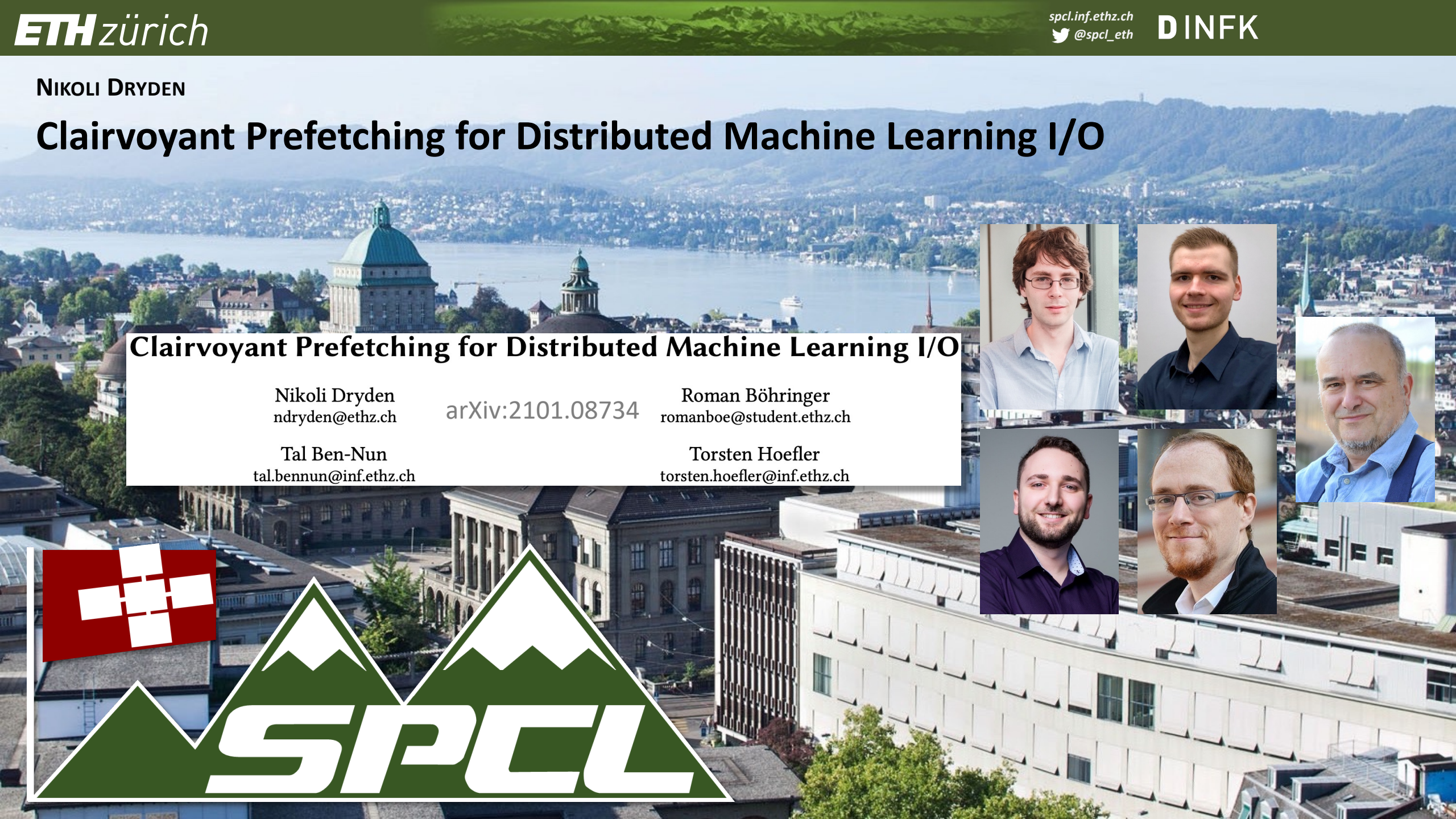
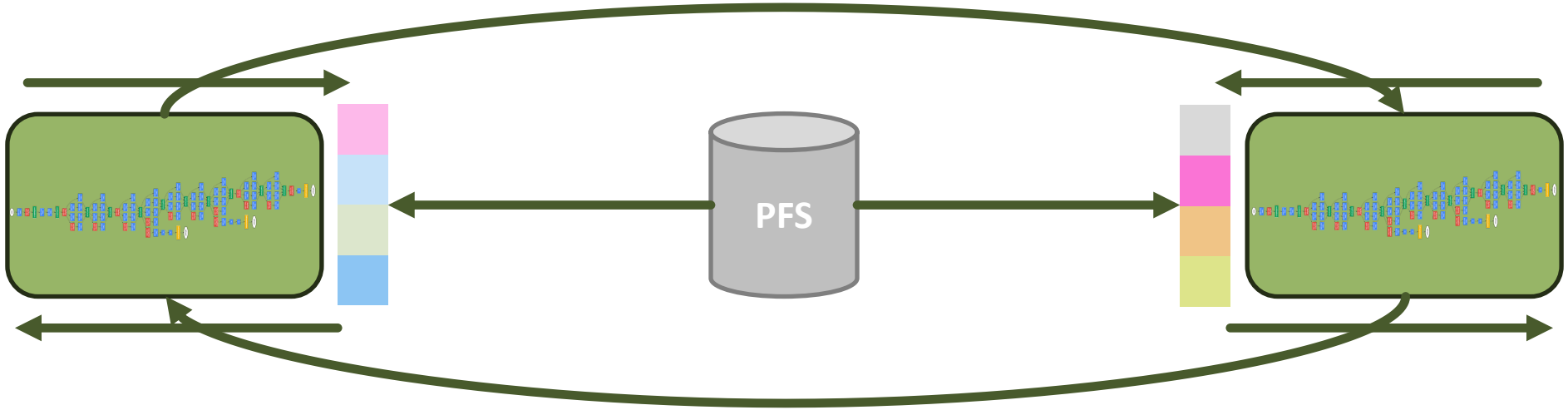
NIKOLI DRYDEN

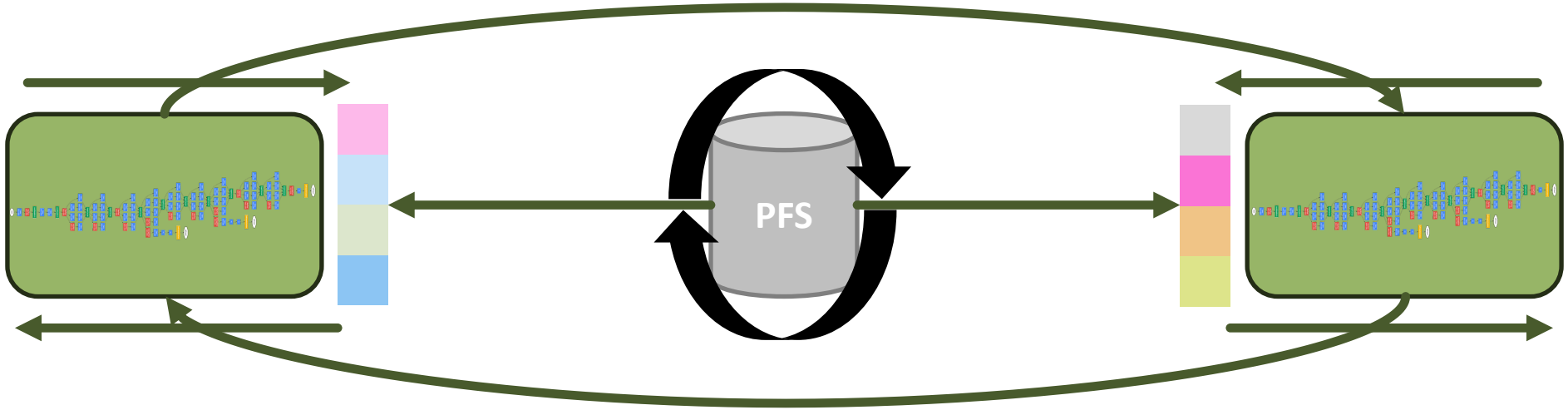
Clairvoyant Prefetching for Distributed Machine Learning I/O



