Deep Learning Optimized - Jean Zay

Introduction – Jean Zay – GPU

cnrs

INSTITUT DU
DÉVELOPPEMENT ET DES
RESSOURCES EN
INFORMATIQUE
SCIENTIFIQUE

DLO-JZ presentation

IDRIS ◂

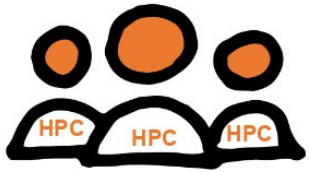
Agenda ◂

Presentation of the participants ◂

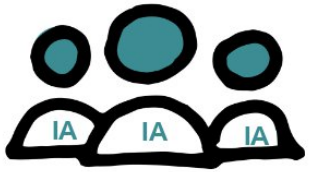
IDRIS

System

User Assistance



10 ingénieur·e·s



10 ingénieur·e·s

BLOOM on Jean Zay

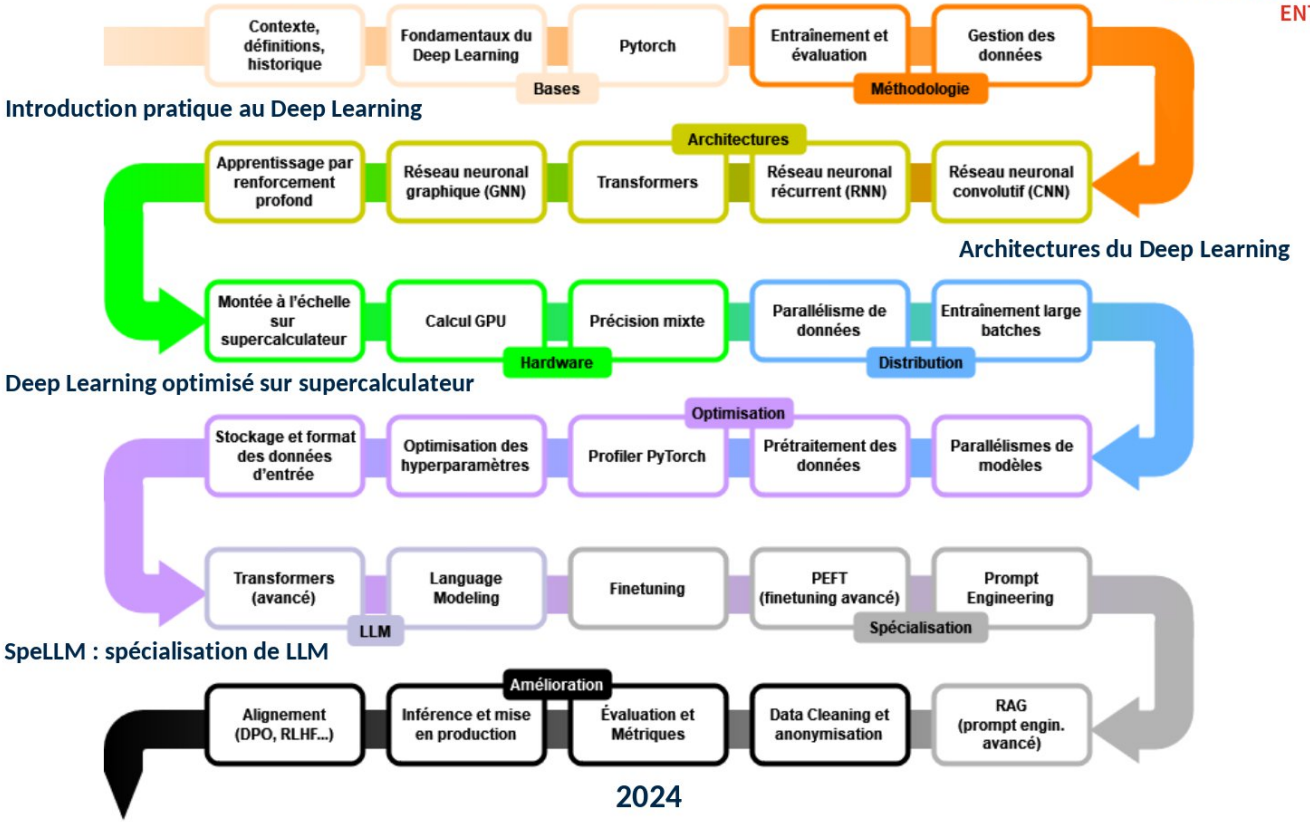
Pre-training :
117 days (2022)
384 x 80GB A100 GPUs

Train modulaire des formations IDRIS

IDRIS

Les formations IA

Pour les inscriptions ou une formation sur mesure contacter
CNRS FORMATION ENTREPRISES



DLO-JZ

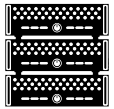
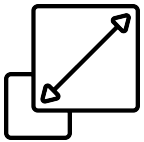
Agenda – Covered topics

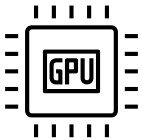
Day 1
- Presentation of Jean Zay
- The challenges of scaling up
- **GPU computing + Mixed Precision**
- Tensor optimisation
- The PyTorch profiler

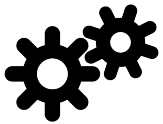
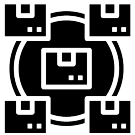
Day 2
- **DataLoader optimizations**
- **Distribution + Data Parallelism** ❤
- **Data Augmentation**

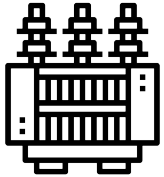
Day 3
- Data storage and formats
- **Training and large batches**
- JIT

Day4
- Good practices
- Large Model Scaling + FSDP
- **Model parallelisms**
- Visualization tools
- HyperParameter Optimization

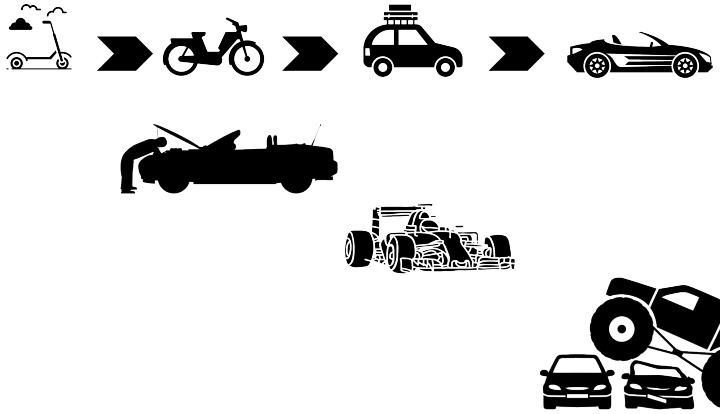





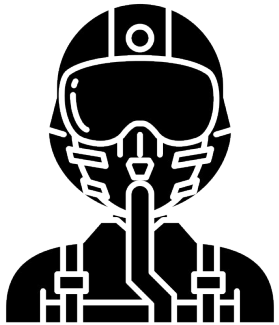
Practical Workshop

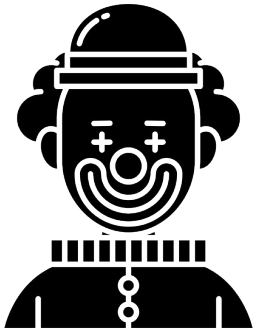
- Day 1, 2, 3, 4 :
  - System Optimization : GPU, Mixed Precision
  - Profiler
  - DataLoader
  - Distributed Data Parallelism
  - Data Augmentation
  - *Optimizer*s & LR scheduler
  - torch.compile & torchscript
  - *FSDP*
  - *Hyper-Parameters Optimization (HPO)*



- Reservation partition A100 JZ

Presentation of participants





Jean Zay

Supercomputer ◂

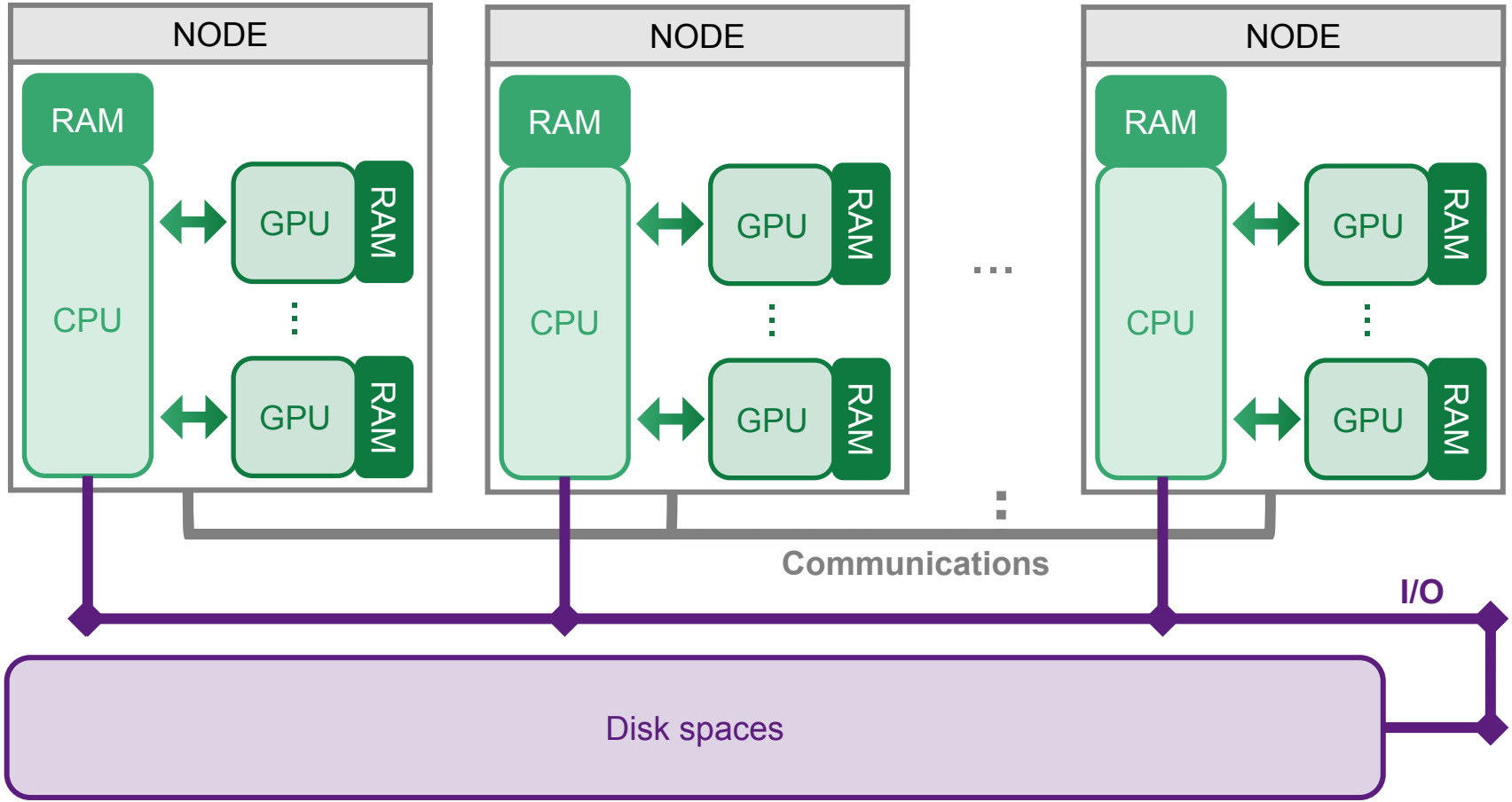
Jean Zay ◂

Job submission with Slurm ◂

JupyterHub on Jean Zay ◂

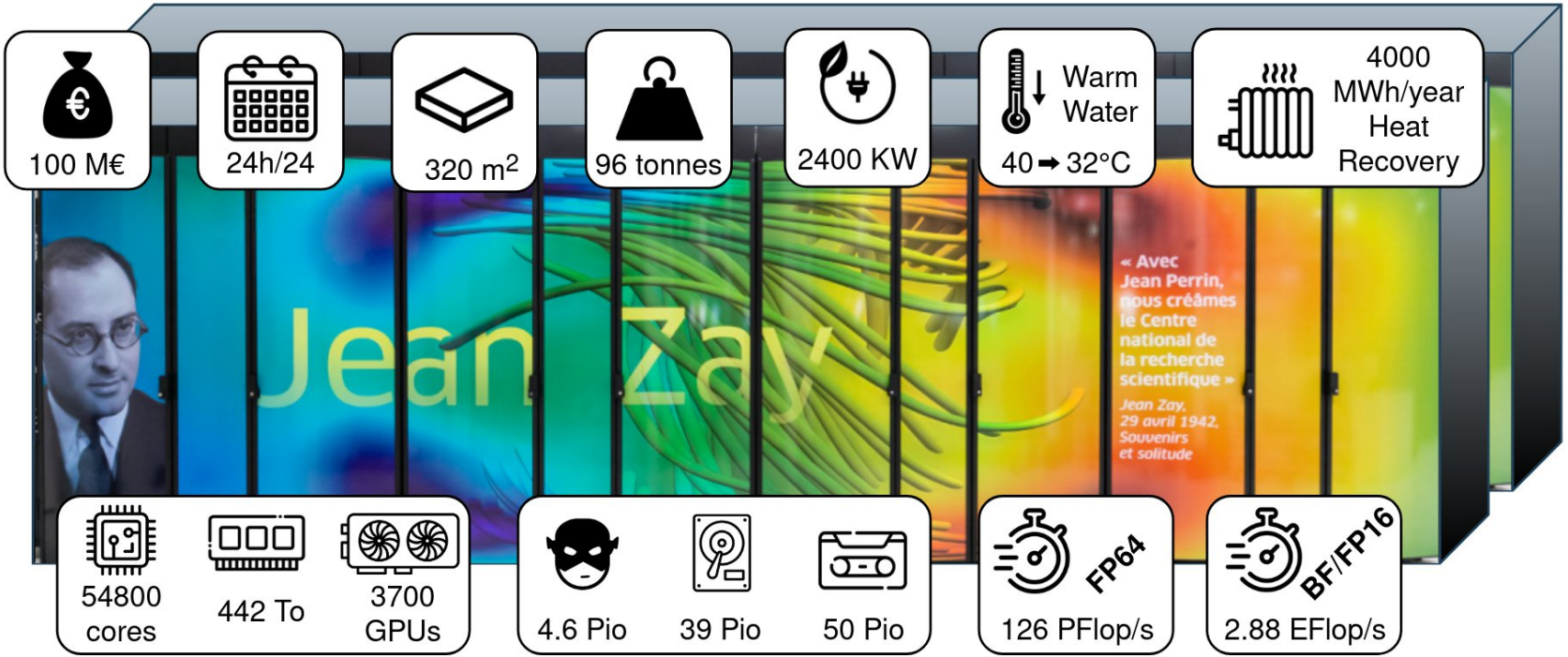
Slurm tools for python notebooks ◂

What's a supercomputer?

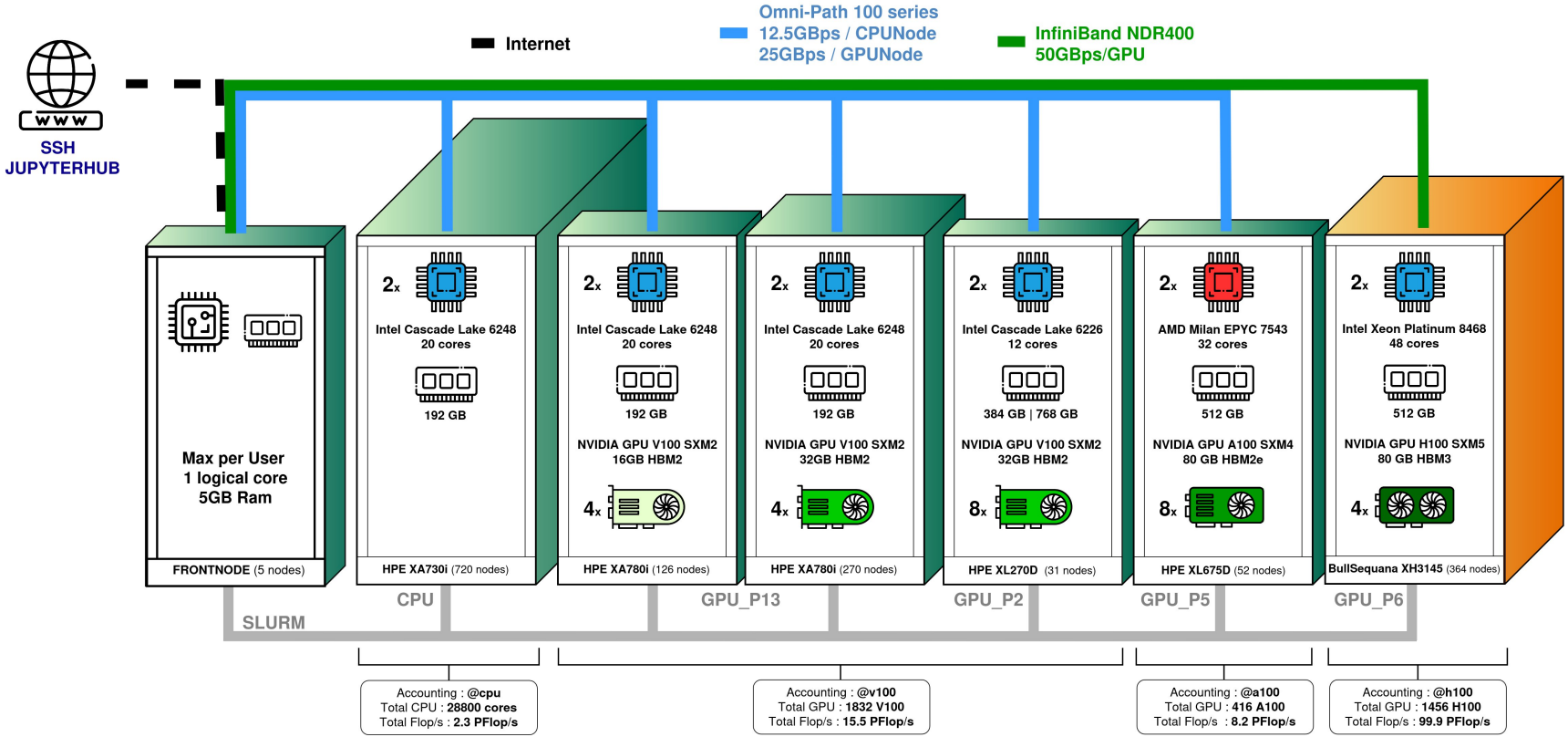


Jean Zay

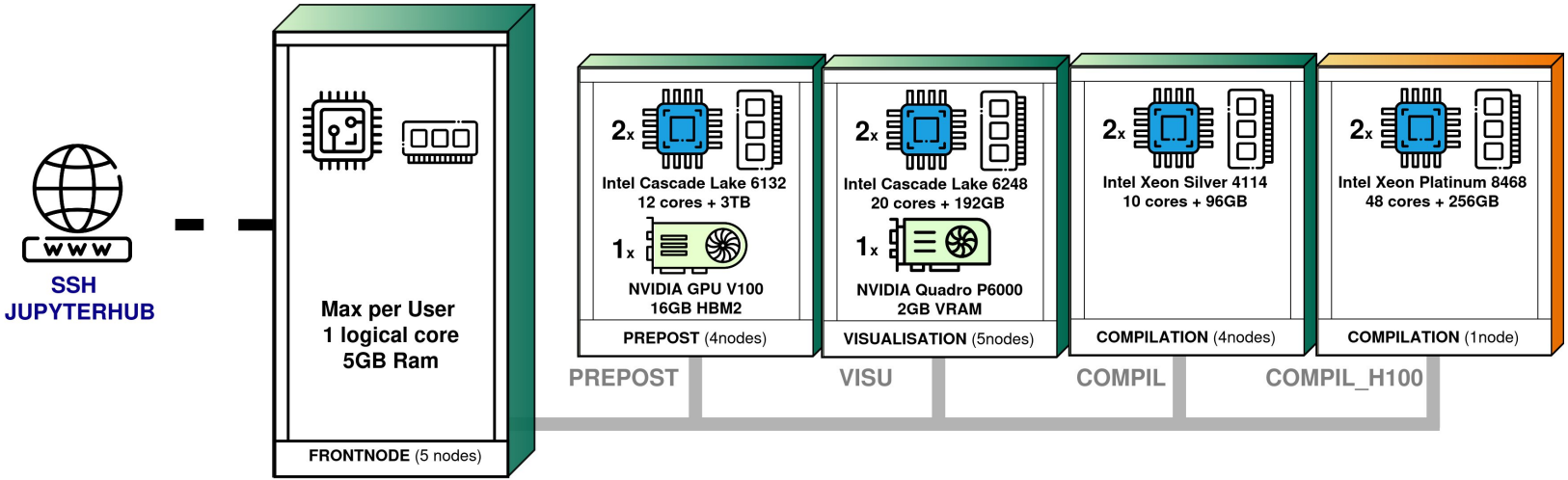
First national converged supercomputer dedicated to Artificial Intelligence (AI) and High Performance Computing (HPC)



Jean Zay


Internet
Omni-Path 100 series
12.5GBps / CPUNode
25GBps / GPUNode
InfiniBand NDR400
50GBps/GPU
www
SSH
JUPYTERHUB
Max per User
1 logical core
5GB Ram
FRONTNODE (5 nodes)
2x
Intel Cascade Lake 6248
20 cores
192 GB
HPE XA730i (720 nodes)
CPU
2x
Intel Cascade Lake 6248
20 cores
192 GB
NVIDIA GPU V100 SXM2
16GB HBM2
4x
HPE XA780i (126 nodes)
GPU_P13
2x
Intel Cascade Lake 6248
20 cores
192 GB
NVIDIA GPU V100 SXM2
32GB HBM2
4x
HPE XA780i (270 nodes)
2x
Intel Cascade Lake 6226
12 cores
384 GB | 768 GB
NVIDIA GPU V100 SXM2
32GB HBM2
8x
HPE XL270D (31 nodes)
GPU_P2
2x
AMD Milan EPYC 7543
32 cores
512 GB
NVIDIA GPU A100 SXM4
80 GB HBM2e
8x
HPE XL675D (52 nodes)
GPU_P5
2x
Intel Xeon Platinum 8468
48 cores
512 GB
NVIDIA GPU H100 SXM5
80 GB HBM3
4x
BullSequana XH3145 (364 nodes)
GPU_P6
SLURM
Accounting : @cpu
Total CPU : 28800 cores
Total Flop/s : 2.3 PFlop/s
Accounting : @v100
Total GPU : 1832 V100
Total Flop/s : 15.5 PFlop/s
Accounting : @a100
Total GPU : 416 A100
Total Flop/s : 8.2 PFlop/s
Accounting : @h100
Total GPU : 1456 H100
Total Flop/s : 99.9 PFlop/s

Jean Zay


www
SSH
JUPYTERHUB
Max per User
1 logical core
5GB Ram
FRONTNODE (5 nodes)
2x
Intel Cascade Lake 6132
12 cores + 3TB
1x
NVIDIA GPU V100
16GB HBM2
PREPOST (4nodes)
2x
Intel Cascade Lake 6248
20 cores + 192GB
1x
NVIDIA Quadro P6000
2GB VRAM
VISUALISATION (5nodes)
2x
Intel Xeon Silver 4114
10 cores + 96GB
COMPILATION (4nodes)
2x
Intel Xeon Platinum 8468
48 cores + 256GB
COMPILATION (1node)
PREPOST
VISU
COMPIL
COMPIL_H100

