UNIVERSITÀ DEGLI STUDI DI PADOVA

J. Pazzini
PADOVA UNIVERSITY

9 - INTRO TO DISTRIBUTED PROCESSING

Management and Analysis of Physics Datasets - Module B

Physics of Data

A.A. 2023/2024

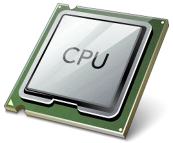
- Processing can scale with the number of processing units **n**
  (provided it is parallelizable, at least in part)

- Speedup studies usually show that processing time scale ~well with **n**
  (depending on the task/figure of merit/use case)

- Lots of processes are inherently highly scalable
  (heavily data-parallel tasks such as in the case of SPMD)

We now want to run some processing on very large (and possibly distributed) datasets

→ **Let's increase n !**



8 cores CPU

PARALLEL PROGRAMMING

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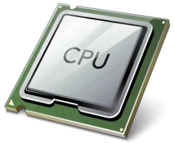

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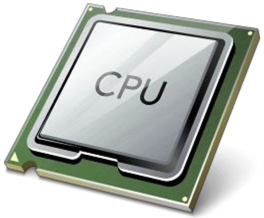

64 cores CPU

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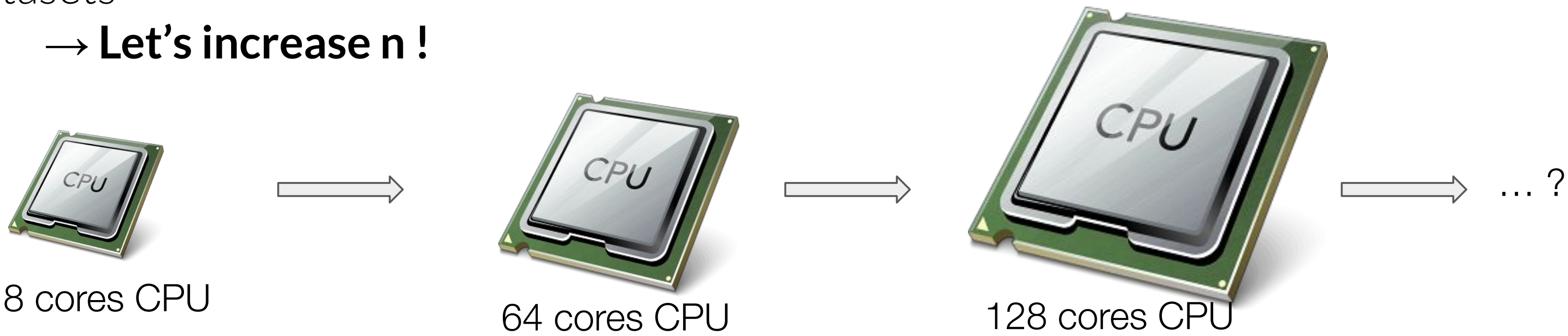
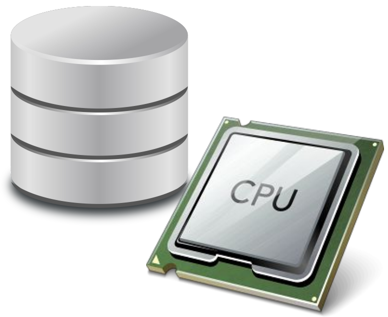
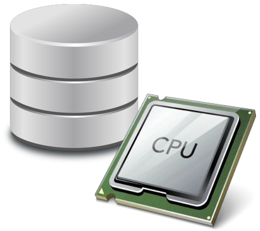


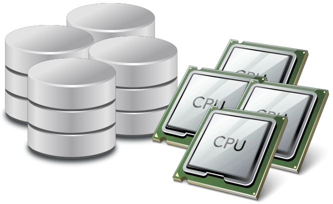
SCALABILITY



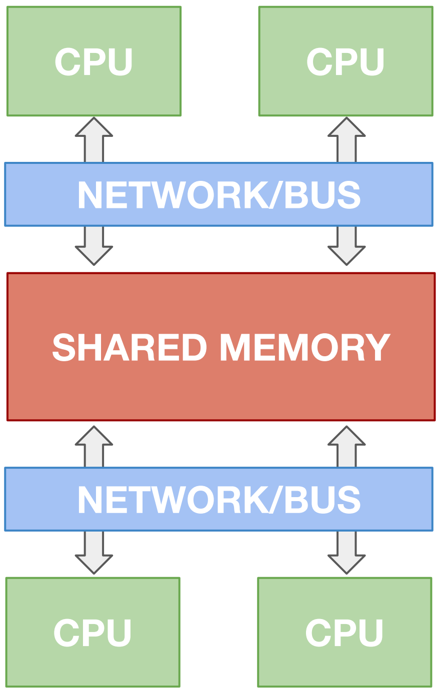
Vertical (Up) → increase the capacity/performance of the available resources (buy better HW)



Horizontal (Out) → add more resources (buy more *commodity* HW)



A number of alternative architectures can be defined depending on the way computing resources are shared, e.g.:



Shared Memory MultiProcessor (SMP)

Memory is shared across a number of parallel CPUs

Ideally all modern computing platforms (including smartphones!) are based on SMP architectures

Scaling this system to incorporate a massive number of processors is demanding and (very) expensive

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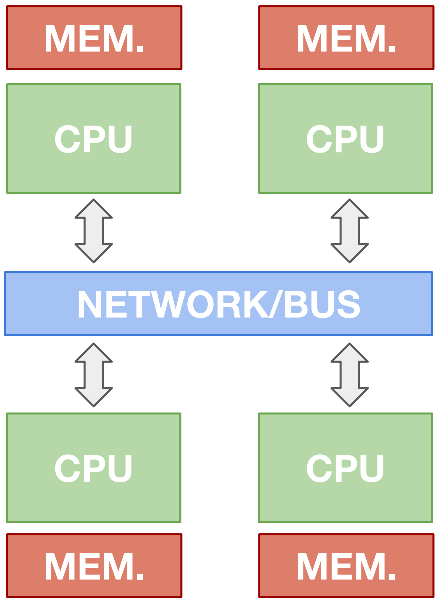