High Performance Training



High Performance Training



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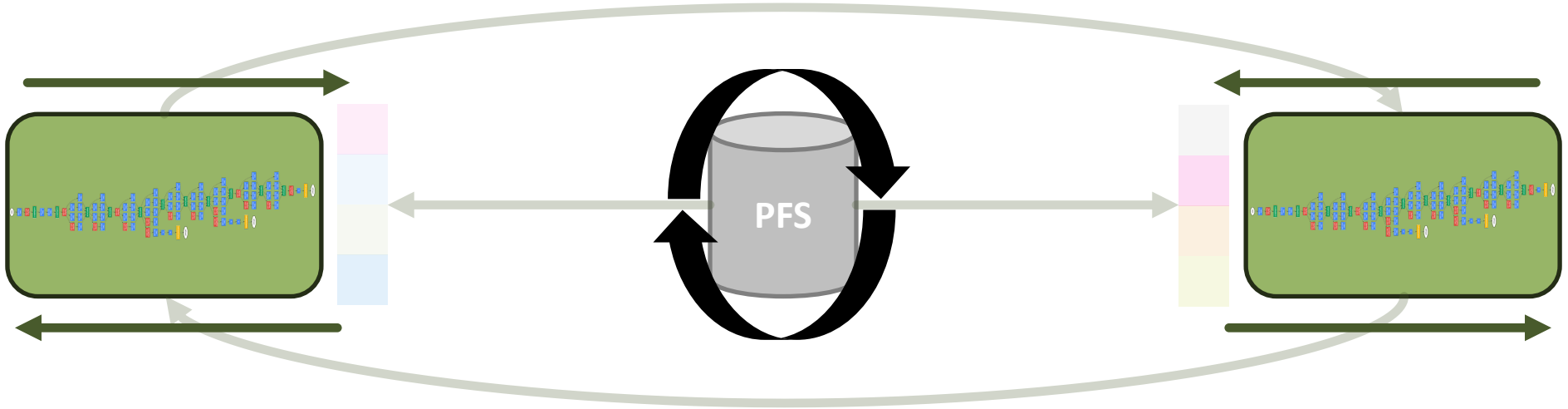
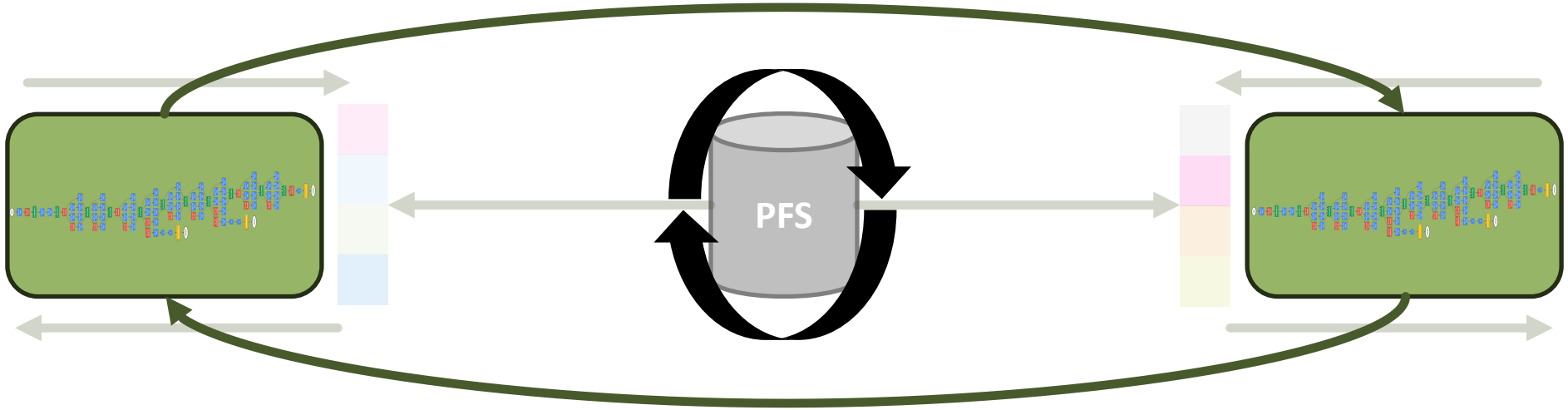


Compute 🙂

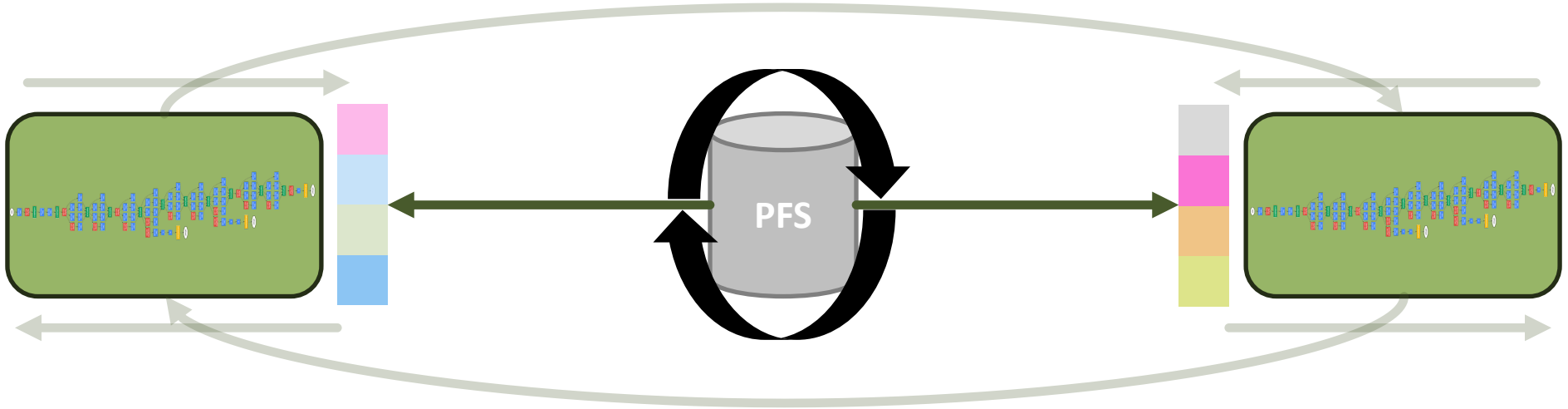
High Performance Training



Compute 🙂

Communication 🙂

High Performance Training

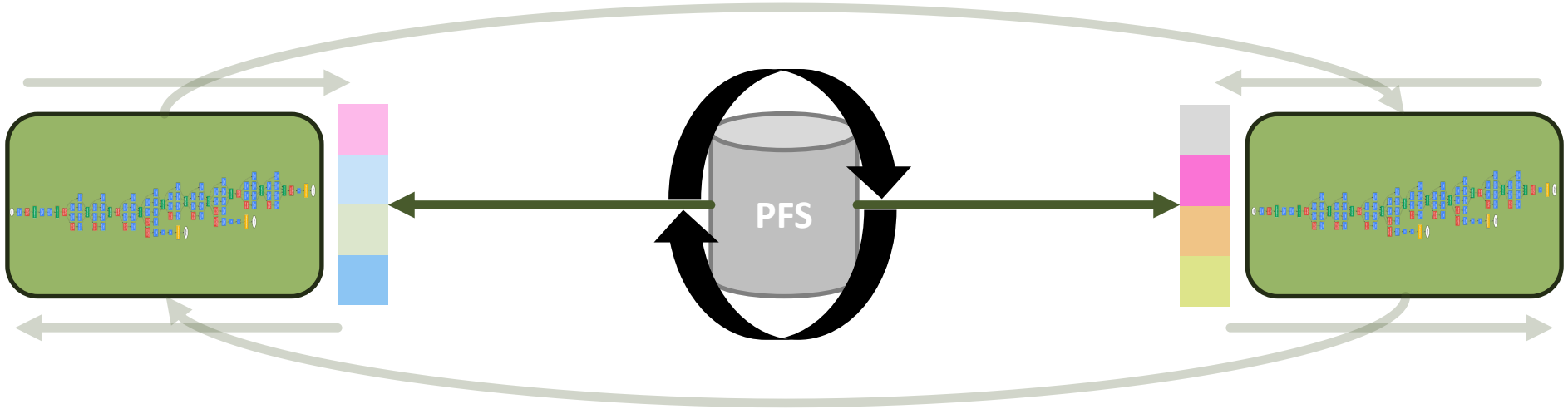


Compute 🙂

Communication 🙂

I/O 😞

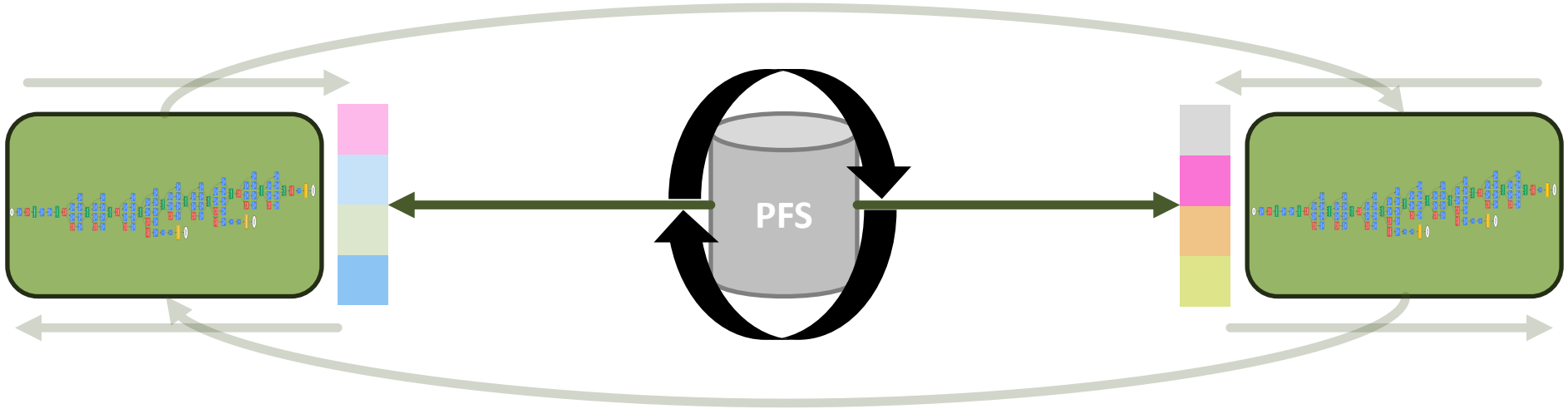
High Performance Training



Compute 🙂 | Communication 🙂 | I/O 😞

I/O overheads up to **85%**!

