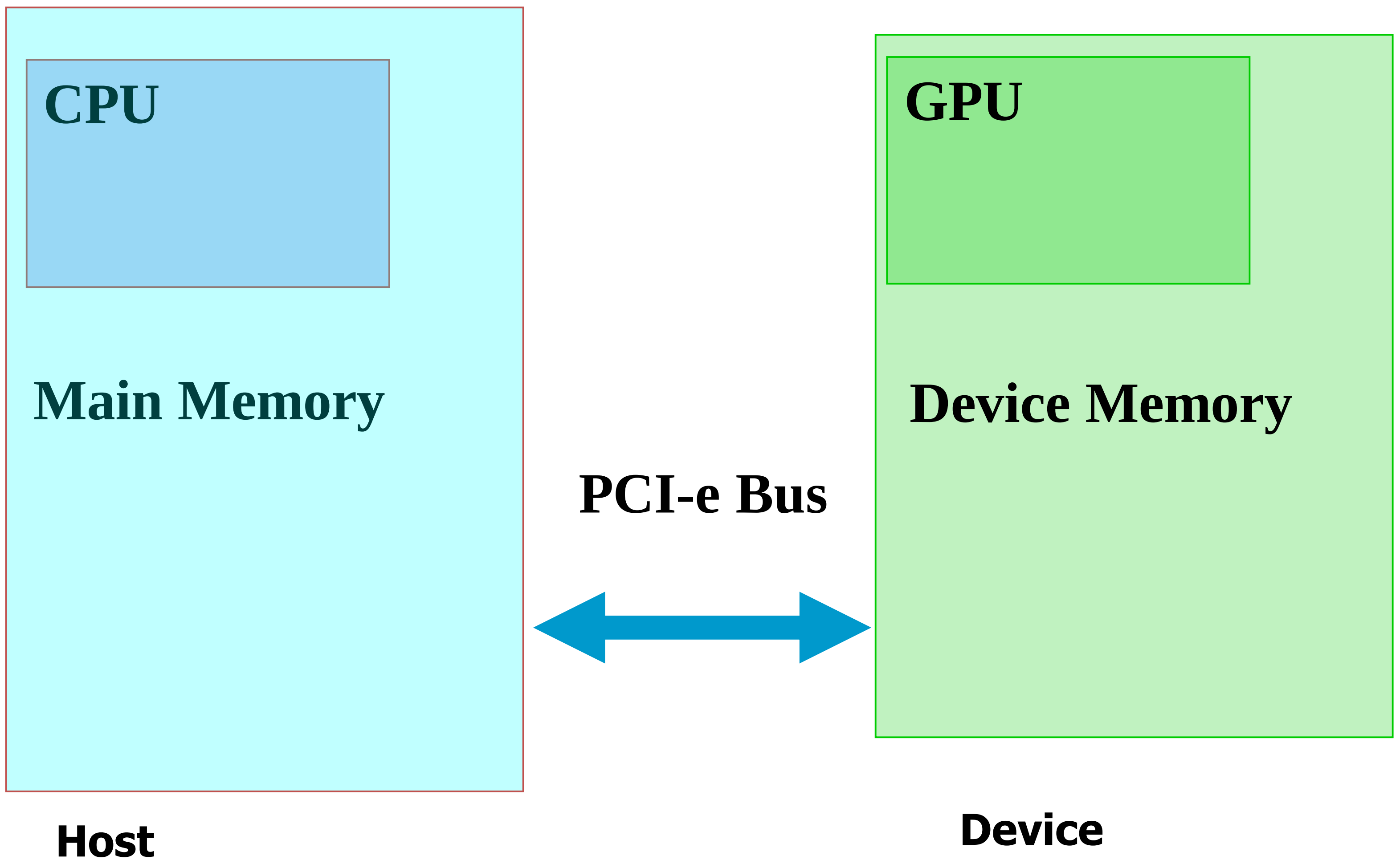
CPU

Latency oriented

GPU

Throughput oriented

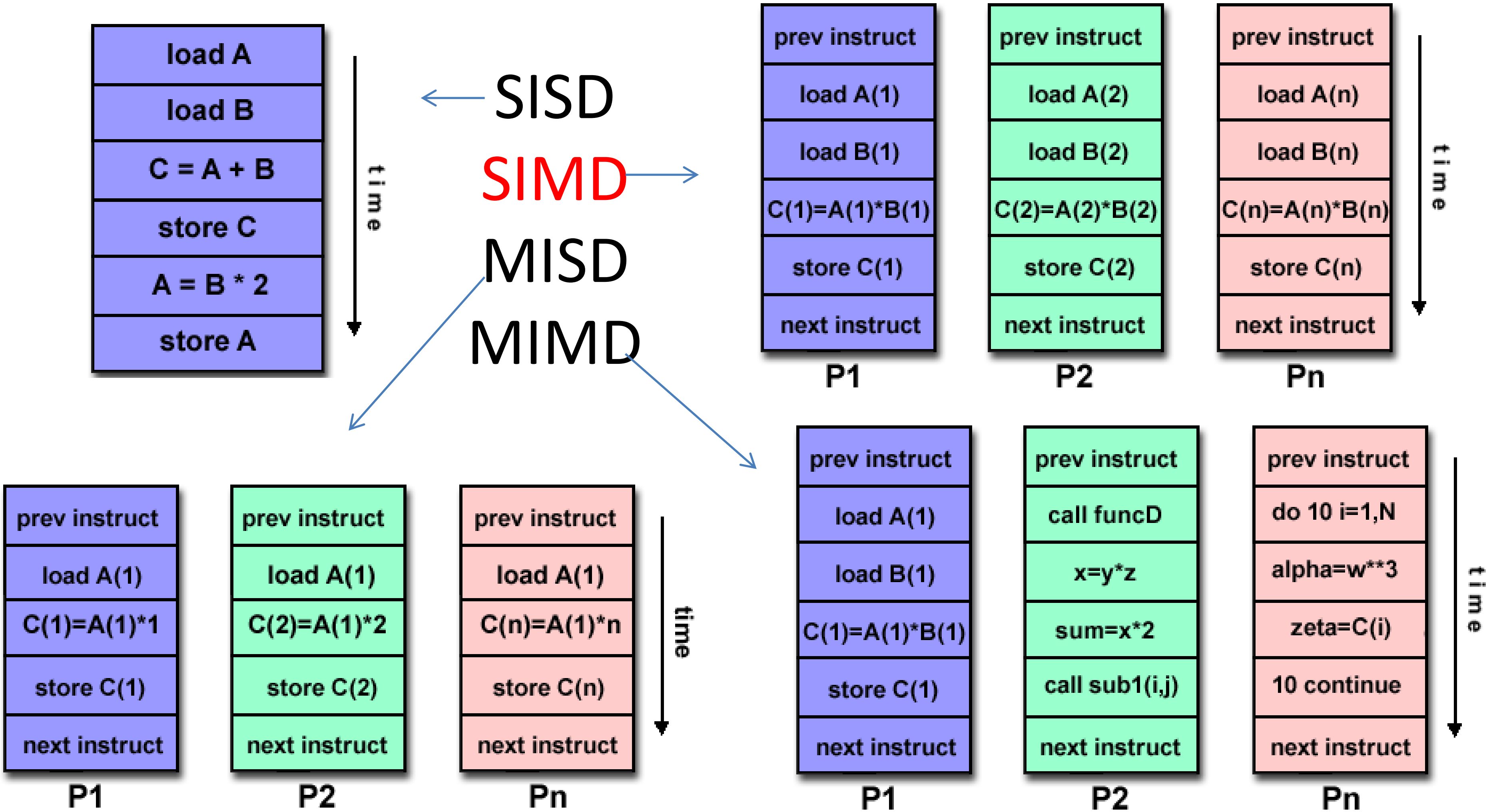
GPU and CPU



Classification of Parallel Architecture

S I S D **Single Instruction, Single Data** A serial (non-parallel) computer **Oldest type of computers**	**S I M D** **Single Instruction, Multiple Data** A type of parallel computer Synchronous execution Suitable for data-parallel applications **Examples: GPUs**
M I S D **Multiple Instruction, Single Data** A type of parallel computer A single data stream is fed into multiple processing units. **Few actual examples**	**M I M D** **Multiple Instruction, Multiple Data** most common type of parallel computer synchronous or asynchronous **Examples: Supercomputers, clusters, multicore PCs**

Illustrations of Execution Flows



Example adapted from https://computing.llnl.gov/tutorials/parallel_comp

SIMT Architecture of NVIDIA GPU

- Single Instruction Multiple Threads
  - Instruction-level parallelism within a single thread
  - Thread-level parallelism through simultaneous hardware multithreading
    - Each multiprocessor creates, manages, schedules, and executes CUDA threads in groups of 32, called **warp**s.
    - Branch divergence occurs only within a warp; different warps execute independently regardless of whether they are executing common or disjoint code paths.