Jean Zay: Storage spaces

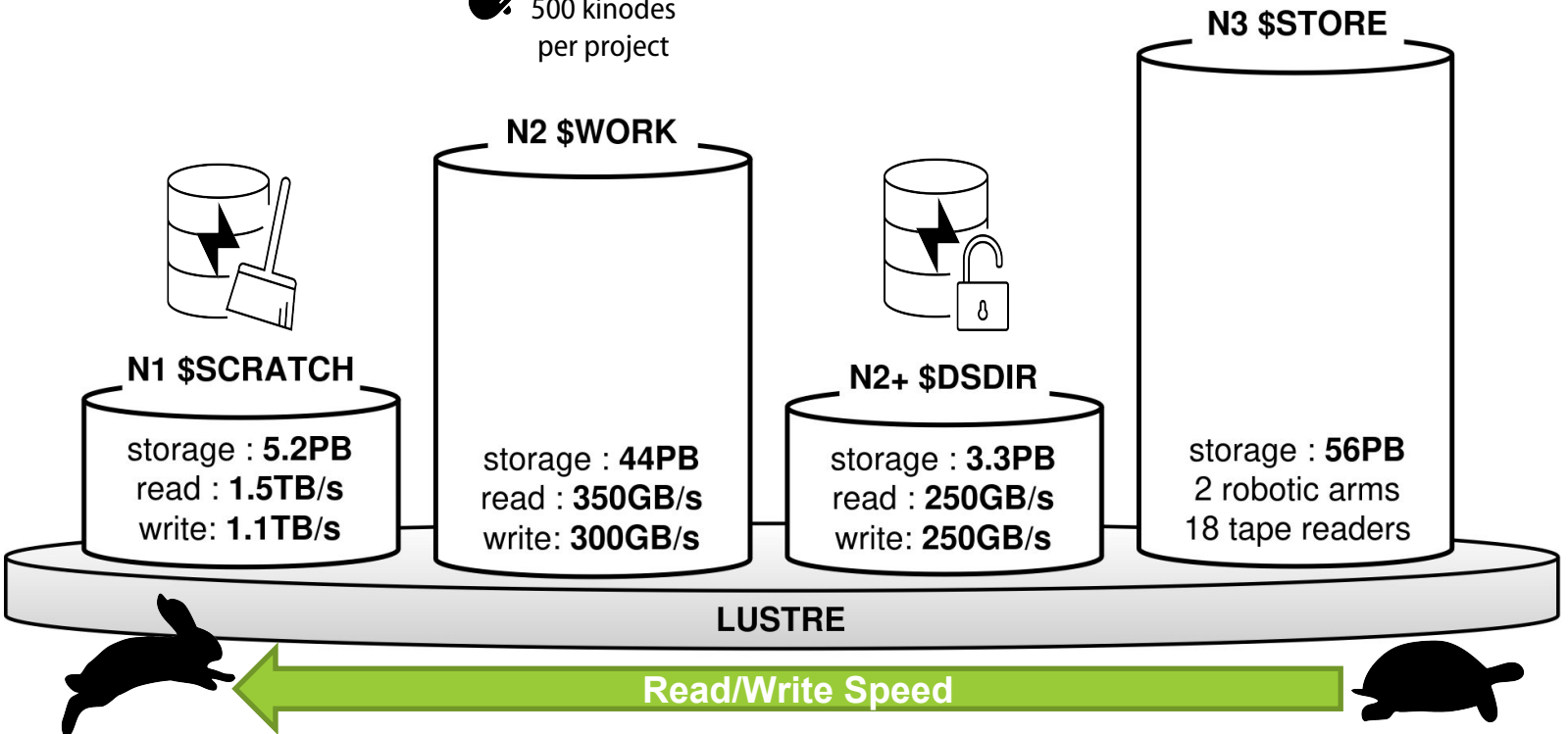
Temporary Datasets
autocleaned limited by
a 30-day file lifespan

3 GB
150 kinodes
per user

5 TB
500 kinodes
per project

Public Datasets
deposit on request

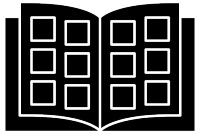
50 TB
100 kinodes
per project



Jean Zay: Work environment

ENVIRONMENT MODULES

Catalogue of shared modules (conda environments)



- Installed by IDRIS
- Completed on request

```
login@jean-zay3:~$ module load pytorch-gpu/py3/1.11.0
  Loading requirement: ...
(pytorch-gpu-1.11.0+py3.9.12) login@jean-zay3:~$
```

- Customizable

```
~$ pip install --user --no-cache-dir <paquet>
```

Conflicts between versions
Storage spaces saturation

Personal conda environments

```
login@jean-zay3:~$ module load anaconda-py3/2023.03
(base) login@jean-zay3:~$ conda create -n myenv
```

Storage spaces saturation ++

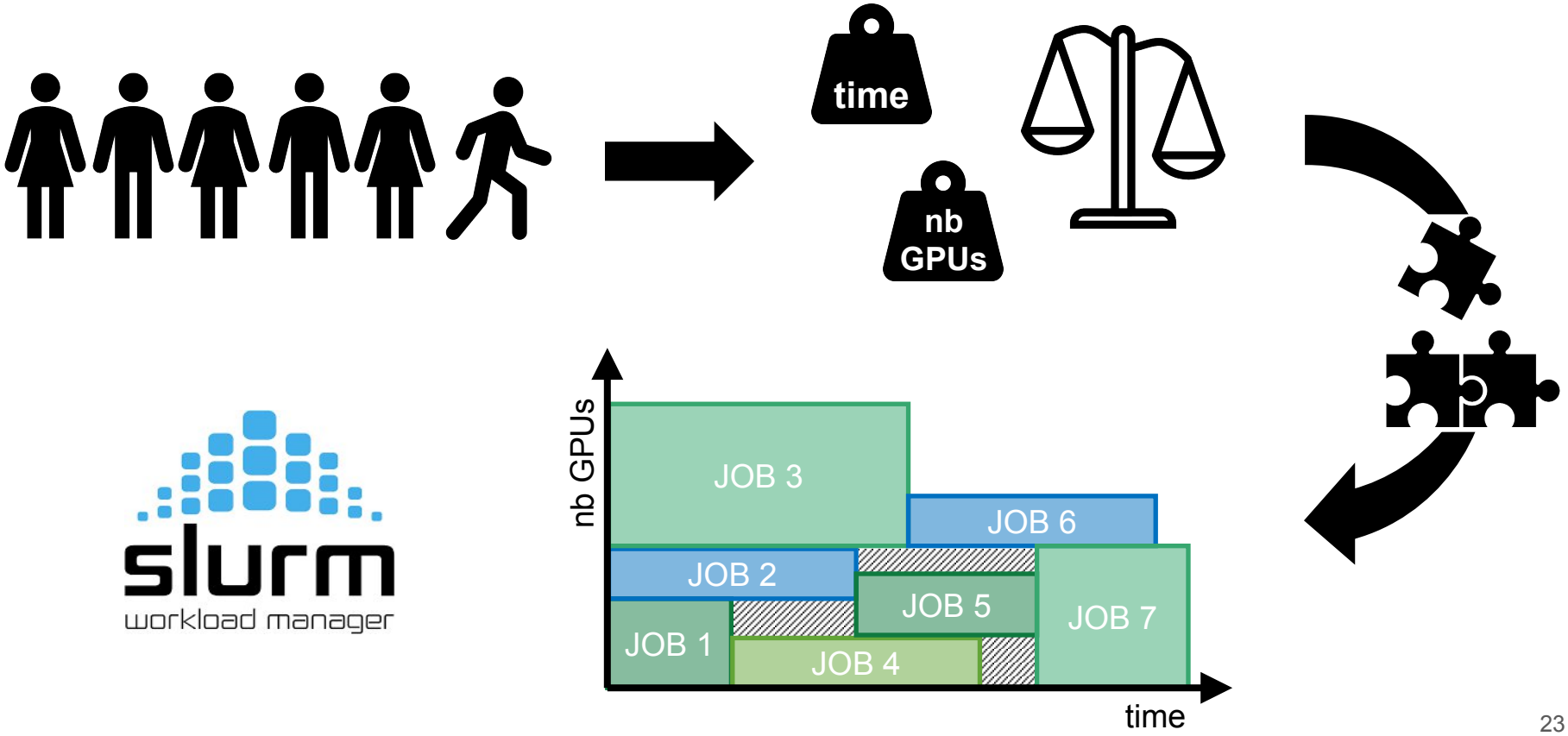
Singularity containers

```
login@jean-zay3:~$ module load singularity
```

Import SIF images on Jean Zay

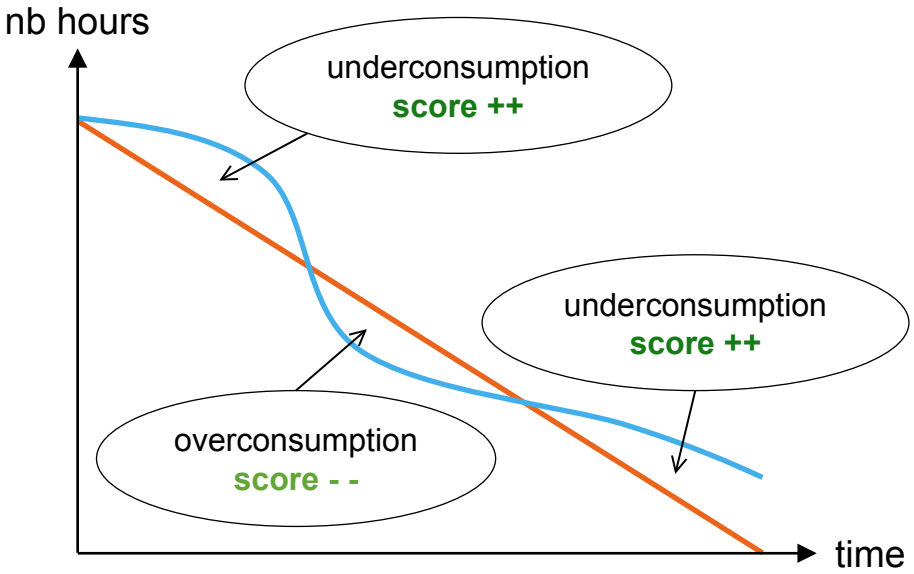
- From your PC
- From public deposits
- Possible conversion from docker

Job submission with Slurm



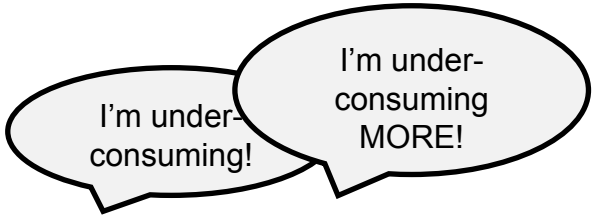
Job submission with Slurm

Slurm gives your job a **priority score** depending on your consumption.



theoretical consumption

real consumption



Slurm compares all users' scores to define job position in the queue.

Job submission with Slurm

Adjust the **QoS (Quality of Service)** to improve the priority score of your job!

QoS	Max elapsed time	Resource limits			
		Per job	Per user	Per project	Per QoS
qos_gpu_ h100-dev	2h	32 GPU	32 GPUs (10 jobs max at the same time)	32 GPU	384 GPU
qos_gpu-t3 (default)	20h	512 GPU	512 GPU	512 GPU	
qos_gpu_ h100-t4	100h	16 GPU	64 GPU	64 GPU	192 GPU

\+ priority -

dev

prod

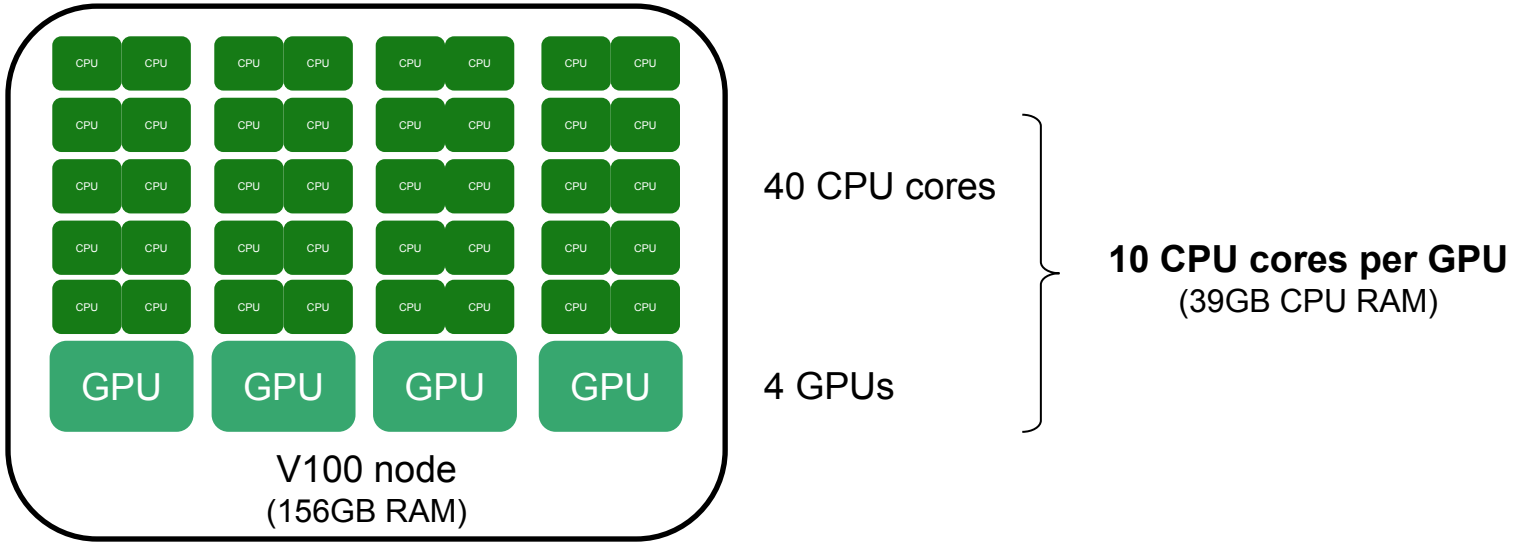
And keep your job in the queue, its priority score will increase with time.

Job submission with Slurm

How to configure my job?

- How many GPUs?
- How much time?
- How many CPUs per GPU?

→ **1 CPU core = 3.9GB RAM** (on V100 nodes)
→ interesting to have **several CPU cores to feed a GPU**
(cf “DataLoader optimizations” part of this course)

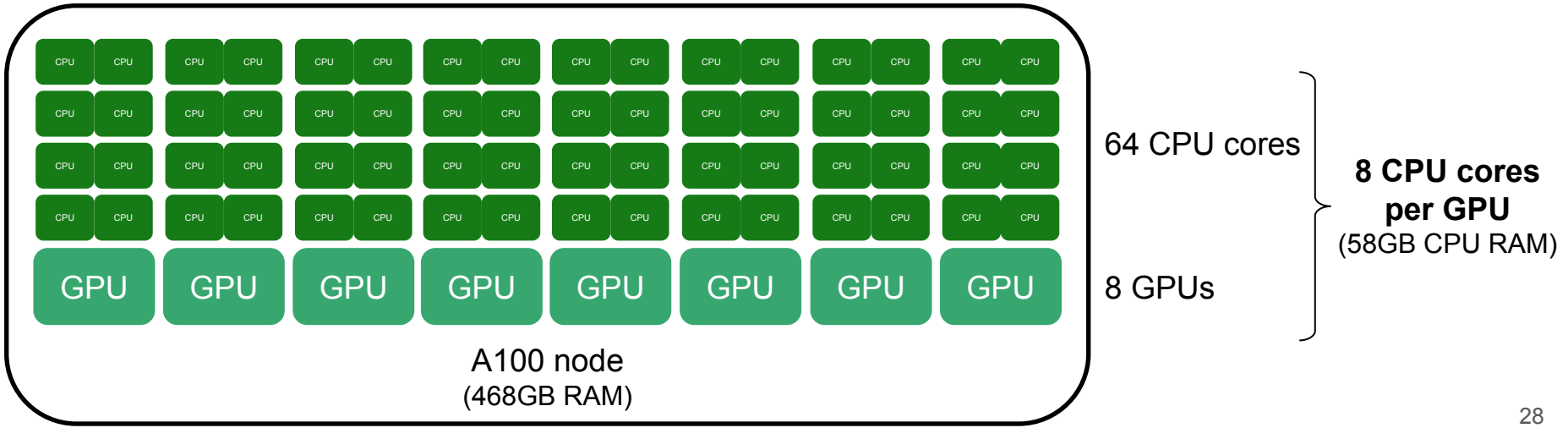


Job submission with Slurm

How to configure my job?

- How many GPUs?
- How many time?
- How many CPUs per GPU?

→ **1 CPU core = 7.3GB RAM** (on A100 nodes)
→ interesting to have **several CPU cores to feed a GPU**
(cf “DataLoader optimizations” part of this course)

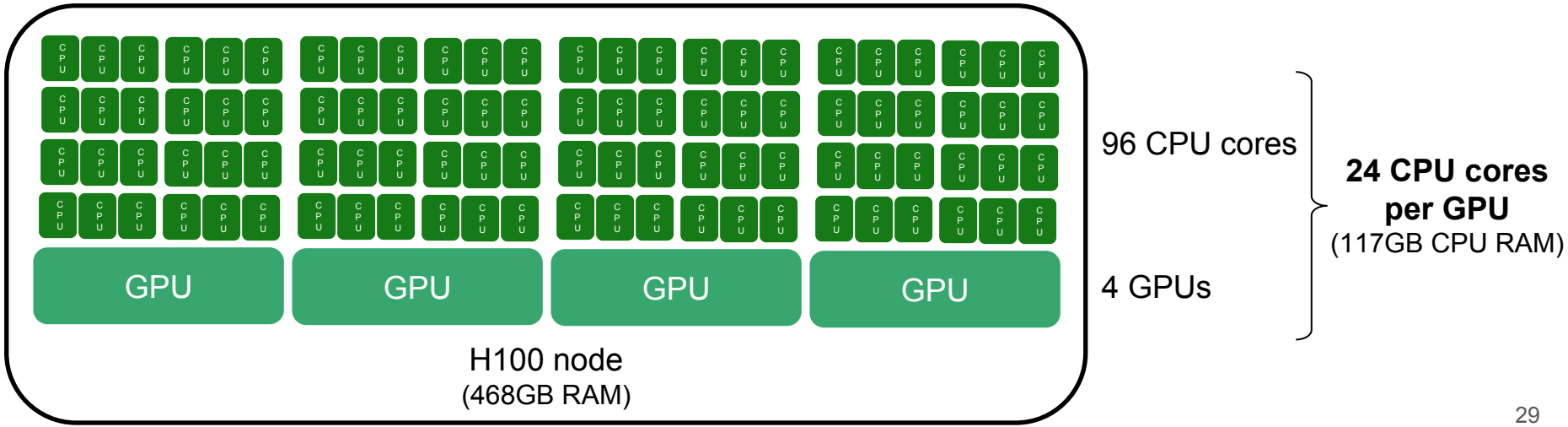


Job submission with Slurm

How to configure my job?

- How many GPUs?
- How many time?
- How many CPUs per GPU?

→ **1 CPU core = 4.87GB RAM** (on H100 nodes)
→ interesting to have **several CPU cores to feed a GPU**
(cf “DataLoader optimizations” part of this course)



Job submission with Slurm

Example: reservation of 2 x 4 H100 GPUs

script.slurm

```
#!/bin/bash

#SBATCH --job-name="dlojz"                # name of the job
#SBATCH --output="dlojz%j.out"            # output file
#SBATCH --error="dlojz%j.err"             # error file
#SBATCH --nodes=2                         # nb of nodes
#SBATCH --gres=gpu:4                      # nb of GPUs/node
#SBATCH --ntasks-per-node=4               # nb of tasks/node
#SBATCH --cpus-per-task=24                # nb of CPU cores/task
#SBATCH --hint=nomultithread              # no hyperthreading
#SBATCH --time=01:00:00                   # max execution time
#SBATCH --qos=qos_gpu_h100-dev            # adjust QoS

module load pytorch-gpu/py3/2.8.0         # environment

srun python script.py                     # run script
```

Job submission with Slurm

script.slurm

```
#!/bin/bash

#SBATCH --job-name="dlojz"
#SBATCH --output="dlojz%j.out"
#SBATCH --error="dlojz%j.err"
#SBATCH --nodes=2
#SBATCH --gres=gpu:4
#SBATCH --ntasks-per-node=4
#SBATCH --cpus-per-task=10
#SBATCH --hint=nomultithread
#SBATCH --time=01:00:00
#SBATCH --qos=qos_gpu-dev

module load pytorch-gpu/py3/2.8.0

srun python script.py
```

```
login@jean-zay3:~$ sbatch script.slurm
```

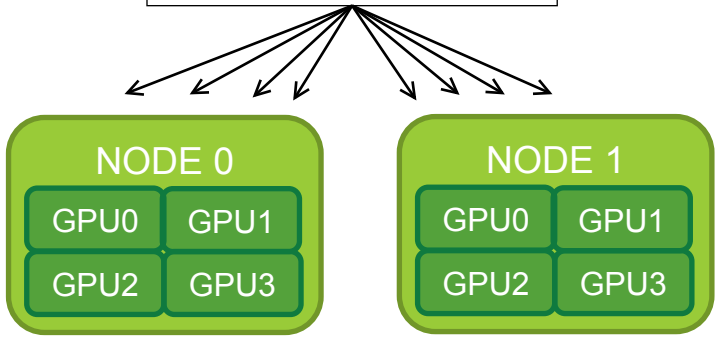
Job submission

Waiting in queue

```
login@jean-zay3:~$ squeue --me
             JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
            223225   gpu_p13    dlojz          PD       0:00      2 (Priority)
```

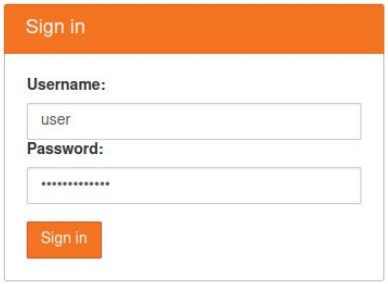
Lauching job

srun python script.py

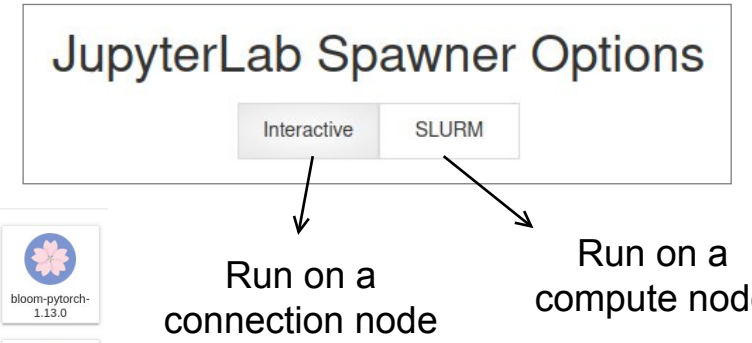


JupyterHub on Jean Zay

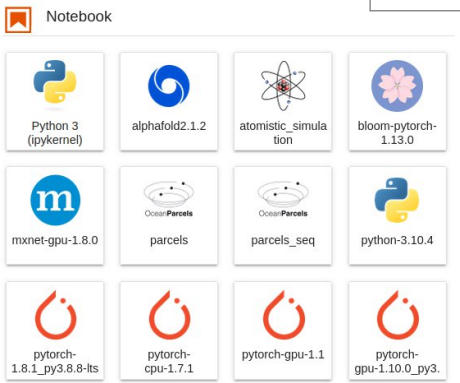
1. Authentication on https://jupyterhub.idris.fr



2. Choose and configure an instance



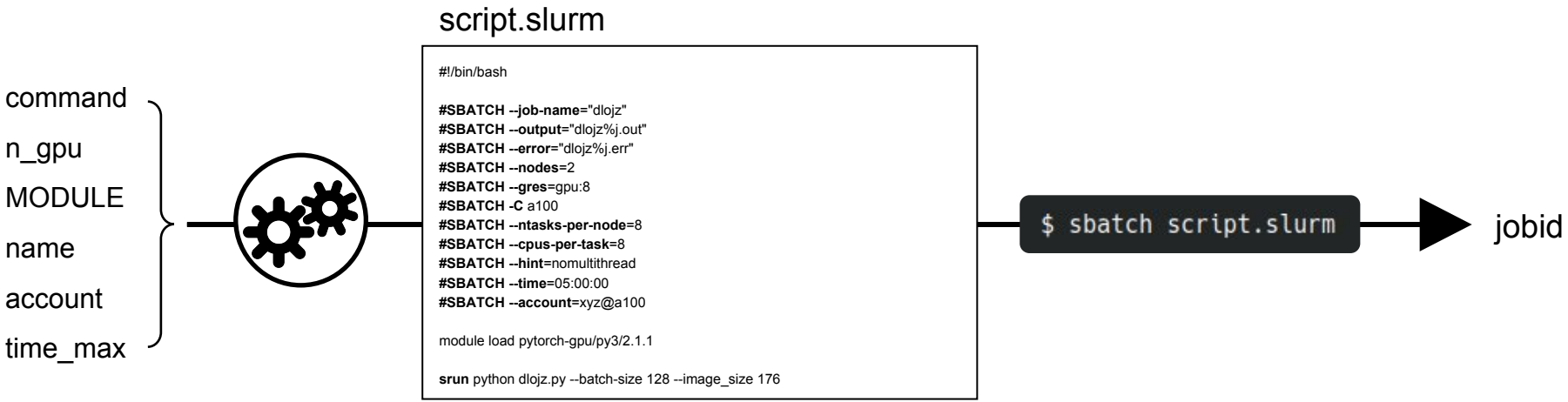
3. Choose a kernel (pytorch-gpu-2.2.0)