High Performance Training



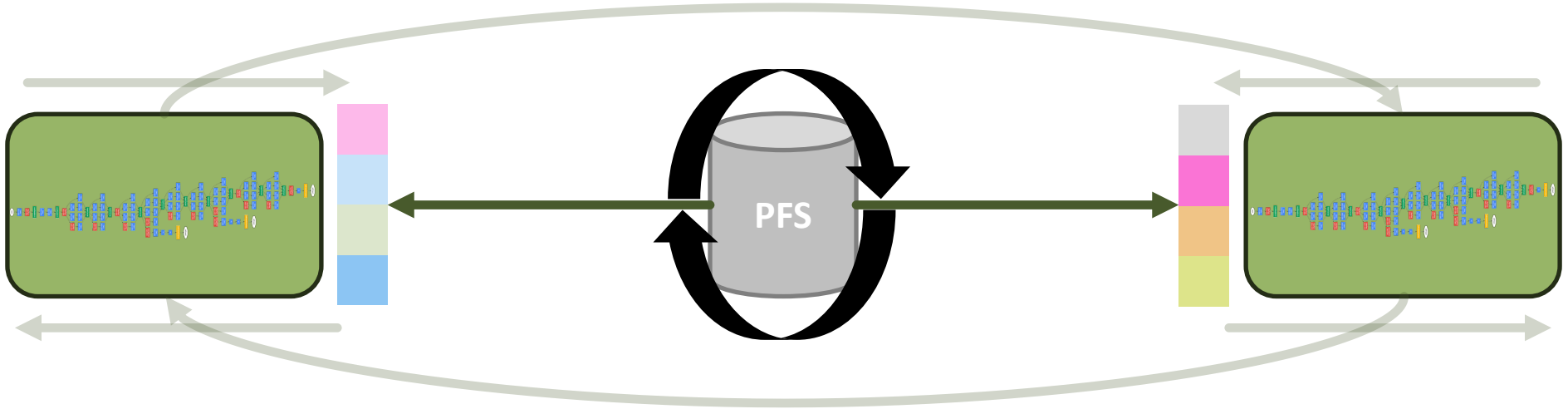
Compute 🙂 | **Communication** 🙂 | **I/O** 😞

I/O overheads up to **85%**!

Example: ResNet-50 on ImageNet-1k

- ImageNet-1k: ~150 GiB, ~1.3M images (average: 115 KiB, range: 508 B – 15 MiB)
- MLPerf on one A100: ~2.9K samples/s ➔ ~333 MiB/s random access
- ➔ **2 SSDs / GPU**
- *2-4x for scientific problems like CosmoFlow*

High Performance Training



Compute 🙂

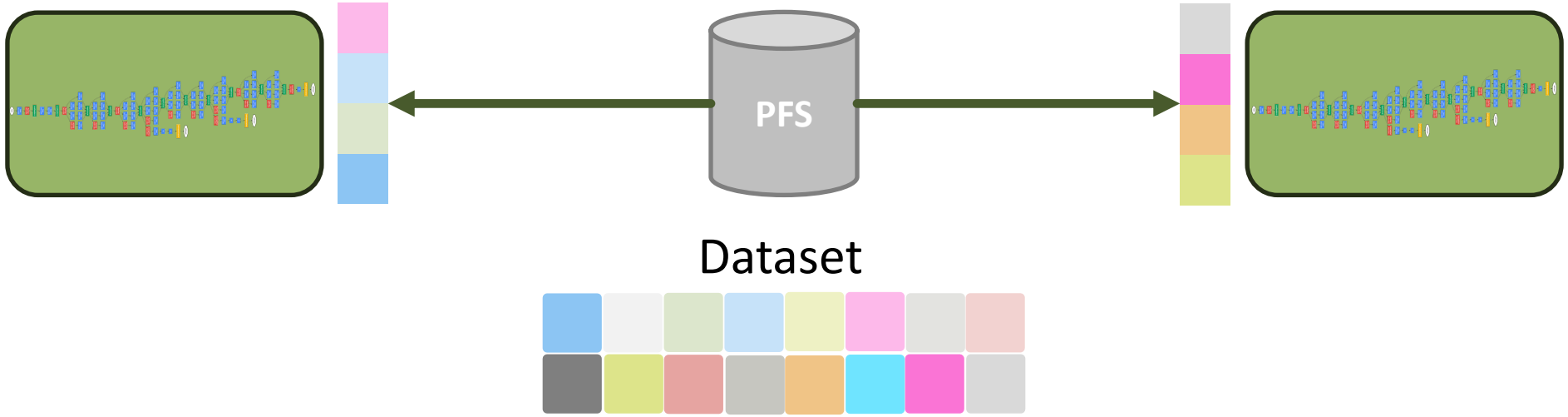
Communication 🙂

I/O 🙂

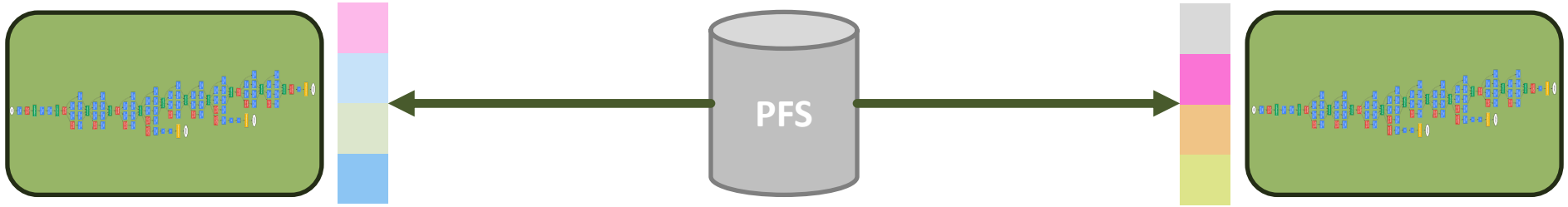
NoPFS: Near-optimal Pre-Fetching System

Up to **5.4x** end-to-end training improvements!