Distributed Memory MultiProcessor (Cluster)

Each processor is associated with its own memory → a *node*

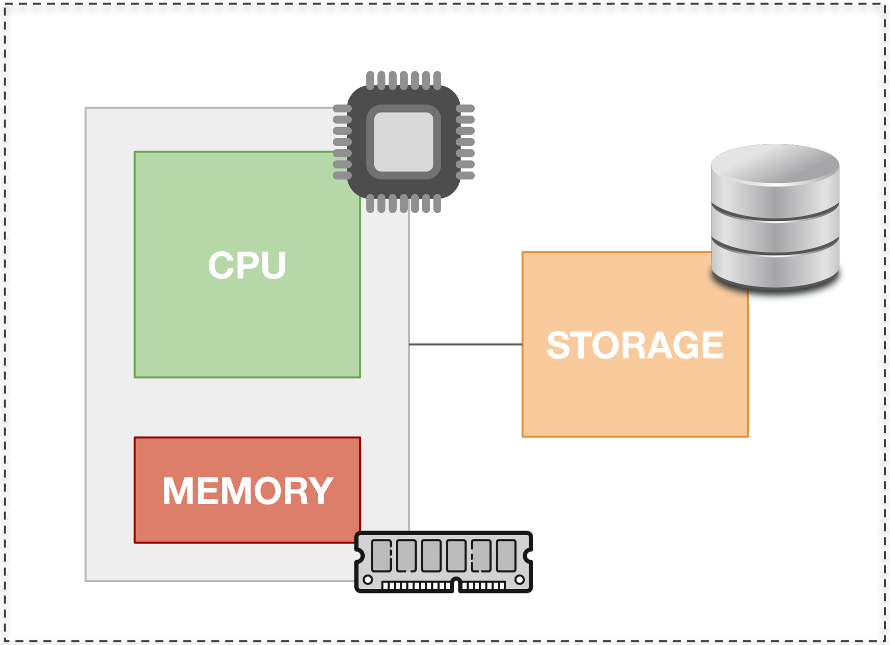
All nodes are connected via a high speed network

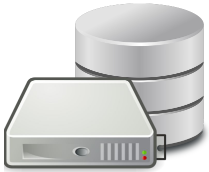
Can obtain good overall performances even from commodity HW

A lot of the complexity is in the communication across the individual units

DISTRIBUTED COMPUTING: CLUSTER

Distribute the processing across multiple *nodes* of a set of computing resources linked together by fast speed networks

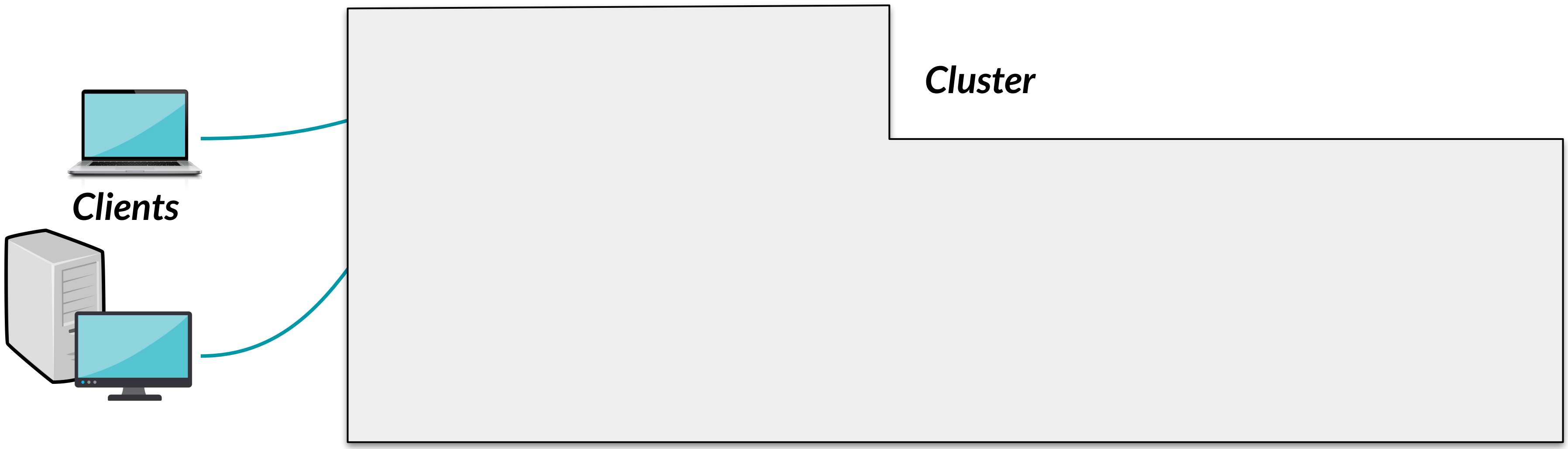




One computing node

DISTRIBUTED COMPUTING: CLUSTER

The nodes share computational workload as a “virtual massive computer”, being exposed to the users as a single system



