Choose the Best Accelerated Technology

Optimize Deep Learning on Intel – Same code just faster!

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Agenda

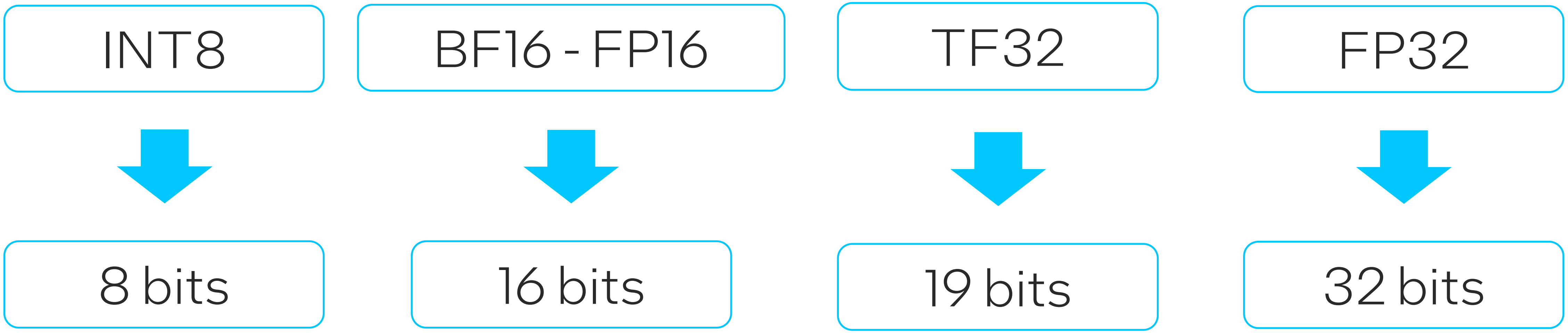
- Data precision
- Optimized DL frameworks
  - oneDNN
  - Tensorflow
  - PyTorch
  - Intel Extension for PyTorch

Data Precision

- Data precision:

  Number of bits used to store numerical values in memory

- Commonly found types of precision in Deep Learning:



INT8

8 bits

BF16 - FP16

16 bits

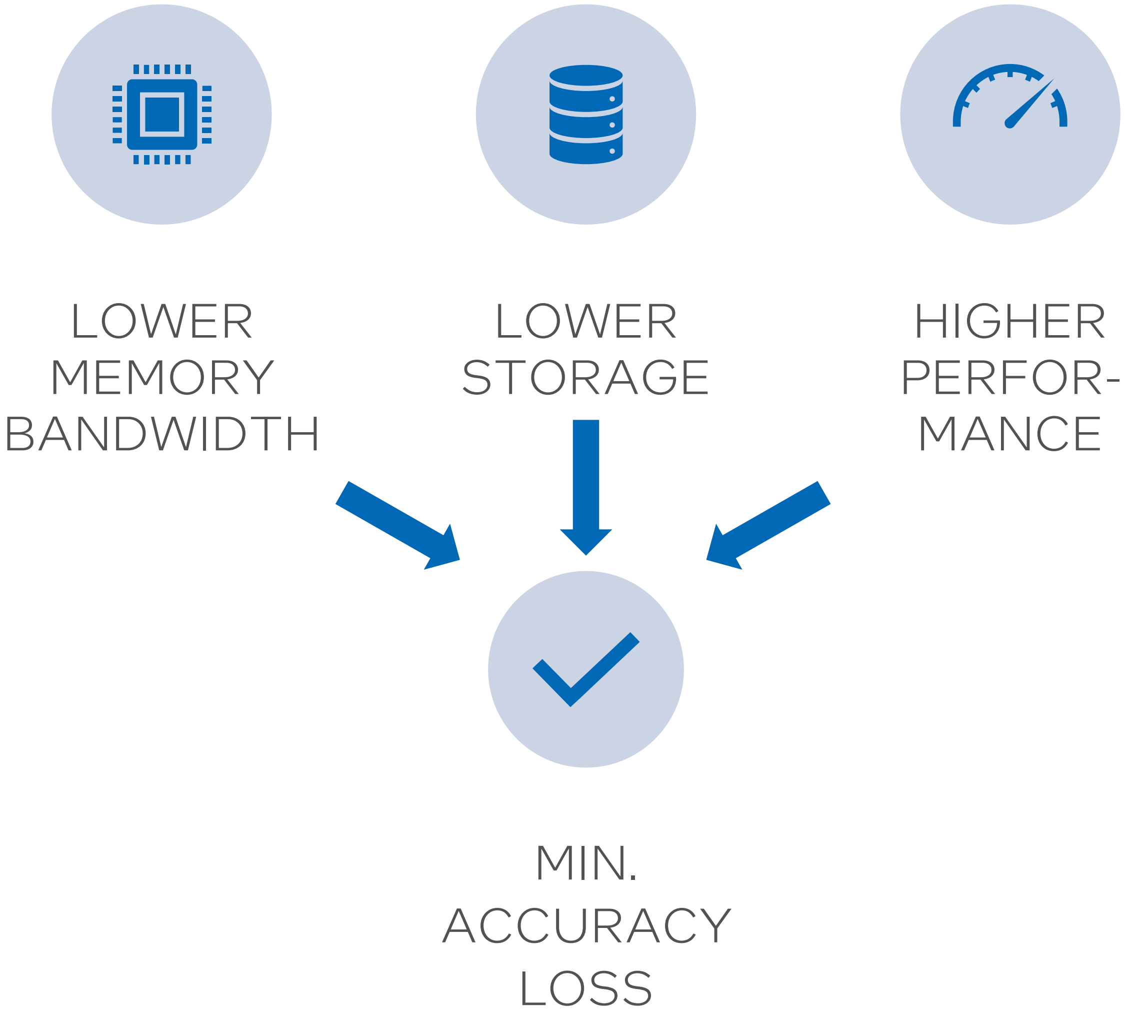
TF32

19 bits

FP32

32 bits

Lower Precision – Summary



LOWER MEMORY BANDWIDTH

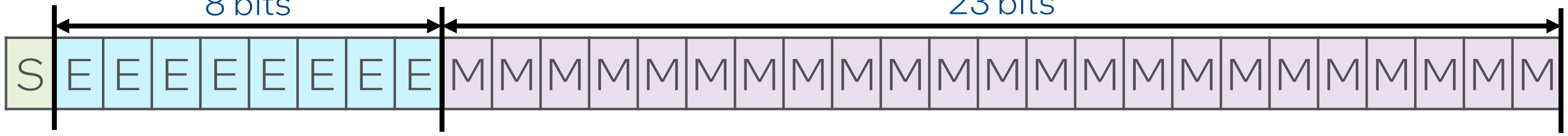
LOWER STORAGE

HIGHER PERFORMANCE

MIN. ACCURACY LOSS

Floating Point – Precision -32 bits

FP32



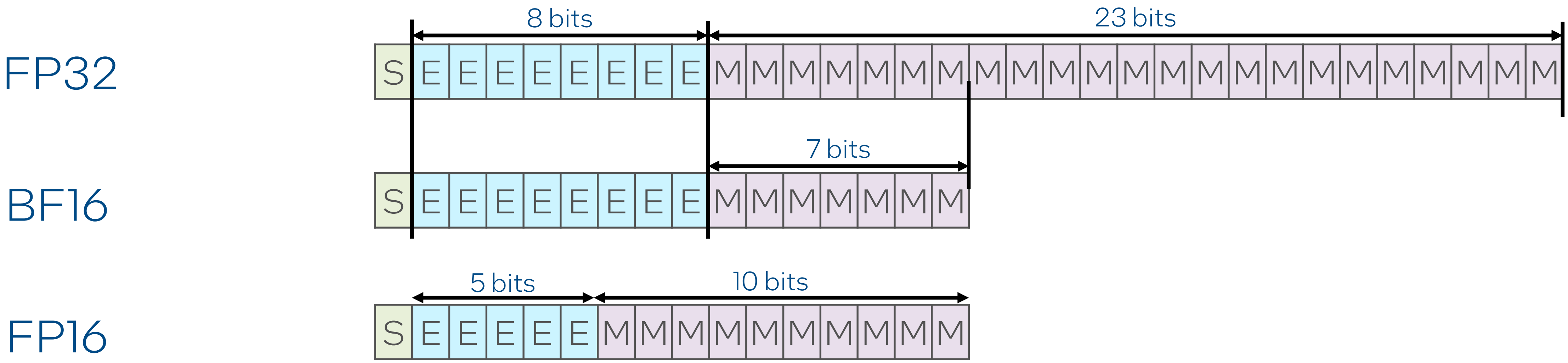
8 bits

23 bits

S E E E E E E E E M M M M M M M M M M M M M M M M M M M M M M M

- FP32: The standard type for all neural network computations

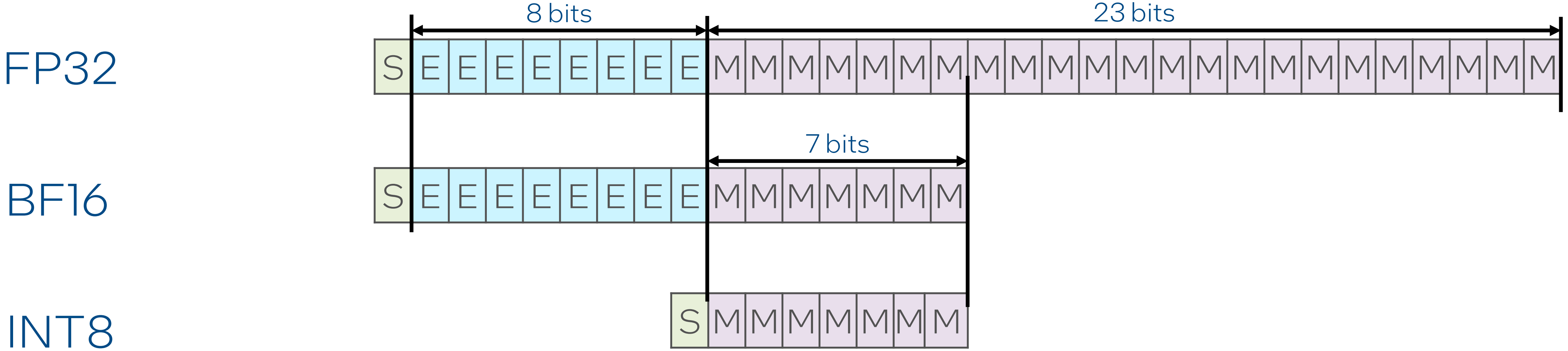
Floating Point – Precision – 16bits


8 bits
23 bits
FP32
S E E E E E E E E M M M M M M M M M M M M M M M M M M M M M M M
7 bits
BF16
S E E E E E E E E M M M M M M M
5 bits
10 bits
FP16
S E E E E E M M M M M M M M M M

- BF16: Efficient replacement for FP32 in training and inference

- Benefit of BF16
  - Performance 2x up
  - Comparable accuracy loss against fp32
  - No loss scaling, compared to fp16
  - Can be used for training (mixed-precision training)

Floating Point – Precision – 8 bits



8 bits

23 bits

FP32

S E E E E E E E E M M M M M M M M M M M M M M M M M M M M M M M

7 bits

BF16

S E E E E E E E E M M M M M M M

INT8

S M M M M M M M

- INT8: Significant speed-up in inference with small loss in accuracy
- Not suitable for training but recommended for inference when a small loss of accuracy is accepted.
- Intel Hardware takes great advantage of INT8 and BF16 precision

Intel® Xeon® Scalable Processors

The Only Data Center CPU with Built-in AI Acceleration

Intel Advanced Vector Extensions 512

Intel Deep Learning Boost (Intel DL Boost)

Intel Optane Persistent Memory

Shipping

Cascade Lake

New Intel DL Boost (VNNI)
New memory storage hierarchy

Cooper Lake

Intel DL Boost (BFLOAT16)

April 2021

Ice Lake

Intel DL Boost (VNNI) and new Intel Software Guard Extensions (Intel® SGX) that enable new AI use cases like federated learning

2022

Sapphire Rapids

Intel Advanced Matrix Extensions (AMX) extends built-in AI acceleration capabilities on Xeon Scalable