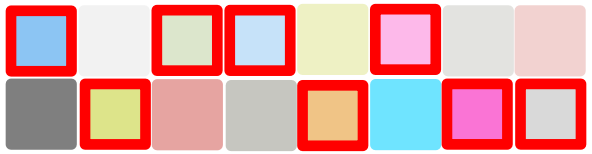
I/O for Machine Learning



I/O for Machine Learning

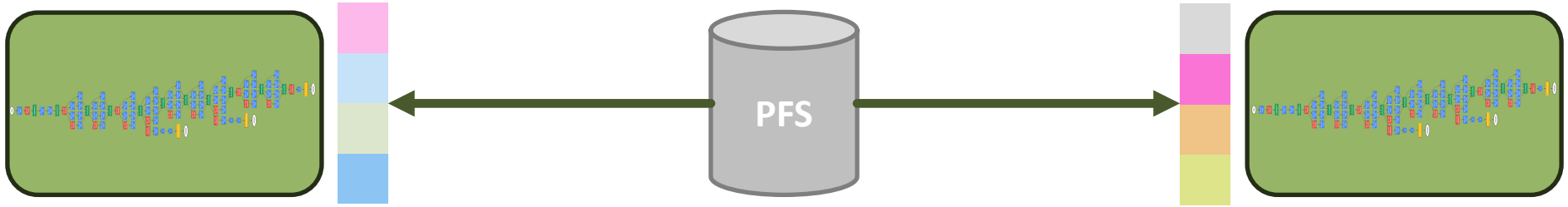


Dataset

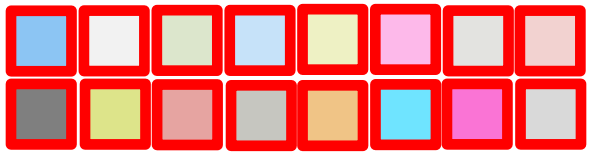


Randomly sample mini-batch

I/O for Machine Learning



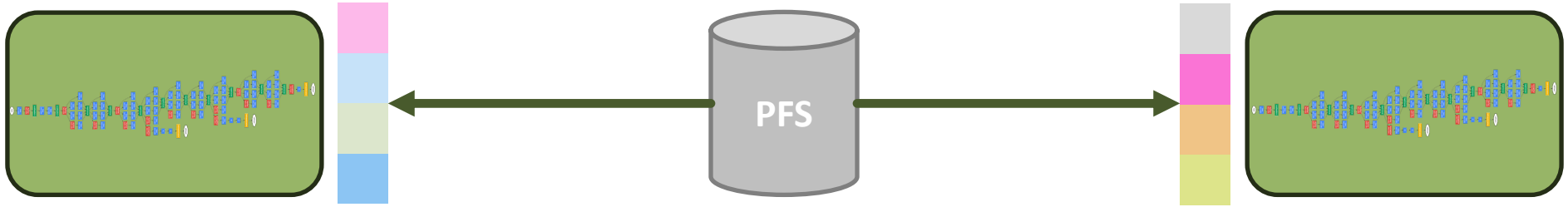
Dataset



Randomly sample mini-batch

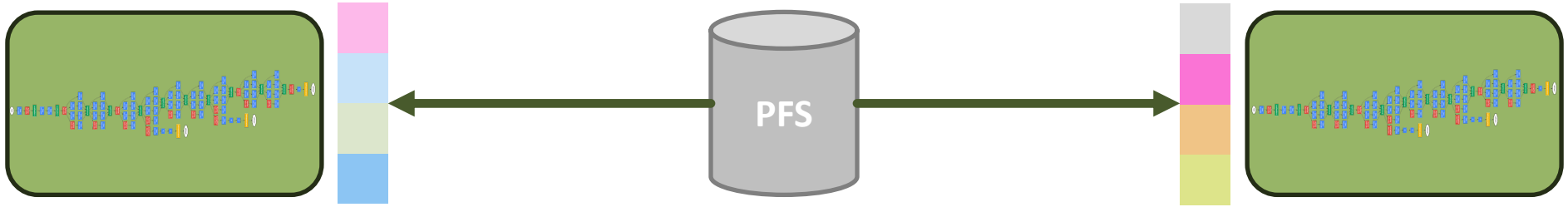
➔ Epoch

I/O for Machine Learning



What makes a good I/O framework?

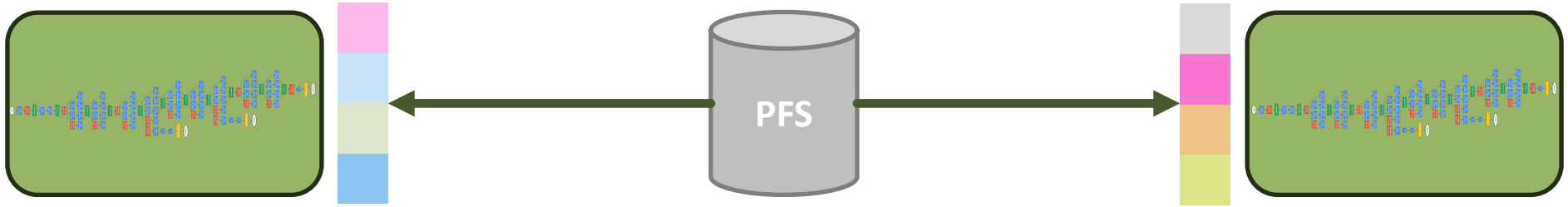
I/O for Machine Learning



What makes a good I/O framework?

System Scalability

I/O for Machine Learning



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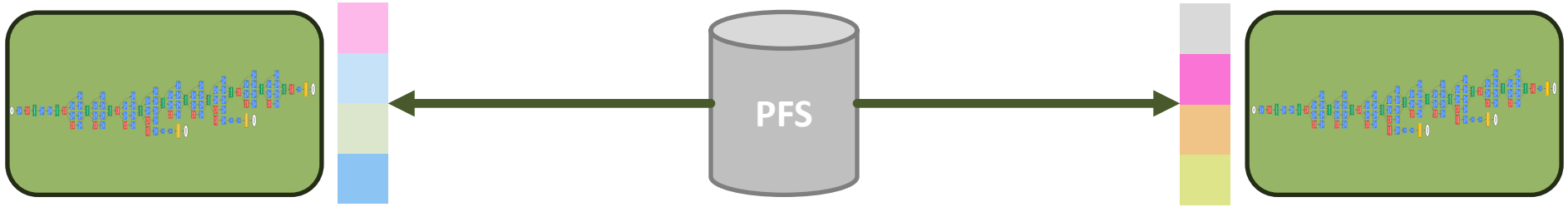

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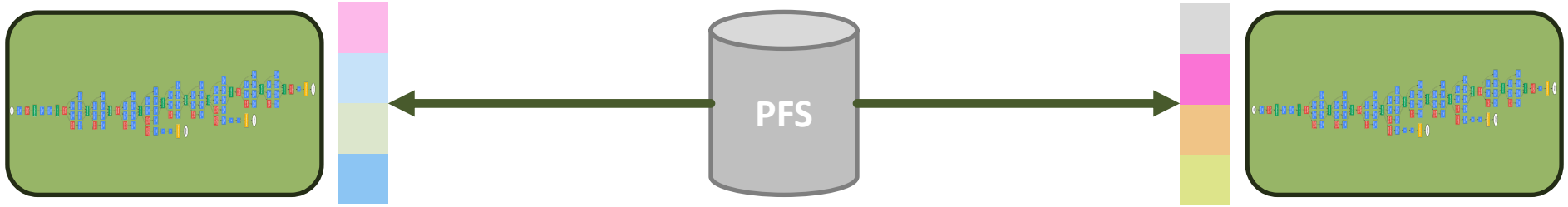
Full Randomization

I/O for Machine Learning



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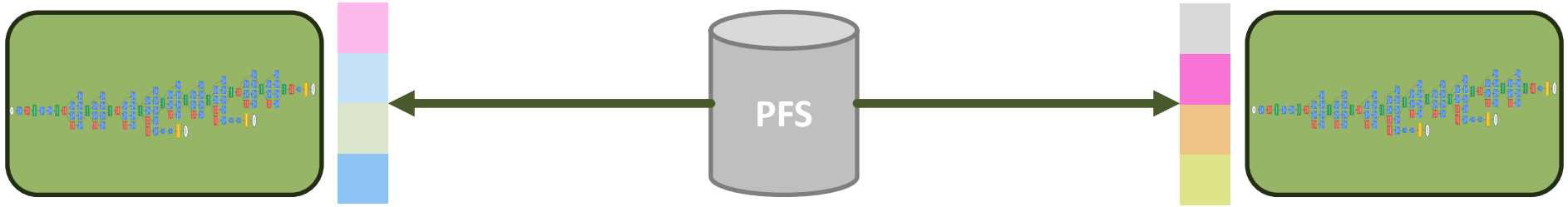
Full Randomization

Hardware Independence

I/O for Machine Learning



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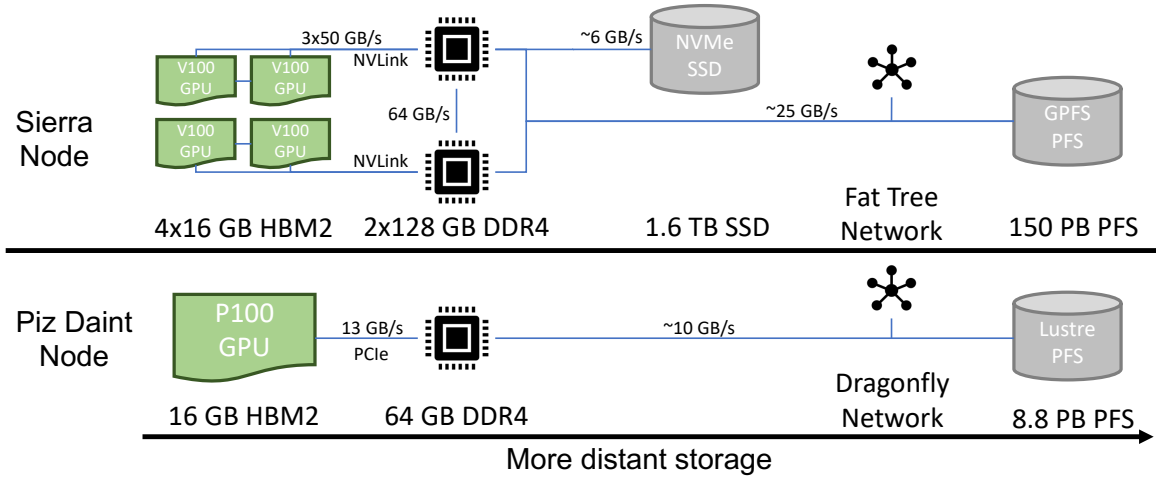

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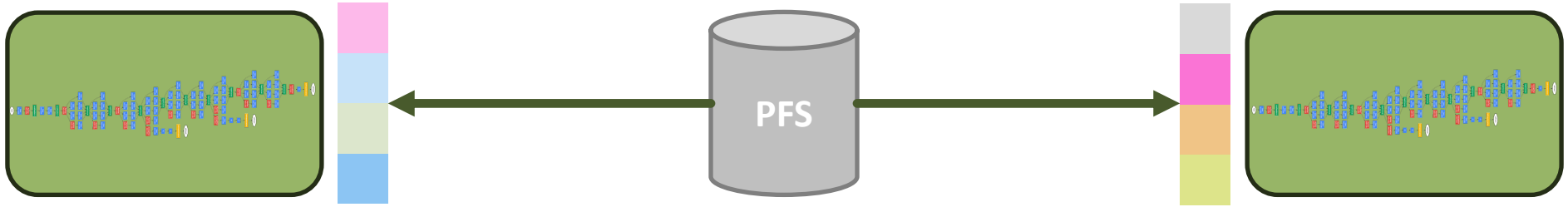

