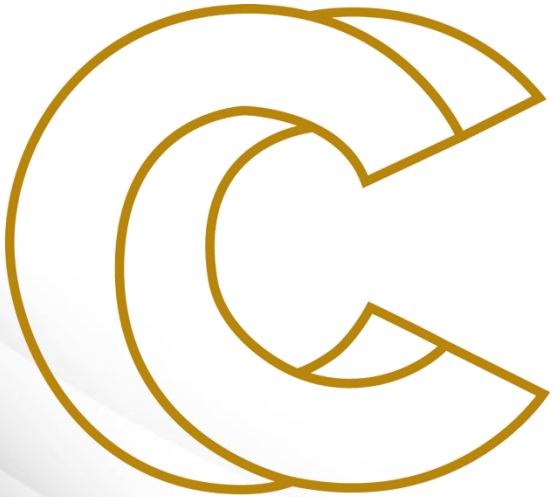

EURO 4SEE

Introduction to HPC using GPUs,

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Lesson 2: Remarks on Parallelism

What is parallelism

- When we want to speed up a calculation, there's only so much things we can do with only one calculator
- In real world, we are trying to reduce total time needed for a work by increasing number of workers assigned to it
- However, some of the work might be non-parallelizable: we should do it sequentially anyway
- Also, organizing workers is not an easy task and would have some overhead: you're really lucky if using 10x workers means 10x less time for parallelizable part too

Lesson 2: Remarks on Parallelism

Scaling

- We want to know how fast a work will be done for how many workers added.
- **Speedup**: the ratio of time to complete the problem on **one PE** (processing element—which can be a node, processor, or core), **versus** time to complete the problem on **N PEs**
- Scaling refers to a program's expected speedup with increasing PEs.

- We evaluate scaling for either **fixed problem size** (strong scaling) or **fixed problem size processor(PE)** (weak scaling)

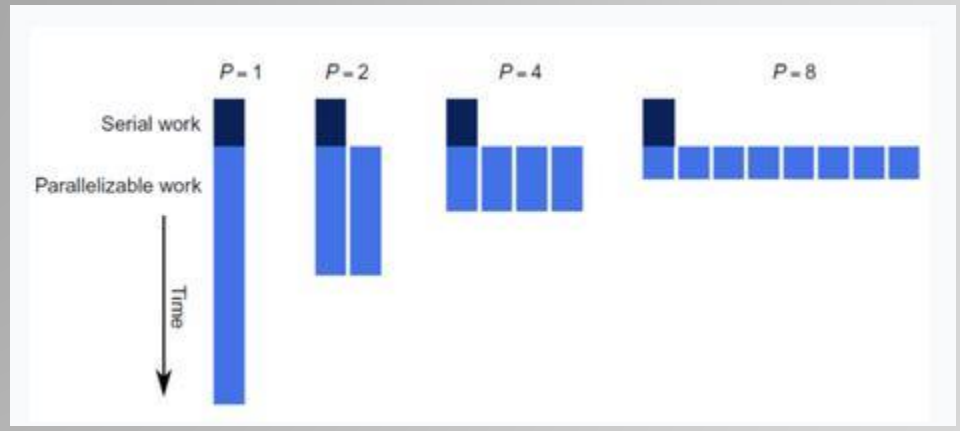
Lesson 2: Remarks on Parallelism

Scaling with Fixed Problem Size (strong scaling, Amdahl's law)

- We will assume our code consists of 2 parts: a serial part, which will not be affected by number of workers, and a parallelizable part, whose needed time will be inversely proportional to the number of workers at limit (best) case.
- Measures **how fast** I'd do **the same work** with more workers
- P: parallelizable part (between 0 and 1)
- N: number of workers (processes, threads, …)