Leadership performance

Optimized Deep Learning FW

TensorFlow

PyTorch

Intel’s oneAPI Ecosystem

Built on Intel’s Rich Heritage of CPU Tools Expanded to XPUs

oneAPI

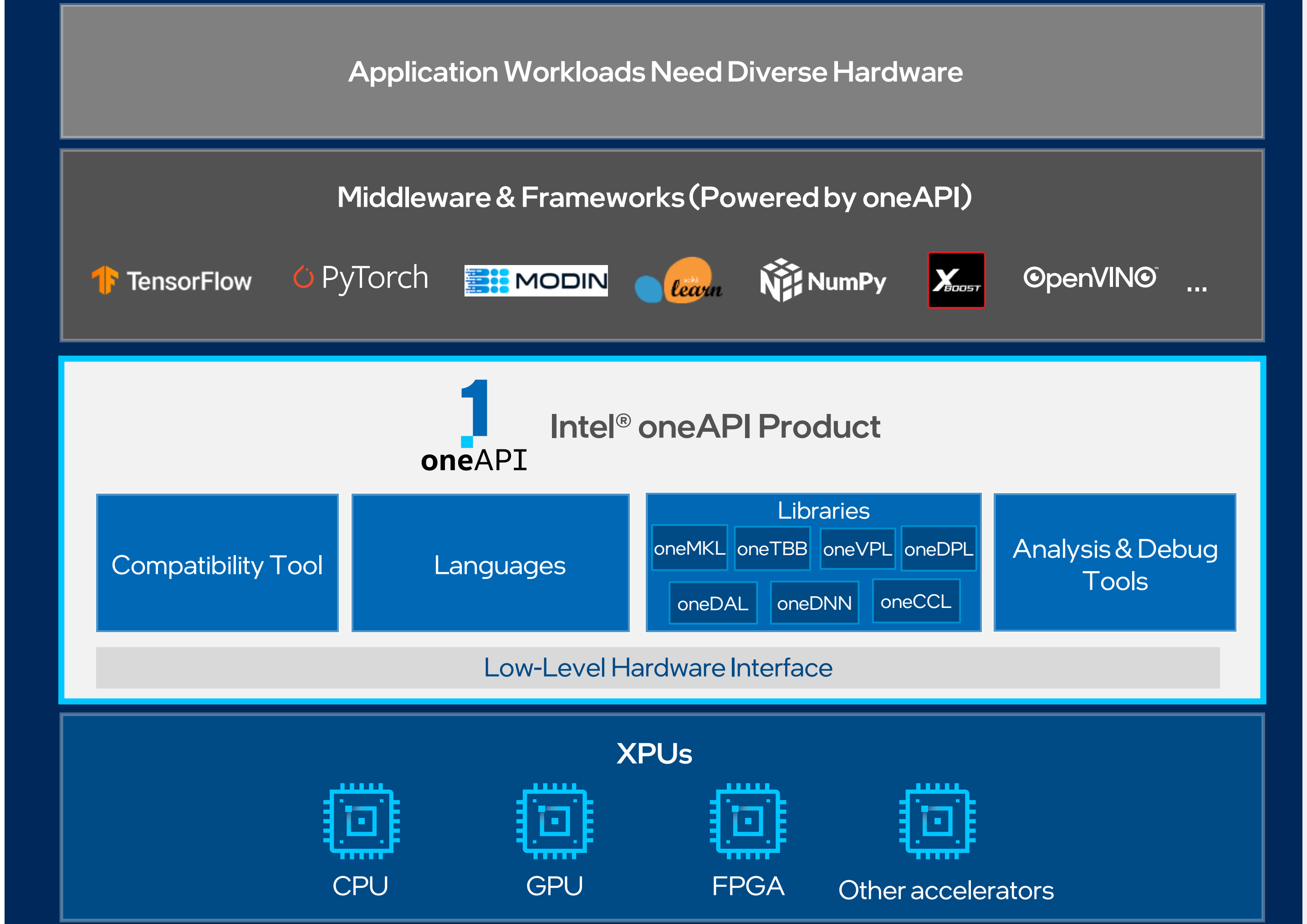
A cross-architecture language based on C++ and SYCL standards

Powerful libraries designed for acceleration of domain-specific functions

A complete set of advanced compilers, libraries, and porting, analysis and debugger tools

Powered by oneAPI

Frameworks and middleware that are built using one or more of the oneAPI industry specification elements, the DPC++ language, and libraries listed on oneapi.com.



Application Workloads Need Diverse Hardware

Middleware & Frameworks (Powered by oneAPI)

TensorFlow PyTorch MODIN learn NumPy XBOOST OpenVINO ...

oneAPI Intel® oneAPI Product

Compatibility Tool

Languages

Libraries

oneMKL oneTBB oneVPL oneDPL

oneDAL oneDNN oneCCL

Analysis & Debug Tools

Low-Level Hardware Interface

XPUs

CPU GPU FPGA Other accelerators

Available Now

Visit software.intel.com/oneapi for more details
Some capabilities may differ per architecture and custom-tuning will still be required. Other accelerators to be supported in the future.

Intel® oneAPI **Base** Toolkit

Native Code Developers

A core set of high-performance tools for building C++, Data Parallel C++ applications & oneAPI library-based applications

Add-on **Domain-specific** Toolkits

Specialized Workloads

Intel® oneAPI Tools for HPC

Deliver fast Fortran, OpenMP & MPI applications that scale

Intel® oneAPI Tools for IoT

Build efficient, reliable solutions that run at network's edge

Intel® oneAPI Rendering Toolkit

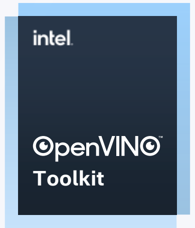
Create performant, high-fidelity visualization applications

Toolkits **powered by oneAPI**

Data Scientists & AI Developers

Intel® AI Analytics Toolkit

Accelerate machine learning & data science pipelines with optimized DL frameworks & high-performing Python libraries



Intel® Distribution of OpenVINO™ Toolkit

Deploy high performance inference & applications from edge to cloud

Intel® AI Analytics Toolkit

Powered by oneAPI

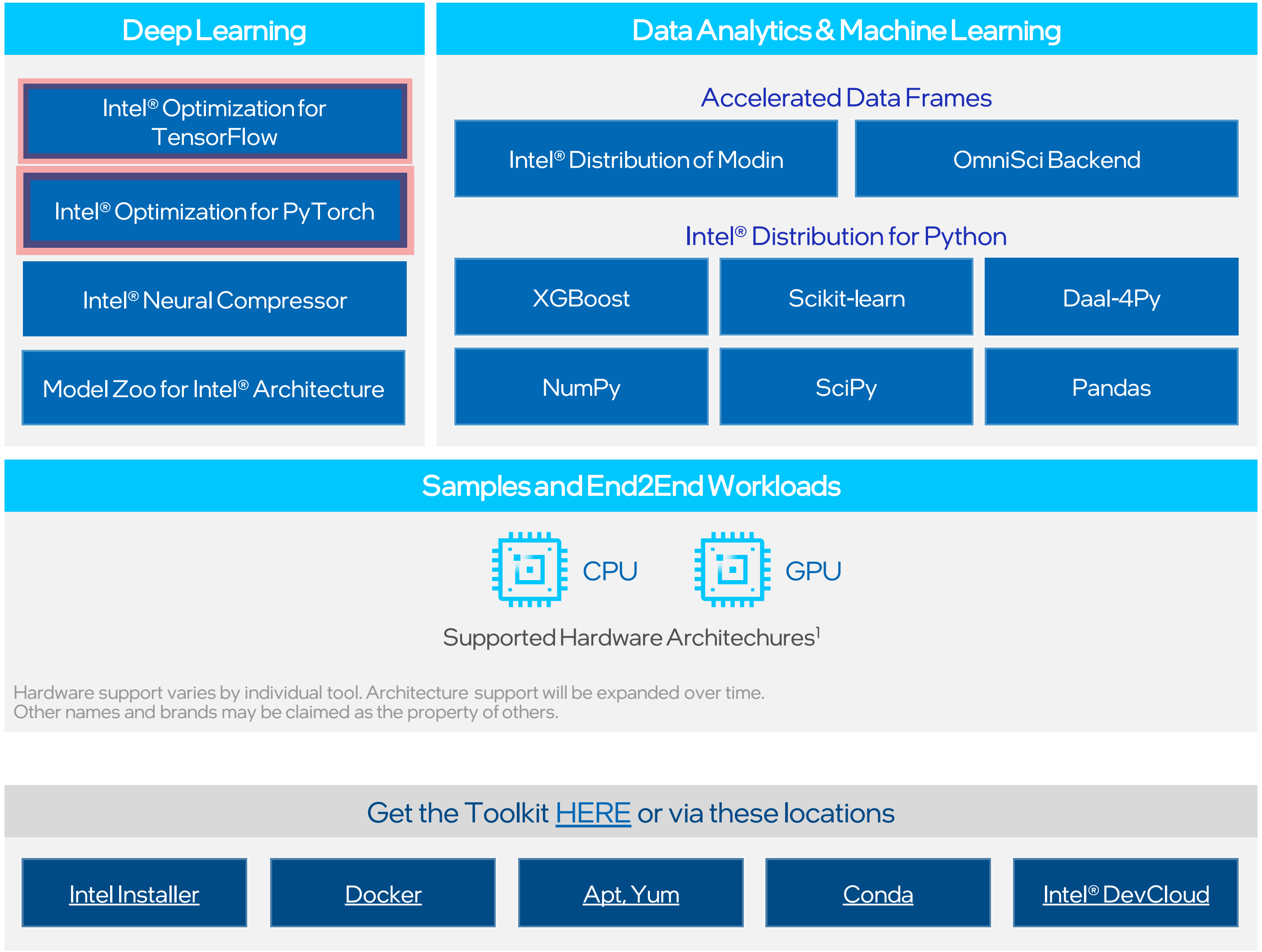
Accelerate end-to-end AI and data analytics pipelines with libraries optimized for Intel® architectures

Who Uses It?

Data scientists, AI researchers, ML and DL developers, AI application developers

Top Features/Benefits

- Deep learning performance for training and inference with Intel optimized DL frameworks and tools
- Drop-in acceleration for data analytics and machine learning workflows with compute-intensive Python packages



Deep Learning

Intel® Optimization for TensorFlow

Intel® Optimization for PyTorch

Intel® Neural Compressor

Model Zoo for Intel® Architecture

Data Analytics & Machine Learning

Accelerated Data Frames

Intel® Distribution of Modin

OmniSci Backend

Intel® Distribution for Python

XGBoost

Scikit-learn

Daal-4Py

NumPy

SciPy

Pandas

Samples and End2End Workloads

CPU

GPU

Supported Hardware Architectures[1]

Hardware support varies by individual tool. Architecture support will be expanded over time.
Other names and brands may be claimed as the property of others.