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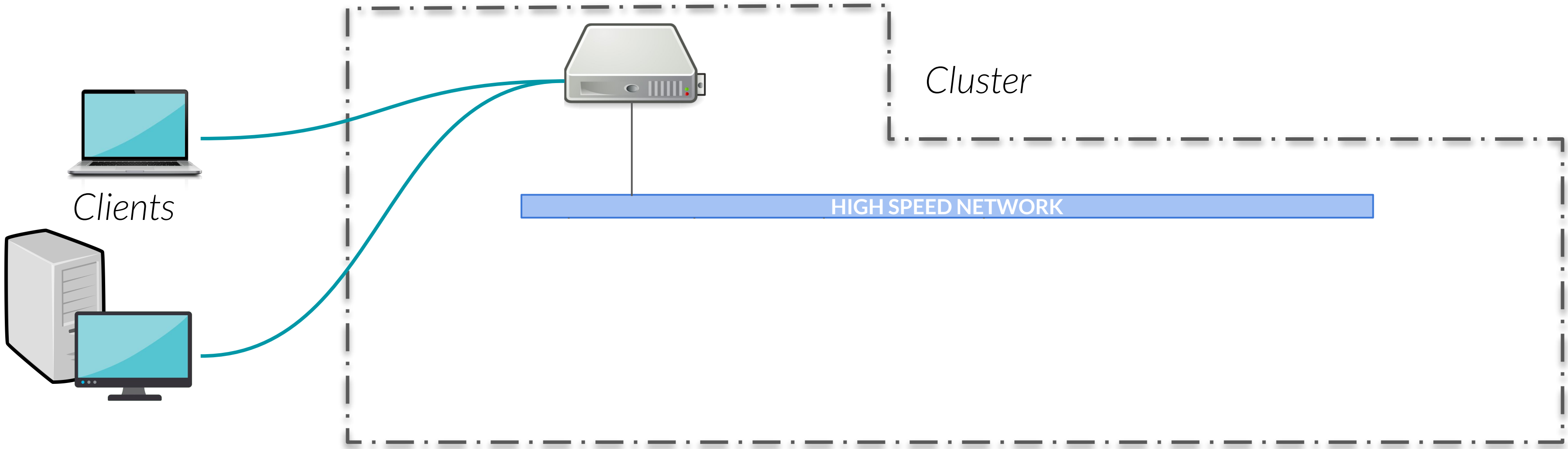

Head node → Access point to the cluster for the clients, distributing the workload to CNs

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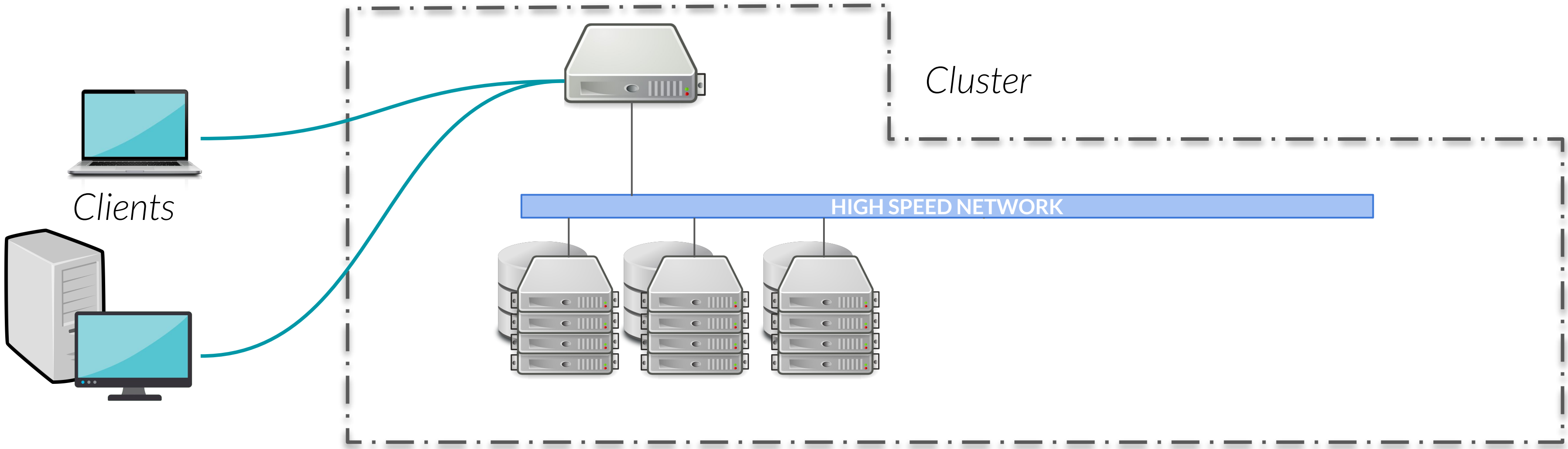

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Computing nodes → Nodes where the actual processing is executed. Usually “invisible” for the users, accessed only via the HN

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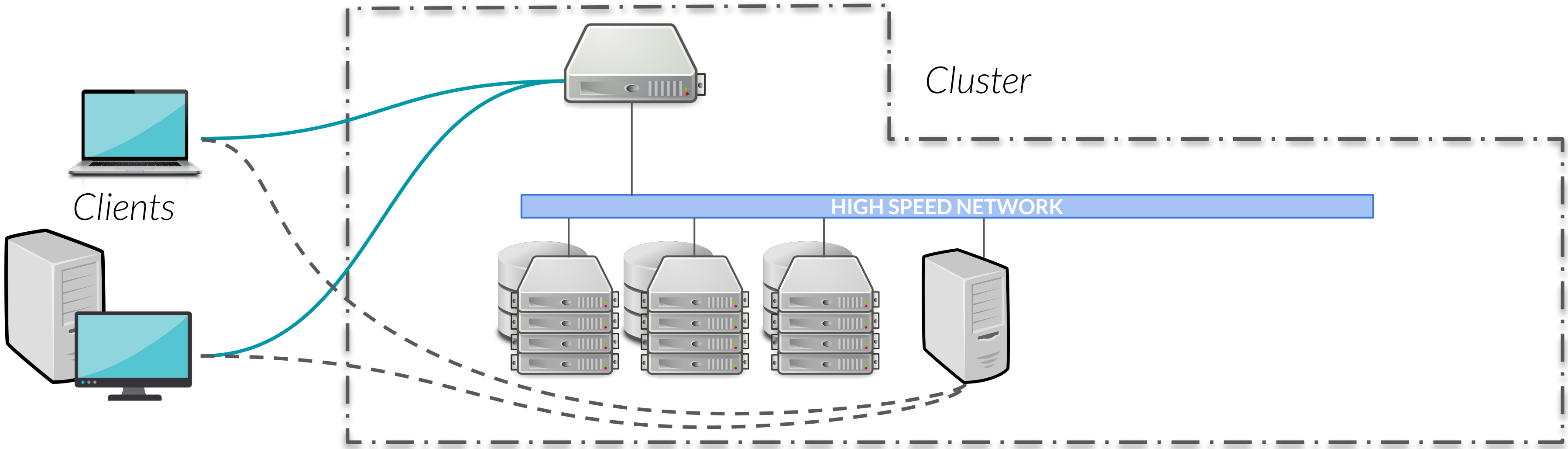