$$\text{Speedup} = \frac{1}{(1-P) + \frac{P}{N}}$$

- Reflects the law of diminishing returns



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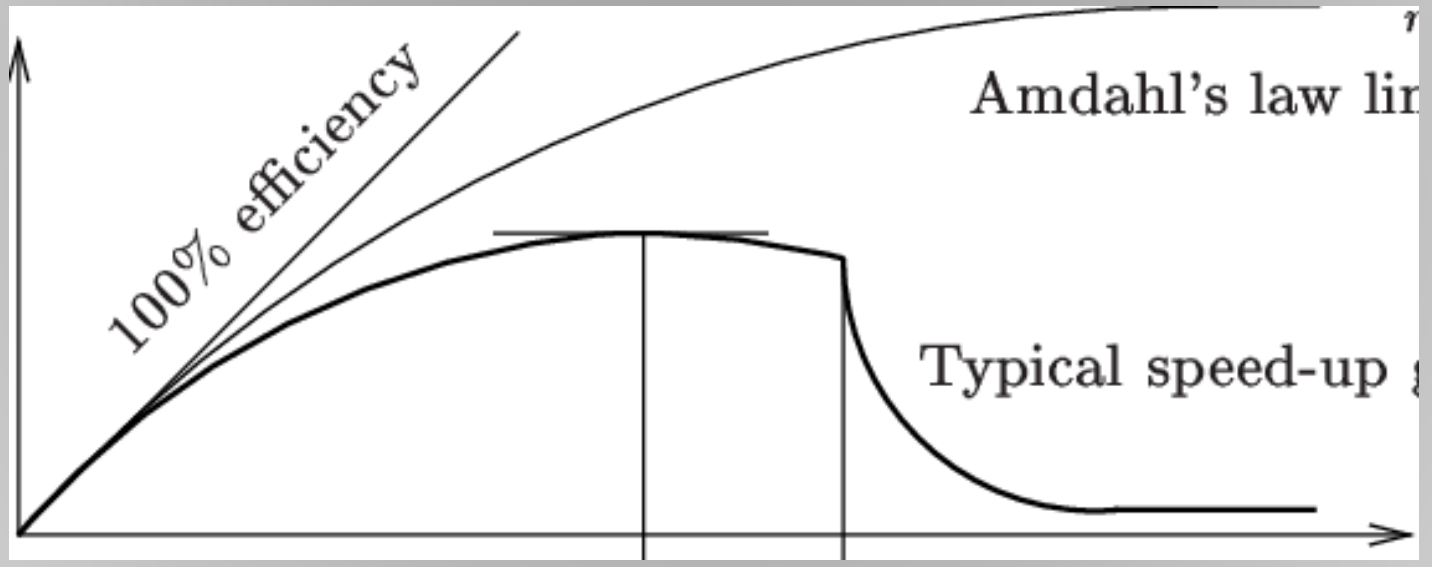
Scaling with Fixed Problem Size (strong scaling, Amdahl's law)

- **Limit** at infinite number of workers: parallel part vanishes, so **1/(1-P)**
- Reflects the law of diminishing returns