Get the Toolkit HERE or via these locations

Intel Installer

Docker

Apt, Yum

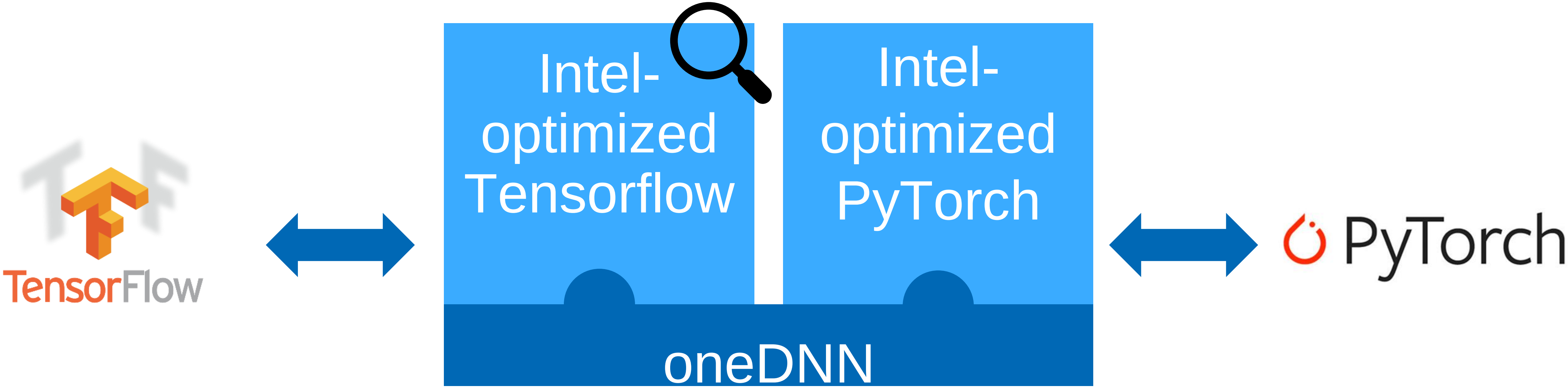
Conda

Intel® DevCloud

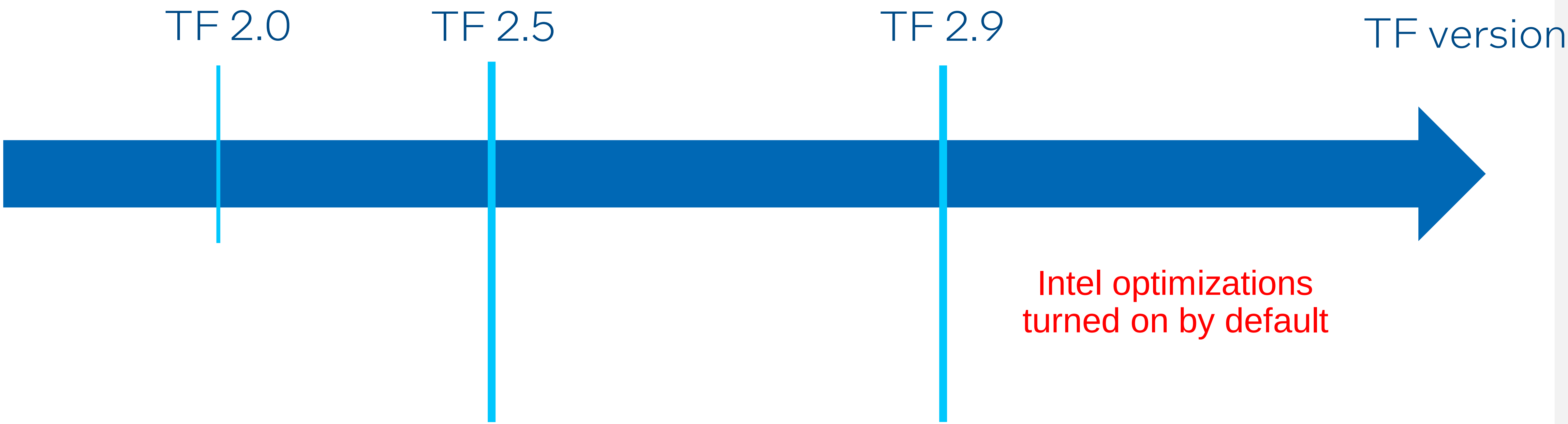
Learn More: software.intel.com/oneapi/ai-kit

Intel-optimized Deep Learning Frameworks

- Intel-optimized DL frameworks are drop-in replacement,
    - **No front code change for the user**
- Optimizations are upstreamed automatically (TF) or on a regular basis (PyTorch) to stock frameworks



Tensorflow timeline of Intel optimizations

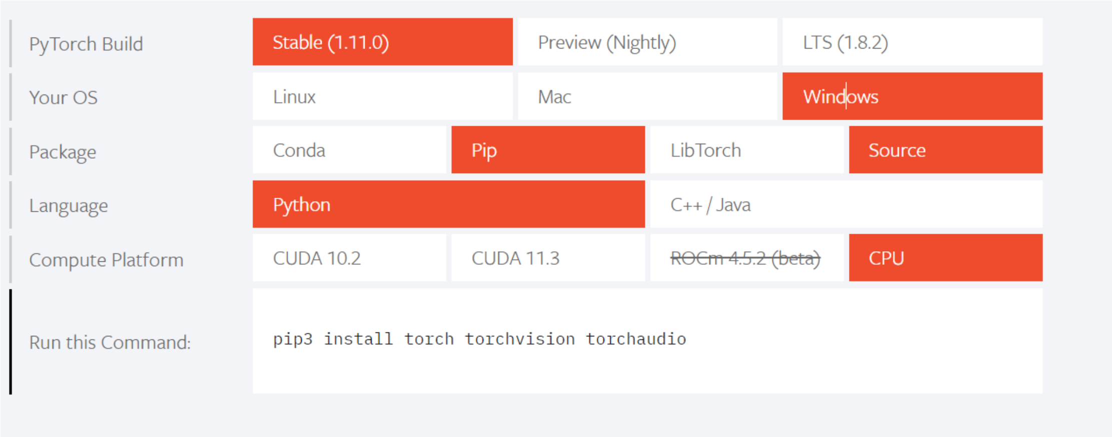


How to get the optimized frameworks

- In the Intel AI Analytics toolkit

No need to call the flag for Tensorflow

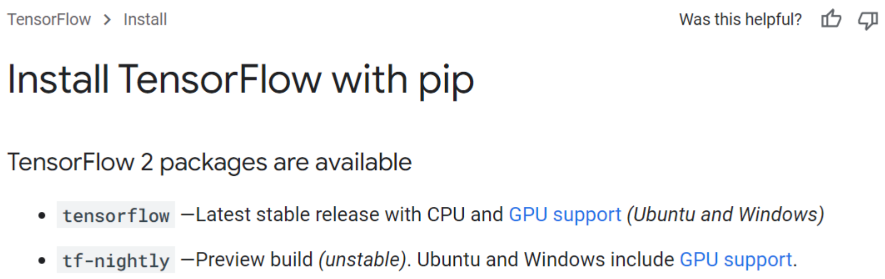
- Through the framework pip/conda wheel:



PyTorch Build	[✓ Stable (1.11.0)]	Preview (Nightly)	LTS (1.8.2)	
Your OS	Linux	Mac	[✓ Windows]	
Package	Conda	[✓ Pip]	LibTorch	[✓ Source]
Language	[✓ Python]	C++ / Java		
Compute Platform	CUDA 10.2	CUDA 11.3	~~ROCm 4.5.2 (beta)~~	[✓ CPU]

Run this Command:

```
pip3 install torch torchvision torchaudio
```



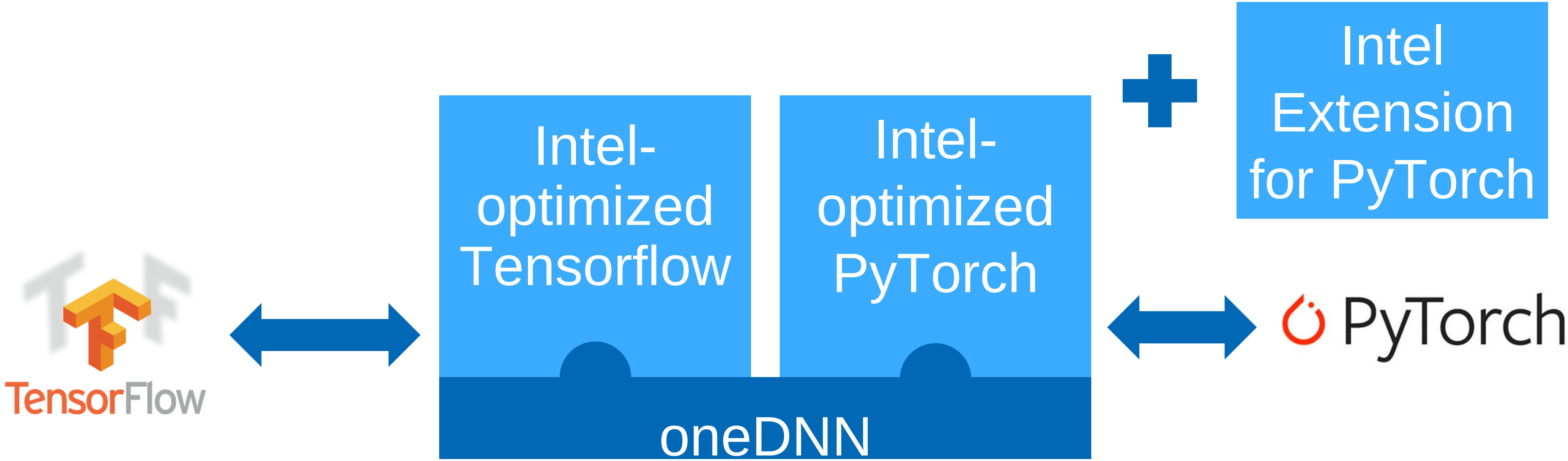
Install TensorFlow with pip

TensorFlow 2 packages are available

- `tensorflow` —Latest stable release with CPU and GPU support *(Ubuntu and Windows)*
- `tf-nightly` —Preview build *(unstable)*. Ubuntu and Windows include GPU support.

Intel-optimized Deep Learning Frameworks

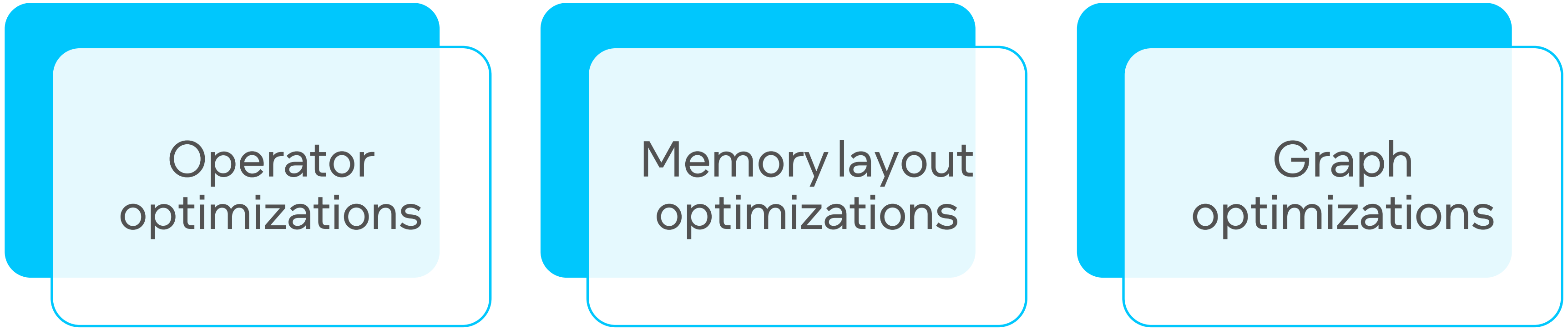
- Intel Extension for PyTorch is an additional module for functions not supported in standard PyTorch (such as mixed precision and dGPU support)
- As they offer more aggressive optimizations, they offer bigger speed-up for training and inference



Optimizations

Same type of optimizations at two different levels:

1) In Intel Extension for PyTorch
2) in oneDNN



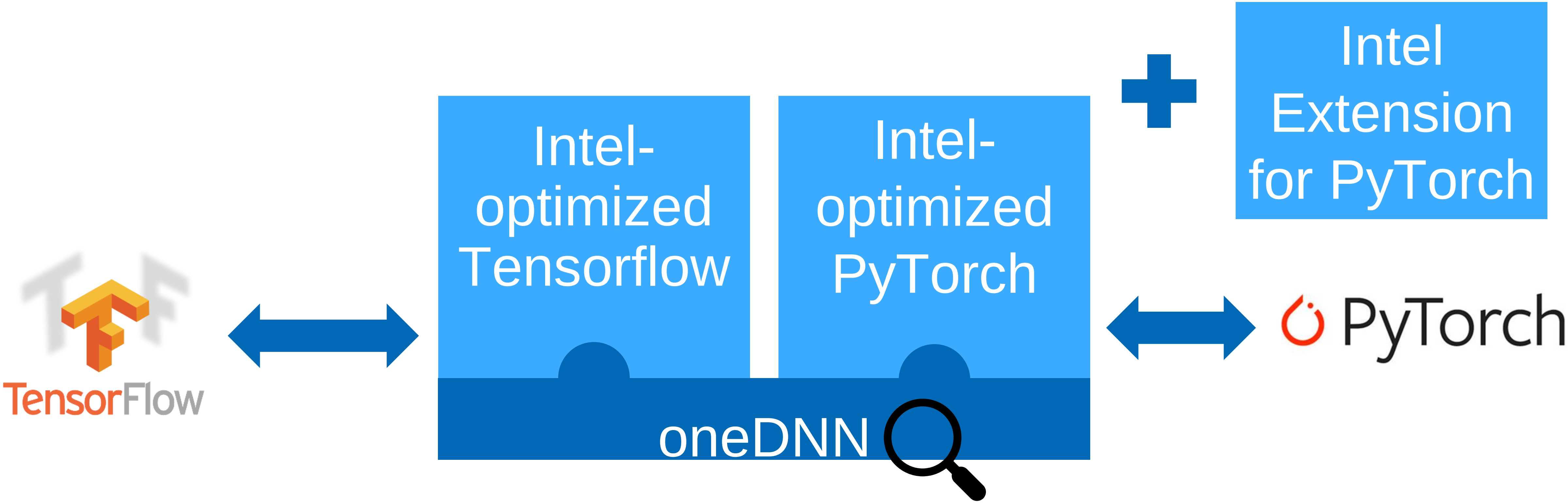
Operator optimizations

Memory layout optimizations

Graph optimizations

Intel Extension for PyTorch optimizations extends the oneDNN optimizations

Intel-optimized Deep Learning Frameworks



oneDNN

Intel® oneAPI Deep Neural Network Library

Intel® oneAPI Deep Neural Network Library (oneDNN)

- An open-source cross-platform performance library for deep learning applications
  - Helps developers create high performance deep learning frameworks
  - Abstracts out instruction set and other complexities of performance optimizations
  - Open source for community contributions

- Supported data precision
  - **Training**: float32, bfloat16
  - **Inference**: float32, bfloat16, float16, and int8

- Runs on Intel CPU and GPU

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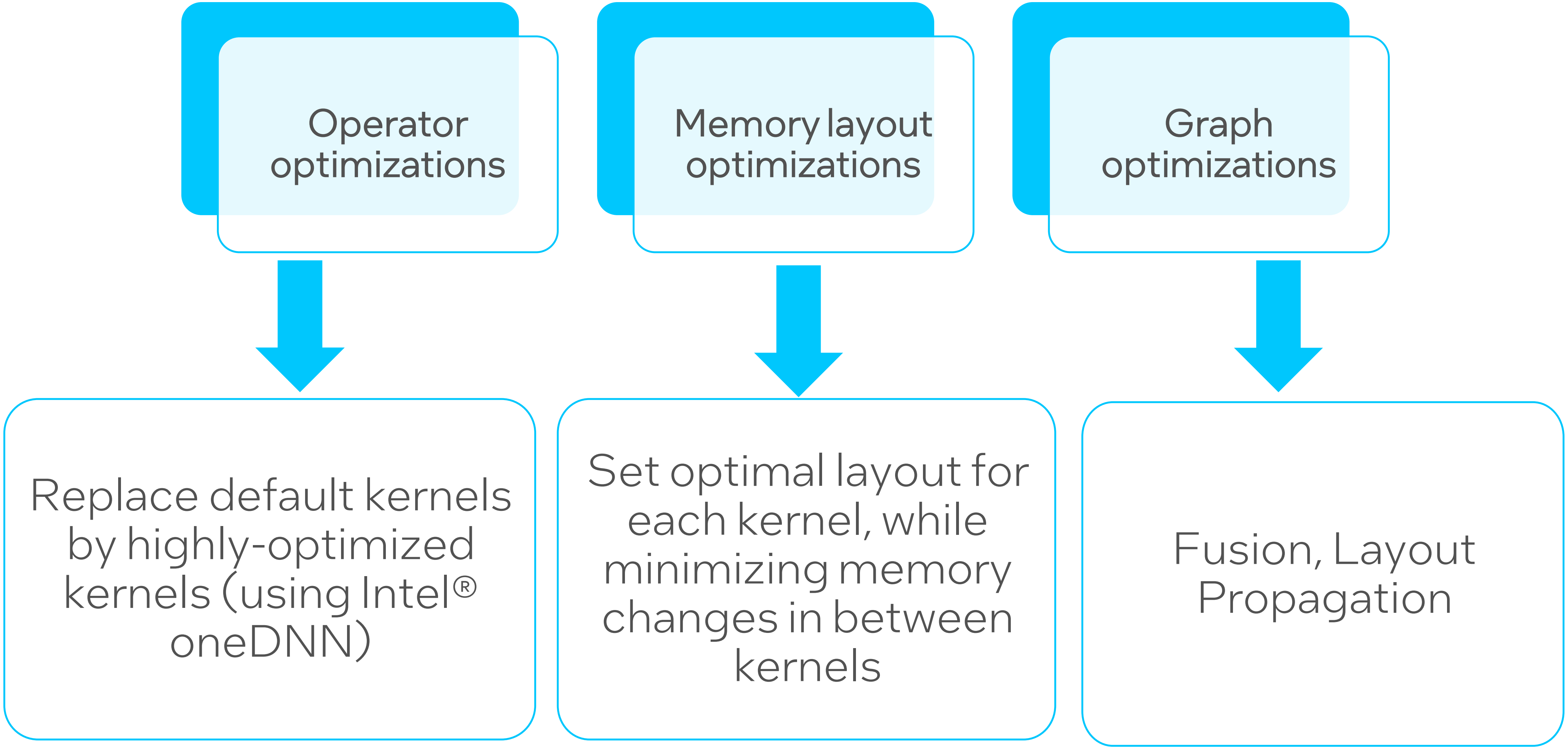


Operator optimizations

Memory layout optimizations

Graph optimizations

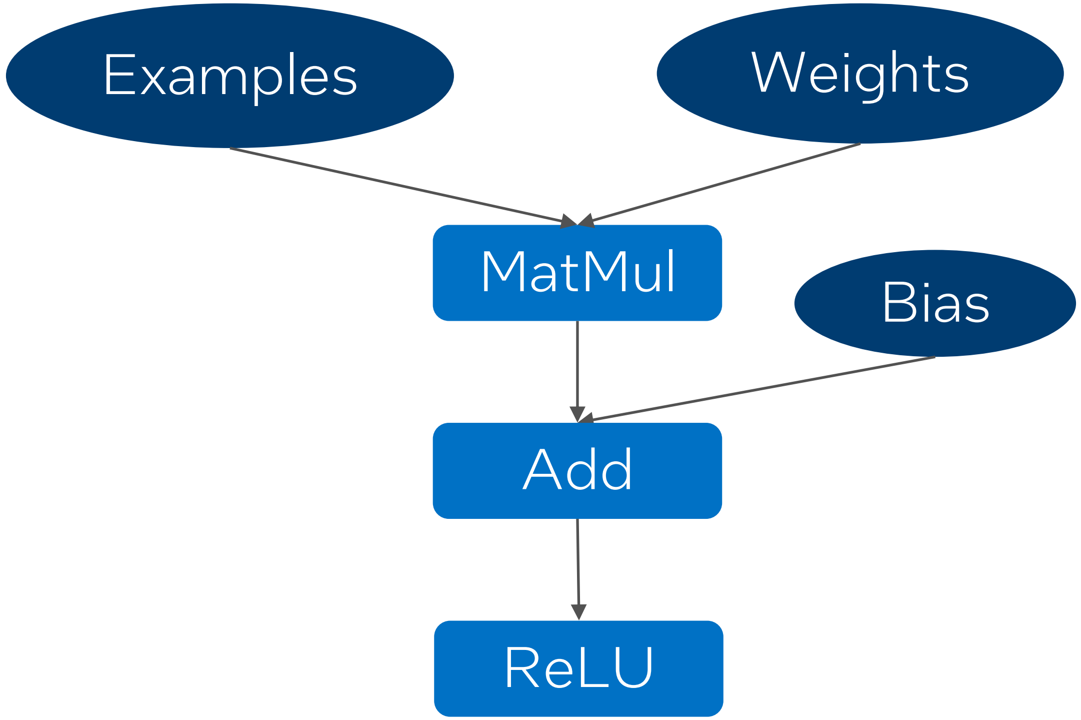
Replace default kernels by highly-optimized kernels (using Intel® oneDNN)

Set optimal layout for each kernel, while minimizing memory changes in between kernels

Fusion, Layout Propagation

Operator optimizations

In TensorFlow, computation graph is a data-flow graph.



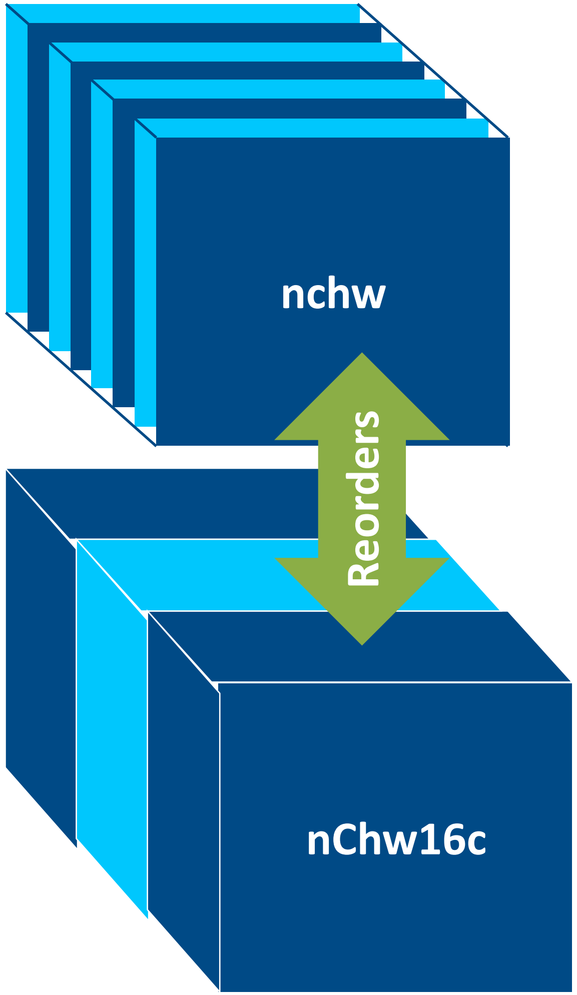
Operator optimizations

- Replace default kernels by highly-optimized kernels (using Intel® oneDNN)
- Adapt to available instruction sets (AVX-512, AVX2, VNNI)
- Adapt to required precision:
  - **Training**: FP32, BF16
  - **Inference**: FP32, BF16, FP16, and INT8

	Intel® oneDNN
Convolution	2D/3D Direct Convolution/Deconvolution, Depthwise separable convolution 2D Winograd convolution
Inner Product	2D/3D Inner Production
Pooling	2D/3D Maximum 2D/3D Average (include/exclude padding)
Normalization	2D/3D LRN across/within channel, 2D/3D Batch normalization
Eltwise (Loss/activation)	ReLU(bounded/soft), ELU, Tanh; Softmax, Logistic, linear; square, sqrt, abs, exp, gelu, swish
Data manipulation	Reorder, sum, concat, View
RNN cell	RNN cell, LSTM cell, GRU cell
Fused primitive	Conv+ReLU+sum, BatchNorm+ReLU
Data type	f32, bfloat16, s8, u8