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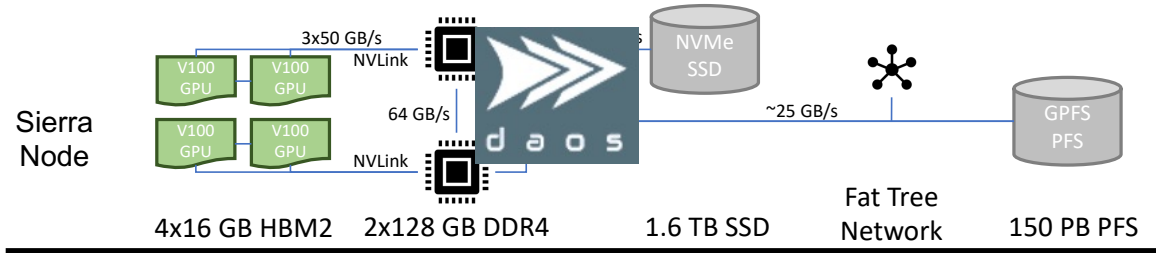
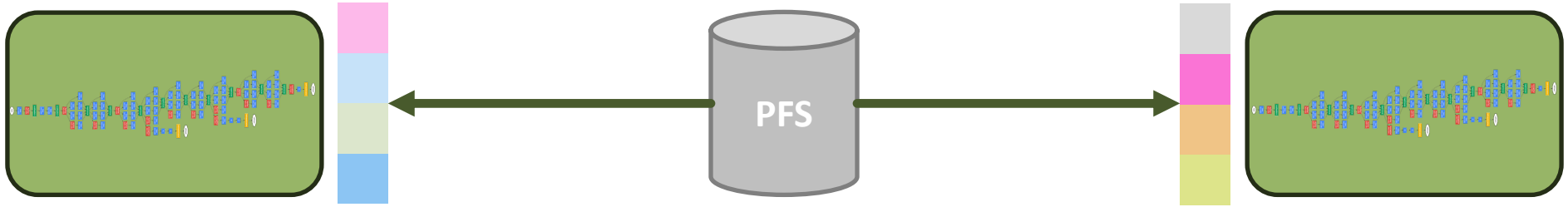


I/O for Machine Learning



What makes a good I/O framework?

System Scalability

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Full Randomization

Hardware Independence

Ease of Use

```
dataset = ImageFolder(data_dir, data_transforms)
dsampler = DistributedSampler(dataset, num_replicas=n, rank=rank)
dataloader = DataLoader(dataset, batch_size, sampler=dsampler)
```

Clairvoyant I/O

"Randomly sample mini-batch"

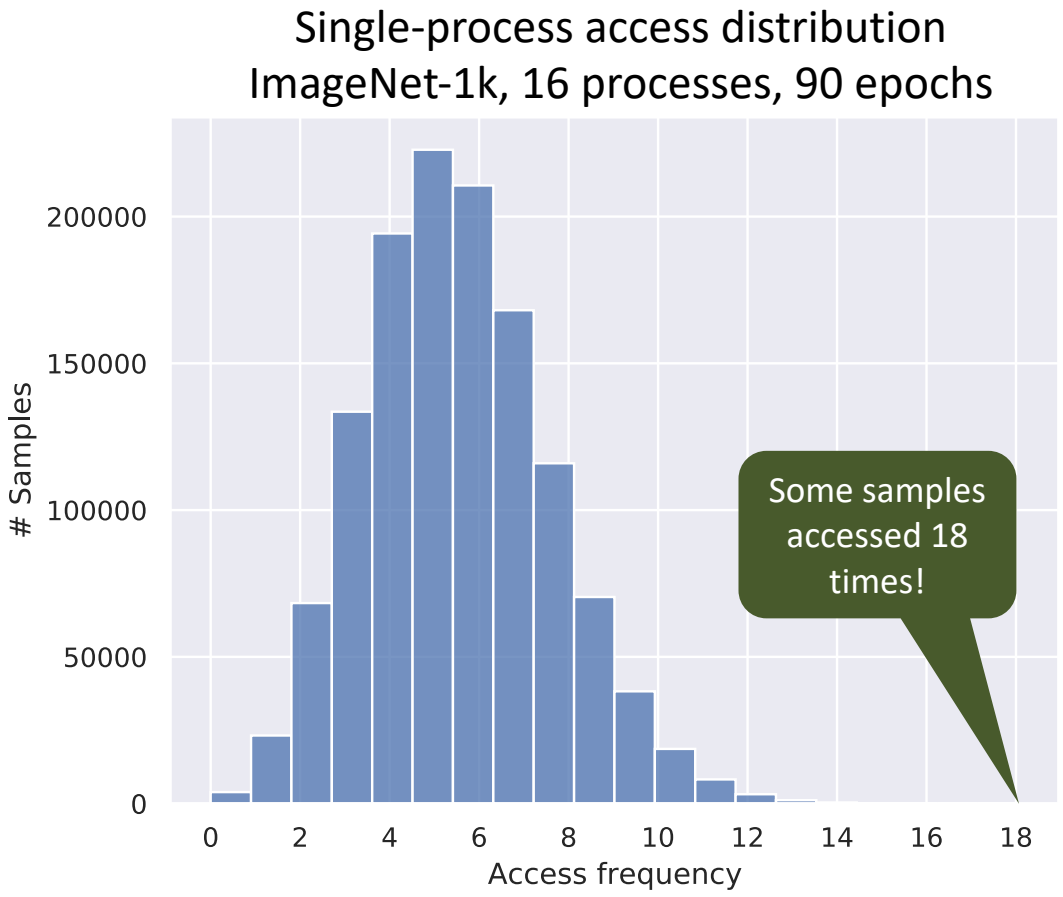
By "random", we really mean pseudorandomly with a known seed!

We know the *exact* access pattern of *every* worker

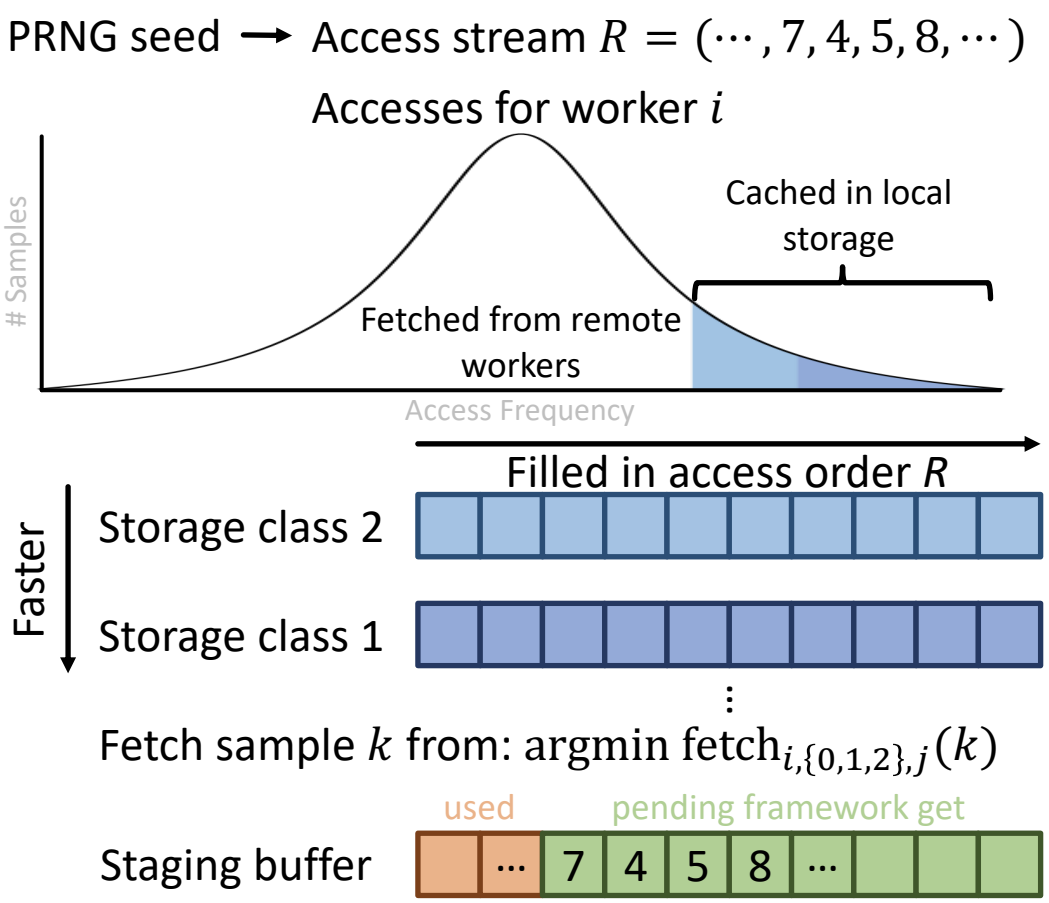
We can exploit clairvoyance to optimize (distributed) I/O

NoPFS is a hierarchical, distributed cache and prefetcher **that knows the future**