SIMT vs SIMD

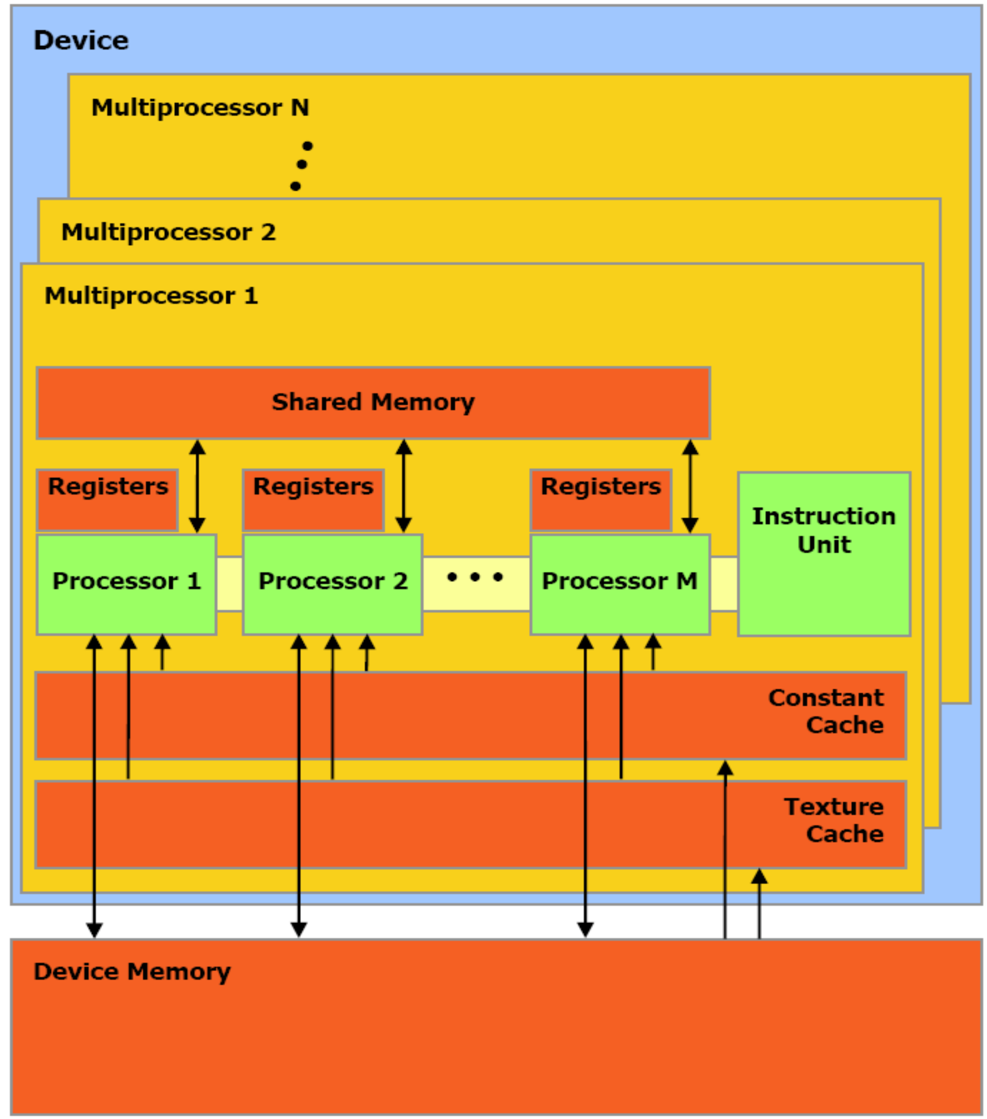
- Similar: a single instruction controls multiple processing units.
- Different:
  - SIMD vector organizations expose the SIMD width to the software
    - E.g., data items are required to aligned into vectors of a fixed size.
  - SIMT instructions specify the execution and branching behavior of a single thread
    - For simplicity, the programmer can ignore the SIMT behavior; however, substantial performance improvements can be realized by taking care of it.