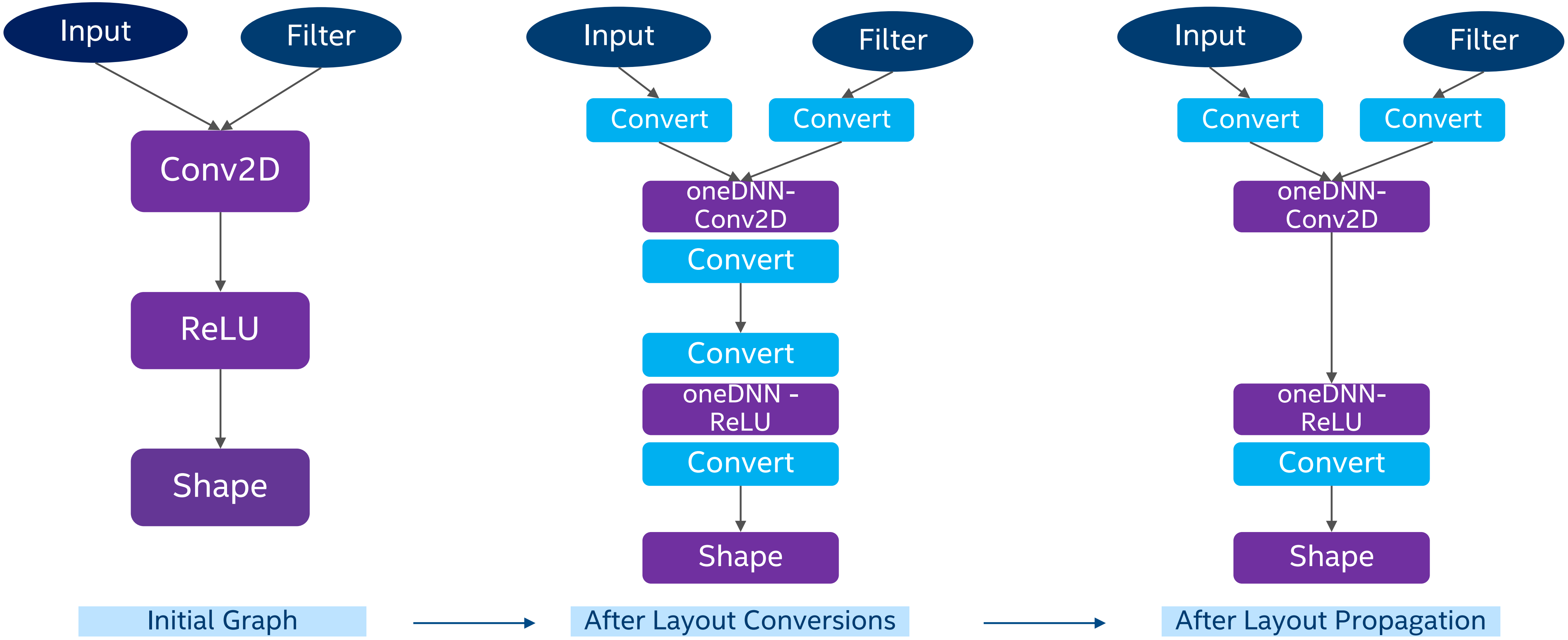
Memory layouts optimization

- Most popular memory layouts for image recognition are **NHWC** and **NCHW**
  - Challenging for Intel processors both for vectorization or for memory accesses
- Intel oneDNN convolutions use blocked layouts
  - Most popular oneDNN data format is nChw16c on AVX512+ systems and nChw8c on SSE4.1+ systems



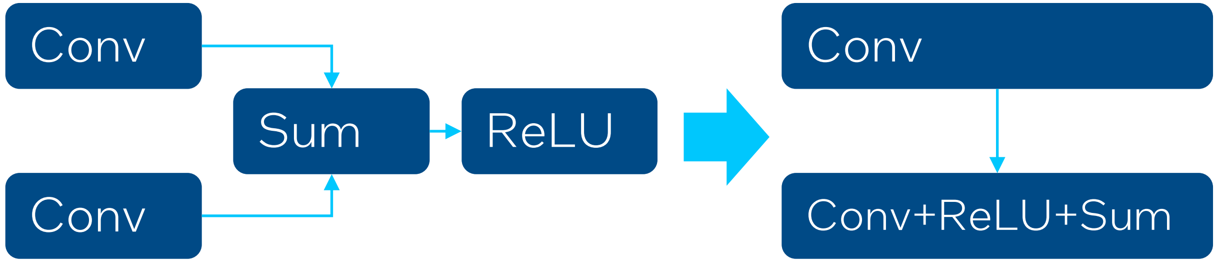
More details: https://oneapi-src.github.io/oneDNN/understanding_memory_formats.html

Graph optimizations: layout propagation

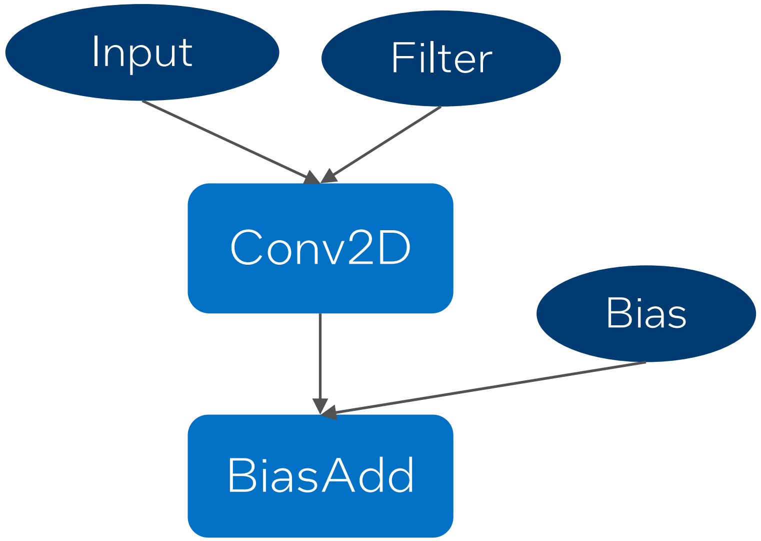


Fusing computations

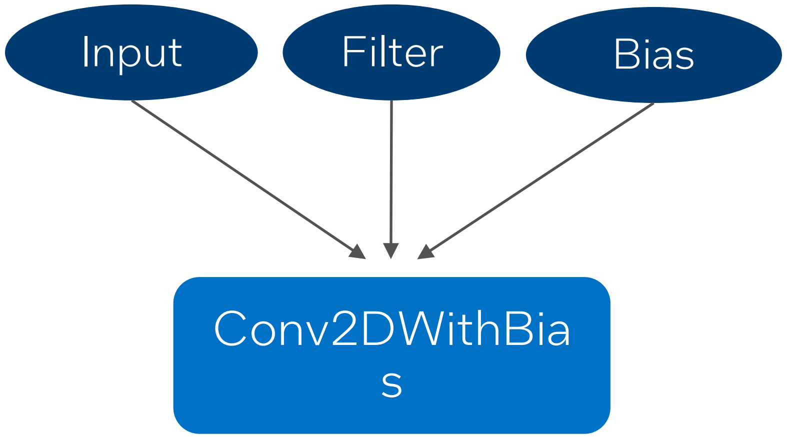
- On Intel processors a high percentage of time is typically spent in bandwidth-limited ops such activation functions
  - ~40% of ResNet-50, even higher for inference
- The solution is to fuse BW-limited ops with convolutions or one with another to reduce the number of memory accesses
  - We fuse patterns: Conv+ReLU+Sum, BatchNorm+ReLU, etc…



Graph optimizations: fusion

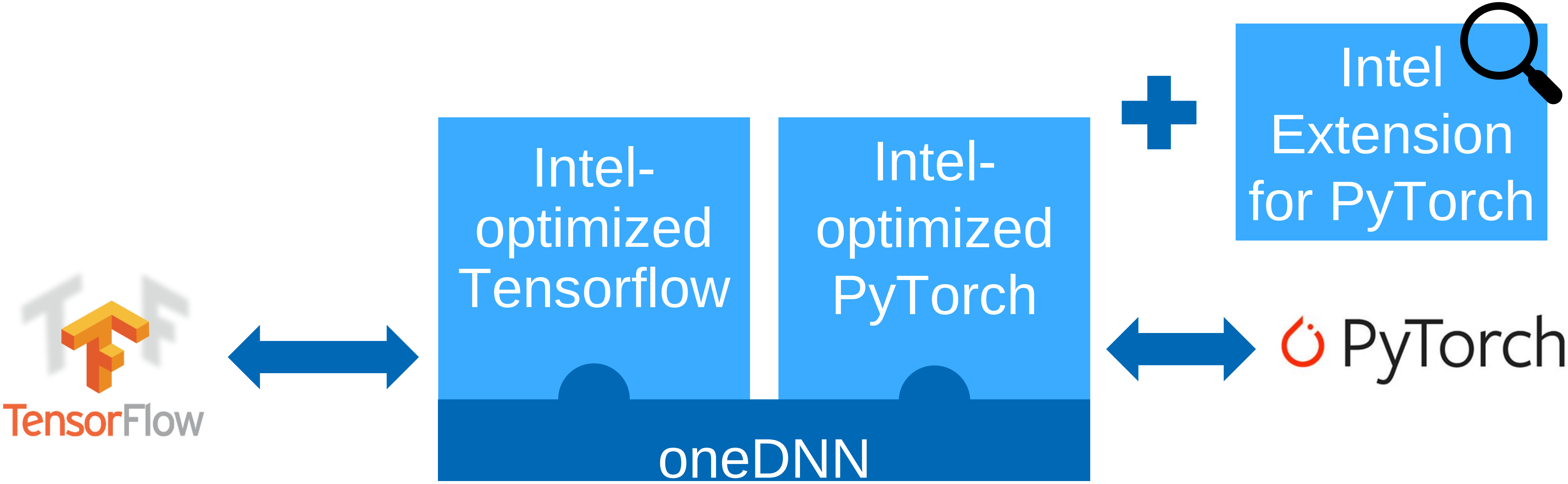


Before Merge



After Merge

Intel-optimized Deep Learning Frameworks



Intel-optimized Tensorflow

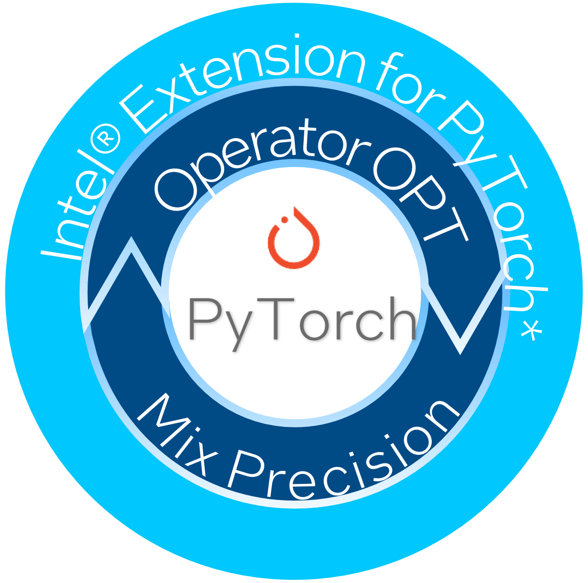
Intel-optimized PyTorch

oneDNN

Intel Extension for PyTorch

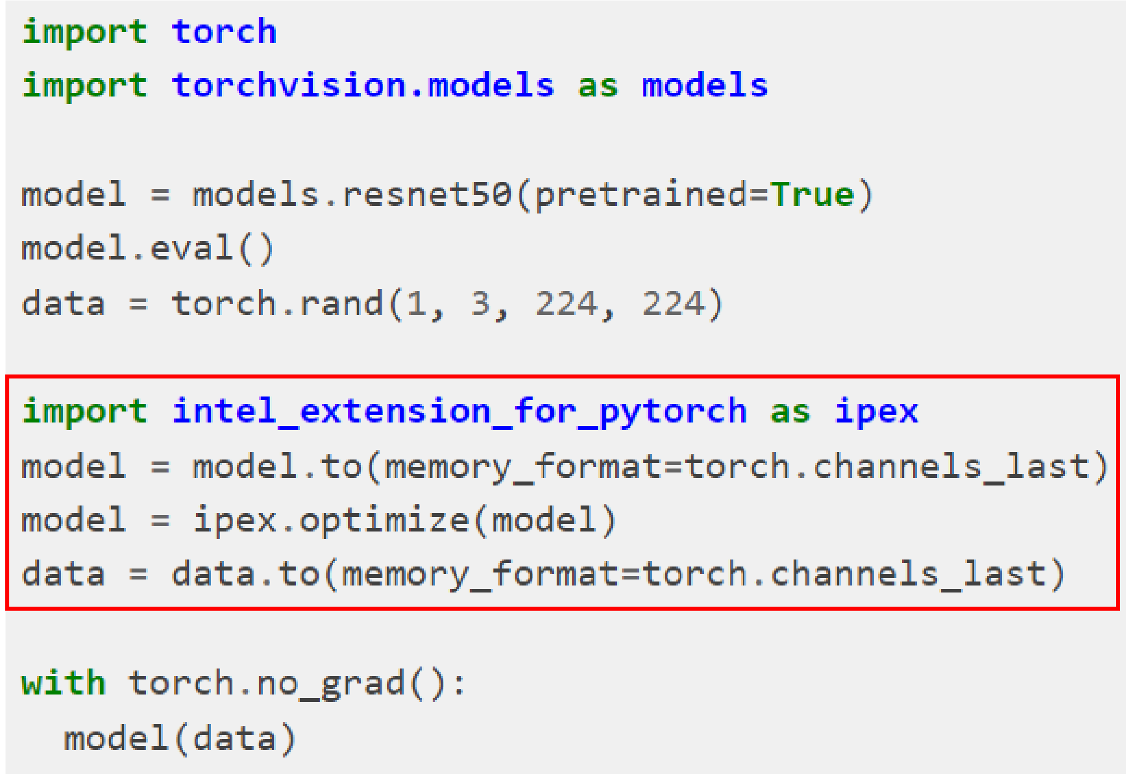
Intel® Extension for PyTorch* (IPEX)