Slurm tools for python notebooks

```
from idr_pytools import gpu_jobs_submitter
```

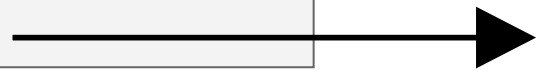
```
command = 'dlojz.py --batch-size 128 --image_size 176'
n_gpu = 8
MODULE = 'pytorch-gpu/py3/2.2.0'
name = 'dlojz'

jobid = gpu_jobs_submitter(command, n_gpu, MODULE, name=name, account='xyz@a100', time_max='05:00:00')
```



Slurm tools for python notebooks

```
from idr_pytools import display_slurm_queue
```

```
name = 'dlojz'
display_slurm_queue(name)
```



```
$ squeue --me -n <name>
```

```
from idr_pytools import search_log
```

```
jobid = ['12345']

search_log(contains=jobid)[0]

search_log(contains=jobid, with_err=True)[0]
```

output filename

error filename

The Challenges of Scaling

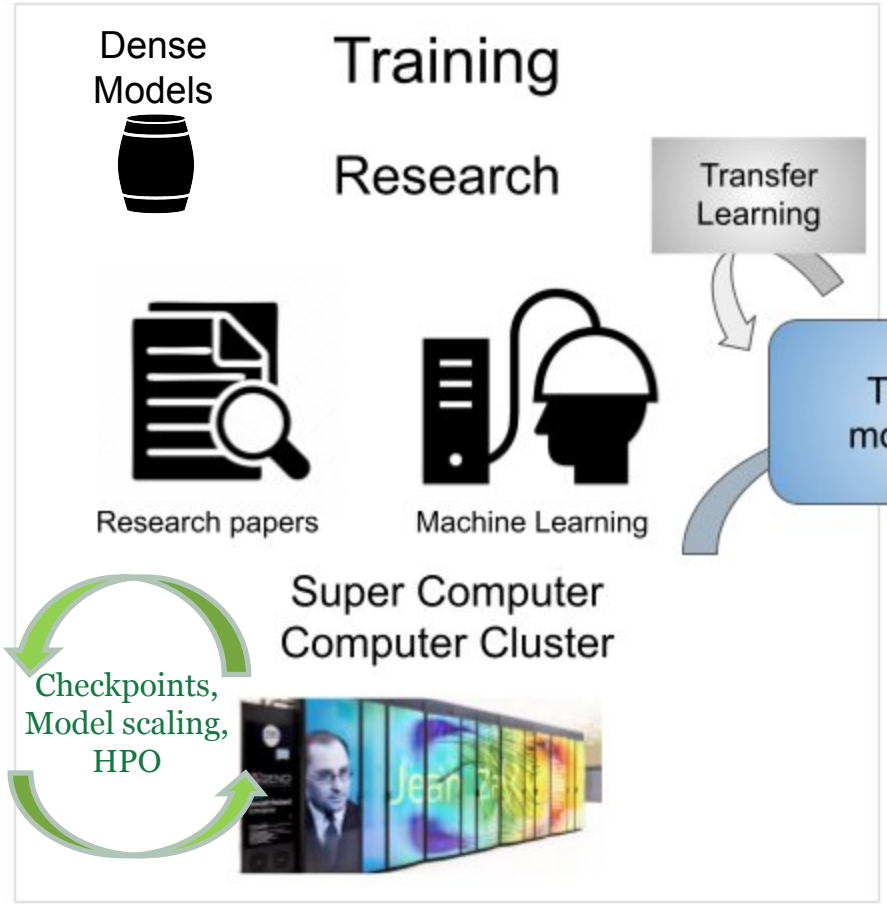
Training Time ◄

Memory Footprint ◄

Solutions ◄

Energy saving ◄

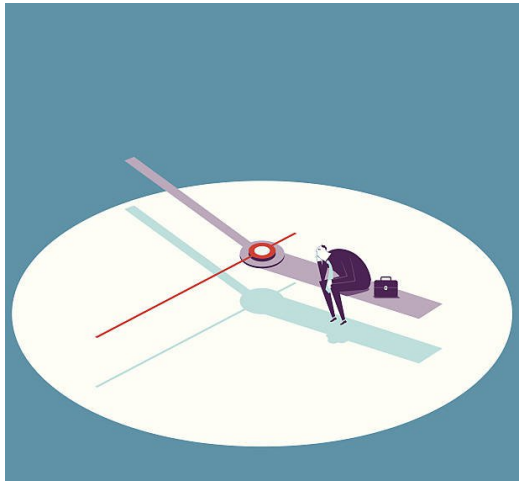
Training / Inference



Constraints of Deep Learning

2 problems to deal with:

Training Time



Memory Overconsumption (OOM)

Training Time

Training Resnet-50 on Imagenet

Goal:

Classification (1000 classes)

Model :

25 M parameters

Dataset:

1,2 M labeled images

2017

14 Days

1 NVIDIA M40 GPU

Training Time

Training Resnet-50 on Imagenet

Facebook Caffe2	UC Berkeley, TACC, UC Davis Tensorflow	Preferred Network ChainerMN	Tencent TensorFlow	Sony Neural Network Library (NNL)	Fujitsu MXNet
1 hour	31 mins	15 mins	6.6 mins	2.0 mins	1.2 mins
Tesla P100 x 256	1,600 CPUs	Tesla P100 x 1,024	Tesla P40 x 2,048	Tesla V100 x 3,456	Tesla V100 x 2,048
Apr	Sept	Nov	July	Nov	Apr
2017				2018	2019

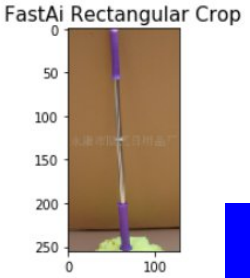
Fast.ai tips and engineering

2018

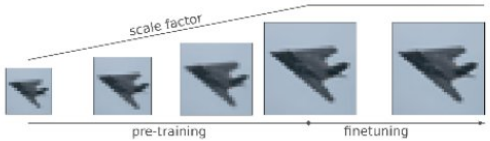
« Now anyone can train Imagenet in 18 minutes »

Our approach uses **128** processing units and costs around **$40** to run.

OneCycle lr scheduler + lr finder → Popularizes the works of Leslie N. Smith



Thanks to Global Average Pooling



Test Rectangular Validation Technique

Progressive image resizing

Dynamic batch size

Training Time

2022

a BigScience initiative

BLOOM

176B params · 59 languages · Open-access

Goal:

Text Generation Fundation Model (LLM)

Model :

176 B parameters

Dataset:

366 B tokens

117 Days

384 A100 GPUs

Training Time

Llama 3
From Meta

54 Days

16 384 H100 GPUs

Goal:

Text Generation Fundation Model (LLM)

Model :

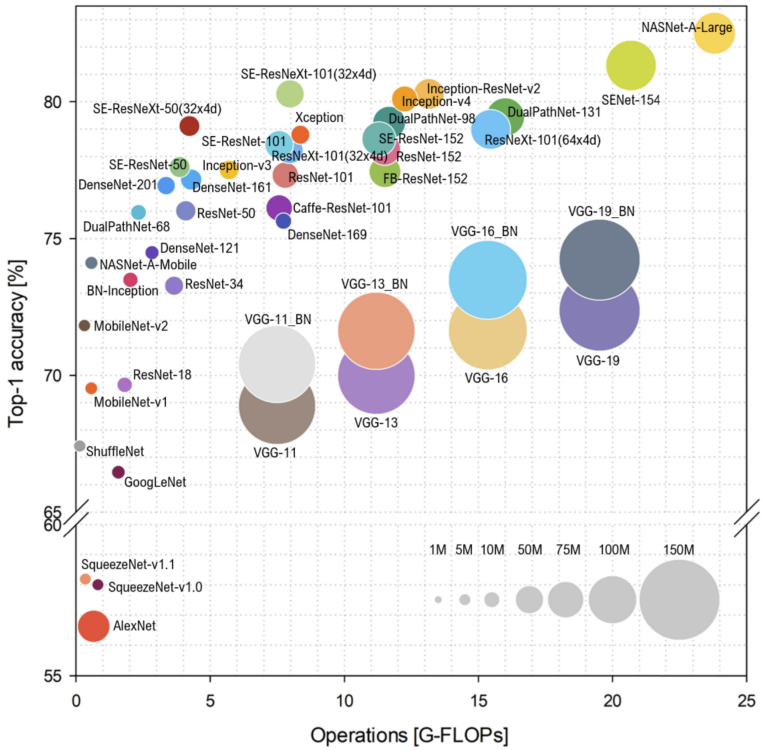
405 B parameters

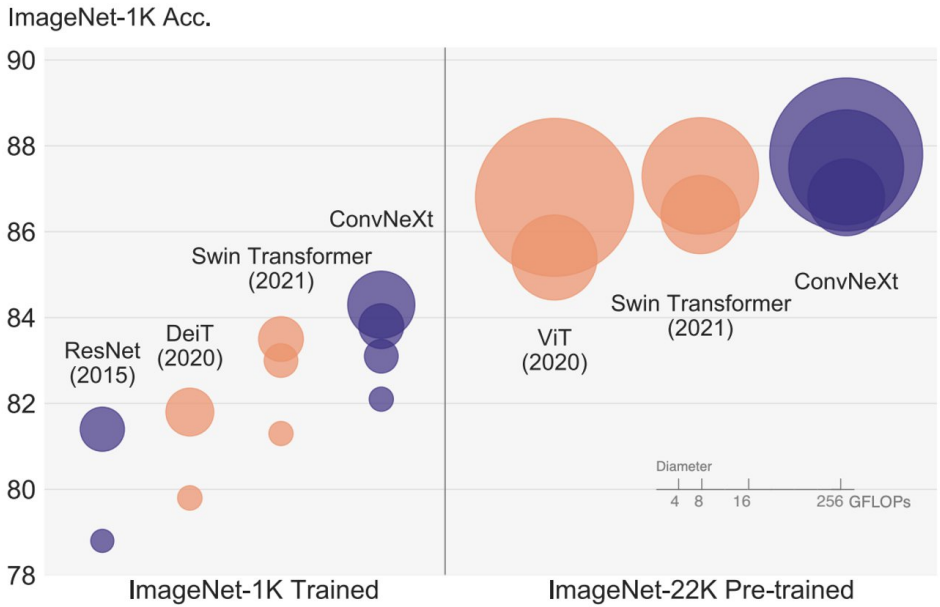
Dataset:

15 T tokens

Large Model

Vision Neural Network

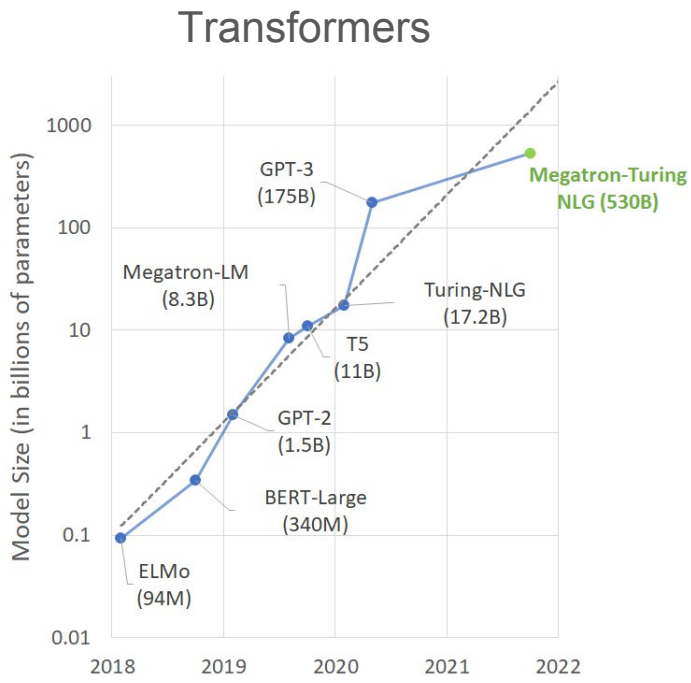


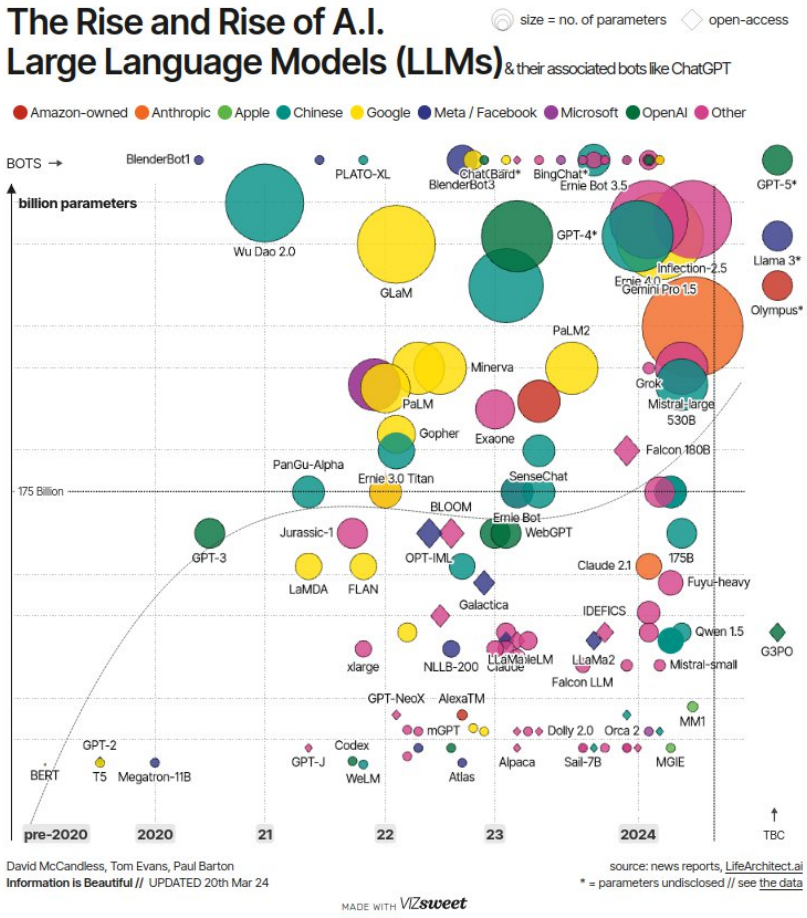


Large and deep models provide better accuracy metrics.

Large Model

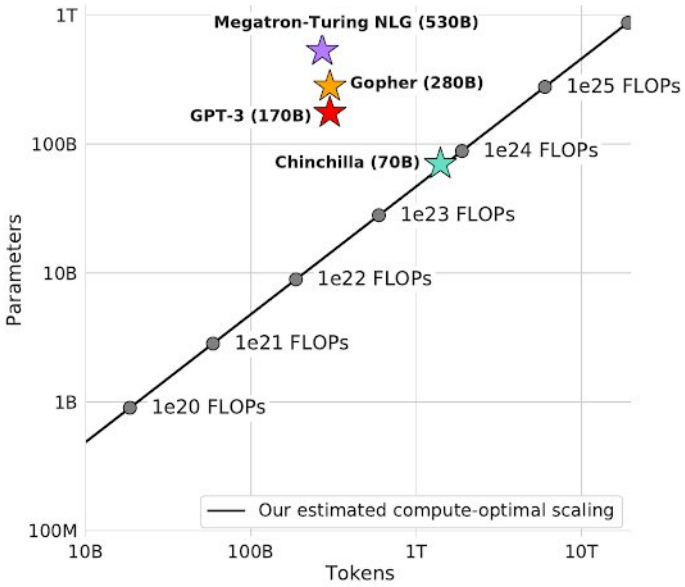
Huge models cause very expensive compute work times and large memory footprints (4 GB for a model with 1 billion parameters).

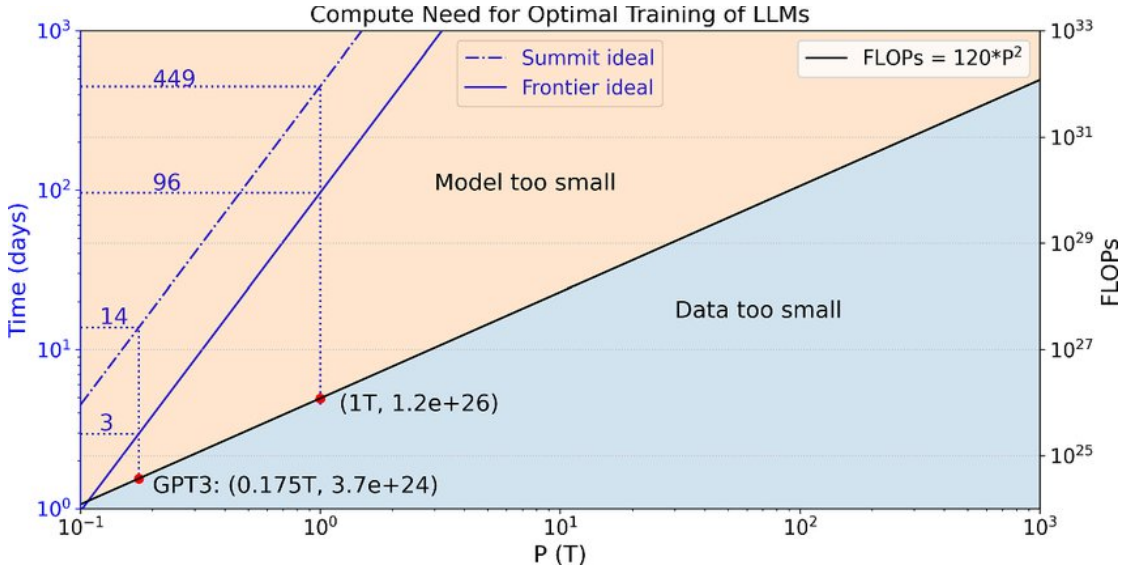




Large Model

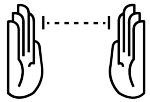
Chinchilla Law Impact





Compute Work Times

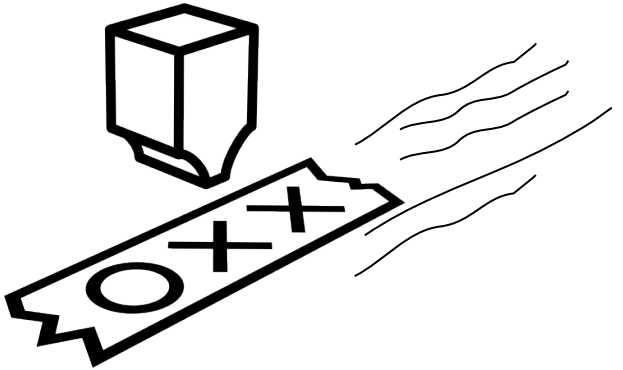
The compute time increases with the **number of FLOPs** required, depending on:

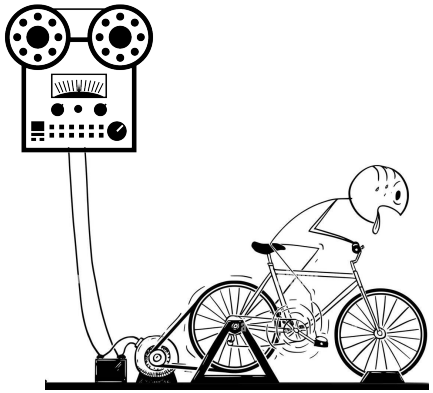


- The size of the model
- The depth of the model
- The size of the input data (image resolution, length of the sequence, etc.)

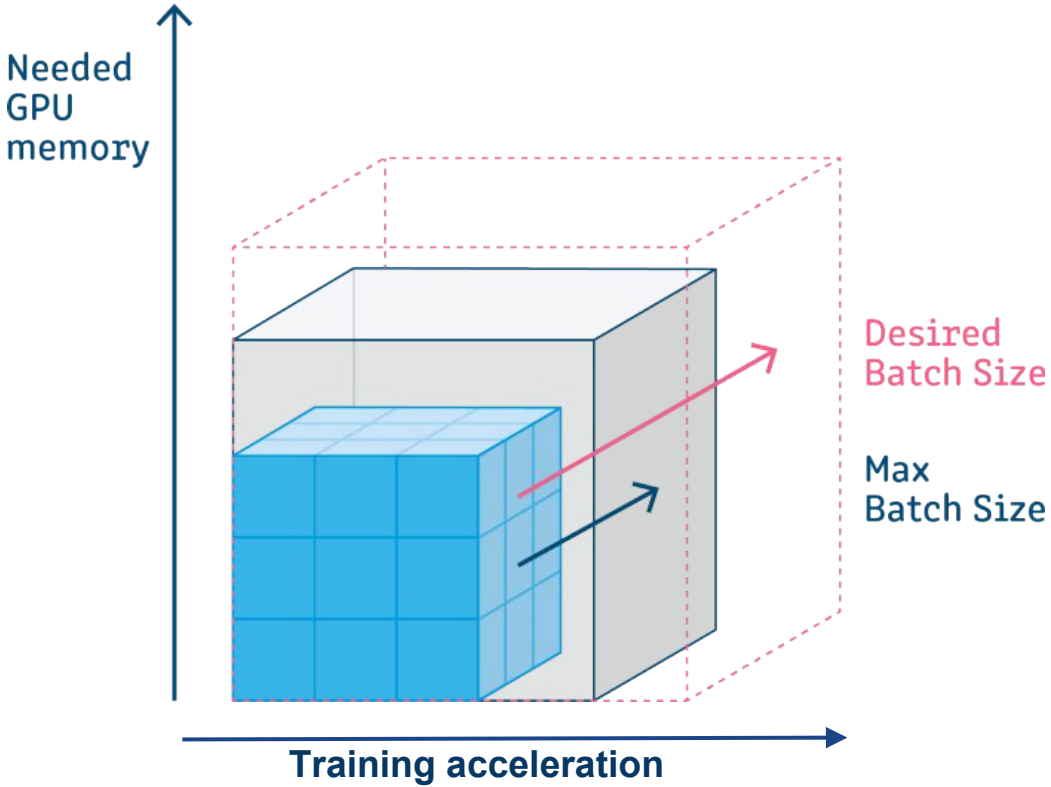
- The size of the dataset

- Number of epochs required

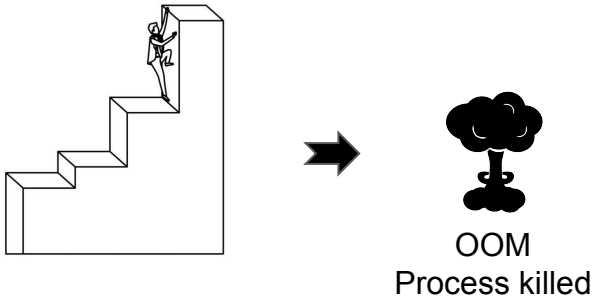




Batch Size & Memory Usage



Increasing the batch size and thus increasing the iteration step speeds up learning.

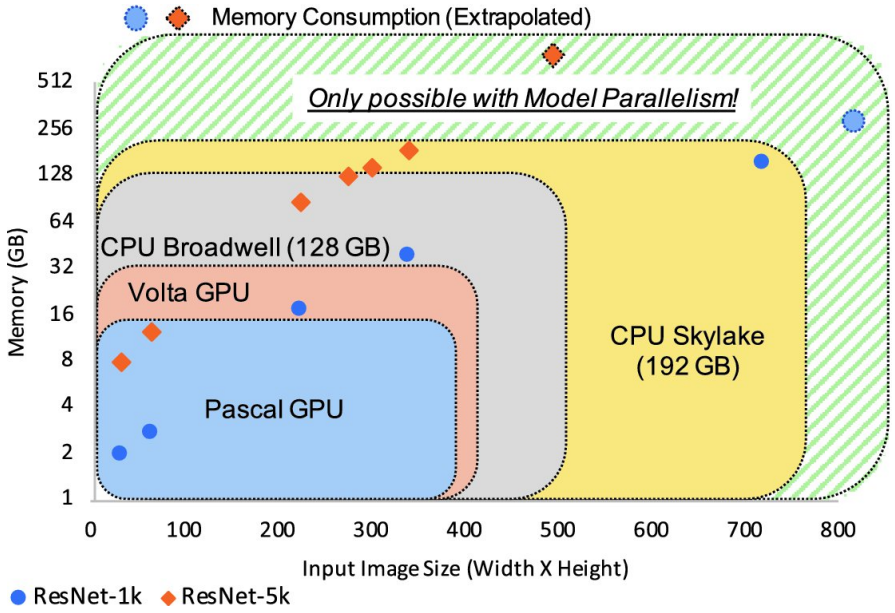


However, this increases the memory footprint and risks reaching the system limit.