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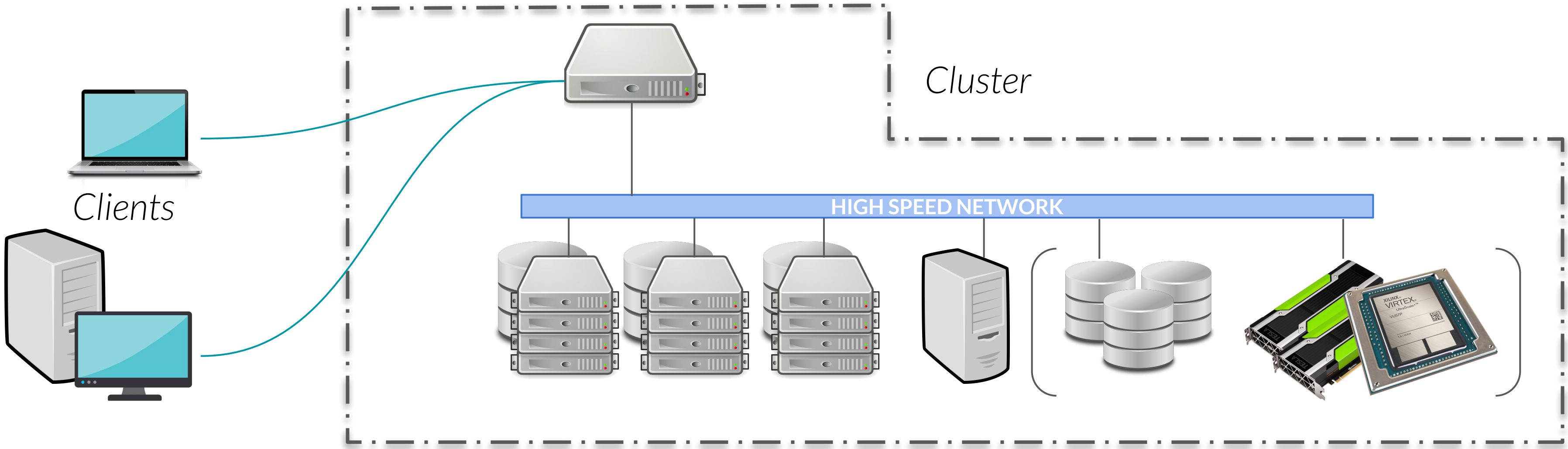

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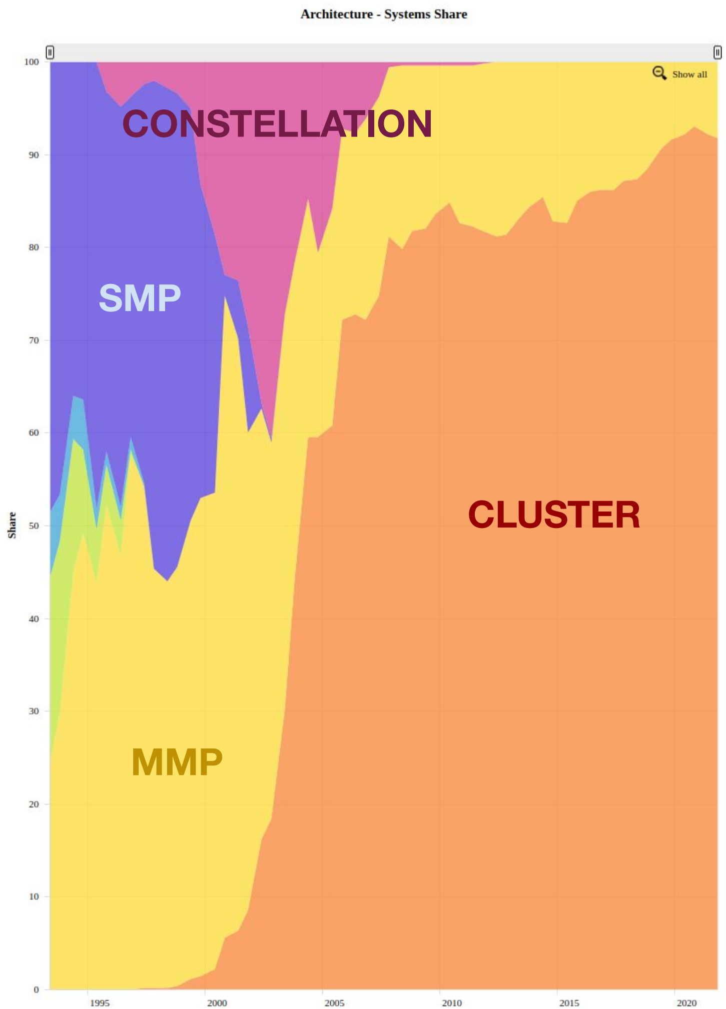
***Specialized nodes** → Nodes with specific hardware capabilities for computing/storage