- Buffer the PRs for stock Pytorch
- Provide users with the up-to-date Intel software/hardware features
- Streamline the work to integrate oneDNN
- Unify user experiences on Intel CPU and GPU



Python – Imperative Mode

- FP32



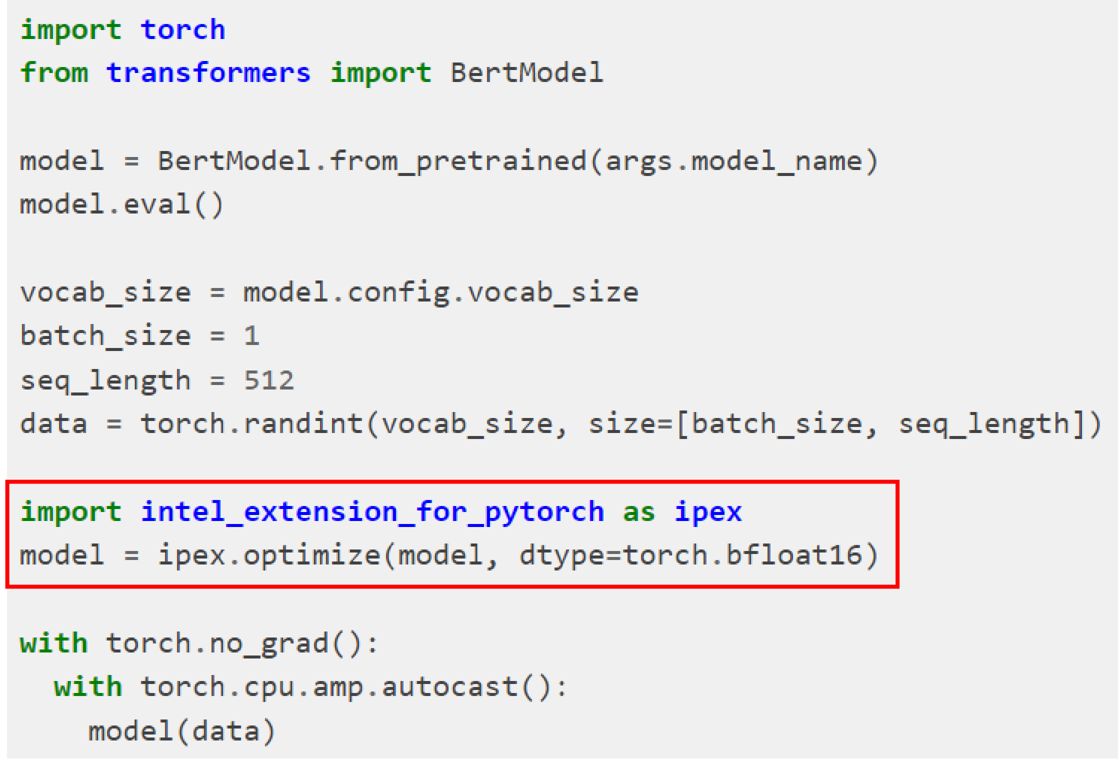
```python
import torch
import torchvision.models as models

model = models.resnet50(pretrained=True)
model.eval()
data = torch.rand(1, 3, 224, 224)

import intel_extension_for_pytorch as ipex
model = model.to(memory_format=torch.channels_last)
model = ipex.optimize(model)
data = data.to(memory_format=torch.channels_last)

with torch.no_grad():
  model(data)
```

- BFloat16



```python
import torch
from transformers import BertModel

model = BertModel.from_pretrained(args.model_name)
model.eval()

vocab_size = model.config.vocab_size
batch_size = 1
seq_length = 512
data = torch.randint(vocab_size, size=[batch_size, seq_length])

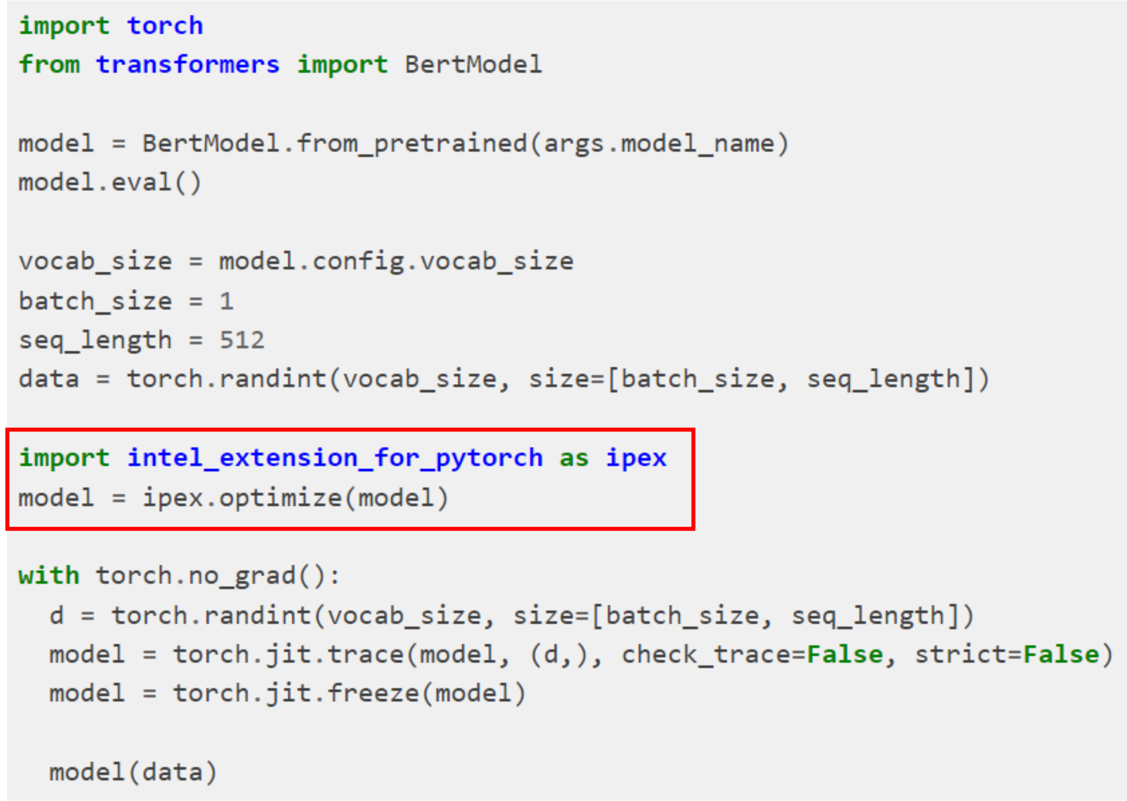
import intel_extension_for_pytorch as ipex
model = ipex.optimize(model, dtype=torch.bfloat16)

with torch.no_grad():
  with torch.cpu.amp.autocast():
    model(data)
```

https://intel.github.io/intel-extension-for-pytorch/1.11.0/tutorials/examples.html

Python – TorchScript Mode

- FP32



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model.eval()

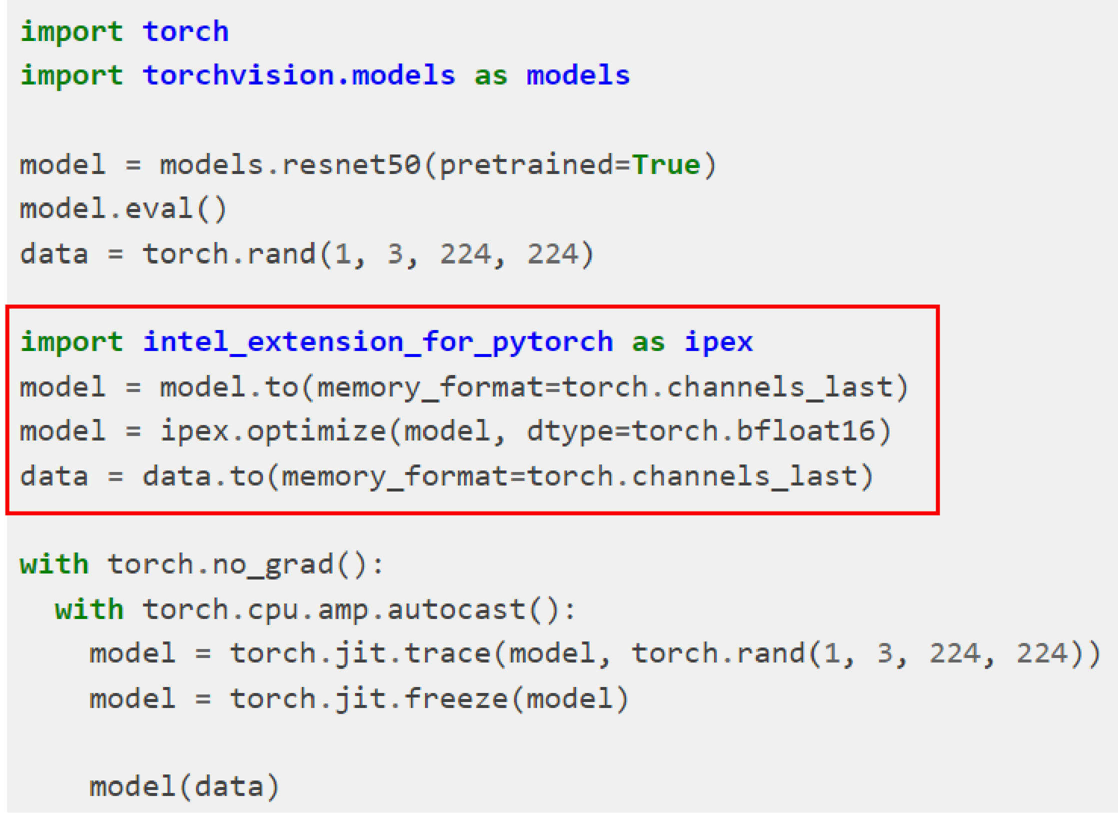
vocab_size = model.config.vocab_size
batch_size = 1
seq_length = 512
data = torch.randint(vocab_size, size=[batch_size, seq_length])

import intel_extension_for_pytorch as ipex
model = ipex.optimize(model)

with torch.no_grad():
  d = torch.randint(vocab_size, size=[batch_size, seq_length])
  model = torch.jit.trace(model, (d,), check_trace=False, strict=False)
  model = torch.jit.freeze(model)

  model(data)
```

- BFloat16



```python
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import torchvision.models as models

model = models.resnet50(pretrained=True)
model.eval()
data = torch.rand(1, 3, 224, 224)

import intel_extension_for_pytorch as ipex
model = model.to(memory_format=torch.channels_last)
model = ipex.optimize(model, dtype=torch.bfloat16)
data = data.to(memory_format=torch.channels_last)