Large size Input Data

Large input data causes **serious memory occupancy problems** during training, **accentuated by the depth of the model**.

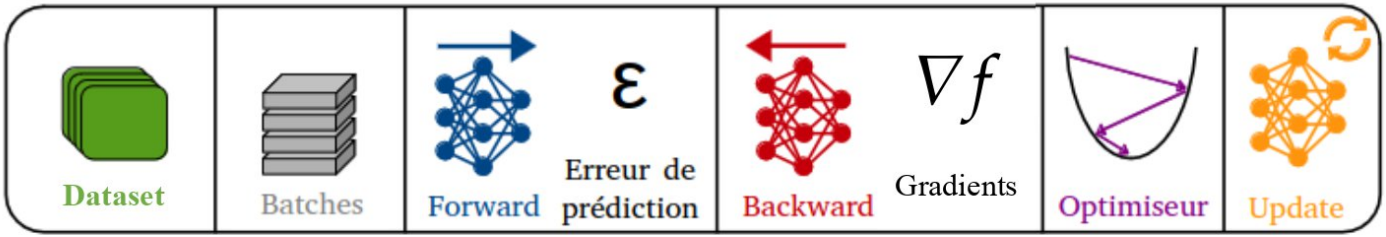
- ➔ Text (N, 100, 500) ***~x1***
- ➔ Image 2D (N, 226, 226, 3) ***~x3***
- ➔ Image 3D (N, 226, 226, 100, 3) ***~x300***
- ➔ Video (N, 100, 226, 226, 3) ***~x300***

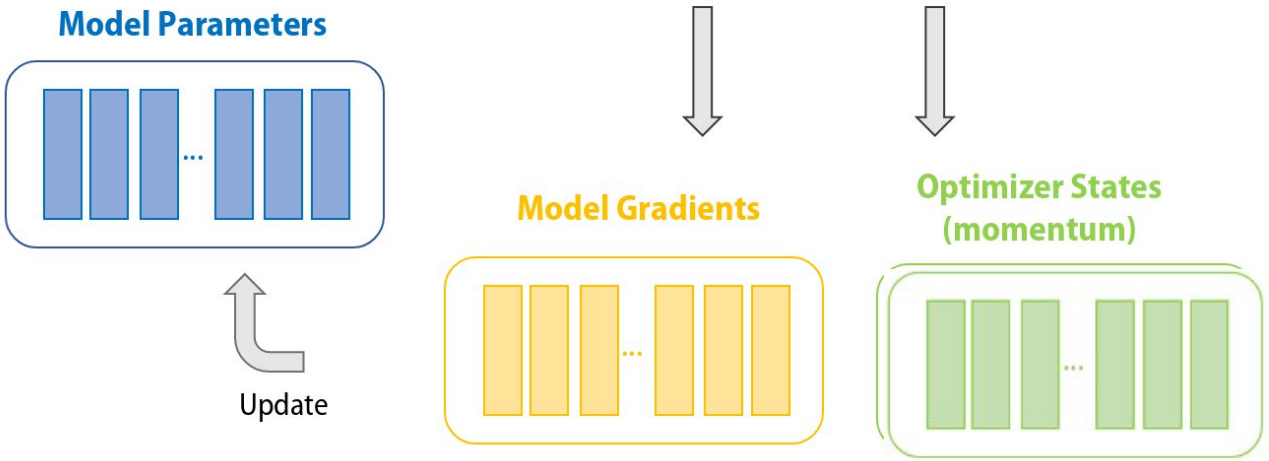


(GNN : Graph from tiny to huge !!)

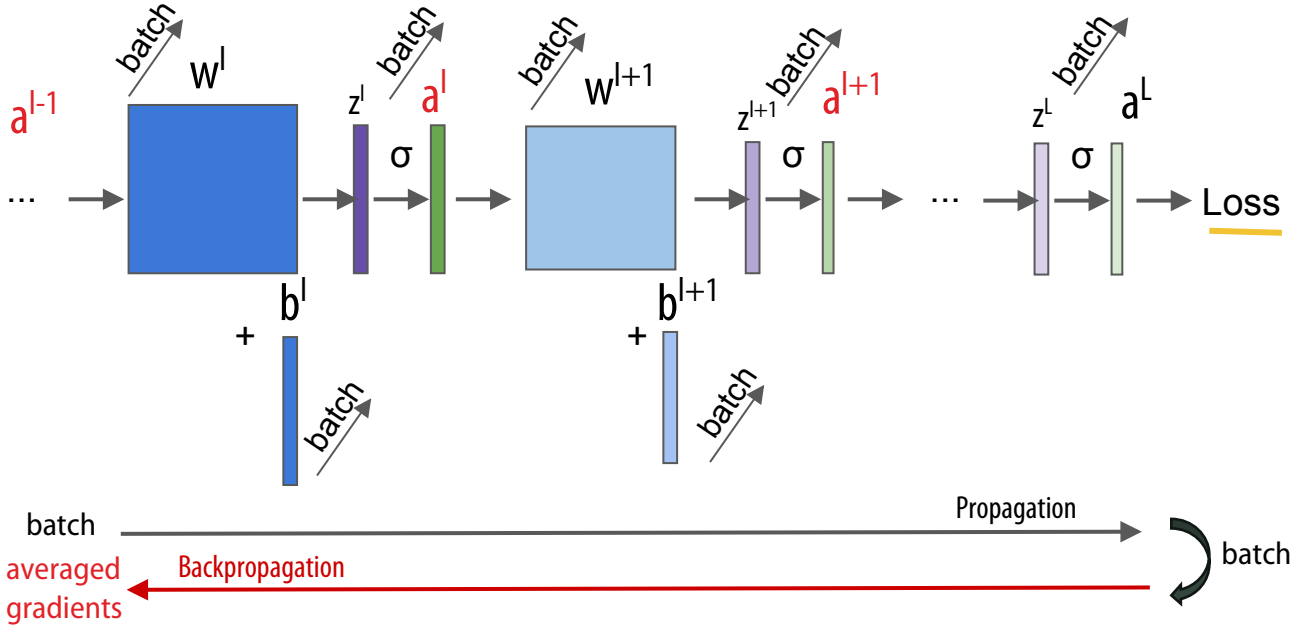
Source : HyPar-Flow

Forward / Backward – Model Memory Occupancy





Forward / Backward – Activations Memory Occupancy



Propagation

$$a^l = \sigma(w^l a^{l-1} + b^l) = \sigma z^l$$

Backpropagation

$$\delta^l = \frac{\partial C}{\partial z^l}$$

$$w^l \to w^l - \frac{\eta}{m} \cdot \frac{\partial C}{\partial w^l}$$

$$b^l \to b^l - \frac{\eta}{m} \cdot \frac{\partial C}{\partial b^l}$$

$$\delta^L = \nabla_a C \odot \sigma'(z^L)$$

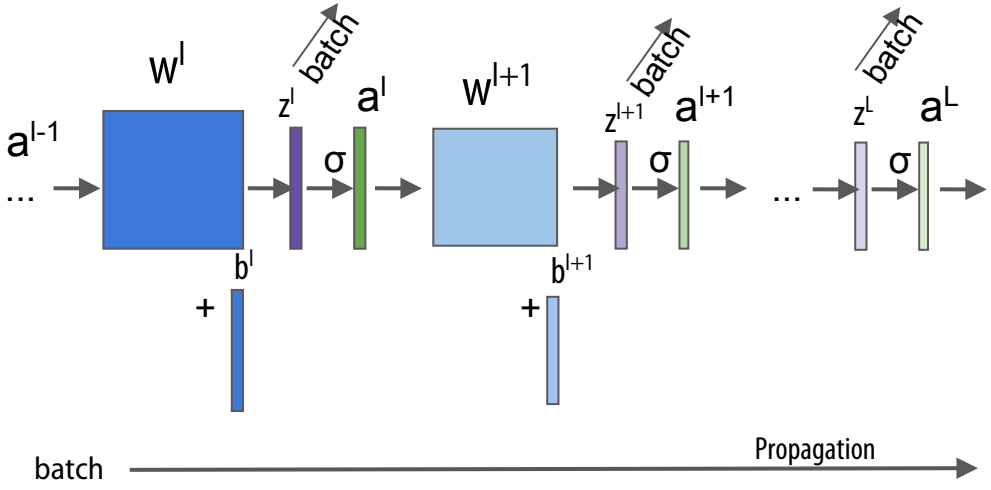
$$\delta^l = ((w^{l+1})^T \delta^{l+1}) \odot \sigma'(z^l)$$

$$\frac{\partial C}{\partial w^l} = \delta^l (a^{l-1})^T$$

$$\frac{\partial C}{\partial b^l} = \delta^l$$

Note: For backpropagation, it is necessary to save intermediate activations.

Inference & evaluation

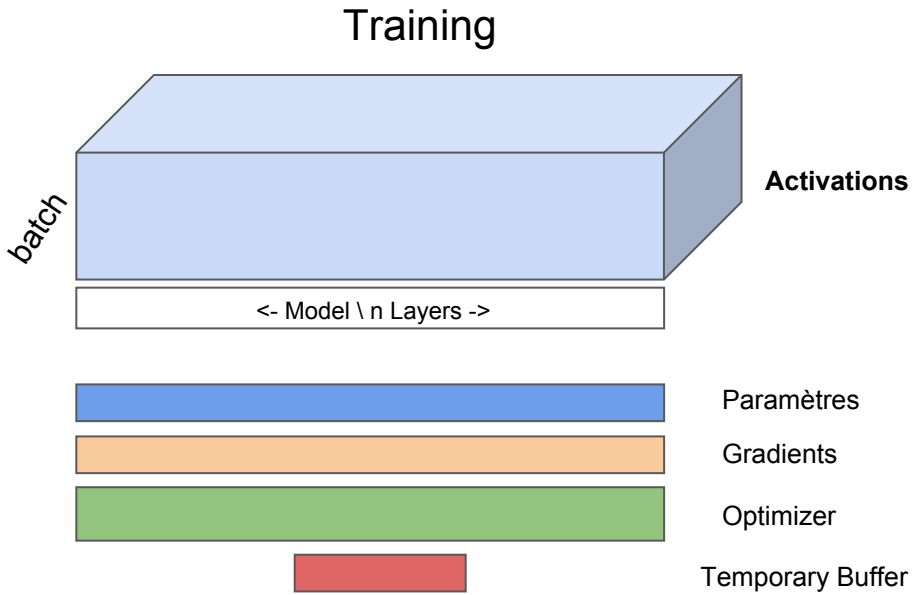


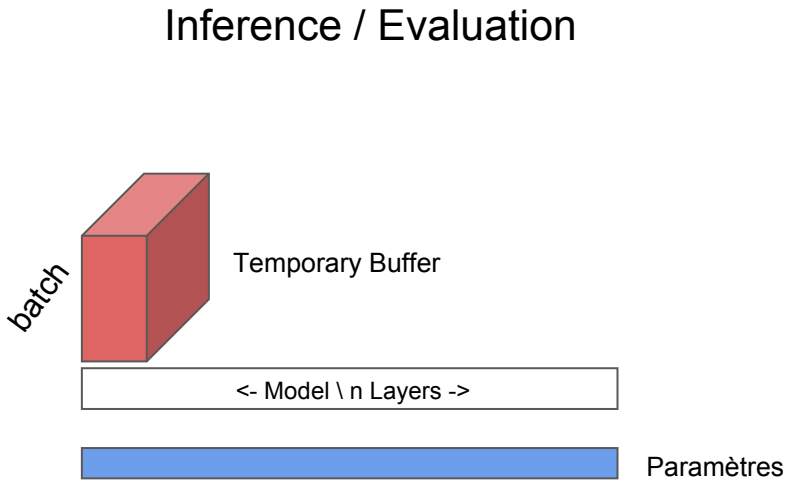
Propagation

$$a^l = \sigma(w^l a^{l-1} + b^l) = \sigma z^l$$

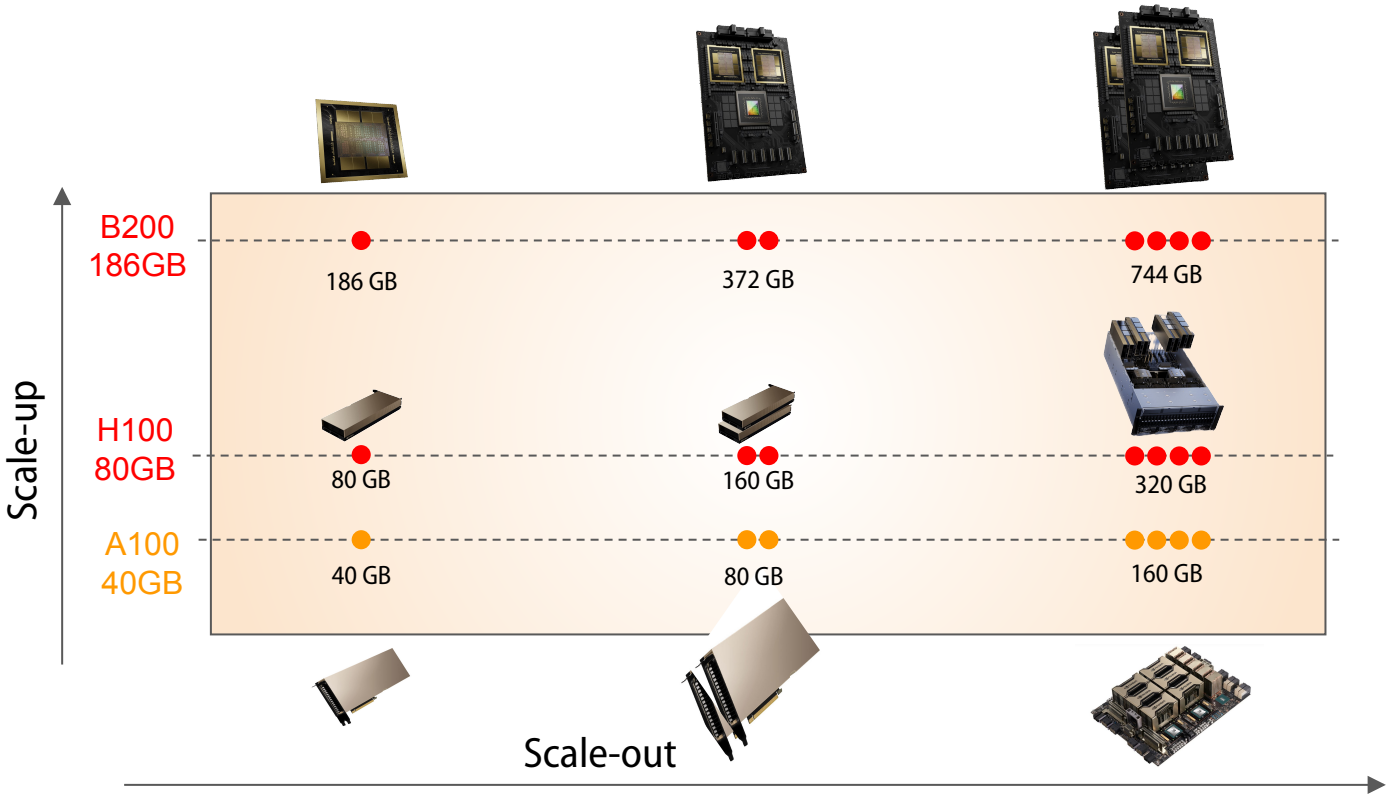
```
…
with torch.no_grad():
    val_outputs = model(val_images)
    loss = criterion(val_outputs, val_labels)
…
```

Memory Footprint



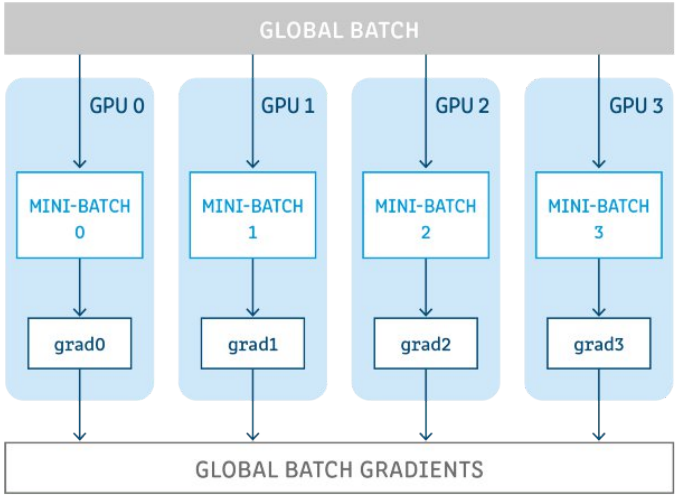


System Solutions

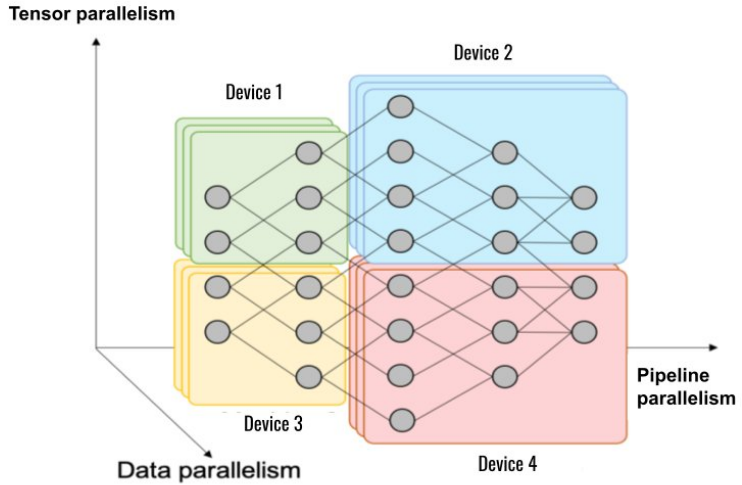


Solutions: Distribution – Scale-out

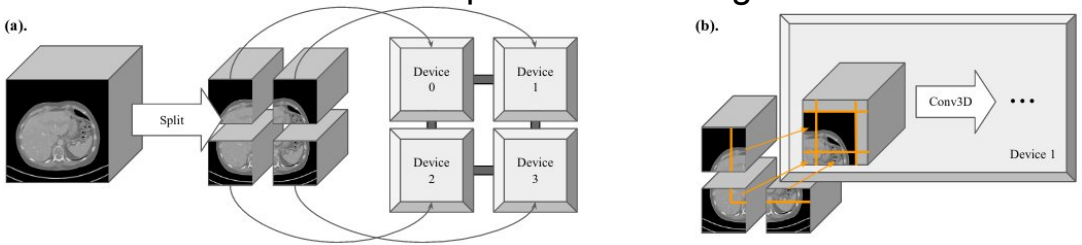
Data Parallelism



Model Parallelism (Tensor + Pipeline)

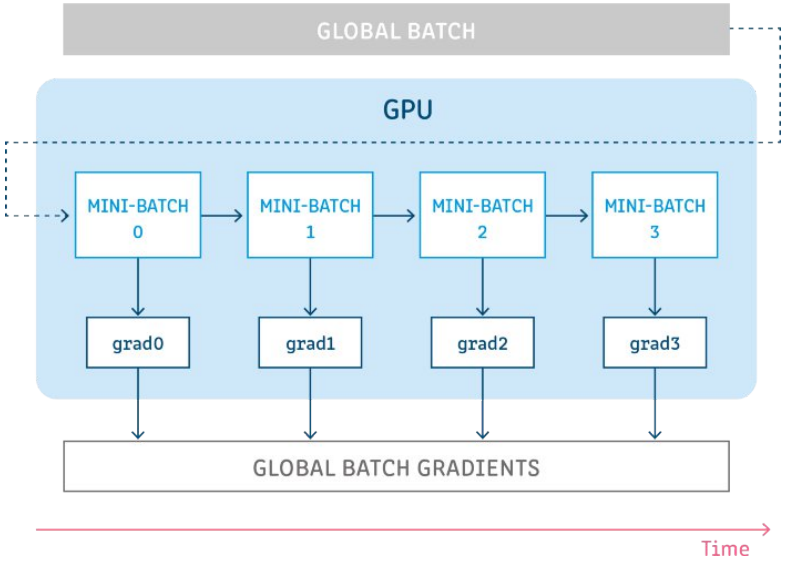


Spatial Partitioning

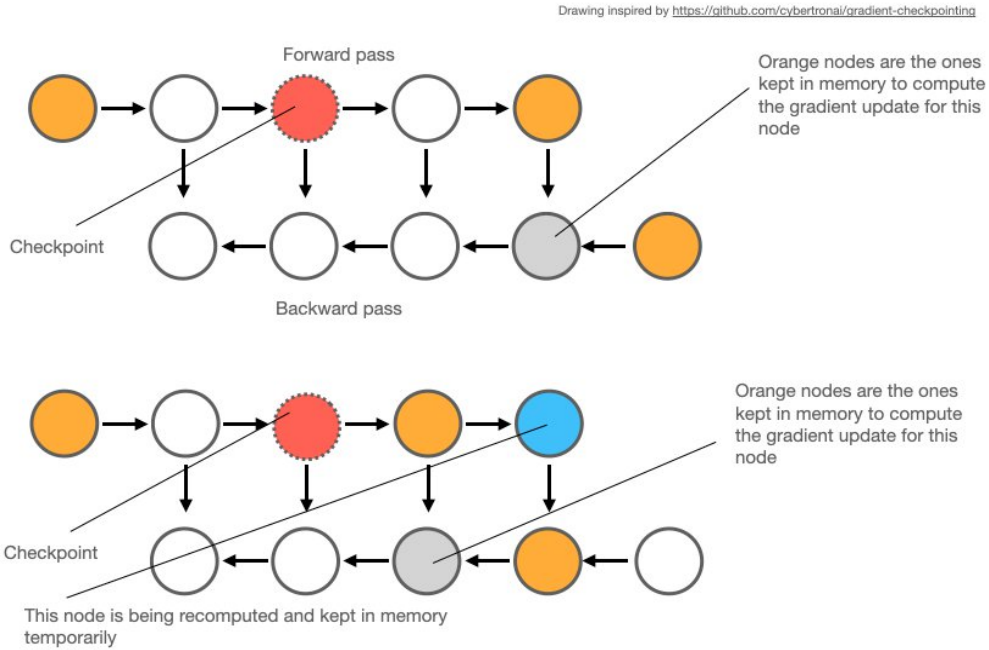


Workaround Solutions

Gradient aggregation



Gradient/activation checkpointing

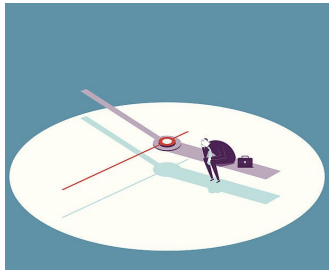


A 3rd problem to deal with ...

Power Consumption !!

2 problems to deal with:

Training Time



Memory Overconsumption (OOM)

Power Consumption

	H100 PCIe	H100 SXM5	A100 PCIe	A100 SXM4	V100 PCIe	V100 SXM2
Max Power	350W	700W	250W	400W	250W	300W
Idle Power	~30W	~55W	~30W	~60W	~40W	~45W
Performance	x3.5	x4	x1.75	x2	x0.9	x1

For a node: The CPU (often 2 processors) consumes what approximately 1 GPU consumes.

Power consumption varies depending on partial or overall GPU usage.

However, the power efficiency ratio is in favor of full use of the GPU.