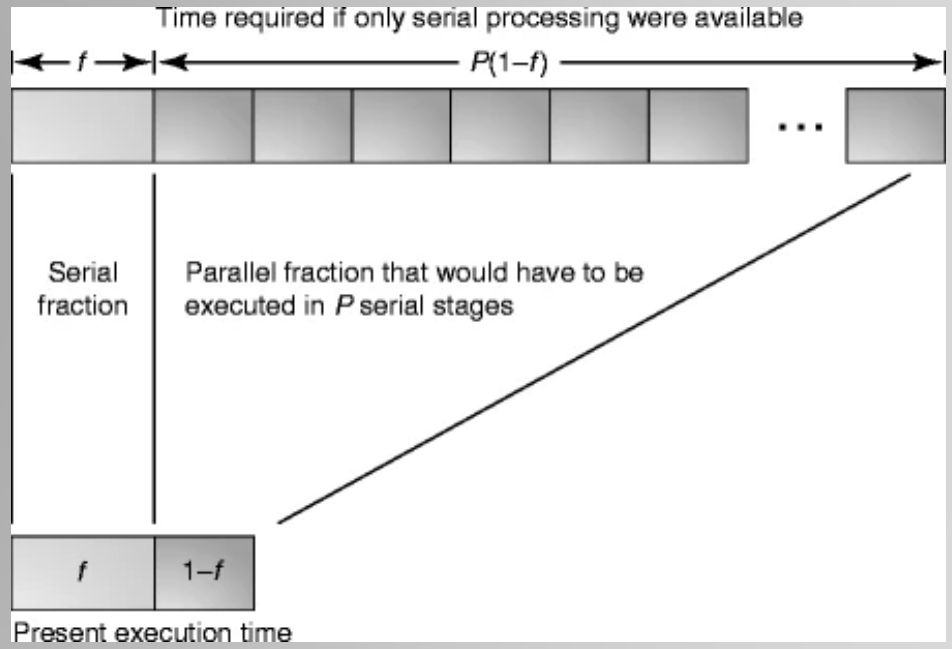


Lesson 2: Remarks on Parallelism

Scaling with Fixed Problem Size <u>per worker</u> (weak scaling, Gustafson's law)

- Measures **how much work** I'd do **in the same time** with more workers
- Speedup: the ratio of time to complete the problem on one PE (processing element—which can be a node, processor, or core), versus time to complete the problem on N PEs **(but problem size = N x reference problem size)**
- Serial time for new problem size: serial part + N*parallelizable part = (1-P) + N*(P)
- Speedup: ((1-P) + N*(P))/ ((1-P) + P = 1) =

  (1-P) + N*(P) = N - (1-P)*(N-1)

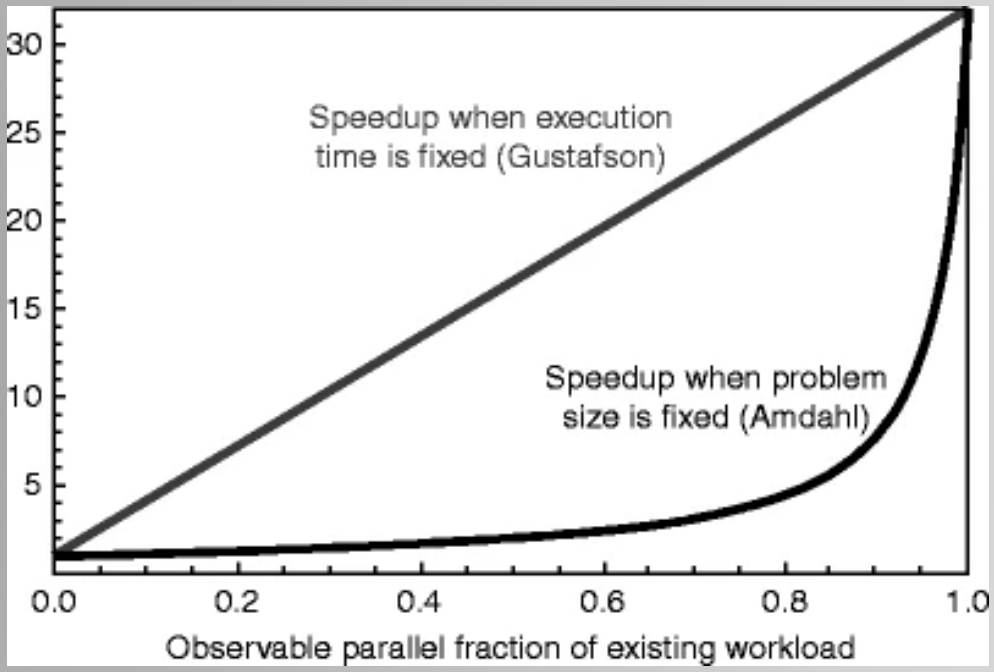


Lesson 2: Remarks on Parallelism

Scaling with Fixed Problem Size <u>per worker</u> (weak scaling, Gustafson's law)

- **Limit** at infinite number of workers: **infinity**

- Comparing two might be meaningless, they measure different kind of returns; but both shows the importance of increasing parallel fraction of the code