with torch.no_grad():
  with torch.cpu.amp.autocast():
    model = torch.jit.trace(model, torch.rand(1, 3, 224, 224))
    model = torch.jit.freeze(model)

    model(data)
```
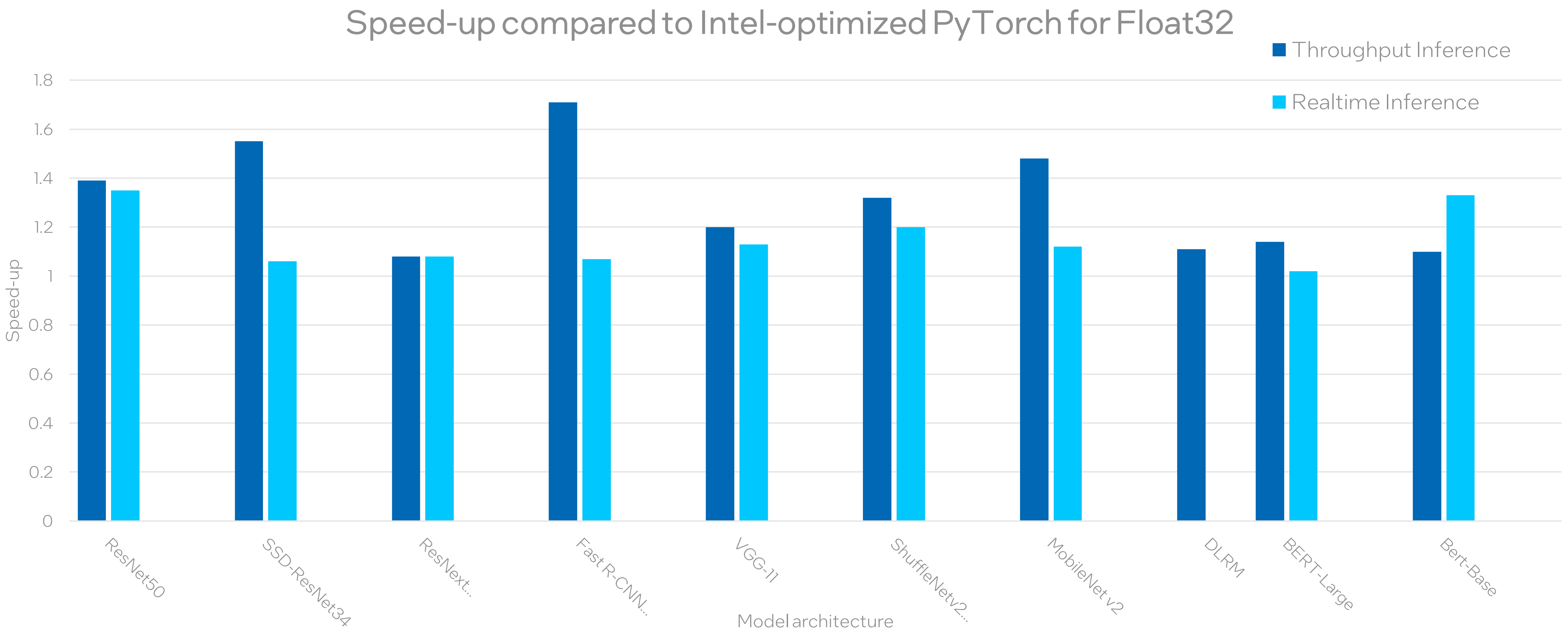
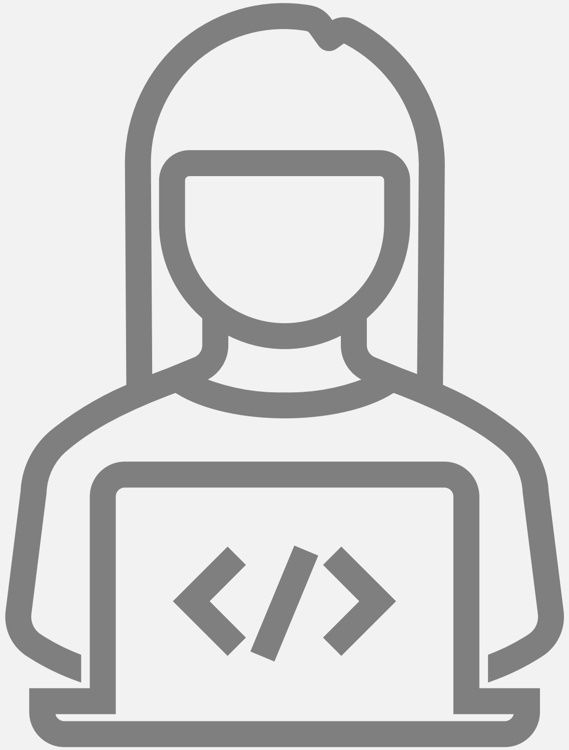

https://intel.github.io/intel-extension-for-pytorch/1.11.0/tutorials/examples.html

Intel Extension for PyTorch benchmark



Refer to: https://intel.github.io/intel-extension-for-pytorch/tutorials/performance.html for configuration details



How to get the Intel Extension for PyTorch

- **pip wheel:**

```
python -m pip install
intel_extension_for_pytorch
```

Operator optimizations

Memory/data layout optimizations

Graph optimizations

Optimal Optimizer

Mixed Precision

Fusing computations

- Intel Extension for PyTorch in JIT/Torchscript mode can fuse:
  - Multi-head-attention fusion, Concat Linear, Linear+Add, Linear+Gelu, Add+LayerNorm fusion and etc.
- Hugging Face reports that ~70% of most popular NLP tasks in question-answering, text-classification, and token-classification can get performance benefits with such fusion patterns [1]
  - for both Float32 precision and BFloat16 Mixed precision

[1] https://huggingface.co/docs/transformers/perf_infer_cpu

Operator optimizations

Memory/data layout optimizations

Graph optimizations

Optimal Optimizer

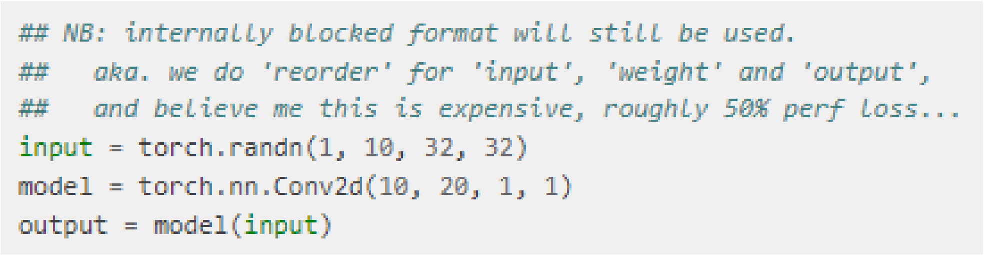
Mixed Precision

Data Layout optimization

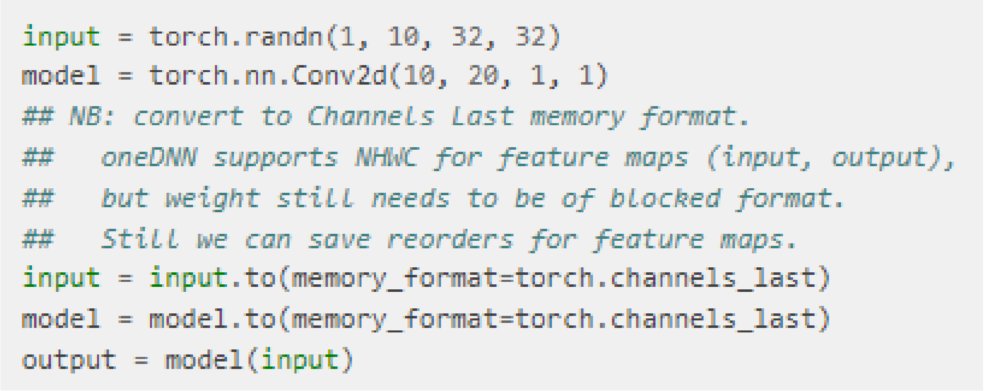
Data Layouts in PyTorch

- Used in Vision workloads
- NCHW
    - Default format
    - *torch.contiguous_format*
- NHWC
    - A working-in-progress feature of PyTorch
    - *torch.channels_last*
    - NHWC format yields higher performance

NCHW	🟥 [0]	🟥 [1]	🟥 [2]	🟥 [3]	🟩 [0]	🟩 [1]	🟩 [2]	🟩 [3]	🟦 [0]	🟦 [1]	🟦 [2]	🟦 [3]
NHWC	🟥 [0]	🟩 [0]	🟦 [0]	🟥 [1]	🟩 [1]	🟦 [1]	🟥 [2]	🟩 [2]	🟦 [2]	🟥 [3]	🟩 [3]	🟦 [3]

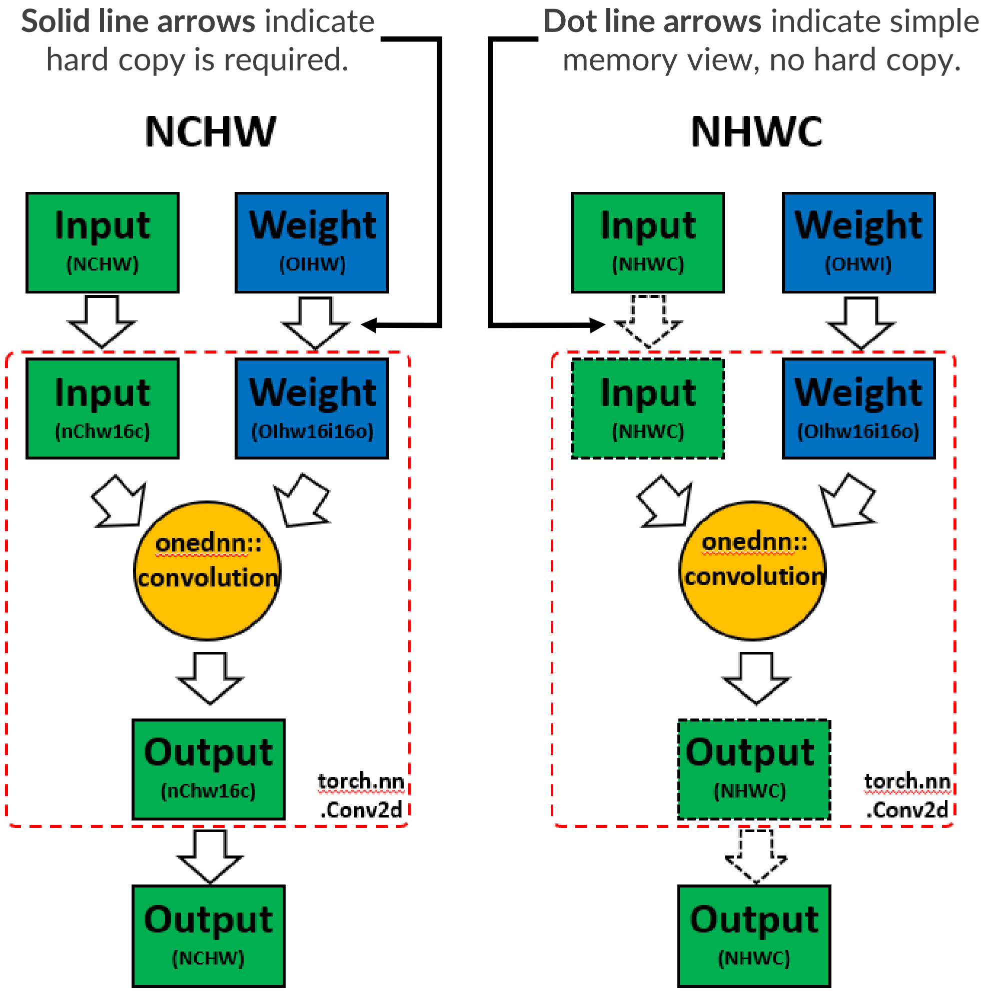


```
## NB: internally blocked format will still be used.
##   aka. we do 'reorder' for 'input', 'weight' and 'output',
##   and believe me this is expensive, roughly 50% perf loss...
input = torch.randn(1, 10, 32, 32)
model = torch.nn.Conv2d(10, 20, 1, 1)
output = model(input)
```