Energy Consumption / GPU Hours

Energy Saving

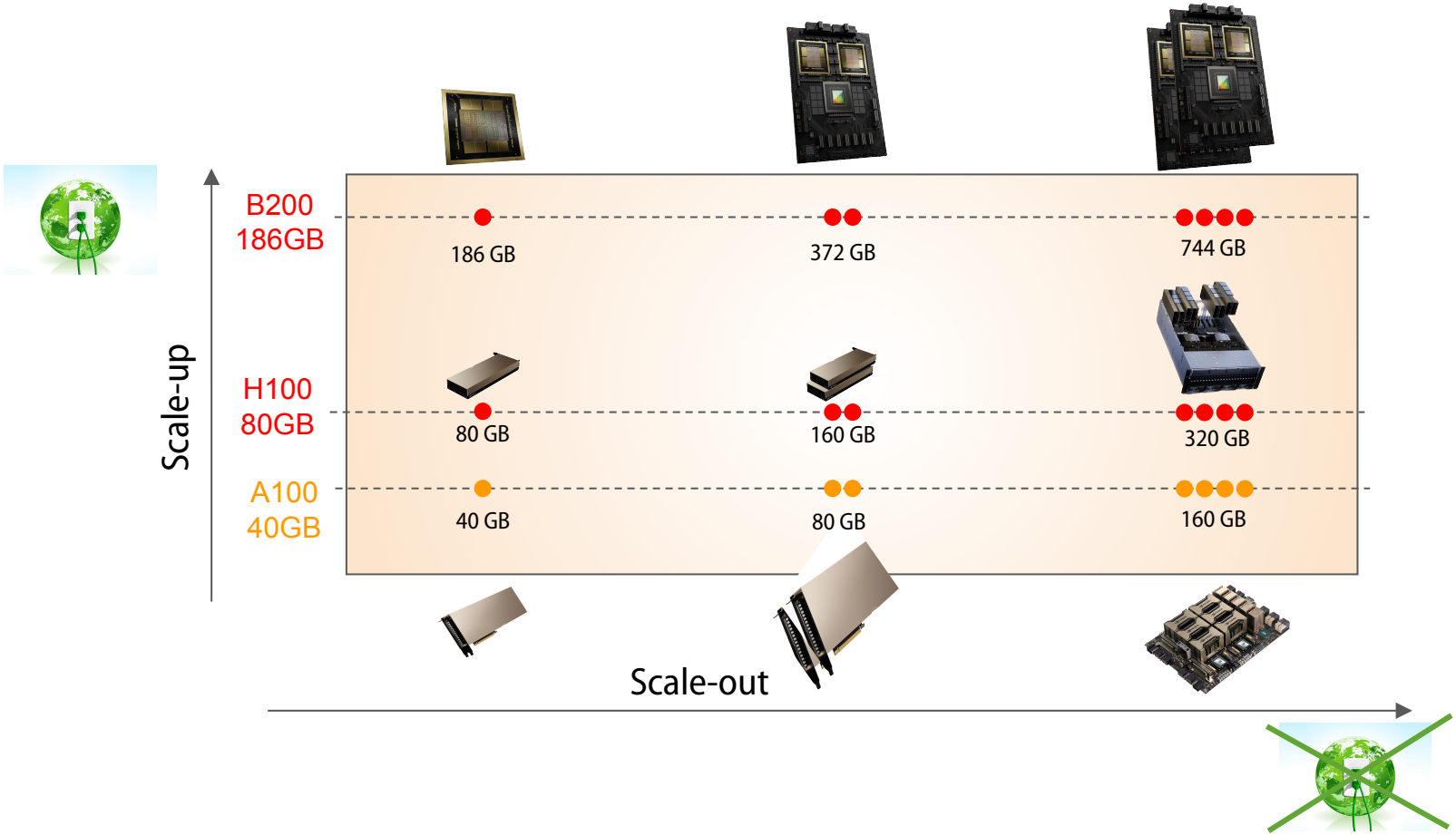
≅

GPU Hours Saving

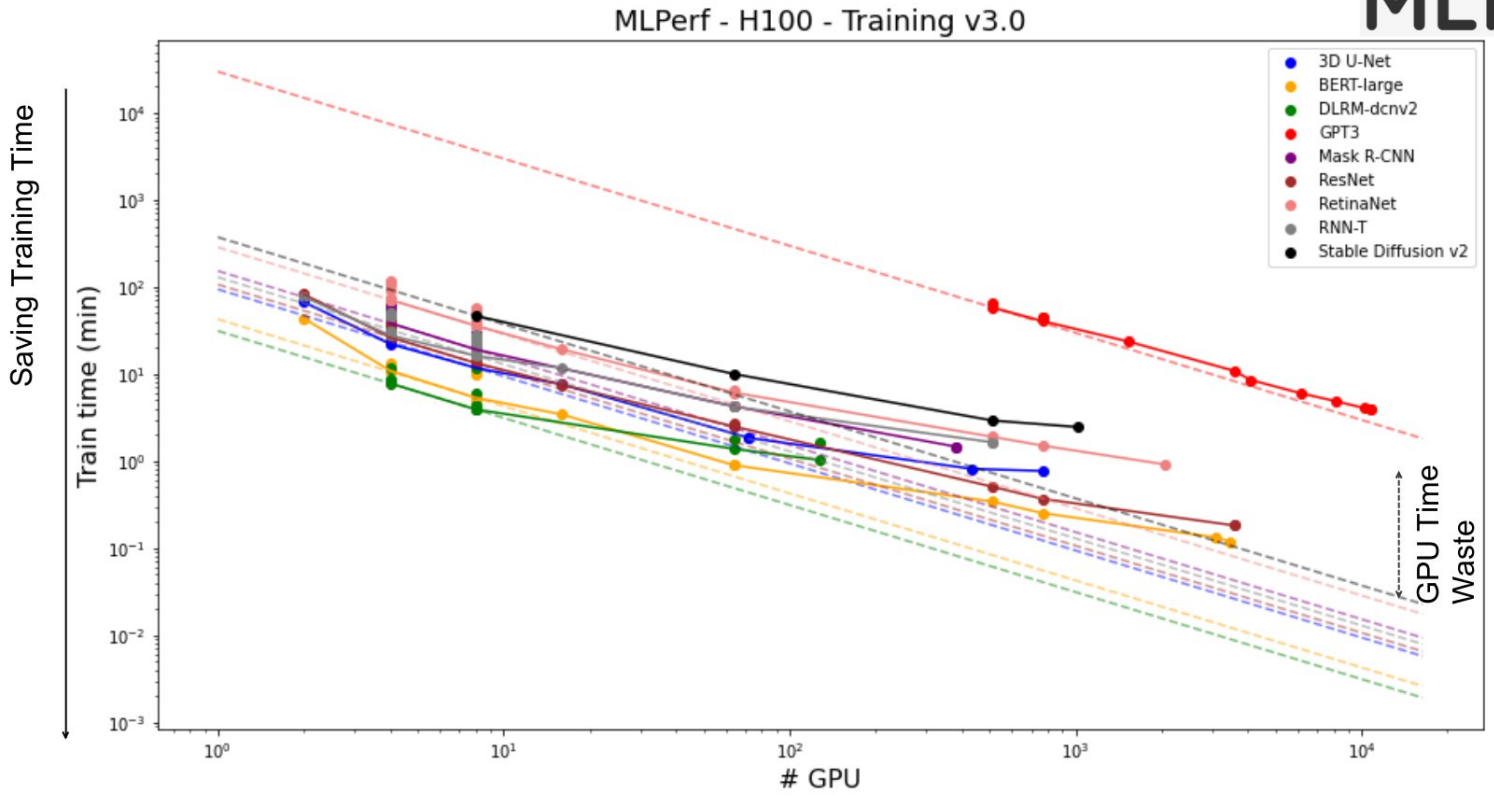
System optimization (DLO-JZ)

- Find the most important throughput
- Optimize data loading to eliminate GPU idle times
- Parallelize training to the right scale: neither too much nor too little

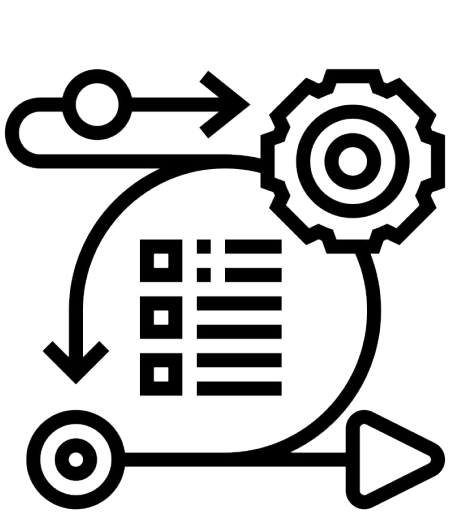
Energy Consumption / GPU Hours

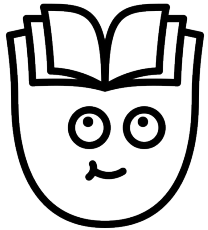


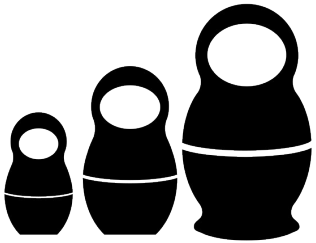
ML Perf Result - Scaling



Energy Consumption / GPU Hours







Methodology (saving research, not repeating learning unnecessarily)

- Search for hyperparameters in publications and reproduce the state-of-the-art
- Find the right hyper parameters on smaller models, then apply them at scale
- *Hyper-Parameter Optimization* (HPO) techniques

Code review

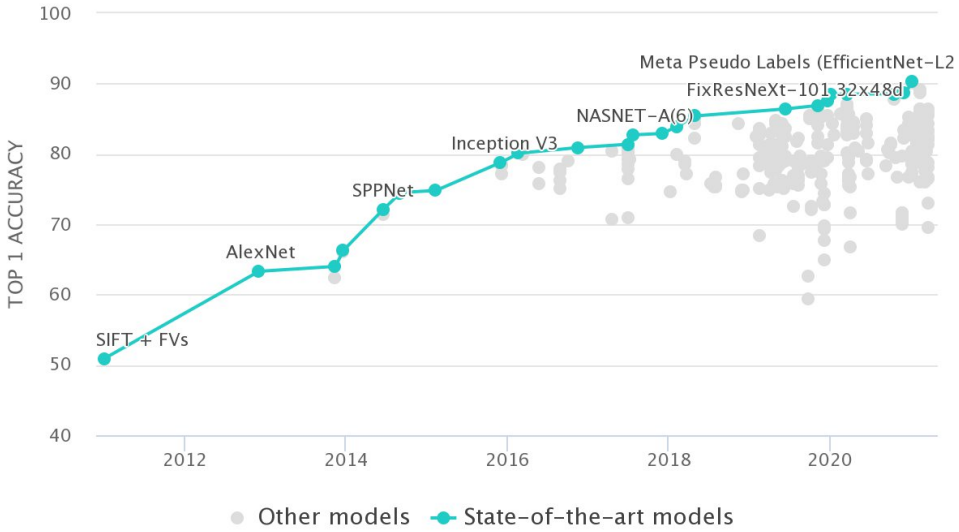
General overview ◂

Detailed overview ◂

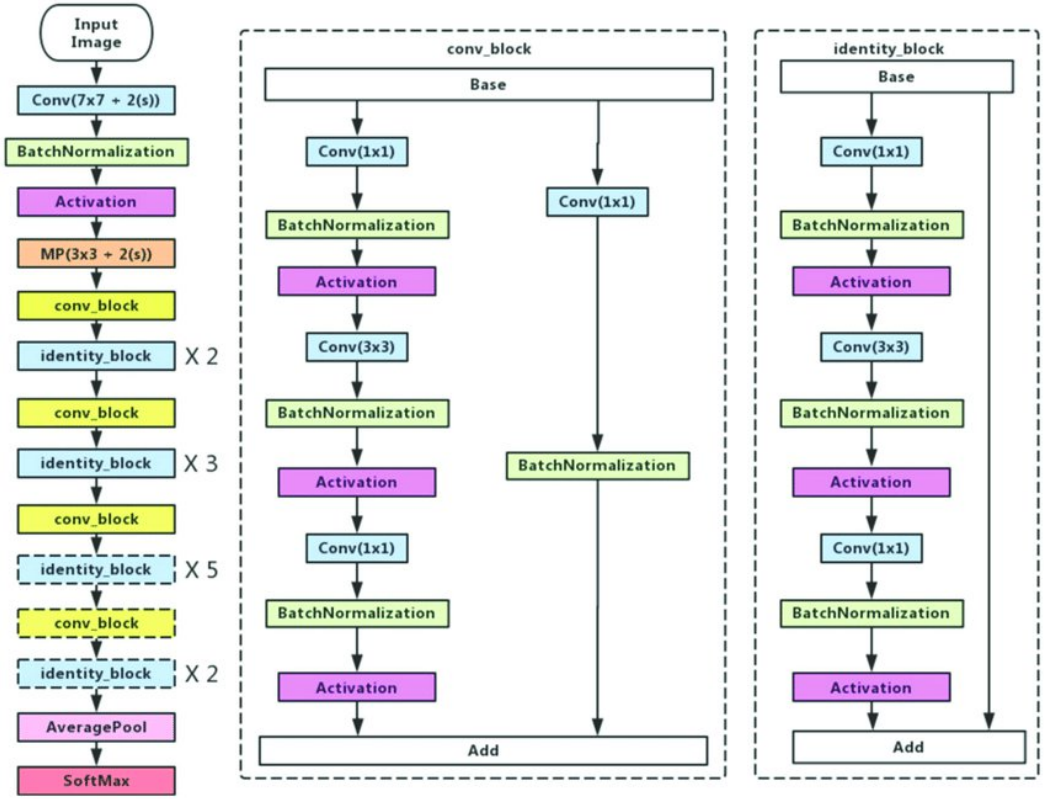
Data - Imagenet

Goal:
Classification (1000 classes)

Dataset:
Train dataset: **1,2 M** labeled images
Validation dataset: **50 000** labeled images
http://www.image-net.org/



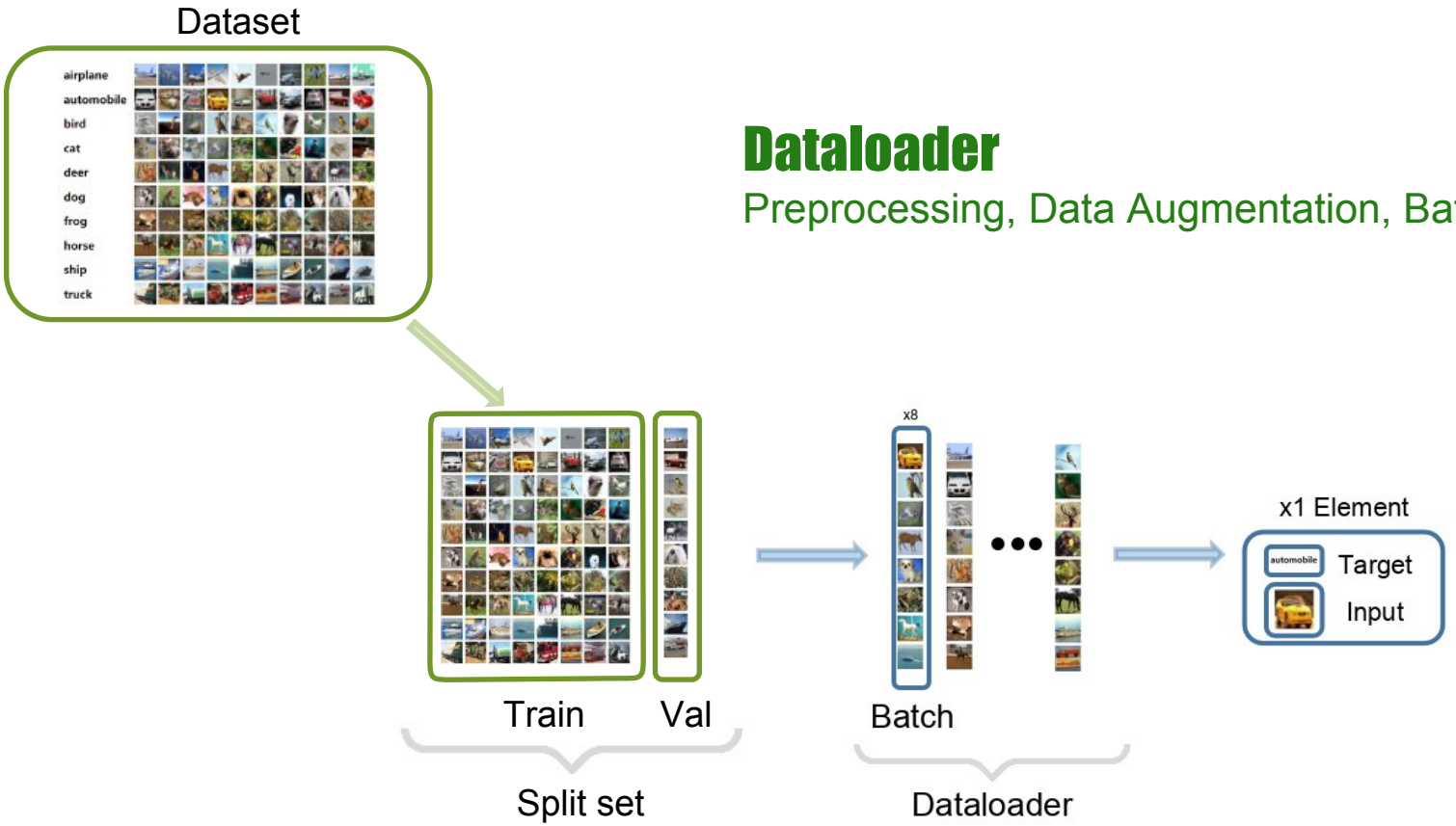
Imagenet - Resnet



Resnet :

- Residual Learning
- BatchNorm layer
  - Instead of Bias layers with conv.
- Average Pooling
  - Makes the model independent of the size of the input images

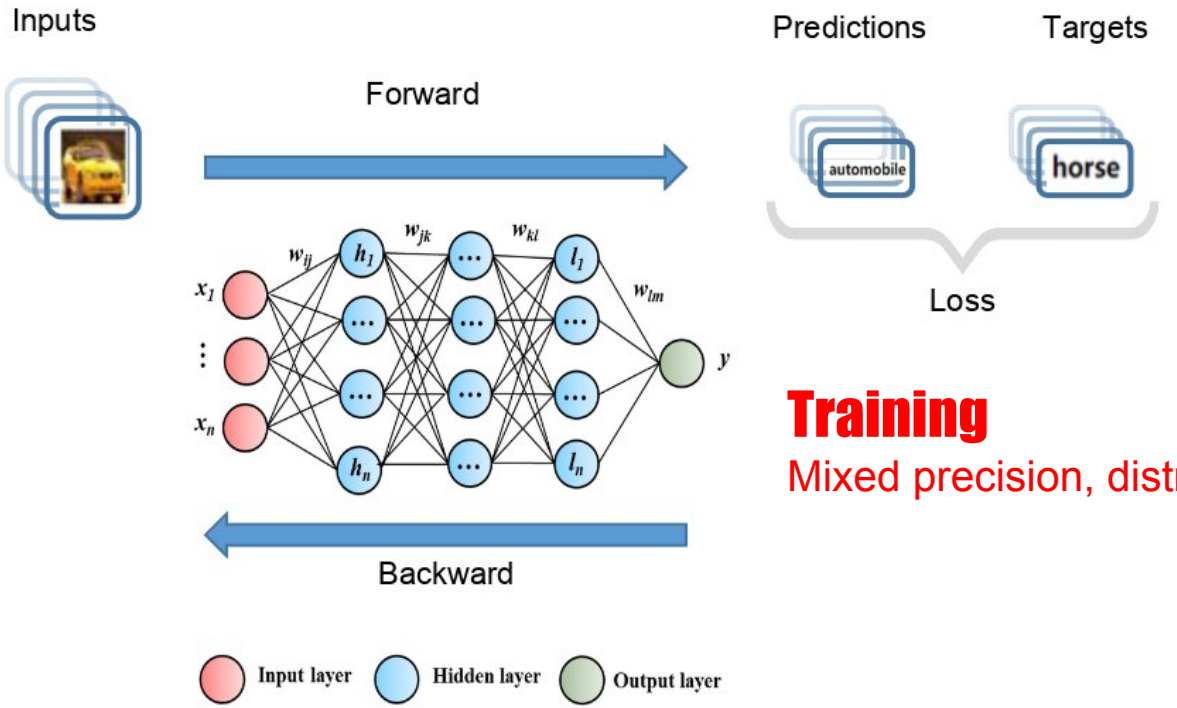
Training Loop – DataLoader



Dataloader

Preprocessing, Data Augmentation, Batching ...

Training Loop – Forward/Backward



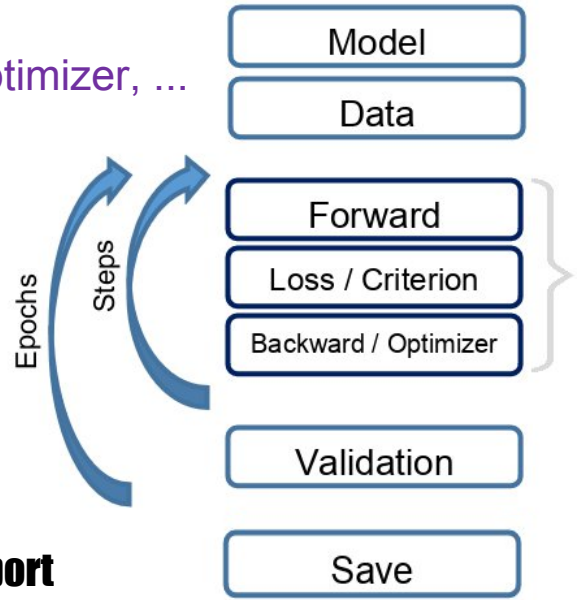
Training

Mixed precision, distribution, ...

Training Loop

Instanciation

Model, distribution, optimizer, ...



Dataloader

Preprocessing, Data Augmentation, Batching ...

Training

Mixed precision, distribution, ...

Validation

Mixed precision, distribution, ...

Checkpoint & report

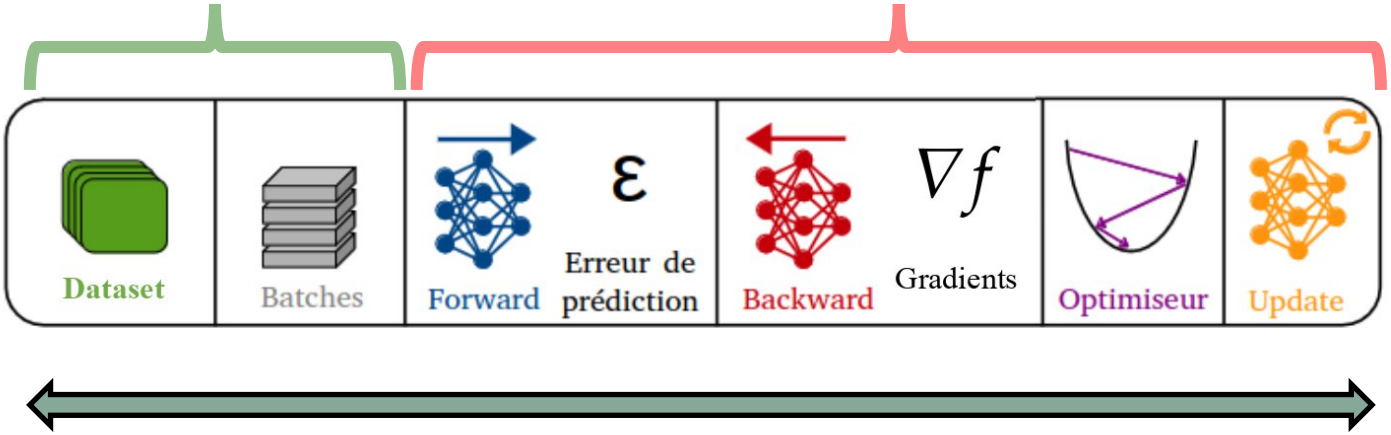
Training step

Dataloader

Preprocessing, Batching , ...