CPU vs GPU Threads

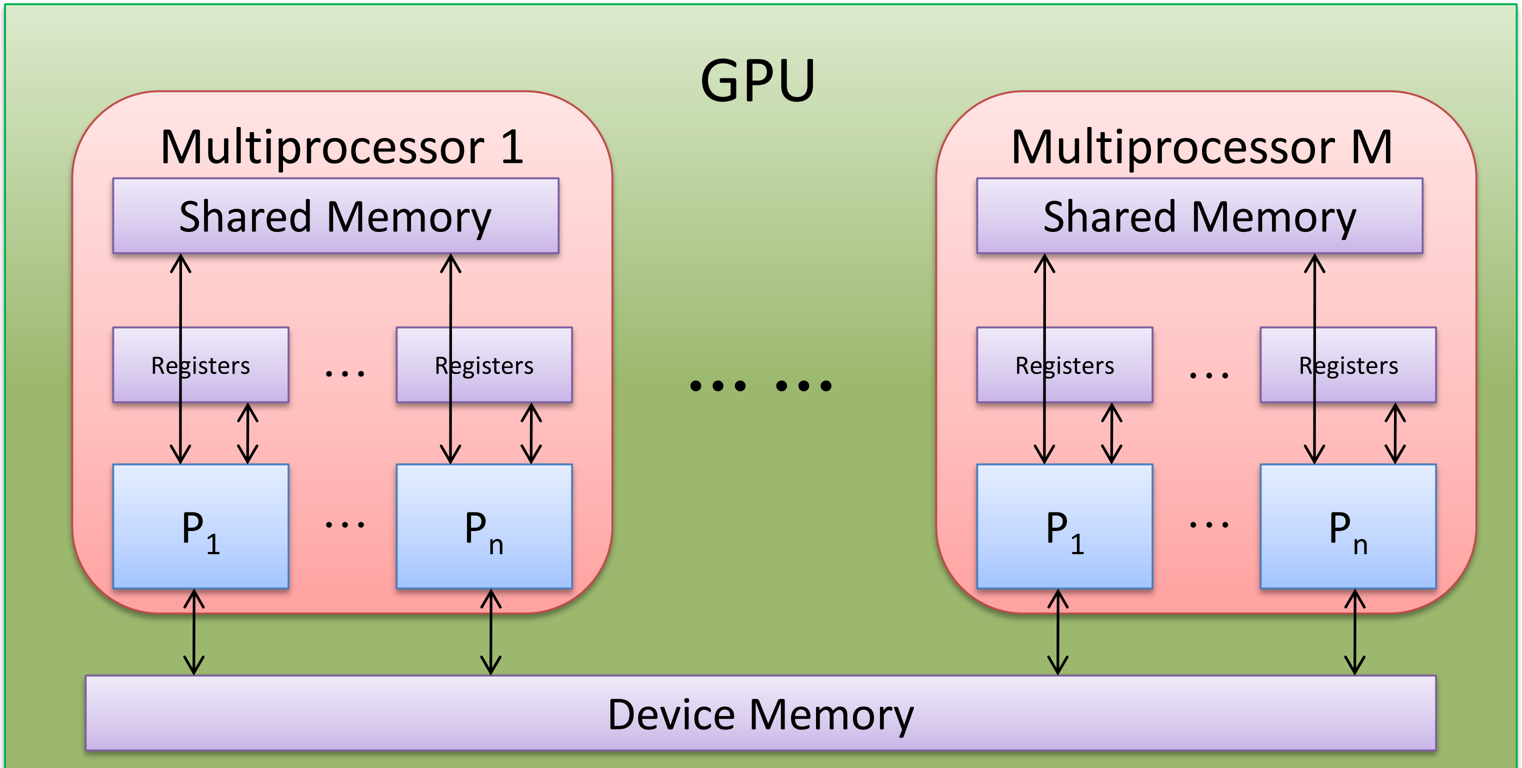
- CPU threads are much more heavyweight than GPU threads to create and maintain.
- Typically there are tens of concurrent CPU threads in a CPU program whereas there can be 1,000s to 10,000s of concurrent GPU threads in a GPU program.
- In a CPU program, threads may execute different code; in a GPU program, typically all threads execute the same piece of code (called a **kernel**).