```
input = torch.randn(1, 10, 32, 32)
model = torch.nn.Conv2d(10, 20, 1, 1)
## NB: convert to Channels Last memory format.
##   oneDNN supports NHWC for feature maps (input, output),
##   but weight still needs to be of blocked format.
##   Still we can save reorders for feature maps.
input = input.to(memory_format=torch.channels_last)
model = model.to(memory_format=torch.channels_last)
output = model(input)
```

Benefit of NHWC in Intel® Extension for PyTorch*



Operator optimizations

Memory/data layout optimizations

Graph optimizations

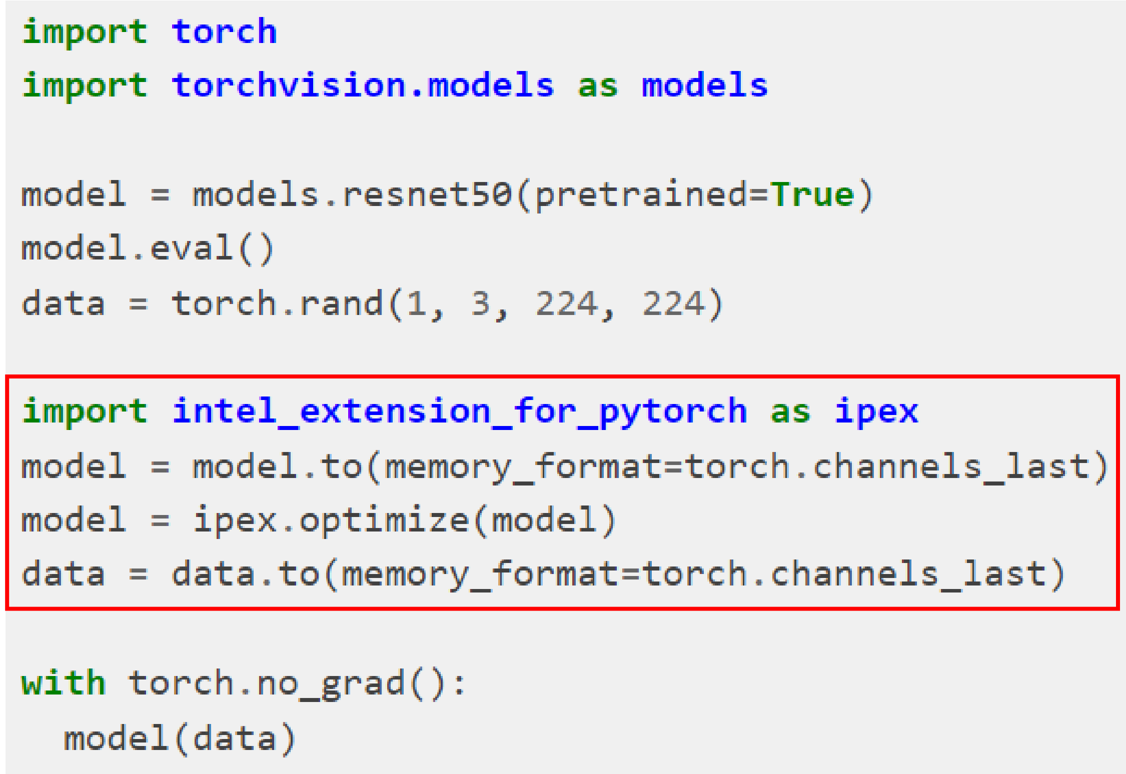
Optimal Optimizer

Mixed Precision

Auto Mixed Precision (AMP)

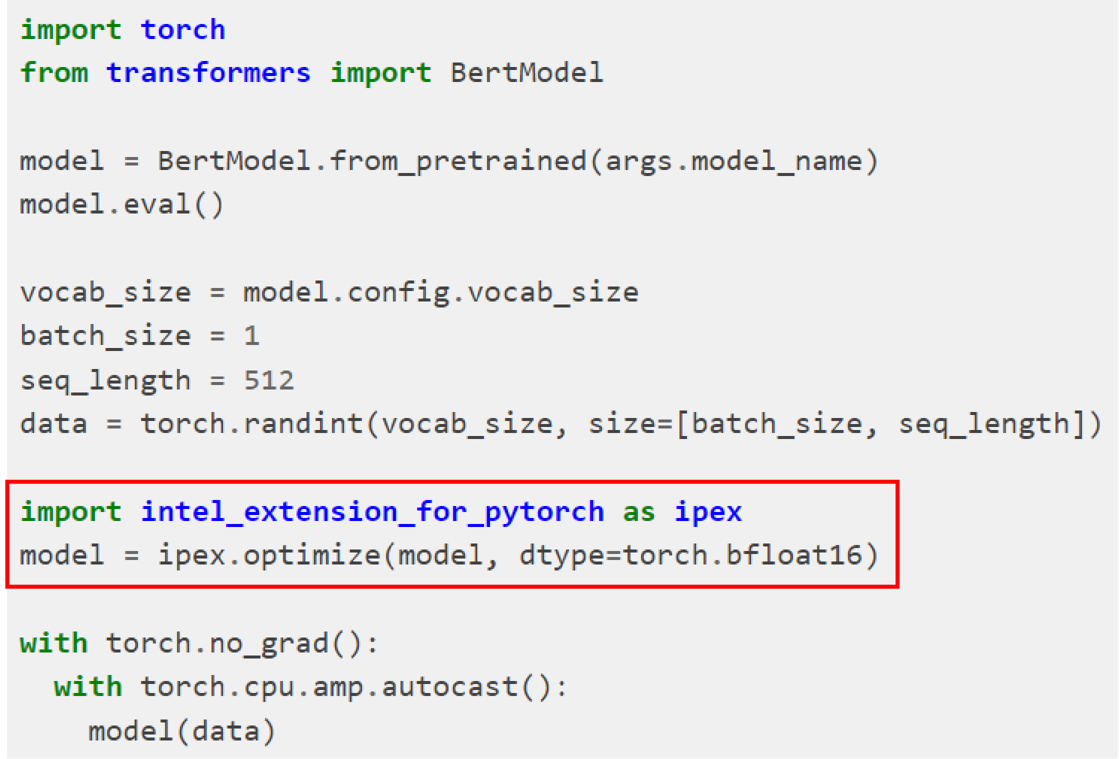
Python – Imperative Mode

- FP32



```
import torch
import torchvision.models as models

model = models.resnet50(pretrained=True)
model.eval()
data = torch.rand(1, 3, 224, 224)

import intel_extension_for_pytorch as ipex
model = model.to(memory_format=torch.channels_last)
model = ipex.optimize(model)
data = data.to(memory_format=torch.channels_last)

with torch.no_grad():
  model(data)
```

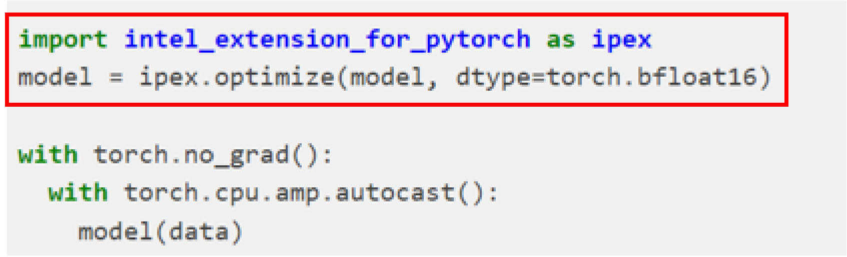
- BFloat16



```
import torch
from transformers import BertModel

model = BertModel.from_pretrained(args.model_name)
model.eval()

vocab_size = model.config.vocab_size
batch_size = 1
seq_length = 512
data = torch.randint(vocab_size, size=[batch_size, seq_length])

import intel_extension_for_pytorch as ipex
model = ipex.optimize(model, dtype=torch.bfloat16)

with torch.no_grad():
  with torch.cpu.amp.autocast():
    model(data)
```

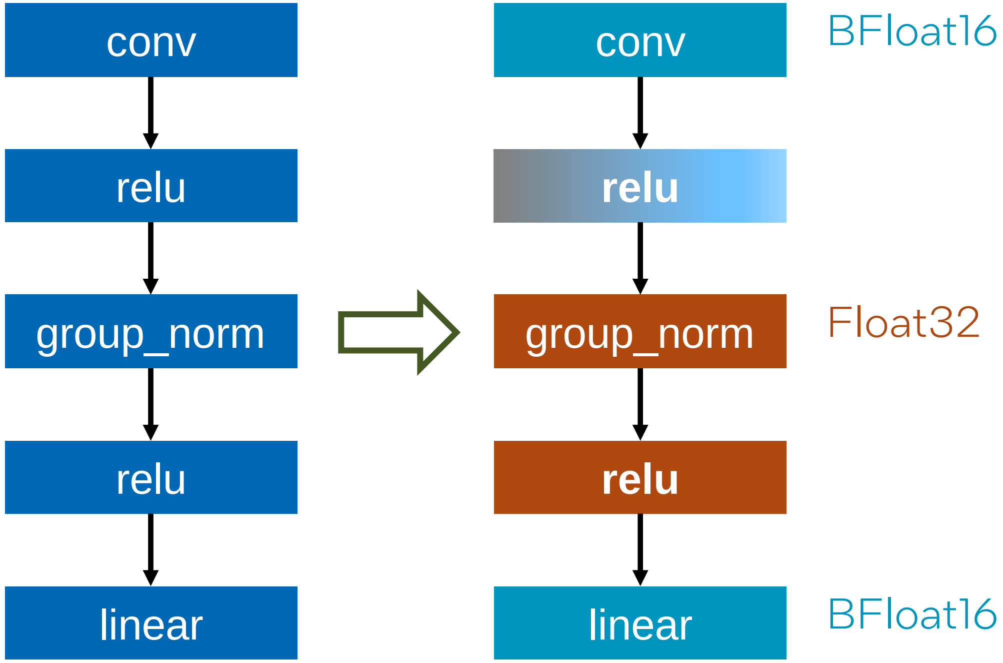
https://intel.github.io/intel-extension-for-pytorch/1.11.0/tutorials/examples.html

Auto Mixed Precision (AMP)

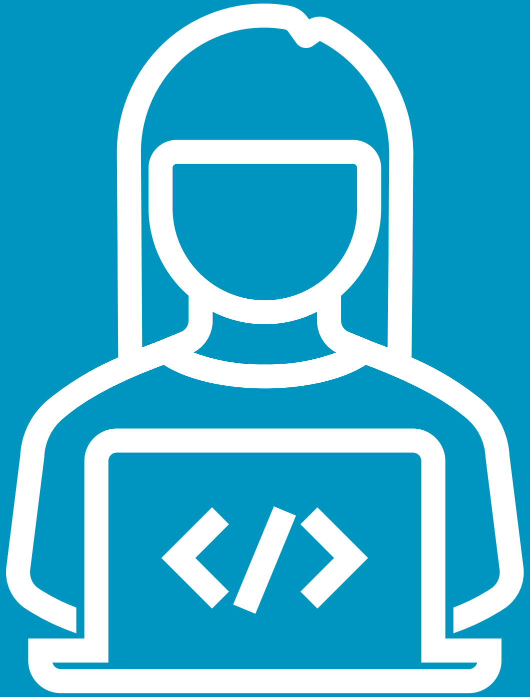


```
import intel_extension_for_pytorch as ipex
model = ipex.optimize(model, dtype=torch.bfloat16)

with torch.no_grad():
  with torch.cpu.amp.autocast():
    model(data)
```

- 3 Categories of operators
  - lower_precision_fp
    - Computation bound operators that could get performance boost with BFloat16.
    - E.g.: conv, linear
  - Fallthrough
    - Operators that runs with both Float32 and BFloat16 but might not get performance boost with BFloat16.
    - E.g.: relu, max_pool2d
  - FP32
    - Operators that are not enabled with BFloat16 support yet. Inputs of them are casted into float32 before execution.
    - E.g.: max_pool3d, group_norm



Demo with Intel Extension for PyTorch



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