Training

Mixed precision, distribution, Metrics, ...



on CPU

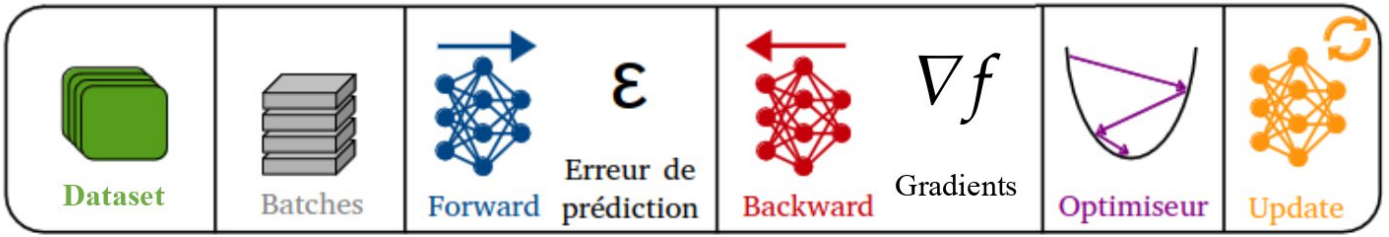
Training step – GPU Acceleration

Dataloader

Preprocessing, Batching , ...

Training

Mixed precision, distribution, Metrics, ...



on CPU

to GPU

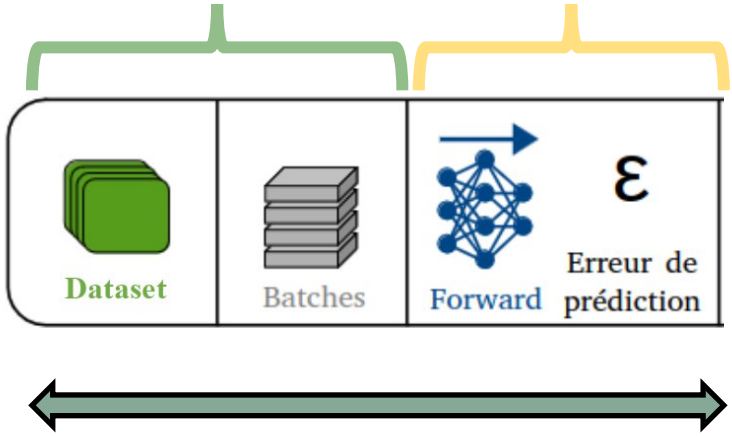
Validation step

Dataloader

Preprocessing, Batching, ...

Validation

Mixed precision, distribution, Metrics, ...



on CPU

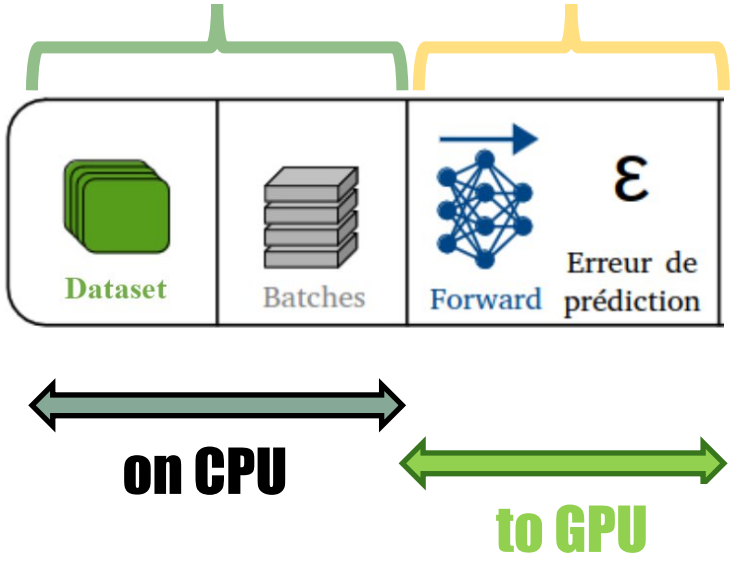
Validation step – GPU Acceleration

Dataloader

Preprocessing, Batching, ...

Validation

Mixed precision, distribution, Metrics, ...



Code dlojz.py Review

Import

argparse : arguments

Instanciation

Model, distribution, optimizer, ...

Dataloader

Preprocessing, Batching, ...

Instanciation

Training

Mixed precision, distribution, ...

Validation

Mixed precision, distribution, ...

Checkpoint & report

Runner

dlojz.py – Import & run

```python
import os
import contextlib
import argparse
import torchvision
import torchvision.transforms as transforms
import torchvision.models as models
from torch.utils.checkpoint import checkpoint_sequential
import torch
import numpy as np
import apex

import idr_torch
from dlojz_chrono import Chronometer
from torchmetrics.aggregation import MeanMetric
from torchmetrics.classification import MulticlassAccuracy

import random
random.seed(123)
np.random.seed(123)
torch.manual_seed(123)
```

reproductibility

idr_torch (JZ users)

distribution utils for Jean Zay

Import libraries

os
contextlib
argparse

PyTorch
NumPy
torchvision
NVIDIA - APEX

Chronometer (DLO-JZ)

time log & home profiler

TorchMetrics

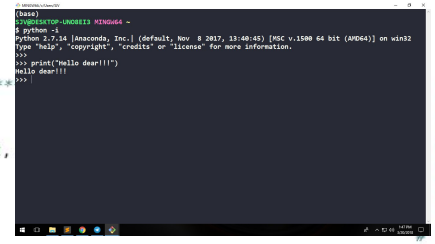
Created by Lightning AI

```python
if __name__ == '__main__':

    # display info
    if idr_torch.rank == 0:
        print(">>> Training on ", len(idr_torch.hostnames), " nodes and ", idr_torch.size, " processes")
    train()
```

```python
#**************************************
def train():
    parser = argparse.ArgumentParser()
    parser.add_argument('-b', '--batch-s
```

dlojz.py - arguments parser

```python
## import ... ## Add here the libraries to import

VAL_BATCH_SIZE=256

#*****************************************************************
def train():
    parser = argparse.ArgumentParser()
    parser.add_argument('-b', '--batch-size', default=128, type =int,
                        help='batch size per GPU')
    parser.add_argument('-e','--epochs', default=1, type=int,
                        help='number of total epochs to run')
    parser.add_argument('--image-size', default=224, type=int,
                        help='Image size')
    parser.add_argument('--lr', default=0.1, type=float,
                        help='learning rate')
    parser.add_argument('--wd', default=0., type=float,
                        help='weight decay')
    parser.add_argument('--mom', default=0.9, type=float,
                        help='momentum')
    parser.add_argument('--test', default=False, action='store_true',     ##    DON'T MODIFY    ########
                        help='Test 50 iterations')
    parser.add_argument('--test-nsteps', default='50', type=int,
                        help='the number of steps in test mode')
    parser.add_argument('--num-workers', default=10, type=int,
                        help='num workers in dataloader')
    parser.add_argument('--persistent-workers', default=True, action=argparse.BooleanOptionalAction,
                        help='activate persistent workers in dataloader')
    parser.add_argument('--pin-memory', default=True, action=argparse.BooleanOptionalAction,
                        help='activate pin memory option in dataloader')
    parser.add_argument('--non-blocking', default=True, action=argparse.BooleanOptionalAction,
                        help='activate asynchronuous GPU transfer')
    parser.add_argument('--prefetch-factor', default=3, type=int,
                        help='prefectch factor in dataloader')
    parser.add_argument('--drop-last', default=False, action=argparse.BooleanOptionalAction,
                        help='activate drop_last option in dataloader')
#*****************************************************************************************************

    ## Add parser arguments

    args = parser.parse_args()
```



Configurable Arguments :

`–batch-size` : batch size per GPU
`–epochs` : number of epochs
`–image-size` : image size

Optimizer :

`–lr` : learning rate
`–wd` : weight decay
`–mom` : momentum

Modes spéciaux :

`–test` : test mode
`–test-nsteps` : n steps for test mode

Optimisation du DataLoader :

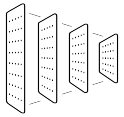
`–num-workers`
`–persistent-workers`
`–pin-memory`
`–non-blocking`
`–prefetch-factor`
`–drop-last`

dlojz.py - instantiation

```python
## chronometer initialisation
chrono = Chronometer()

# define model
model = models.resnet152()
archi_model = 'Resnet-152'

if idr_torch.rank == 0: print(f'model: {archi_model}')
if idr_torch.rank == 0: print('number of parameters: {}'.format(sum([p.numel()
                                        for p in model.parameters()])))
# distribute batch size (mini-batch)
num_replica = idr_torch.size
mini_batch_size = args.batch_size
global_batch_size = mini_batch_size * num_replica

if idr_torch.rank == 0:
    print(f'global batch size: {global_batch_size} - mini batch size: {mini_batch_size}')

# define loss function (criterion) and optimizer
criterion = torch.nn.CrossEntropyLoss(label_smoothing=0.1)
optimizer = torch.optim.SGD(model.parameters(), args.lr, momentum=args.mom, weight_decay=args.wd)

if idr_torch.rank == 0: print(f'Optimizer: {optimizer}')

# define metrics
train_metric = {}
train_metric['loss'] = MeanMetric()
train_metric['acc'] = MulticlassAccuracy(num_classes=1000, average='micro')
val_metric = {}
val_metric['loss'] = MeanMetric()
val_metric['acc'] = MulticlassAccuracy(num_classes=1000, average='micro')
```

```python
#LR scheduler to accelerate the training time
scheduler = torch.optim.lr_scheduler.OneCycleLR(optimizer, max_lr=args.lr,
                                                steps_per_epoch=N_batch, epochs=args.epochs)
```

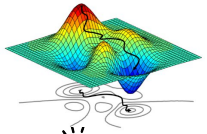
Chronometer



model : Resnet-152

mini batch size ⟺ global batch size

$\mathcal{E}$ CrossEntropyLoss

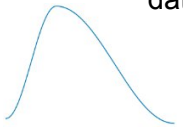


SGD Optimizer

Metric

?

need *N_batch*, given by dataloader



LR scheduler

dlojz.py - Dataloader

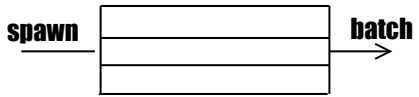
```
######### DATALOADER ############
# Define a transform to pre-process the training images.

if idr_torch.rank == 0: print(f"DATALOADER {args.num_workers} {args.persistent_workers} {args.pin_memory}")

transform = transforms.Compose([
        transforms.RandomResizedCrop(args.image_size),  # Random resize - Data Augmentation
        transforms.RandomHorizontalFlip(),              # Horizontal Flip - Data Augmentation
        transforms.ToTensor(),                          # convert the PIL Image to a tensor
        transforms.Normalize(mean=(0.485, 0.456, 0.406),
                             std=(0.229, 0.224, 0.225))
        ])



train_dataset = torchvision.datasets.ImageNet(root=os.environ['ALL_CCFRSCRATCH']+'/imagenet',
                                              transform=transform)

train_loader = torch.utils.data.DataLoader(dataset=train_dataset,
                                           batch_size=mini_batch_size,
                                           shuffle=True,
                                           num_workers=args.num_workers,
                                           persistent_workers=args.persistent_workers,
                                           pin_memory=args.pin_memory,
                                           prefetch_factor=args.prefetch_factor,
                                           drop_last=args.drop_last)


val_transform = transforms.Compose([
          transforms.Resize((256, 256)),
          transforms.CenterCrop(224),
          transforms.ToTensor(),    # convert the PIL Image to a tensor
          transforms.Normalize(mean=(0.485, 0.456, 0.406),
                               std=(0.229, 0.224, 0.225))])

val_dataset = torchvision.datasets.ImageNet(root=os.environ['ALL_CCFRSCRATCH']+'/imagenet', split='val',
                    transform=val_transform)

val_loader = torch.utils.data.DataLoader(dataset=val_dataset,
                                         batch_size=VAL_BATCH_SIZE,
                                         shuffle=False,
                                         num_workers=args.num_workers,
                                         persistent_workers=args.persistent_workers,
                                         pin_memory=args.pin_memory,
                                         prefetch_factor=args.prefetch_factor,
                                         drop_last=args.drop_last)


N_batch = len(train_loader)
N_val_batch = len(val_loader)
N_val = len(val_dataset)
```

train dataset :

RandomResizedCrop
RandomHorizontalFlip
+ Normalize

Shuffling

DataLoader optimization

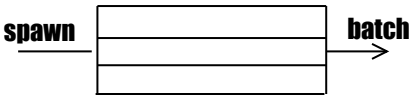


validation dataset :

Resize
CenterCrop
+ Normalize

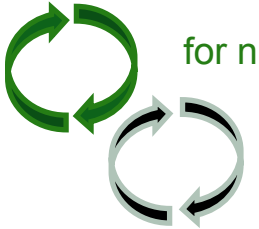
no shuffling

DataLoader optimization



dlojz.py - Training

```python
chrono.start()

#### TRAINING ############
for epoch in range(args.epochs):

    if args.test: chrono.next_iter()
    if idr_torch.rank == 0: chrono.tac_time(clear=True)

    for i, (images, labels) in enumerate(train_loader):

        csteps = i + 1 + epoch * N_batch
        if args.test and csteps > args.test_nsteps: break
        if i == 0 and idr_torch.rank == 0:
            print(f'image batch shape : {images.size()}')

        if args.test: chrono.forward()

        optimizer.zero_grad()
        outputs = model(images)
        loss = criterion(outputs, labels)

        if args.test: chrono.backward()

        loss.backward()
        optimizer.step()

        # Metric mesurement
        train_metric['loss'].update(loss)
        train_metric['acc'].update(outputs, labels)

        if args.test: chrono.update()

        if ((i + 1) % (N_batch//10) == 0 or i == N_batch - 1):
            train_loss, accuracy = train_metric['loss'].compute(), train_metric['acc'].compute()
            train_metric['loss'].reset(), train_metric['acc'].reset()
            if idr_torch.rank == 0:
                print('Epoch [{}/{}], Step [{}/{}], Time: {:.3f}, Loss: {:.4f}, Acc:{:.4f}'.format(
                      epoch + 1, args.epochs, i+1, N_batch,
                      chrono.tac_time(), train_loss, accuracy))

        # scheduler update
        scheduler.step()
```



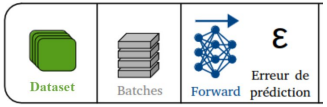
for n epochs

for each *batch*

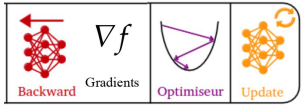
test mode : 50 steps

CPU compute by default !!

```
optimizer.zero_grad()
outputs = model(images)
loss = criterion(outputs, labels)
```




```
loss.backward()
optimizer.step()
```



Aggregate the metrics (loss, accuracy)
10x per epoch, compute and print the metrics

Log 10x per epoch

Step up LR scheduler

dlojz.py - Validation

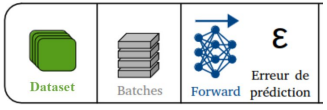
```
#### VALIDATION #############
if ((i == N_batch - 1) or (args.test and i==args.test_nsteps-1)) :

    chrono.validation()
    model.eval()

    for iv, (val_images, val_labels) in enumerate(val_loader):

        # Runs the forward pass with no grad mode.
        with torch.no_grad():
            val_outputs = model(val_images)
            val_loss = criterion(val_outputs, val_labels)

        val_metric['loss'].update(val_loss)
        val_metric['acc'].update(val_outputs, val_labels)

        if args.test and iv >= 20: break

    val_loss, val_accuracy = val_metric['loss'].compute(), val_metric['acc'].compute()
    val_metric['loss'].reset(), val_metric['acc'].reset()

    model.train()
    chrono.validation()
    if not args.test and idr_torch.rank == 0:
        print('##EVALUATION STEP##')
        print('Epoch [{}/{}], Validation Loss: {:.4f}, Validation Accuracy: {:.4f}'.format(
                                epoch + 1, args.epochs, val_loss, val_accuracy))
        print(">>> Validation complete in: " + str(chrono.val_time))

#### END OF VALIDATION #############
```

after each epoch
(or at the end of test mode)

for each *batch of validation*

(test mode : 20 steps)

```
# Runs the forward pass with no grad mode.
with torch.no_grad():
    val_outputs = model(val_images)
    loss = criterion(val_outputs, val_labels)
```



Aggregate the metrics (loss, accuracy)

when it is over:

compute & **Log**

dlojz.py – Checkpoint & Report

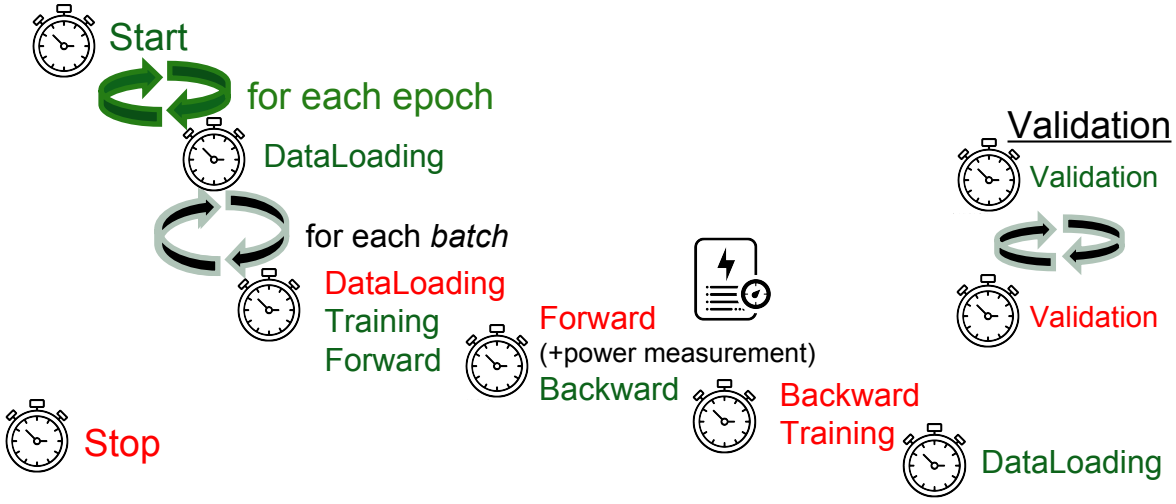
```
chrono.stop()
if idr_torch.rank == 0:
    chrono.display()
    print(">>> Number of batch per epoch: {}".format(N_batch))
    print(f'Max Memory Allocated {torch.cuda.max_memory_allocated()} Bytes')


# Save last checkpoint
if not args.test and idr_torch.rank == 0:
    checkpoint_path = f"checkpoints/{os.environ['SLURM_JOBID']}_{global_batch_size}.pt"
    torch.save(model.state_dict(), checkpoint_path)
    print("Last epoch checkpointed to " + checkpoint_path)
```

Log + Chronometer Display

Checkpoint at the end of training (=> not in test mode)

pre-trained model

dlojz.py - Chronometer



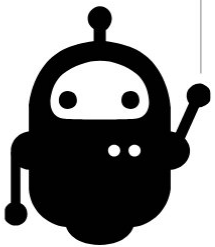
Display

```
    def display(self, val_steps):
        if self.rank == 0:
            print(">>> Training complete in: " + str(datetime.now() - self.start_proc))
            if self.test:
                print(">>> Training performance time: min {} avg {} seconds (+/- {})".format(np.min(self.time_perf_train[1:]), np.median(self.time_perf_train[1:]),
np.std(self.time_perf_train[1:])))
                print(">>> Loading performance time: min {} avg {} seconds (+/- {})".format(np.min(self.time_perf_load[1:]), np.mean(self.time_perf_load[1:]),
np.std(self.time_perf_load[1:])))
                print(">>> Forward performance time: {} seconds (+/- {})".format(np.mean(self.time_perf_forward[1:]), np.std(self.time_perf_forward[1:])))
                print(">>> Backward performance time: {} seconds (+/- {})".format(np.mean(self.time_perf_backward[1:]), np.std(self.time_perf_backward[1:])))
                if len(self.power)>0: print(">>> Peak Power during training: {} W)".format(np.max(self.power)))
                print(">>> Validation time estimation: {}".format(self.val_time/20 * val_steps))
                print(">>> Sortie trace ###################################" )
                print(">>>JSON", json.dumps({'GPU process - Forward/Backward':self.time_perf_train, 'CPU process - Dataloader':self.time_perf_load}))
```

TP0 : Préparation de l'environnement

- Lancer un terminal et faire les copies nécéssaires

```
local:~$ ssh jean-zay

jz:~$ cd $WORK
jz:~$ git clone https://github.com/IDRIS-CNRS/DLO-JZ.git
```



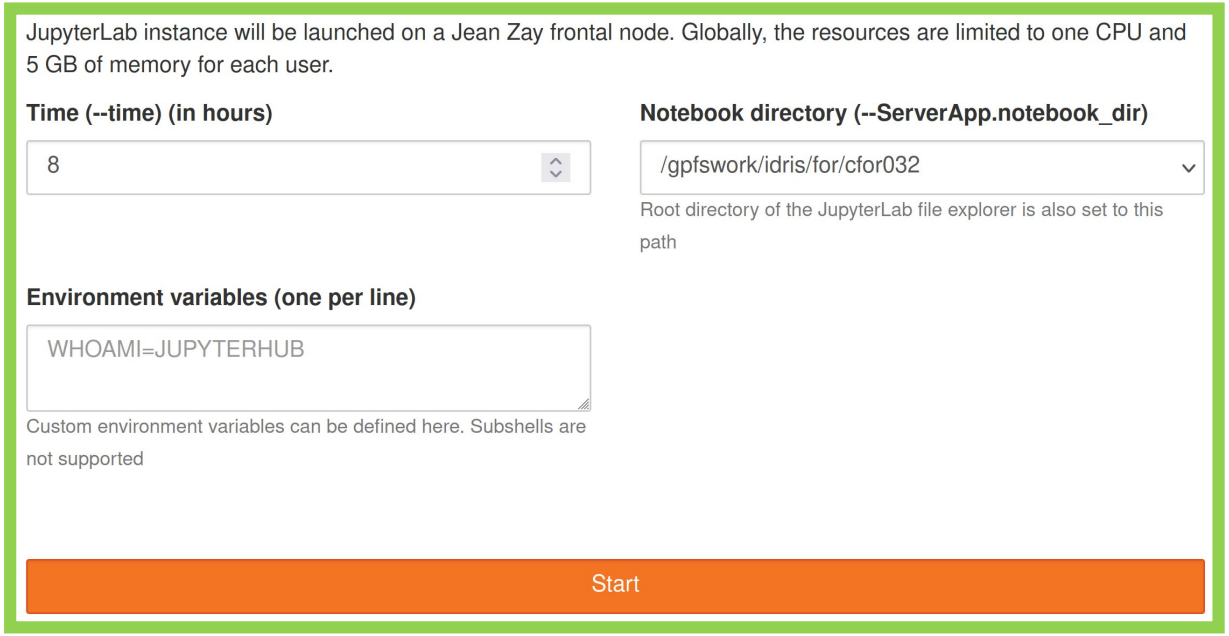
- Lancer firefox
- Accéder à jupyterhub.idris.fr

TP0 : Accès et prise en main de JupyterHub

- Se connecter avec vos identifiants de formation
- Lancer une instance

- Sélectionner le spawner ‘Interactive’

- Remplir la configuration



- Start

TP0 : Accès et prise en main du notebook

- Ouvrir le notebook DLO-JZ_Jour1.ipynb
- Choisir le kernel pytorch-gpu/py3/2.1.1 (en haut à droite) s'il n'est pas détecté automatiquement
- Choisir un pseudonyme
- Lancer un job
- Prendre en main le script de référence et les différentes fonctionnalités