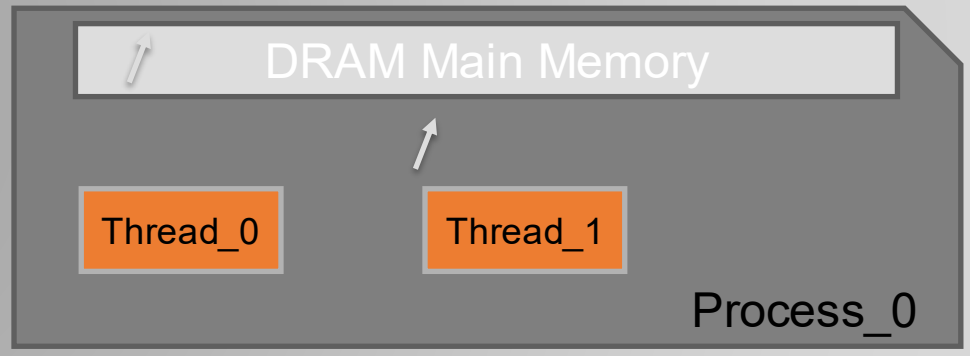
For 32 threads

Lesson 2: Remarks on Parallelism

Types of Parallelism

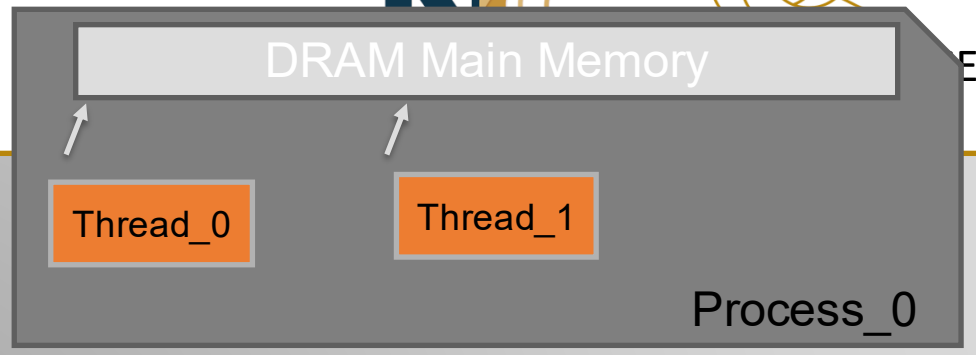
- Shared Memory: OpenMP
  - Better suited for Uniform Memory Access (UMA) cases
  - Compiler & CPU handles copy which data & when & where

```
#include <omp.h>
// Function to perform y = ax + b
void y_ax_plus_b(const std::vector<double>&x,
 std::vector<double>& y, double a, double b) {
   int n = x.size();
   omp_set_num_threads(thread_count); //optional
      #pragma omp parallel for
   for (int i = 0; i < n; i++) { y[i] = a * x[i] + b;
} }
```



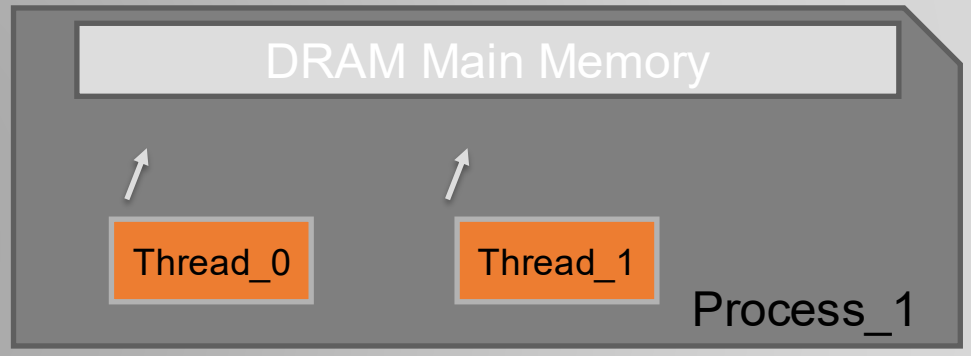

```
g++ -fopenmp -o myprogram
mycode.cpp ./myprogram
```

Lesson 2: Remarks on Parallelism



Types of Parallelism

- Distributed Memory: MPI
- More suitable to NUMA (Non-Uniform Memory Access)



- Process doesn't share
  - Memory addresses as return of malloc
    Except of memory Windows in MPI-2 and 3
  - Accesible memory addresses
  - Most variable values (global variables are possible but a headache)
  - Usually CPU core they run into (often 1 or 2 process per core)