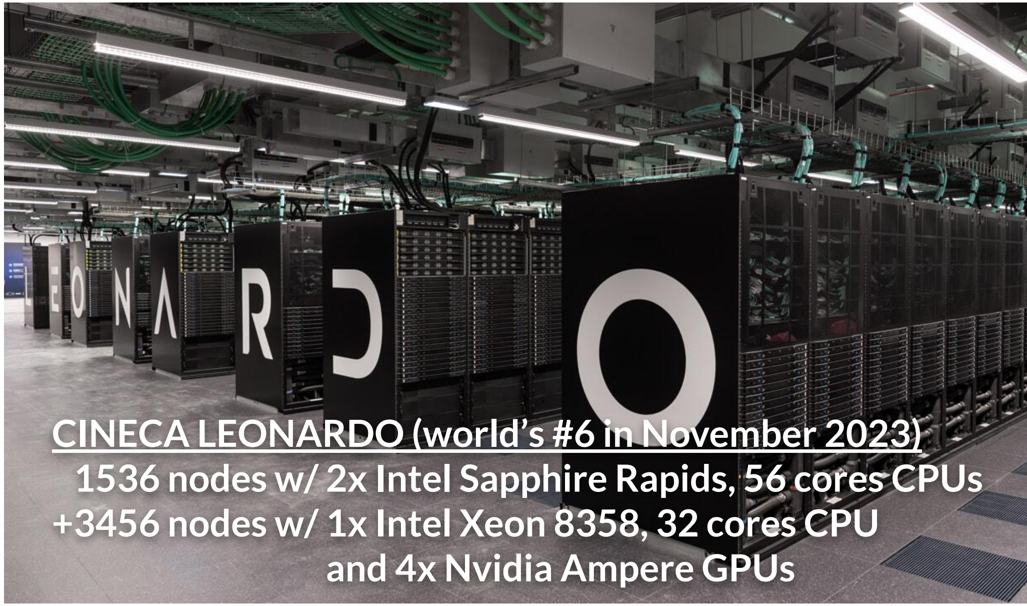
FROM WORLD'S TOP500 SUPERCOMPUTERS



https://www.top500.org/statistics/overtime/

Most of today's supercomputers are actually clusters

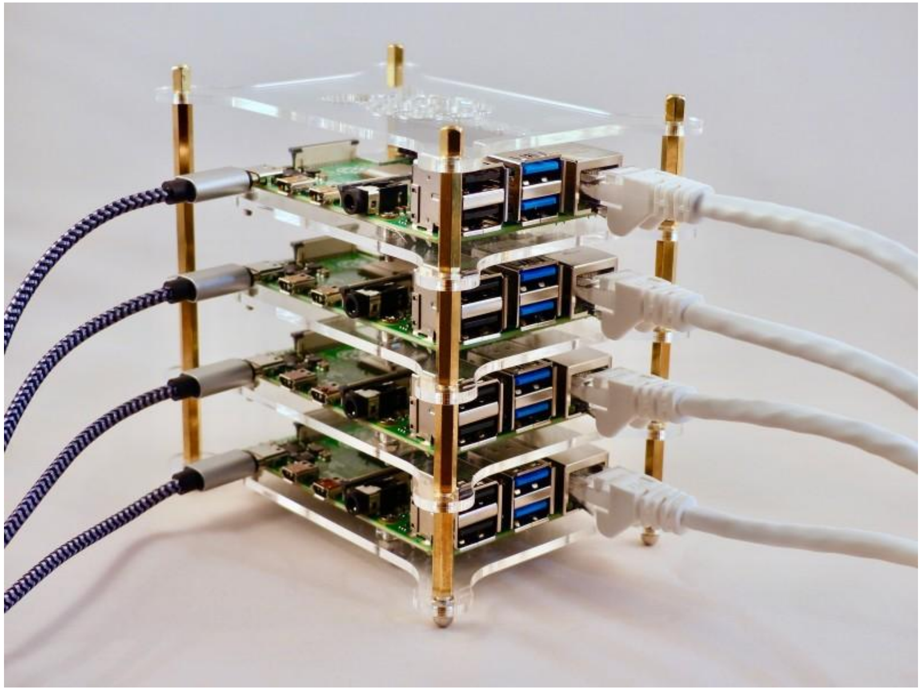
- Extremely powerful processing HW in each node
- Frequently with additional accelerators (GPUs, i.e. SIMD/SIMT-like)
- Hosting a vast number of nodes

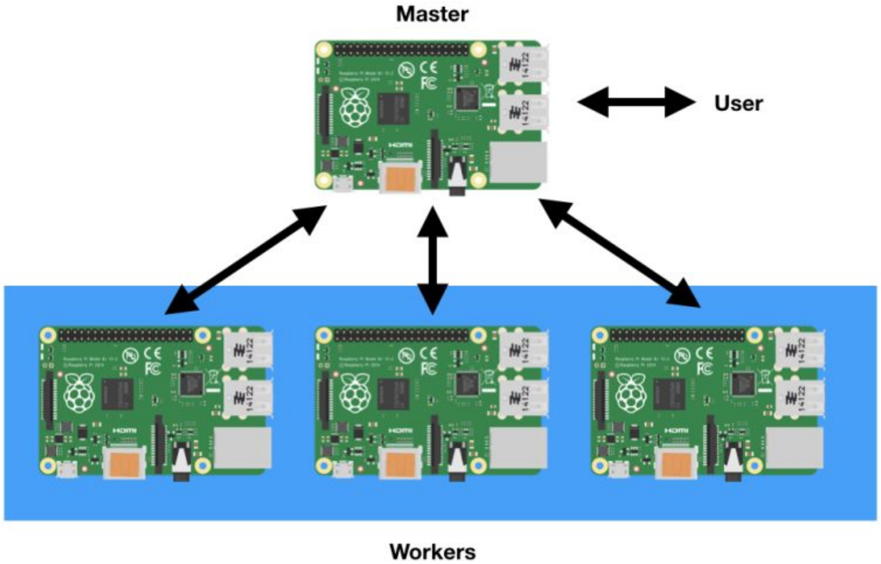


TO WORLD'S SMALLEST CLUSTERS

On the other hand, clusters can be an excellent solution to exploit modest HW to efficiently perform parallel tasks