GPU computing

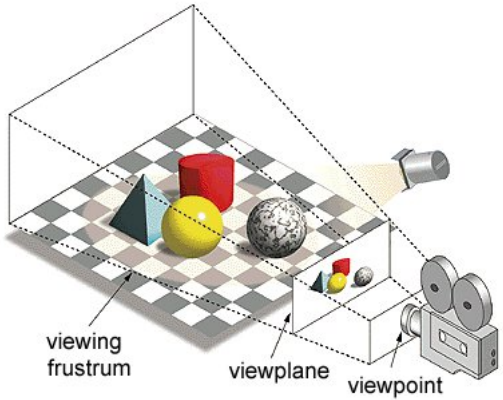
V100, A100, H100 ◂

CUDA ◂

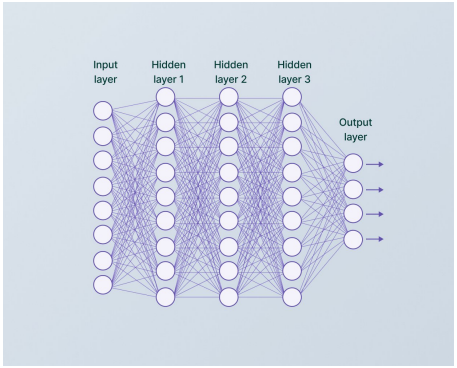
CuDNN ◂

AMP ◂

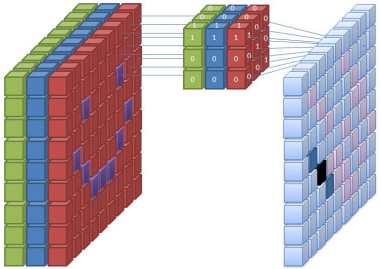
GPU computing



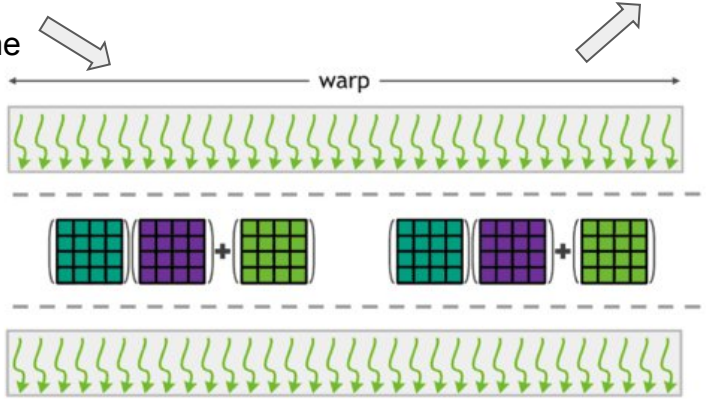
GPU Rendering & Game Graphics Pipeline



NN

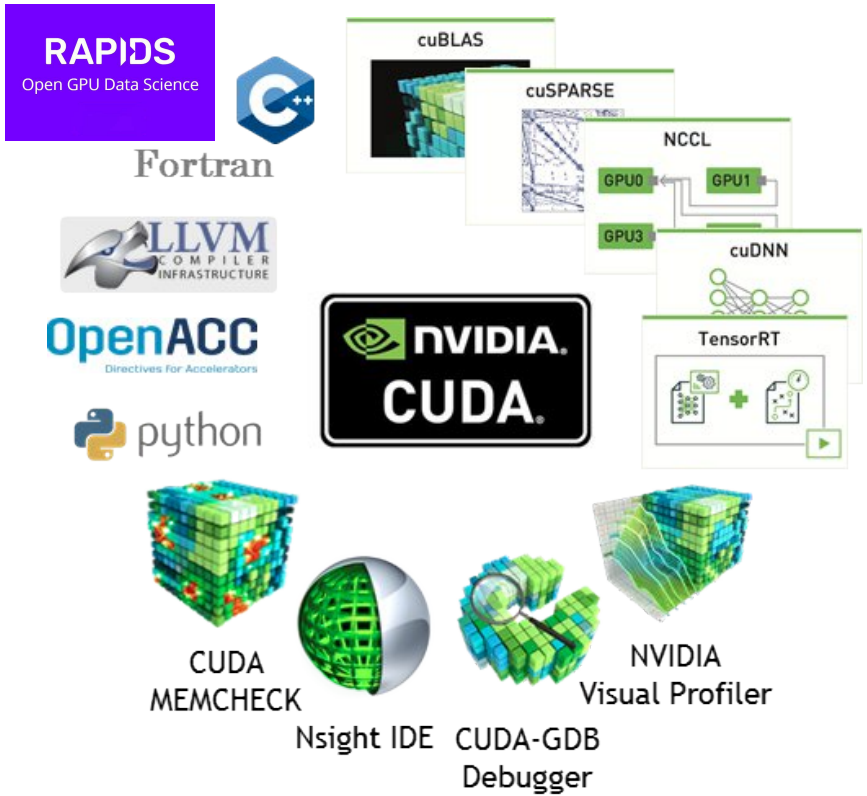


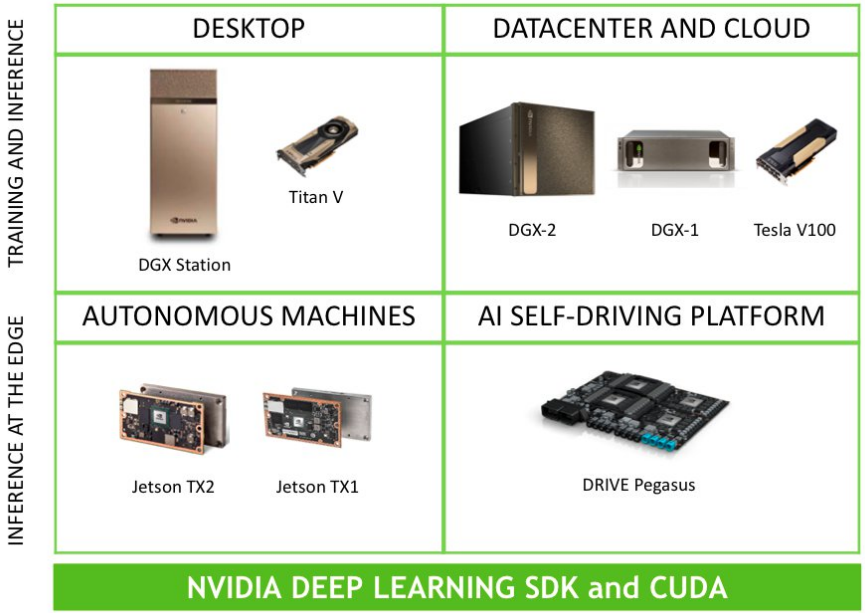
CNN



Matrix Multiply-accumulate operations

NVIDIA Galaxy



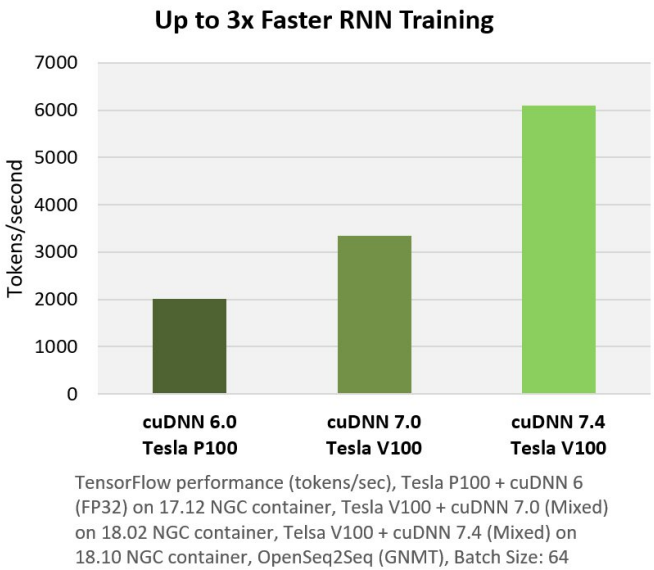


Source : NVidia

CuDNN

PyTorch

NVIDIA CUDA cuDNN



TensorFlow performance (tokens/sec), Tesla P100 + cuDNN 6 (FP32) on 17.12 NGC container, Tesla V100 + cuDNN 7.0 (Mixed) on 18.02 NGC container, Telsa V100 + cuDNN 7.4 (Mixed) on 18.10 NGC container, OpenSeq2Seq (GNMT), Batch Size: 64

Caffe Caffe2 Chainer Cognitive Toolkit MATLAB

mxnet PaddlePaddle PYTORCH TensorFlow ...

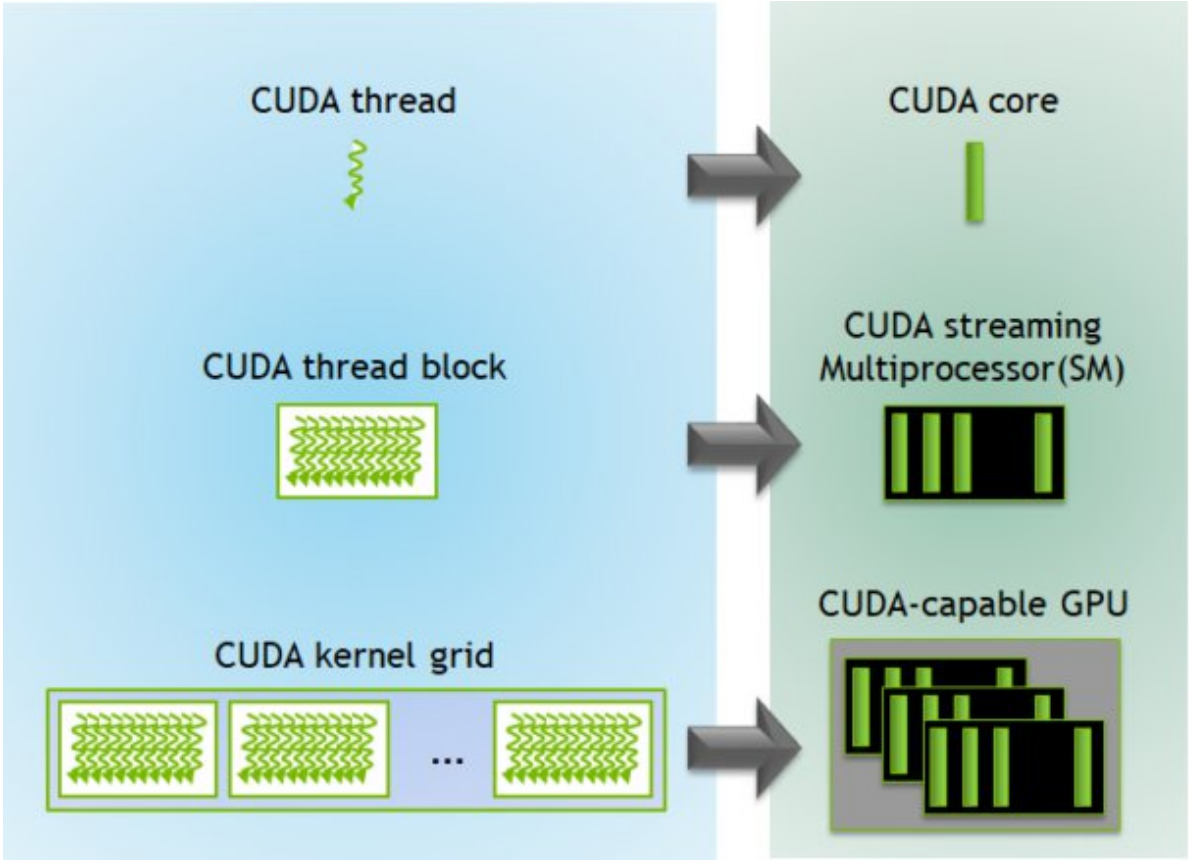
NVIDIA

NVIDIA DEEP LEARNING SDK and CUDA

CUDA engineering for deep learning on GPU is handled by cuDNN.
Thanks cuDNN!!

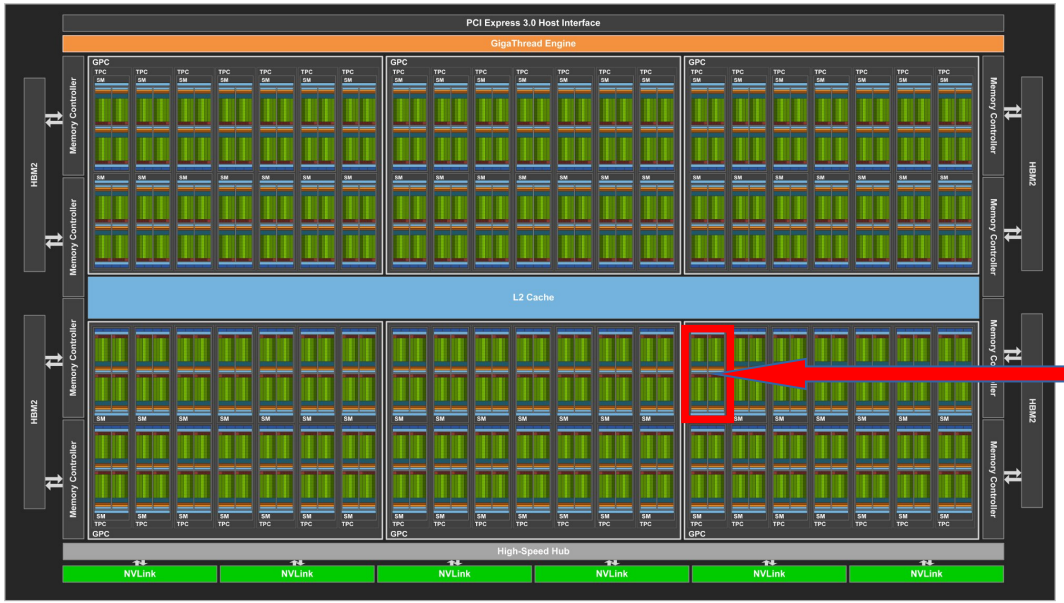
Recommendation: to optimize the use of Tensor Cores and Cuda Cores: Use tensors with dimensions (batch size, sample size, channel, layer dimension, etc.) **multiples of 8**!!

GPU computing : CUDA



Source : NVidia

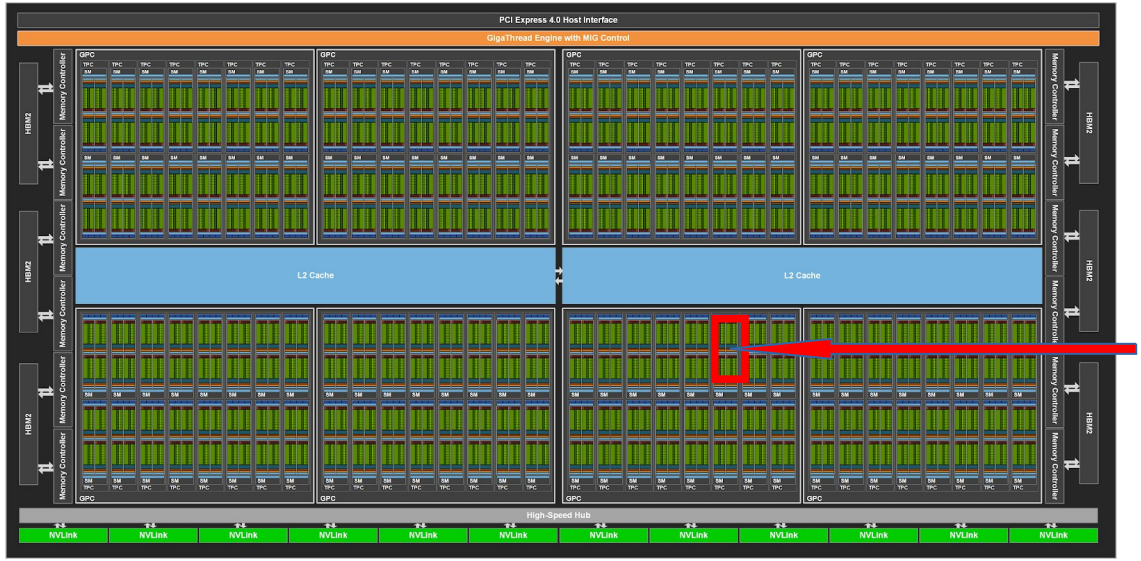
V100 Architecture



- 6 GPC
- **84** Streaming Multiprocessors (SMs)
- 5376 CUDA Cores
- **672 2eGen** Tensor Cores per full GPU

Source : NVidia

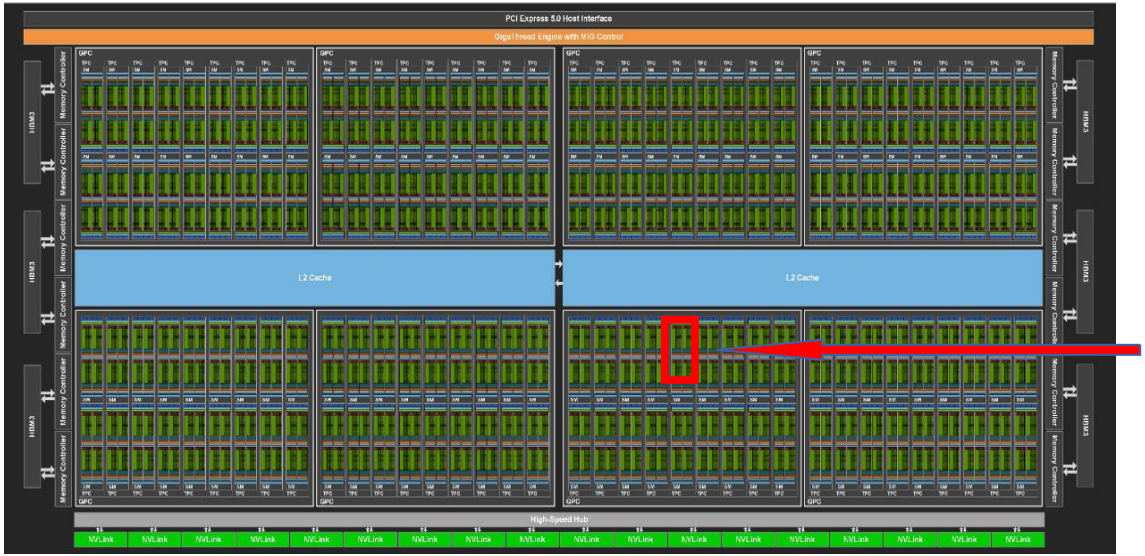
A100 Architecture



- 8 GPC
- **128** Streaming Multiprocessors (SMs)
- 8192 CUDA Cores
- **512 3eGen** Tensor Cores per full GPU

Source : NVidia

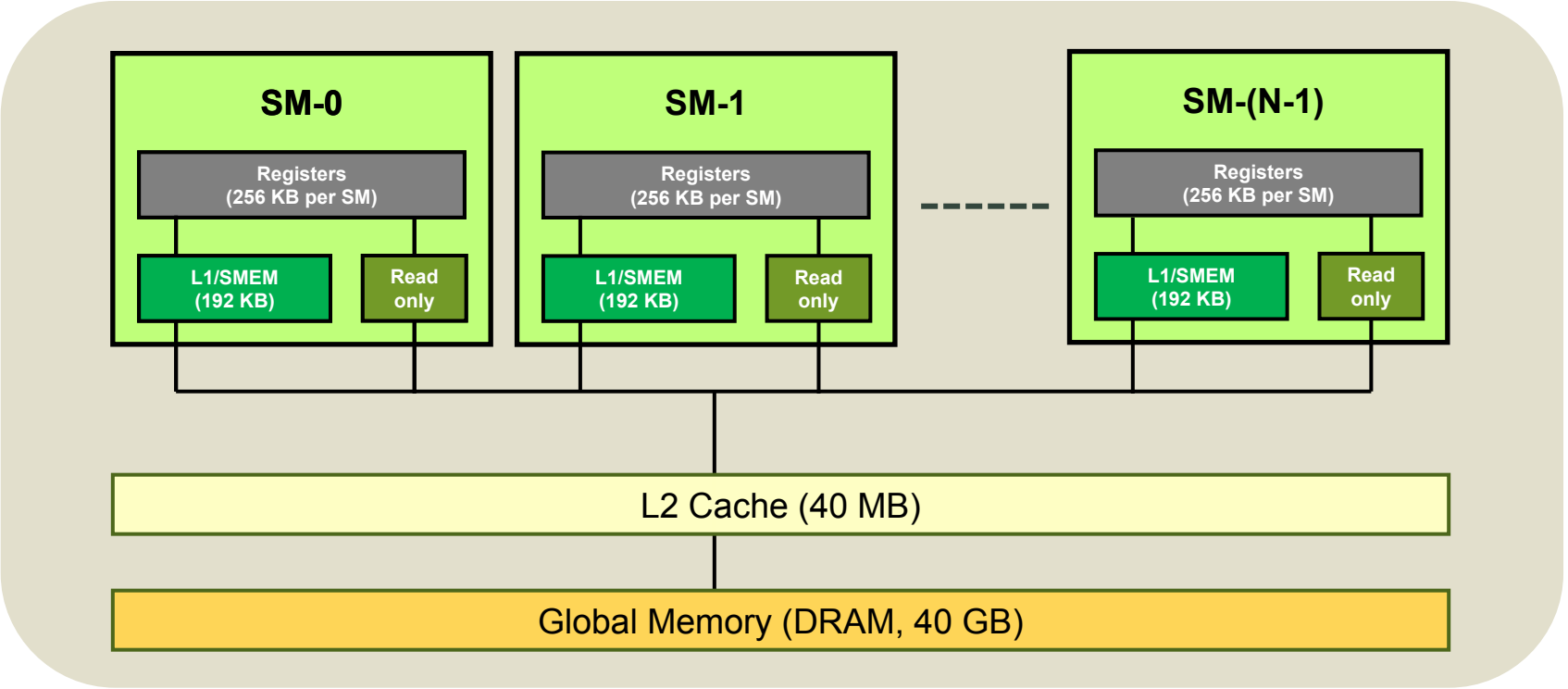
H100 Architecture



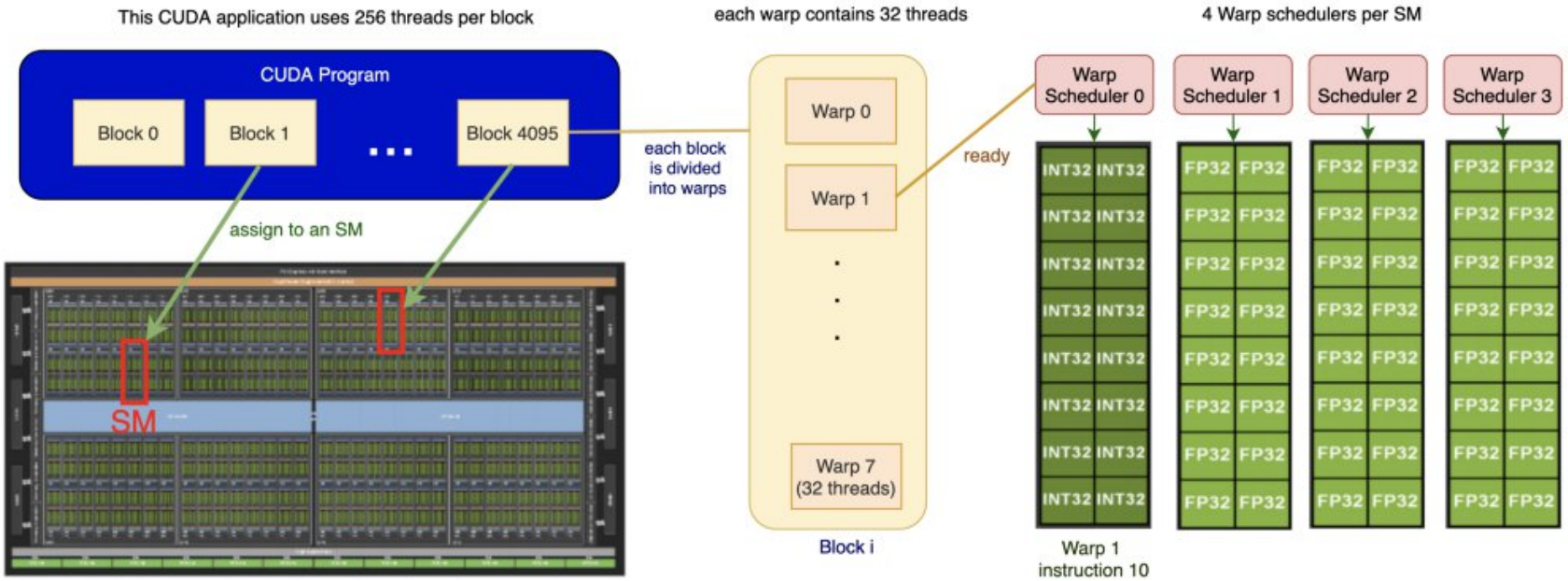
- 8 GPC
- **132** Streaming Multiprocessors (SMs)
- 16896 CUDA Cores
- **528 4eGen** Tensor Cores per full GPU

Source : NVidia

Optimized memory management



CUDA Engineering



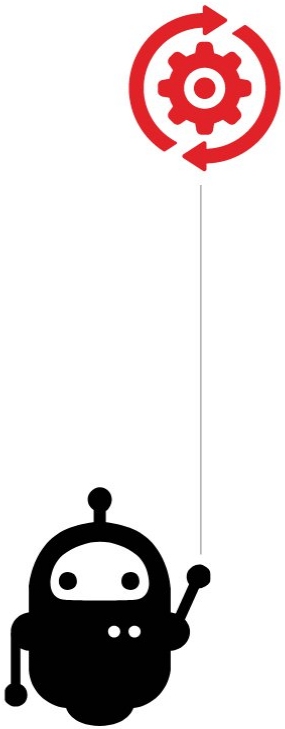
Optimzation :

- Block occupancy
- Streaming dispersion

Advanced Optimization :

- Kernel Fusion to override initialization times

TP1 : Accélération GPU



- Envoyer le calcul sur le GPU
- Test Mémoire

Tensor Cores

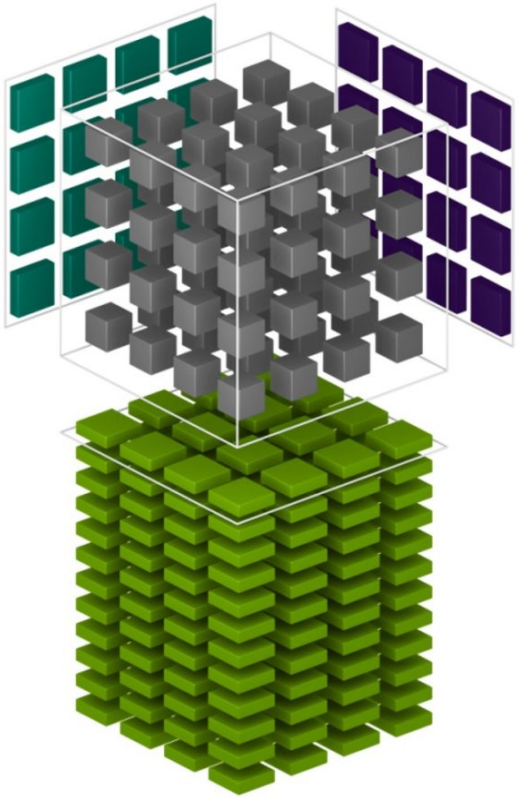
Tensor Cores ◂

Precisions ◂

AMP ◂

Channel last memory format ◂

Tensor Cores



CUDA Core are specialized for **vector computing**.