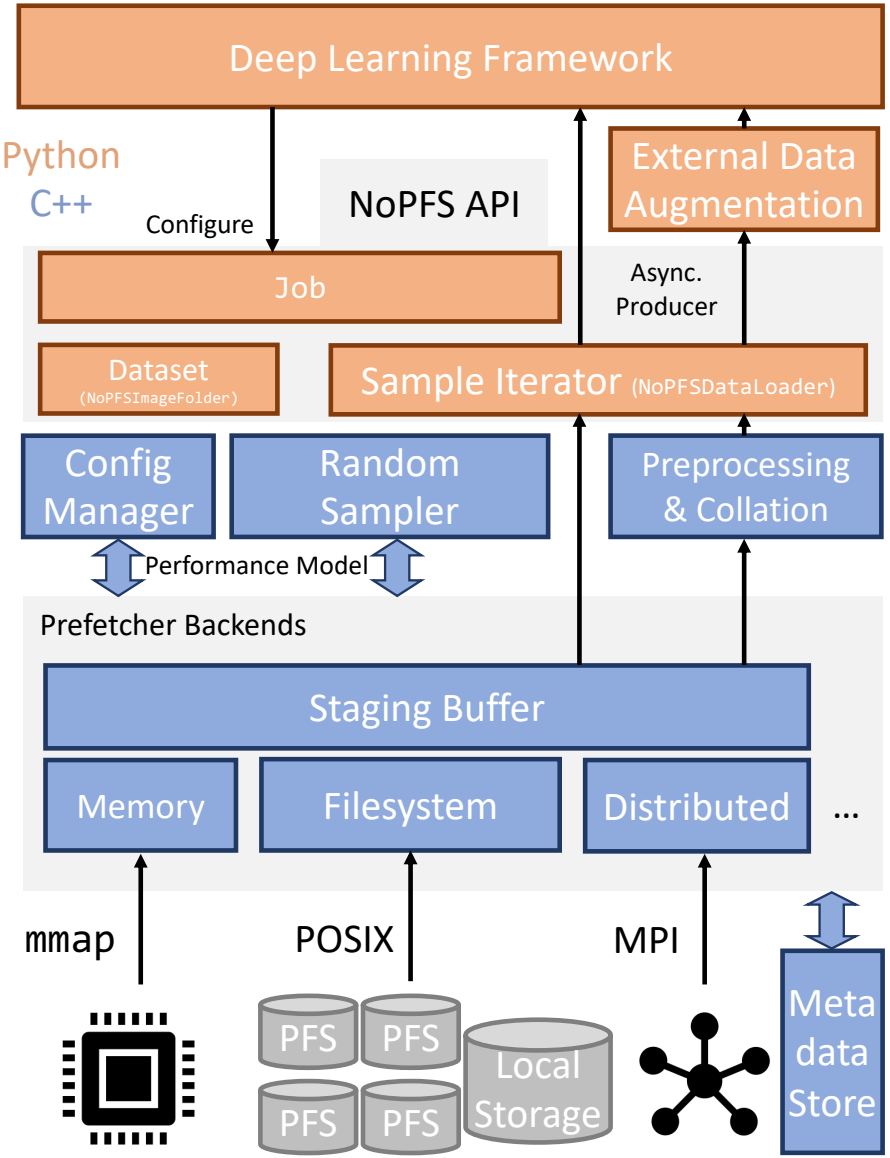
Clairvoyant 🔮 Prefetching and Caching



LEMMA 1. *If a worker accesses a sample* $\lceil (1+\delta)\frac{E}{N} \rceil$ *times (resp.* $\lfloor (1-\delta)\frac{E}{N} \rfloor$ *times), at least one other worker will access the sample at most* $\lceil (\frac{N-1-\delta}{N-1})\frac{E}{N} \rceil$ *(resp. at least* $\lfloor (\frac{N-1+\delta}{N-1})\frac{E}{N} \rfloor$*) times.*



NoPFS



Loading ImageNet:

PyTorch:

```
dataset = ImageFolder(data_dir, data_transforms)
dsampler = DistributedSampler(dataset, num_replicas=n, rank=rank)
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```
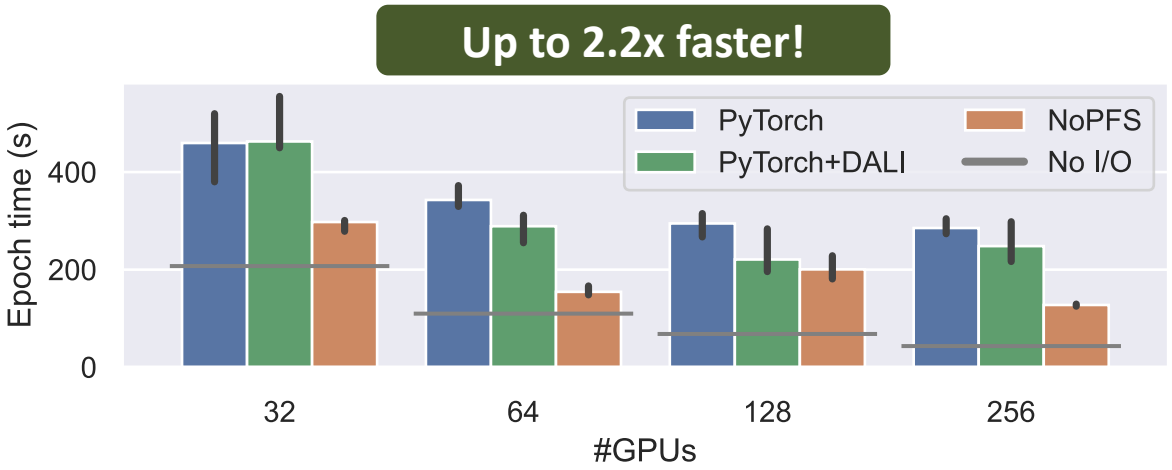
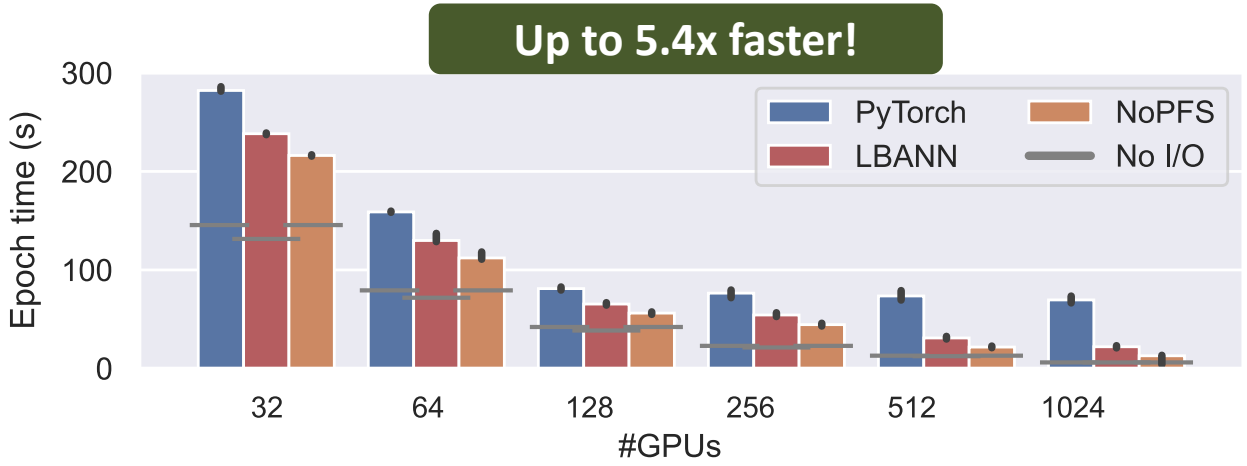

NoPFS:

```
job = Job(data_dir, batch_size, num_epochs, 'uniform', drop_last)
dataset = NoPFSImageFolder(data_dir, job, data_transforms)
dataloader = NoPFSDataLoader(dataset)
```

Performance

Runtime per epoch

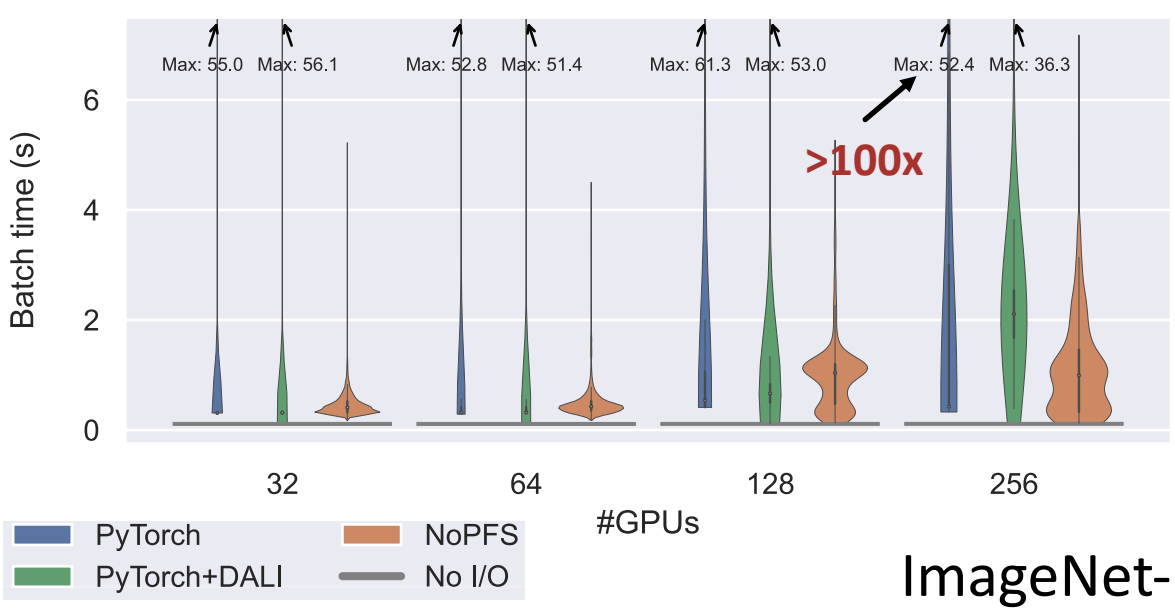


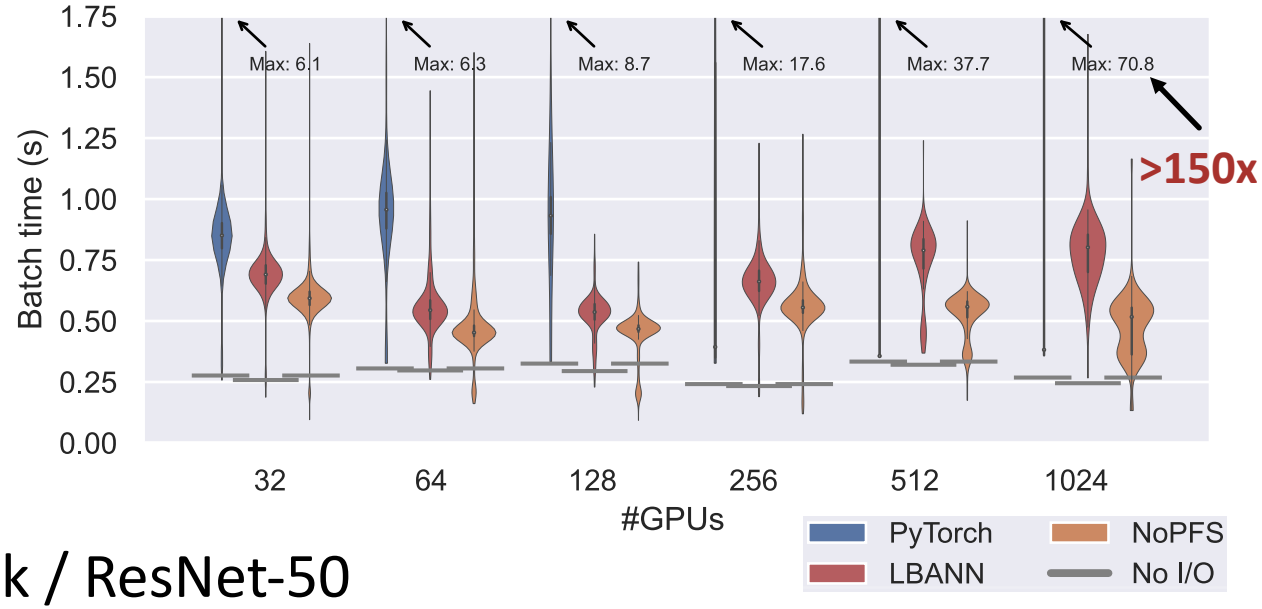


ImageNet-1k / ResNet-50

Performance

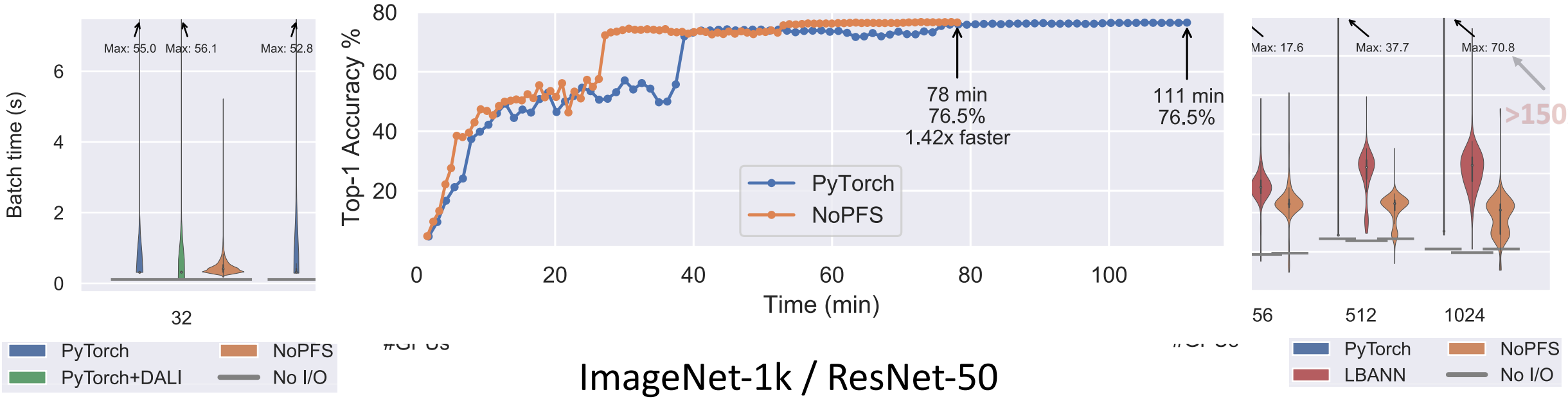
Runtime per batch





ImageNet-1k / ResNet-50

Performance



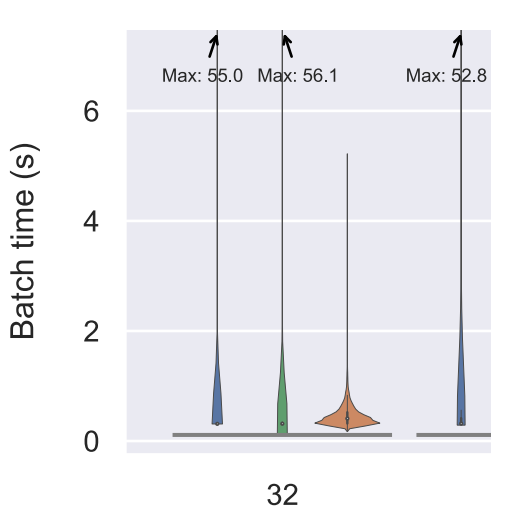
ImageNet-1k / ResNet-50

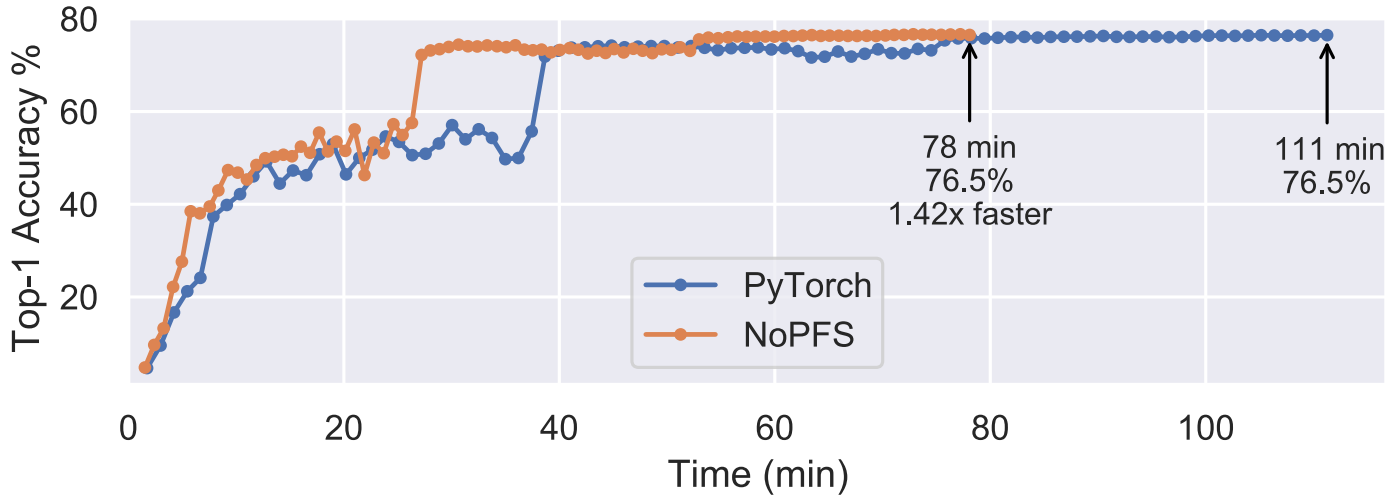
Performance

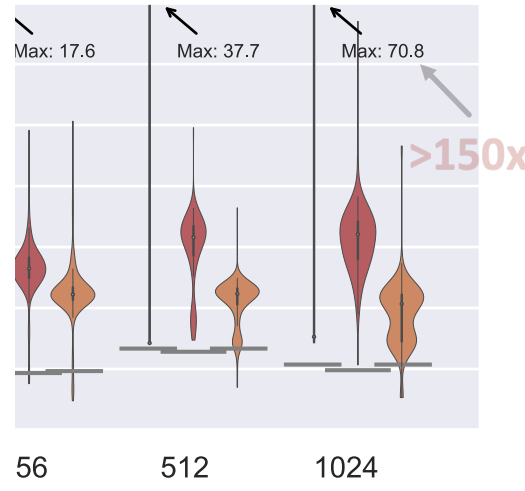