NVIDIA GPU Memory Hierarchy

- Registers: smallest, fastest on-chip memory
- On-chip shared memory: small, fast, software-managed consistency
- Off-chip device memory: high-bandwidth, high-latency



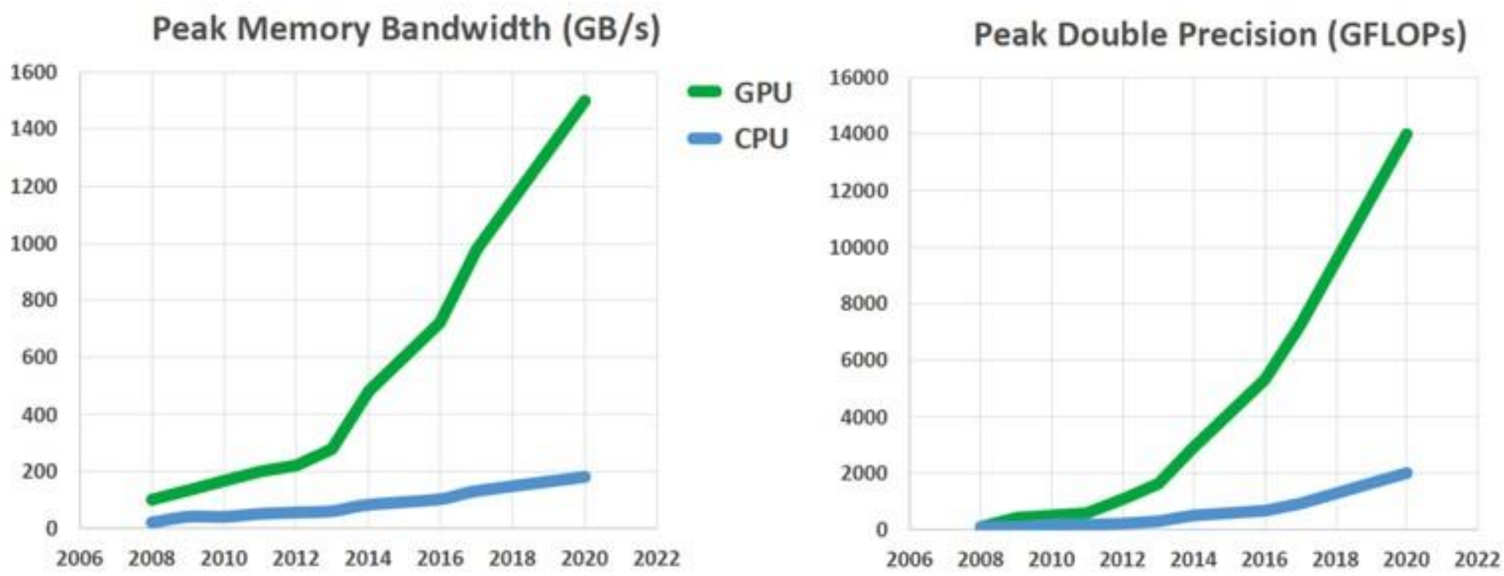
Putting it Together



- 10s~100s of identical streaming multiprocessors (SMs)
- 10s of identical uniprocessors (cores) in a multiprocessor

=> Hundreds to thousands of cores, or thread processors

GPU versus CPU: Performance Trend



Source: https://www.nextplatform.com/2019/07/10/a-decade-of-accelerated-computing-augurs-well-for-gpus/

GPGPU Applications

- 3D real-time graphics
- Weather and climate forecast and simulation
- Molecular dynamics
- Computational finance
- Bioinformatics
- Computational physics and chemistry
- …

Issues about GPU Architecture

- Co-processor nature
- Bus transfer bandwidth
- Suitable mainly for data-parallel applications
- Unusual memory hierarchy
- Programmer-responsible correctness
- Programmer-responsible optimizations
- High power consumption

Summary

- GPUs are highly parallel architectures.
  - Single Instruction Multiple Thread
  - Support a massive number of threads
  - Threads scheduled in unit of warps
- They are suitable for many data-parallel, computation-intensive applications.
- Programming GPU requires architectural considerations.