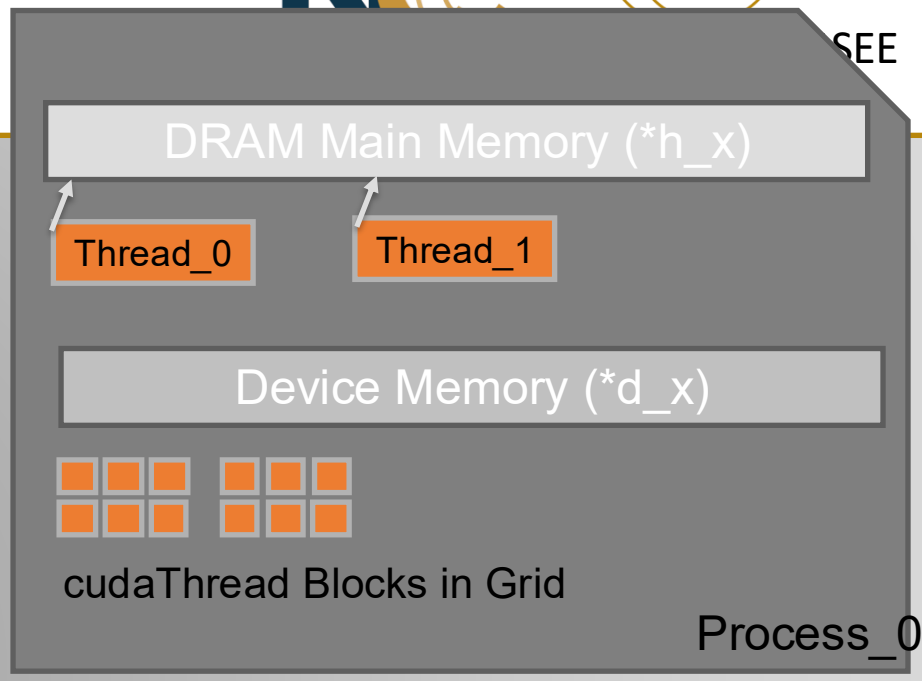
Lesson 2: Remarks on Parallelism

Types of Parallelism

- Using a device/accelerator
  - Resources are seperate bw device&host

  (dereferencing a device pointer on host would cause a crash) (but unified memory is implemented)
  - Resources are shared by threads

  (we use built-in variables that differs by thread to organize reaching different places, but pointers hold same addresses) -> fetching, synchronization etc. more similar to OpenMP



Lesson 2: Remarks on Parallelism

Types of Parallelism

Feature	CUDA	OpenMP	MPI	(C++17+)
Programming Model	GPU-based parallelism (SIMT)	Shared-memory CPU parallelism	Distributed-memory parallelism	Shared-memory CPU parallelism (with STL)
Ease of Use	Complex (requires GPU knowledge)	Simple (directives)	Moderate (requires communication handling)	Simple (via `std::for_each` with execution policies)
Scalability	Excellent on GPUs	Limited to CPU cores (shared memory)	Excellent on clusters and large systems	Limited to CPU cores (shared memory)
Performance	High for GPU-accelerated tasks	Good for CPU multi-core	Good for large-scale distributed systems	Good for CPU multi-core with optimizations
Use Cases	Deep learning, simulations, HPC	Data parallelism, scientific computing	Large-scale scientific computing, supercomputing	Data parallelism, general-purpose CPU tasks
Complexity	High (GPU-specific optimizations)	Low (easy to add directives)	Moderate (requires managing inter-process communication)	Low (just add `std::execution::par` to STL algorithms)
Key Features	Explicit memory management, thread/block management, GPU-specific optimizations	Compiler directives (`#pragma`) for parallel loops	Message-passing (e.g., `MPI_Send`, `MPI_Recv`)	Parallel algorithms (e.g., `std::for_each`, `std::transform`) with execution policies
Hardware Requirements	Requires NVIDIA GPUs	Multi-core CPUs	Multi-node distributed systems	Multi-core CPUs (with C++17 and later)