Piz Daint

Lassen

NoPFS improves performance and reduces noise across systems and scales



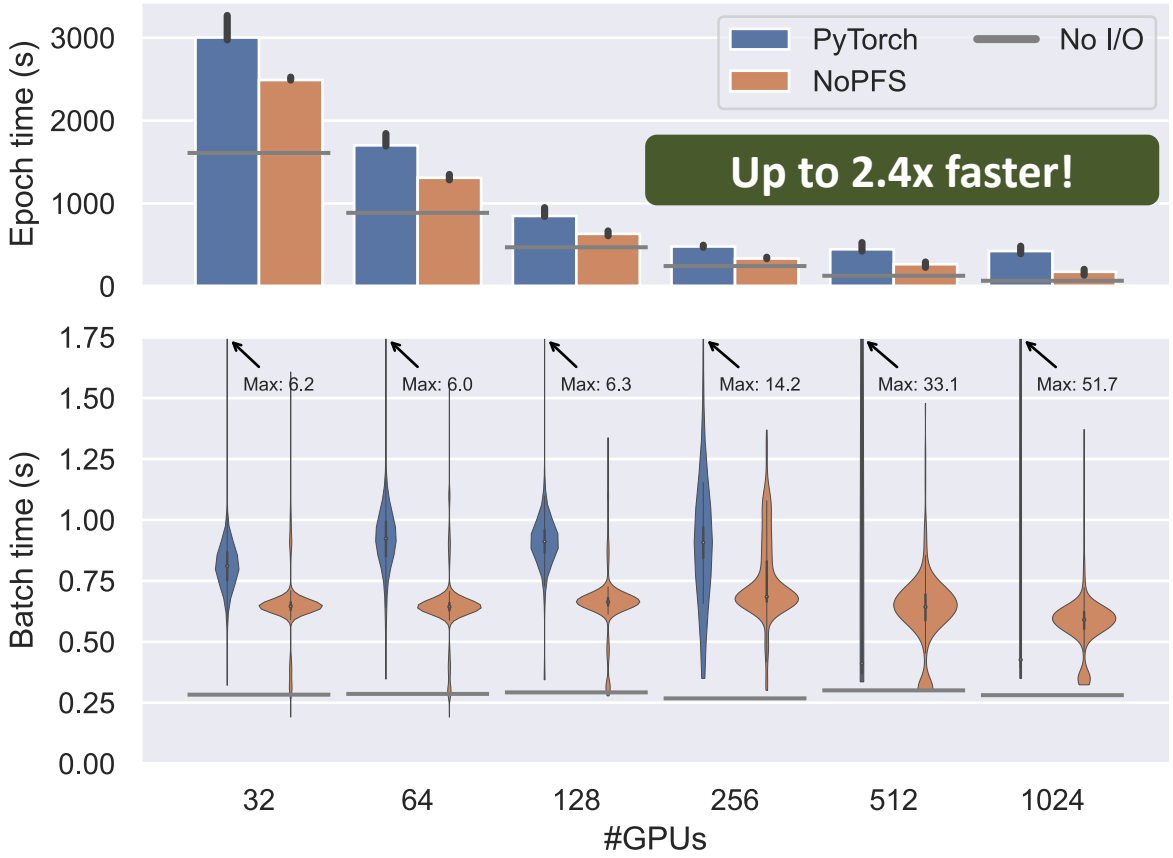




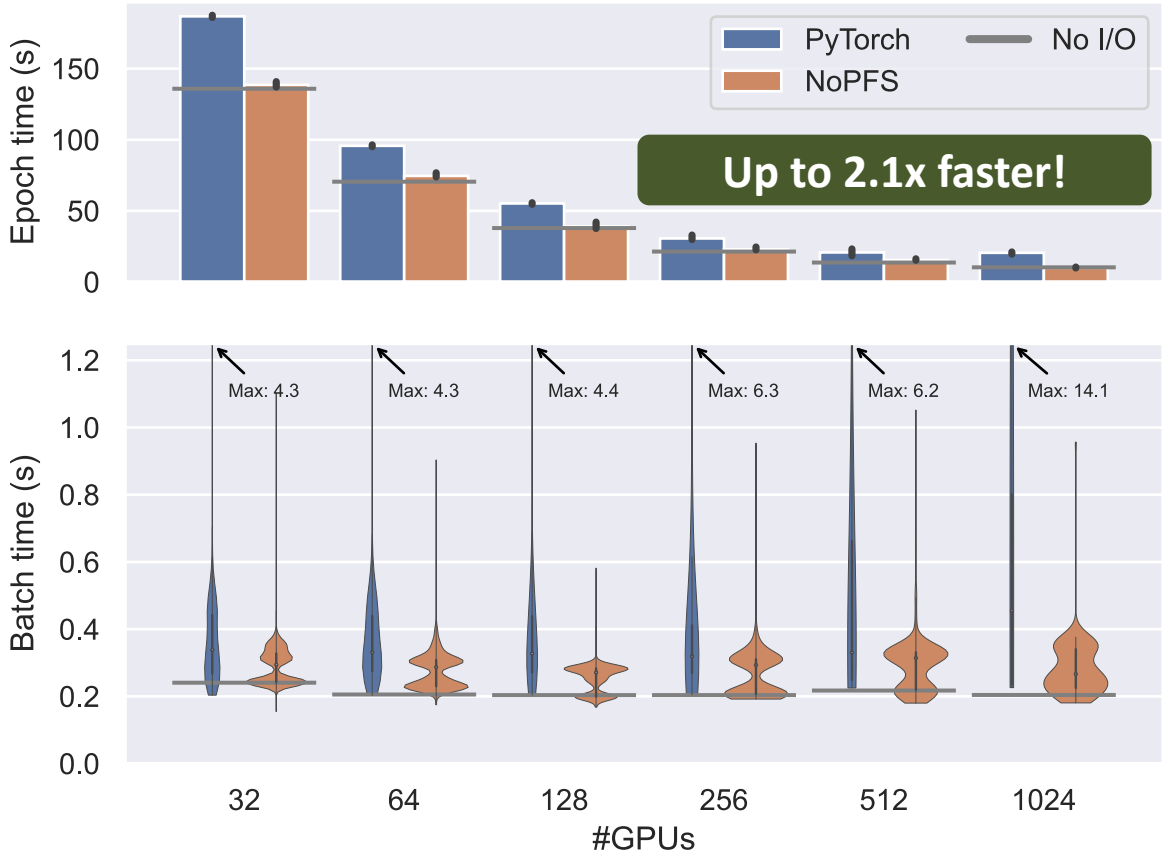
ImageNet-1k / ResNet-50

Performance: Going Bigger

ResNet-50 / ImageNet-22k (1.5 TB)



CosmoFlow (4 TB)



Conclusions

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System Scalability ✓

Dataset Scalability ✓

Full Randomization ✓

Hardware Independence ✓

Ease of Use ✓

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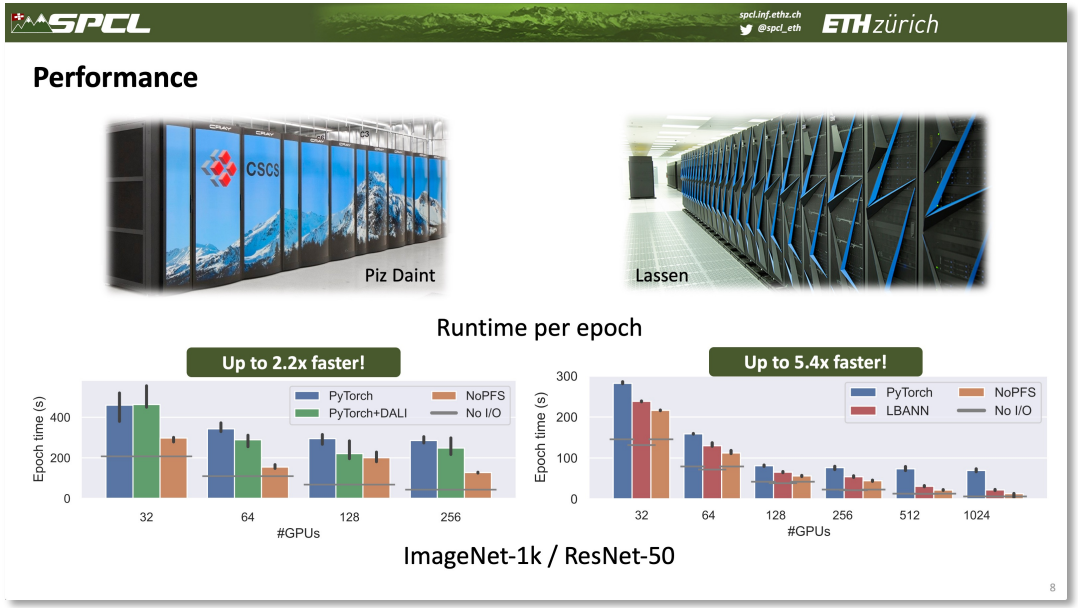

https://github.com/spcl/nopfs