Tensor Cores are specialized for **matrix calculation**.

$$D = \begin{pmatrix} A_{0,0} & A_{0,1} & A_{0,2} & A_{0,3} \\ A_{1,0} & A_{1,1} & A_{1,2} & A_{1,3} \\ A_{2,0} & A_{2,1} & A_{2,2} & A_{2,3} \\ A_{3,0} & A_{3,1} & A_{3,2} & A_{3,3} \end{pmatrix} \begin{pmatrix} B_{0,0} & B_{0,1} & B_{0,2} & B_{0,3} \\ B_{1,0} & B_{1,1} & B_{1,2} & B_{1,3} \\ B_{2,0} & B_{2,1} & B_{2,2} & B_{2,3} \\ B_{3,0} & B_{3,1} & B_{3,2} & B_{3,3} \end{pmatrix} + \begin{pmatrix} C_{0,0} & C_{0,1} & C_{0,2} & C_{0,3} \\ C_{1,0} & C_{1,1} & C_{1,2} & C_{1,3} \\ C_{2,0} & C_{2,1} & C_{2,2} & C_{2,3} \\ C_{3,0} & C_{3,1} & C_{3,2} & C_{3,3} \end{pmatrix}$$

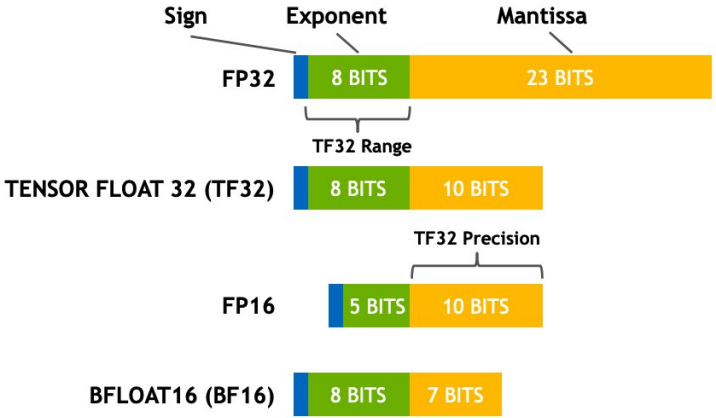
FP16 or FP32 FP16 FP16 FP16 or FP32

Each Tensor Core is capable of processing 64 operations in 1 clock time.

Source : NVidia

Precisions & Tensor Cores

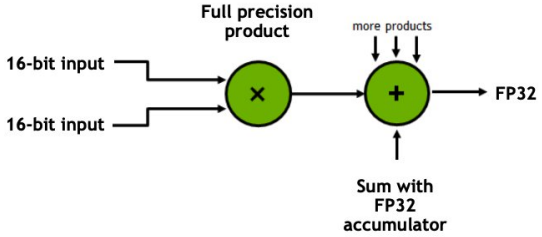
	NVIDIA H100	NVIDIA A100	NVIDIA Volta
Supported Tensor Core Precisions	**FP8**, FP64, TF32, bfloat16, FP16, ...	FP64, TF32, bfloat16, FP16, INT8, INT4, INT1	FP16
Supported CUDA® Core Precisions	FP64, FP32, FP16, bfloat16, INT8	FP64, FP32, FP16, bfloat16, INT8	FP64, FP32, FP16, INT8

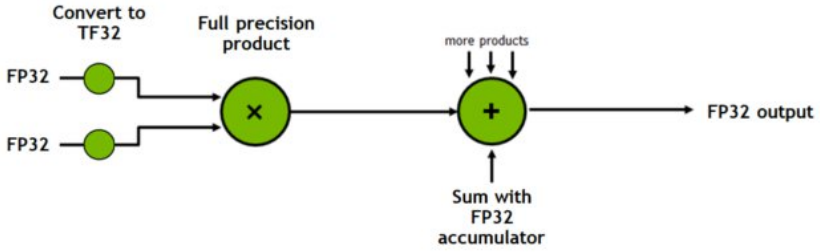


Source : NVidia

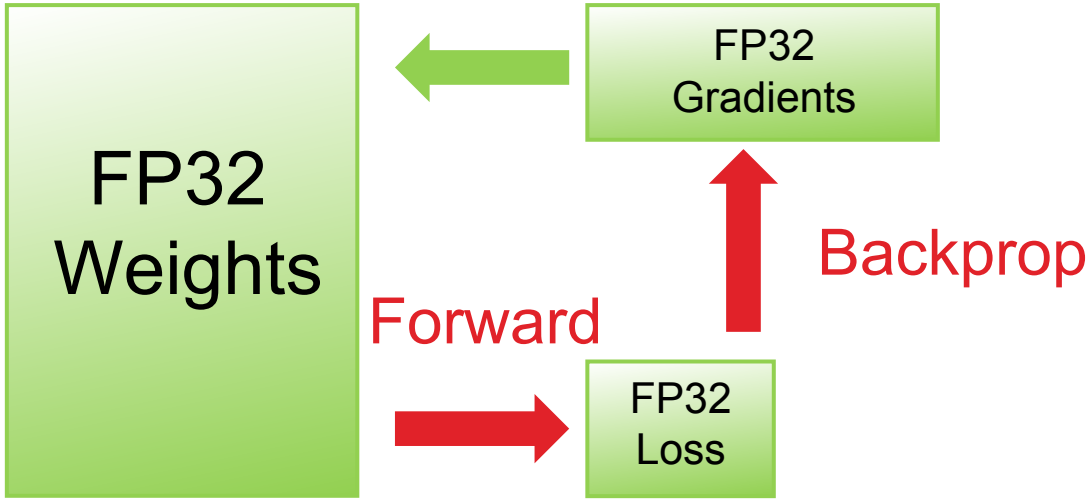
Precisions & Tensor Cores

	INPUT OPERANDS	ACCUMULATOR	TOPS	X-factor vs. FFMA	SPARSE TOPS	SPARSE X-factor vs. FFMA
V100	FP32	FP32	15.7	1x	-	-
	FP16	FP32	125	8x	-	-
A100	FP32	FP32	19.5	1x	-	-
	TF32	FP32	156	8x	312	16x
	FP16	FP32	312	16x	624	32x
	BF16	FP32	312	16x	624	32x
	FP16	FP16	312	16x	624	32x
	INT8	INT32	624	32x	1248	64x
	INT4	INT32	1248	64x	2496	128x
	BINARY	INT32	4992	256x	-	-
	IEEE FP64		19.5	1x	-	-



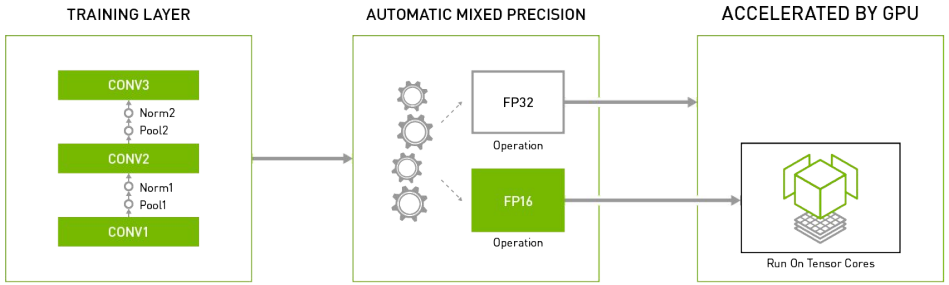


Normal Precision Training Loop

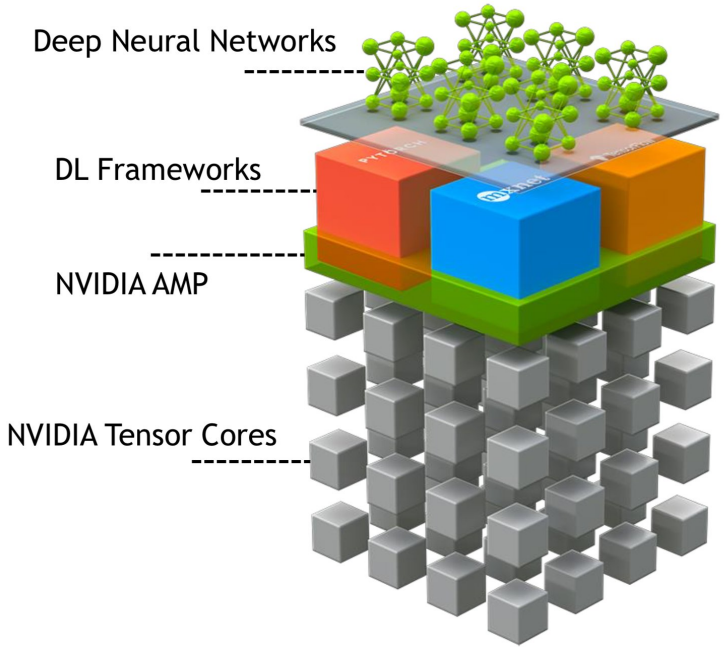


Automatic Mixed Precision

- Automatic Mixed Precision :
  - Necessary with V100 to use Tensor Core
  - The A100s use Tensor Cores with or without MP



- Pros:
  - **Insignificant** loss of precision for model training (gradient, loss, accuracy)
  - **Reduces memory** footprint
  - **Speeds up** calculations
- 2 steps to code :
  - Transforms eligible layers into FP16
  - Uses scaling to calculate gradients

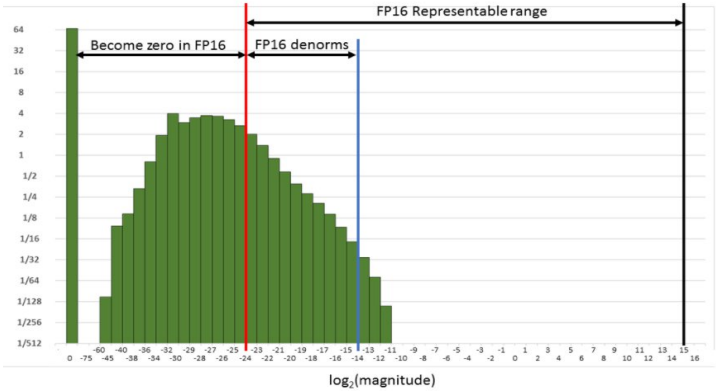


AMP FP16 with Scaler

FP16

In FP16, values lower than 2^{-24} ($5.96e^{-8}$) are considered 0.

Gradients Distribution



Optimizer

FP32 Master Weights

FP32 Gradients

Scaled FP32 Gradients

Scaled FP16 Gradients

FP16 Activations

Forward

FP16 Weights

FP32 Loss

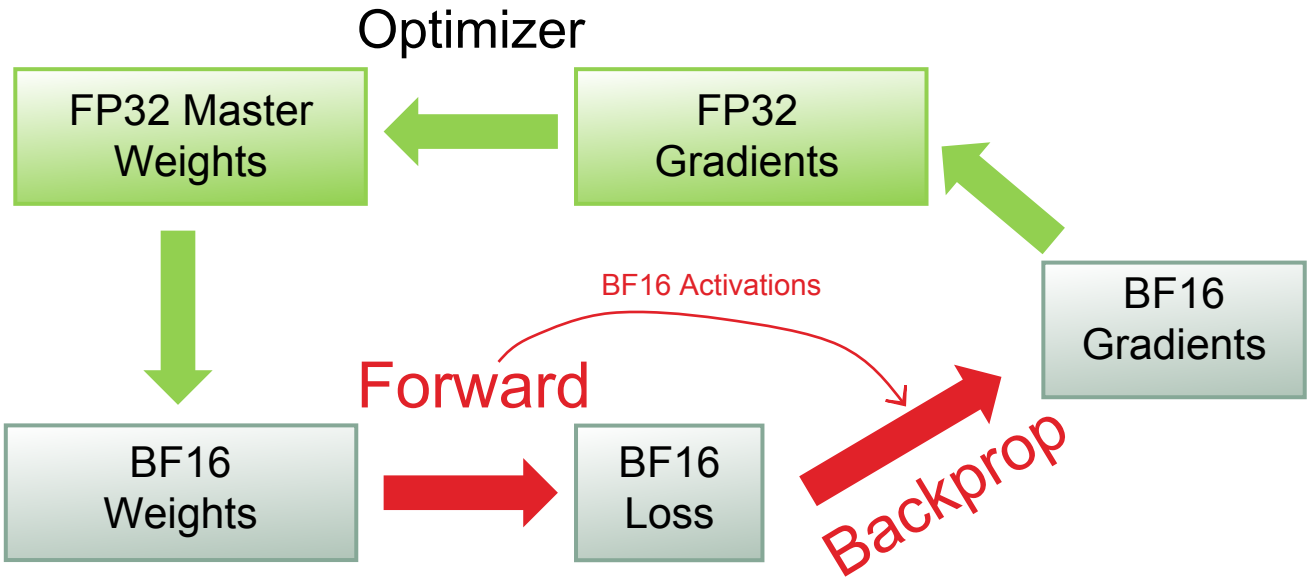
Scaled FP16 Loss

Backprop

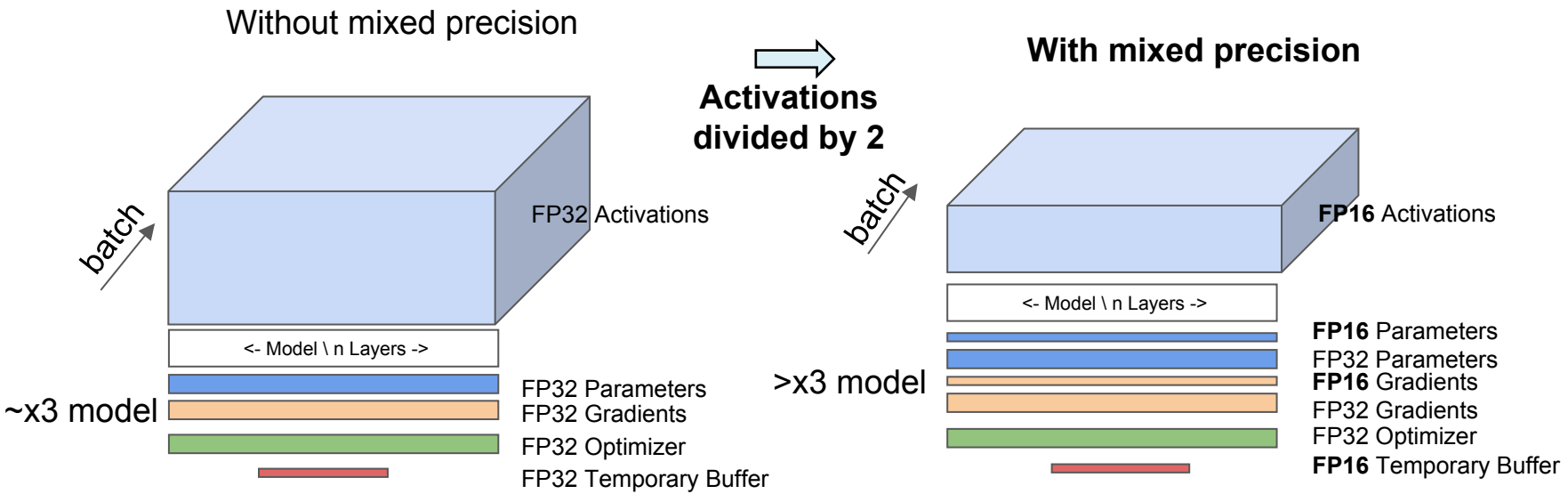
AMP BF16 without Scaler

BF16

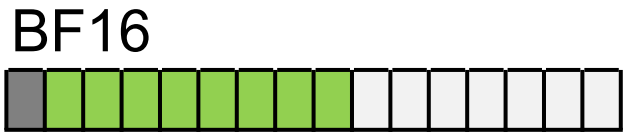
No Scaler !



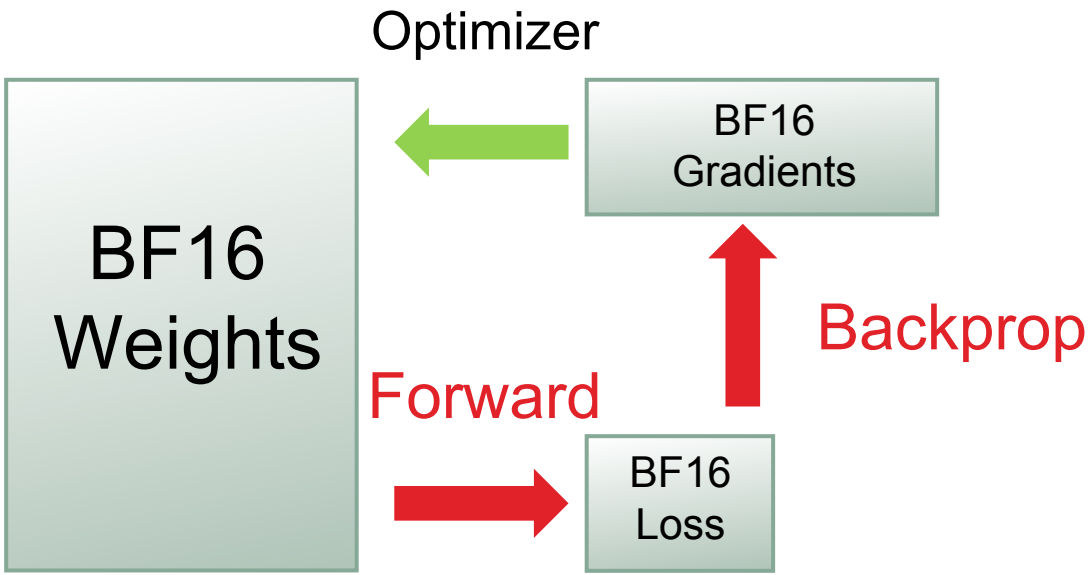
Memory Footprint with Mixed Precision



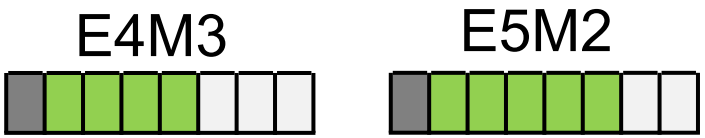
Full Degraded Precision (BF16)



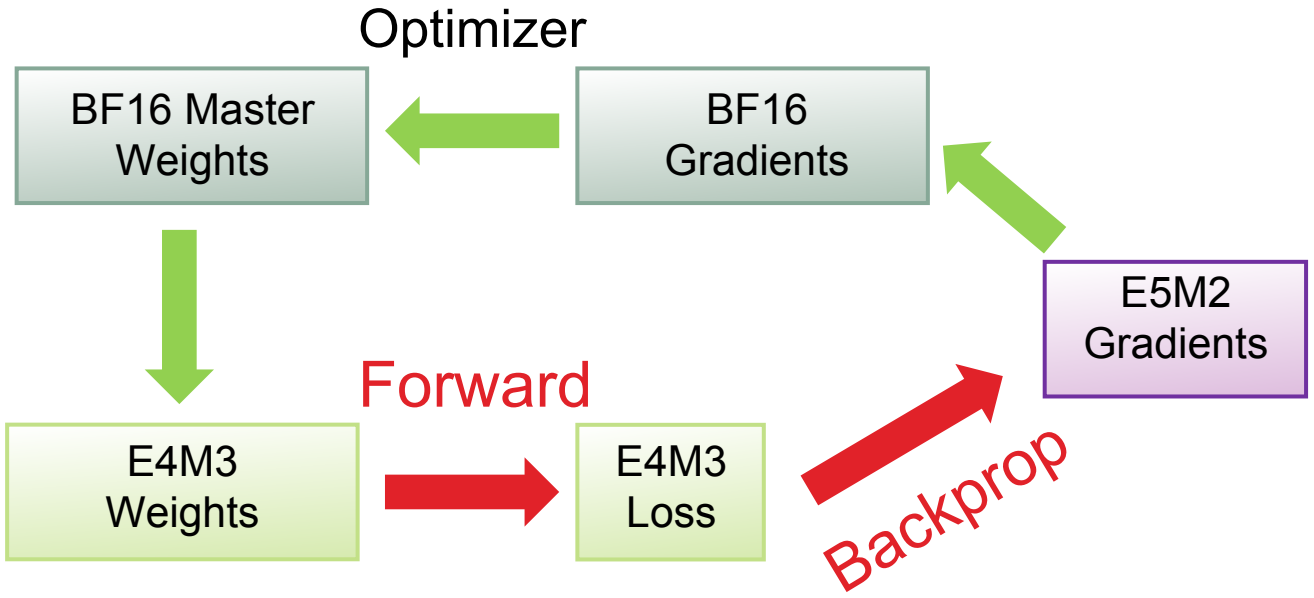
Modern Large Model Training Way !



FP8 Mixed Precision



Modern Large Model Training Way !



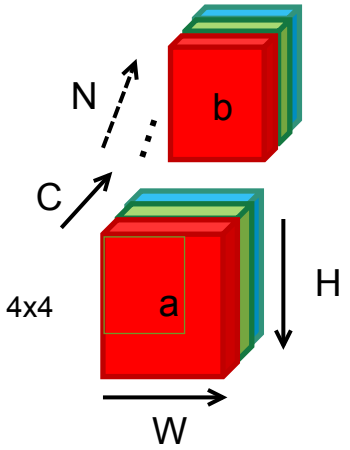
Channel last memory format

batch channel height width

NCHW

.shape()

memory contiguity by default



.stride()

classic (contiguous) memory storage of NCHW tensor :

b 0x: 0 1 2 3 4 5 6 7 8 9 a b c d e f 0 1 2 3 4 5 6 7 8 9 a b c d e f 0 1 2 3 4 5 6 7 8 9 a b c d e f

a 0x: 0 1 2 3 4 5 6 7 8 9 a b c d e f 0 1 2 3 4 5 6 7 8 9 a b c d e f 0 1 2 3 4 5 6 7 8 9 a b c d e f

Channels last memory format orders data differently:

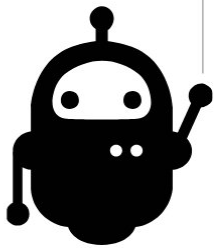
.stride()

b 0x: 0 0 0 1 1 1 2 2 2 3 3 3 4 4 4 5 5 5 6 6 6 7 7 7 8 8 8 9 9 9 a a a b b b c c c d d d e e e f f f

a 0x: 0 0 0 1 1 1 2 2 2 3 3 3 4 4 4 5 5 5 6 6 6 7 7 7 8 8 8 9 9 9 a a a b b b c c c d d d e e e f f f

3x3 Convolution filter

TP2&3 : Automatic Mixed Precision



- Activer l’Automatic Mixed Precision
- Test Mémoire
- Activer le channel last memory format