- Usage of Commodity Off The Shelf (COST) HW
- Opportunistic computing (use shared computing resources when others are not)





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- Usage
- Oppor re not)

A COMMON JOB SUBMISSION PATTERN: BATCH SYSTEMS

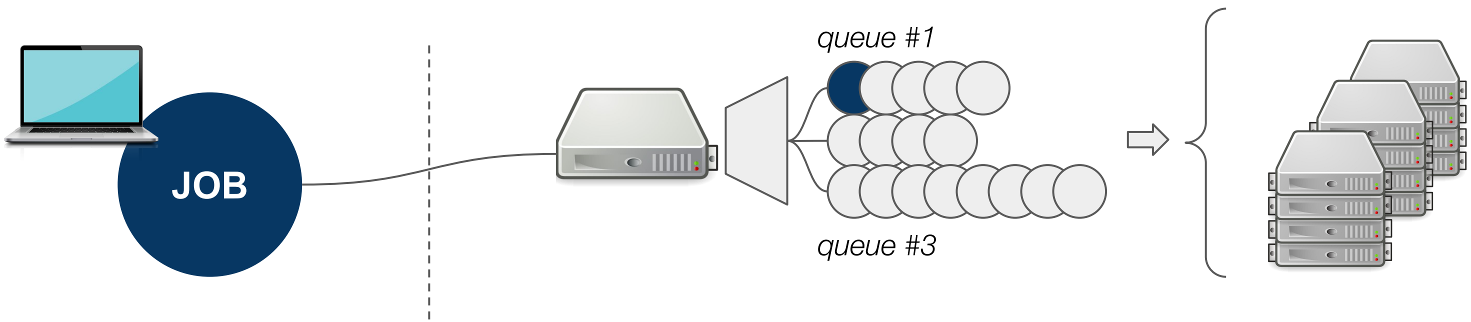
Users usually schedule and submit jobs to a cluster through a batch system, each job including:

1. an executable + optional arguments (e.g. n. of CPUs, memory, …)
2. info on potential requirements (e.g. libraries, …)

The batch system accepts the job and put in the desired *queue*

The batch system's scheduler manages the current workload, and determines which job will start next (depending on priorities / previous use of resources / …)

The tasks contained in the job's instructions are dispatched on the Computing nodes for execution



A COMMON JOB SUBMISSION PATTERN: BATCH SYSTEMS

Several batch system schedulers available:

- PBS
- SLURM
- LSF
- HTCondor
- …

```
$> condor_submit my_job.sub
Submitting job(s).
50 job(s) submitted to cluster 5146936.

$> condor_q
-- Schedd: bigbird12.cern.ch : <137.138.120.116:9618?... @ 10/04/20 17:29:52
OWNER    BATCH_NAME     SUBMITTED   DONE   RUN    IDLE  TOTAL JOB_IDS
jpazzini ID: 5146936  10/4  17:29     12    25      13     50 5146936.0-49
```

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```
executable = my_exec    #or my script
arguments = --input input_file_$(ProcId).txt

transfer_input_files = input_file_$(ProcId).txt

log = my_job_$(ProcId).log
error = my_job_$(ProcId).err
output = my_job_$(ProcId).out