Lesson 2: Remarks on Parallelism

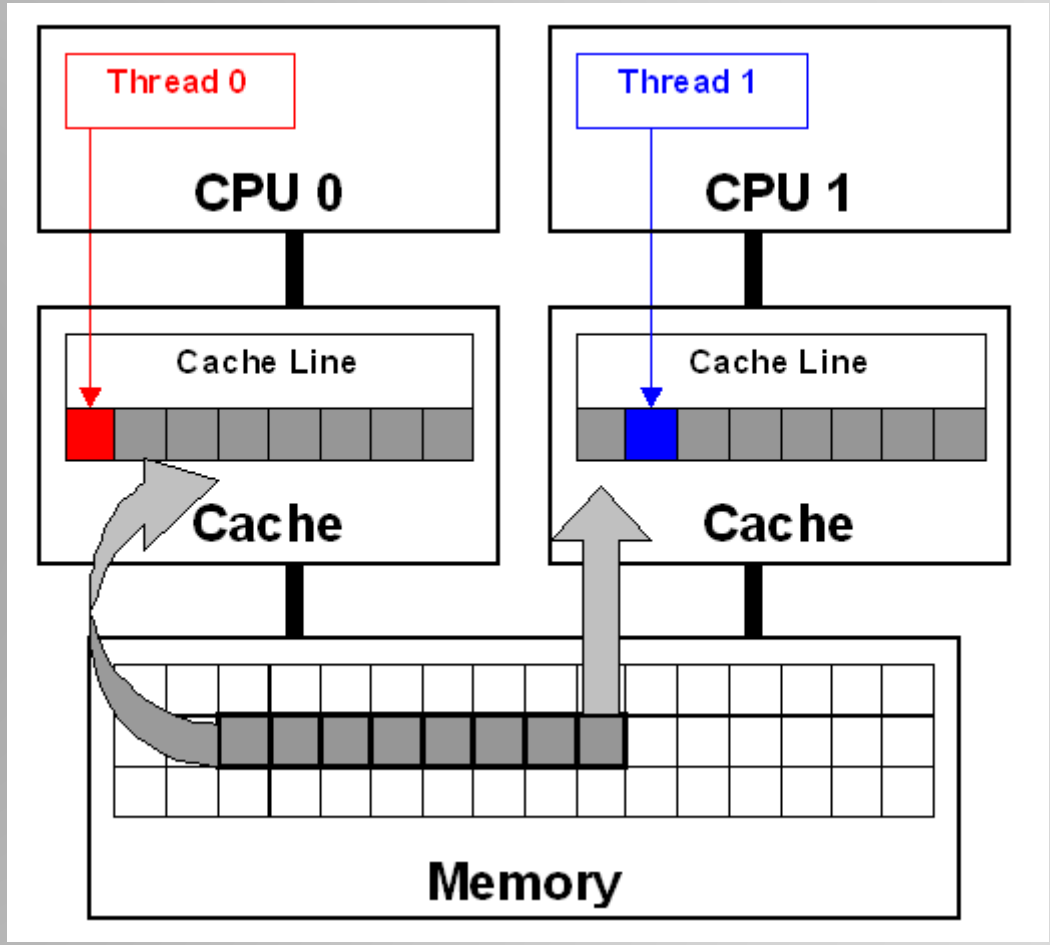
OpenMP examples

- Ex-1: for loop that initializes array
- Ex-2: private variables & **race condition**
- Ex-3: sum of an array: preventing race condition by serializing the work

Lesson 2: Remarks on Parallelism

Race Condition & False Sharing

- Race Conditions may happen when more than one thread access the same data (at least one writes)
- It make the program wrong, so must be dealt with
- In many cases, that'll be done by a locking mechanism that ensures that only one thread is modifying the data, serializing the workflow for that operation (keyword: **cache coherence**)
- Threads will still take nearby elements into cache, so modifying nearby elements would be serialized too (**false sharing**): it's closely related to bank conflicts on GPU



Next lecture

Introduction to GPUs

References

- https://link.springer.com/rwe/10.1007/978-0-387-09766-4_78
- https://akarshbolar.wordpress.com/2017/03/12/false-sharing-and-race-condition/

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Thanks!

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