request_disk = 8GB
request_memory = 2GB

queue 50    #number of tasks to run
```

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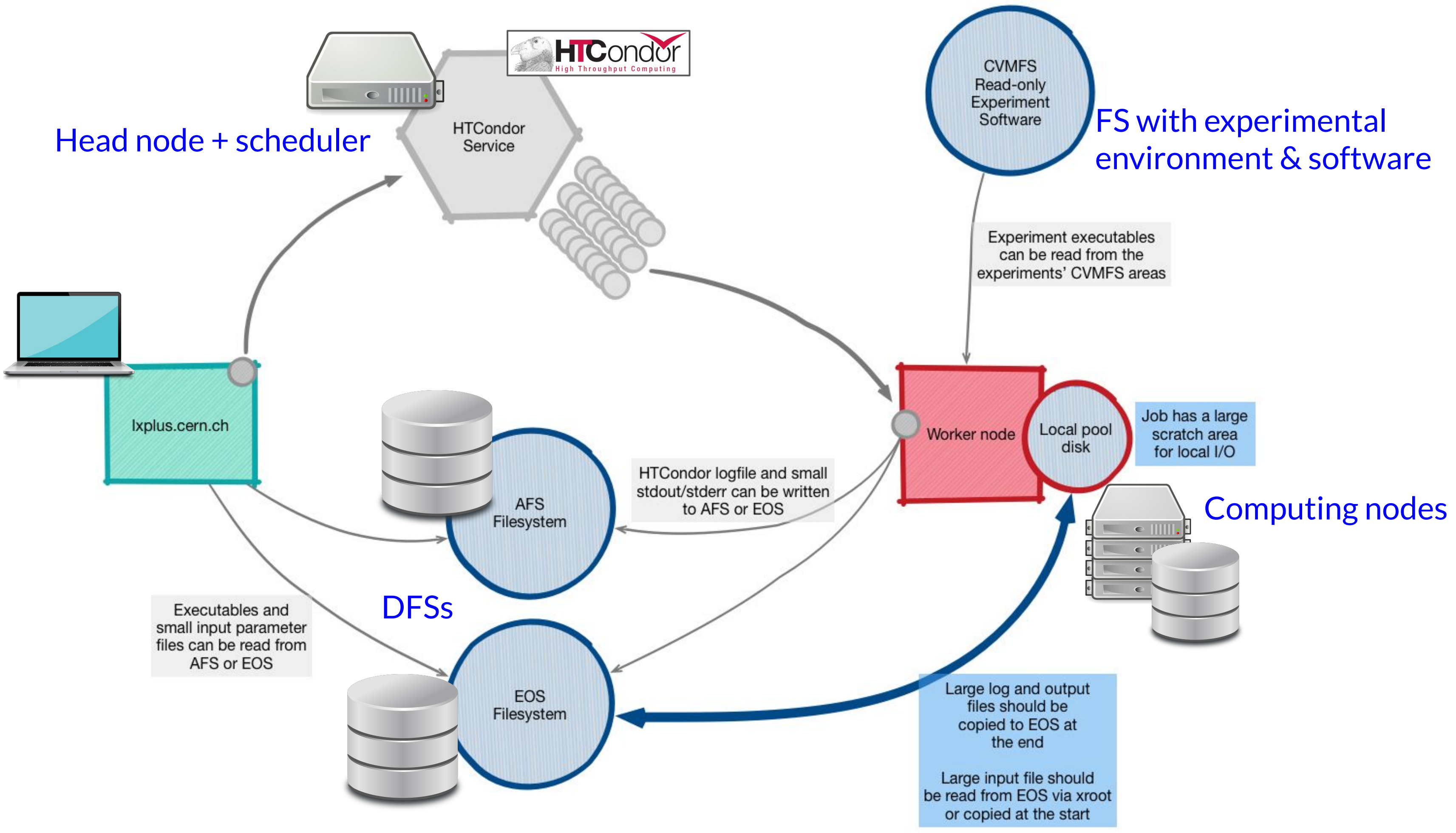
HTCondor High Throughput Computing

BATCH SYSTEMS - CERN EXAMPLE



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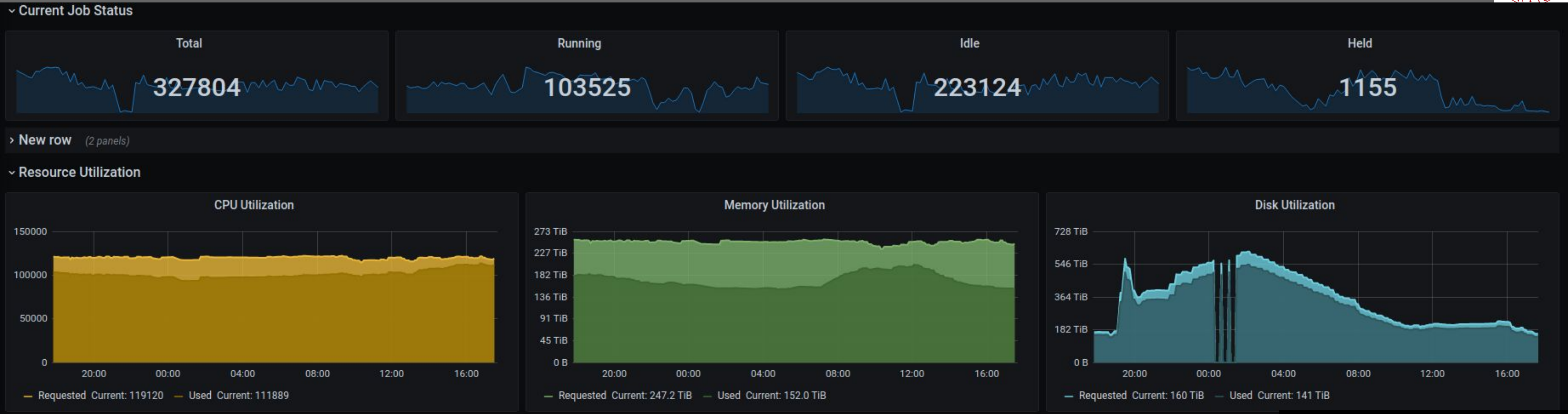
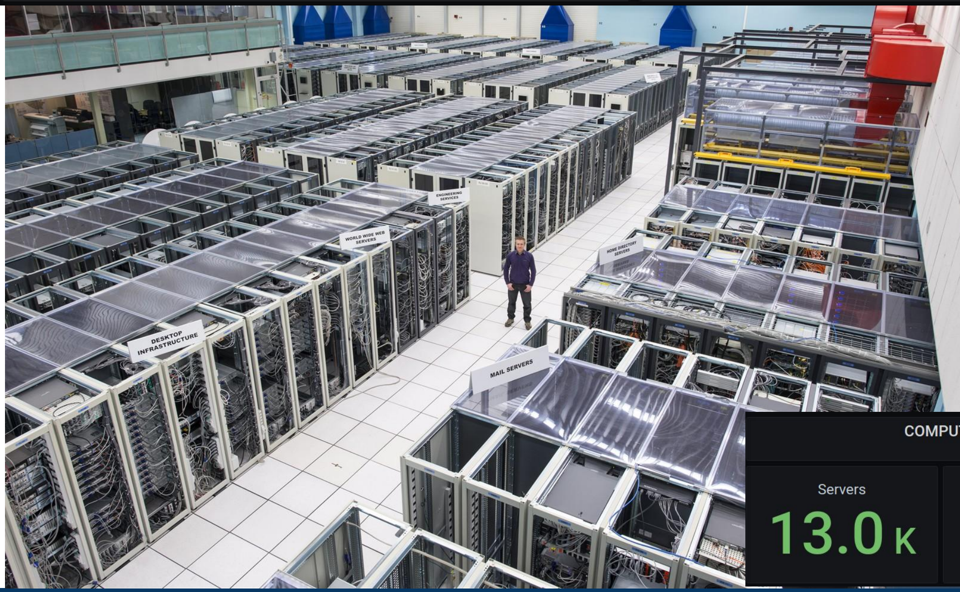
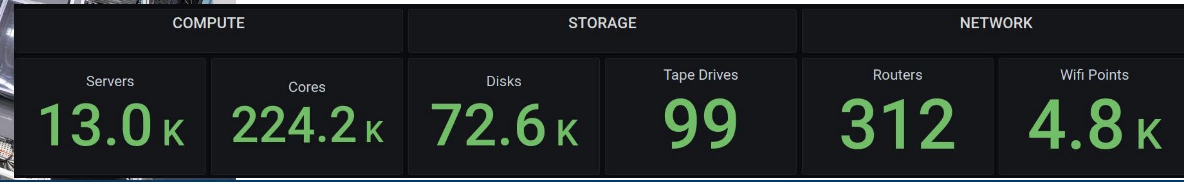




… over 24 h



Optimizing the execution of complex tasks using parallel and distributed computing systems requires a knowledge of specific programming standards and frameworks, including:

- *OpenMP (Message Passing)* to handle parallelization, typically on single nodes with shared-memory multiple CPUs
- *Message Passing Interfaces (MPI)* to handle communication and synchronization across nodes of a cluster
- *CUDA/HIP* to handle vector processing on GPUs
- …

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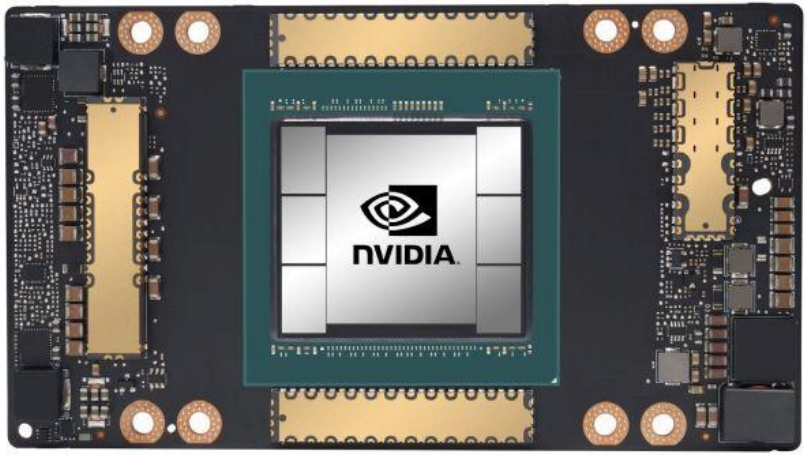
In our class we'll focus on a relatively simple paradigm for data processing in distributed systems which was at the core of BigData blow-up in the 2000s-2010s

For its applications we'll use modern distributed processing frameworks which require little-to-no knowledge of the innermost workings of distributed systems

PARALLEL PROGRAMMING FOR GPUs

If interested in diving deeper into parallel programming for GPU-enabled acceleration, consider the optional course **Modern Computing for Physics**



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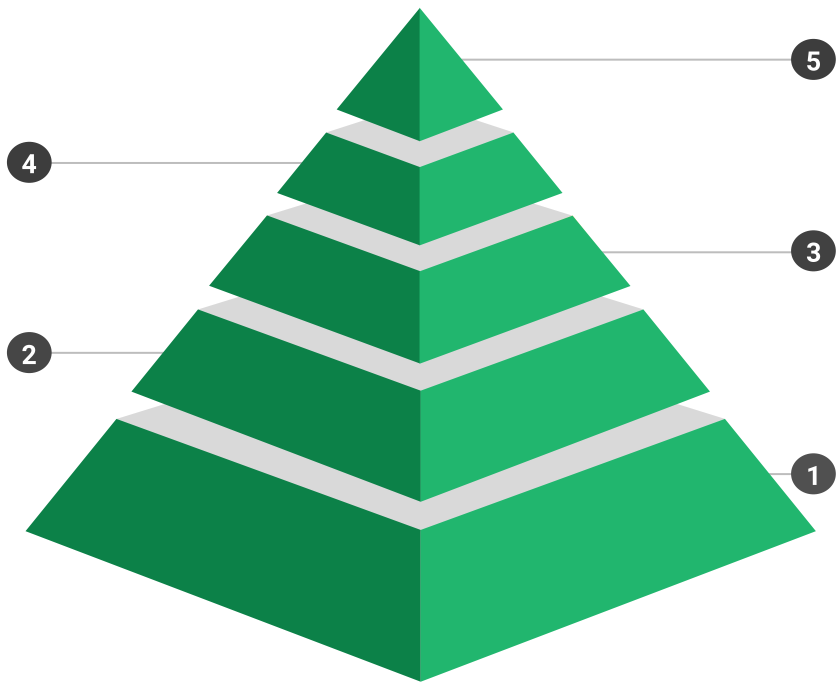

CUDA in Python

- Higher-level abstractions for programming GPUs
- Numba as a bridge between Python and CUDA-C
- An excursion on the available “tools” PyCuda, CuPy, PyTorch, RAPIDS…

General Purpose GPUs

- Understanding the hardware to be able exploit it
- Differences between CPU vs GPU
- Handling memory and thread execution

Streaming processing

- Using GPUs to process continuous streams of data

Basics of CUDA

- How to create and launch threads for vector/matrix processing on GPU
- Low-level language (C++) to understand the basics
- Higher-level programming models such as OpenACC

Parallel processing/programming

- Where and how parallel programming impacts physics computation
- Recap on concurrency and parallelization
- Figures of merits for GPU programming