ACES Tutorial for using Graphcore Intelligence Processing Units (IPUs) for AI/ML workflows

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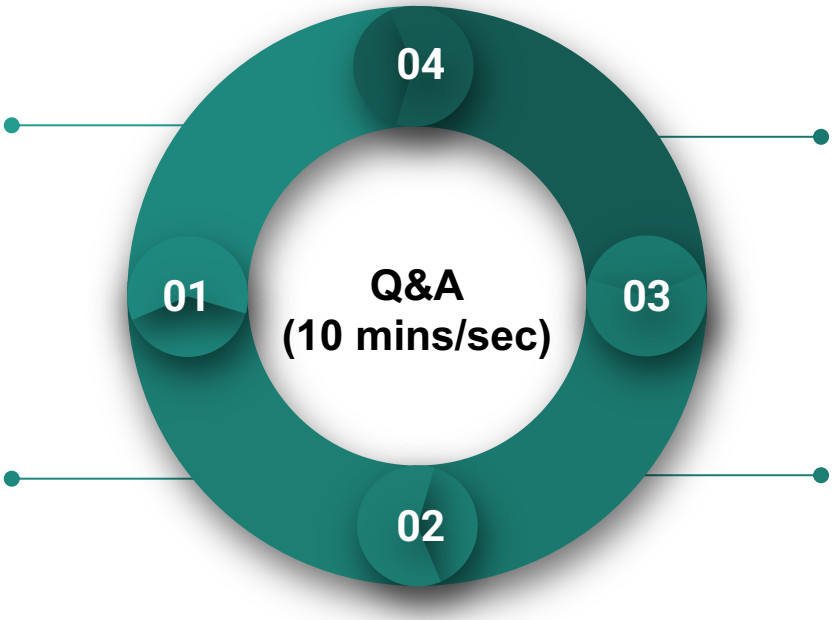
IPU Tutorial

Section I. Intro to IPUs

We will introduce Graphcore IPU architecture, and the IPU systems on TAMU ACES platform.

Section II. Demo on ACES

We will demonstrate how to run models of different frameworks on ACES IPU system.



Structure of the IPU Tutorial.

Section IV. Porting PyTorch code to IPU

We will learn to port a PyTorch Fashion-MNIST classification model to run on IPU

Section III Porting TensorFlow code to IPU

We will learn to port a Keras MNIST classification model to run on IPU

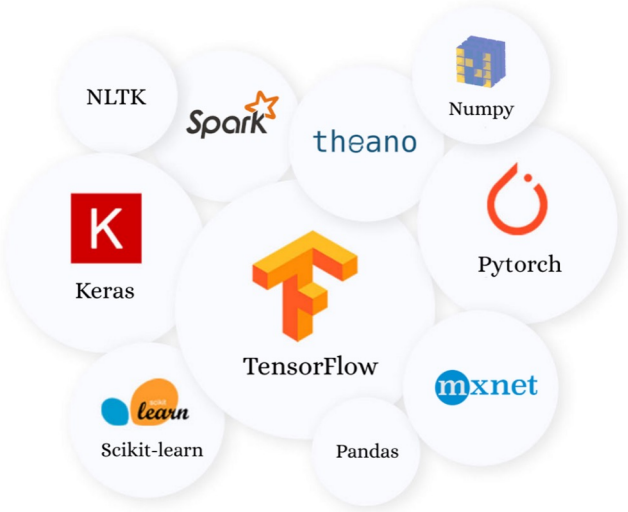
Section I. ACES and IPU Systems Overview

ACES

Accelerating Computing for Emerging Sciences

Mission:

- Offer an accelerator testbed for numerical simulations and **AI/ML**
- Provide consulting, technical guidance, and training to researchers
- Collaborate on computational and data-enabled research.



Credit: towardsdatascience.com

BOW IPU PROCESSOR

Deep Trench Capacitor

Efficient power delivery
Enables increase in operational performance

Wafer-On-Wafer

Advanced silicon 3D stacking technology

Closely coupled power delivery die

Higher operating frequency and enhanced overall performance

Solder Bumps

IPU-Links™

10x IPU-Links,
320GB/s chip to chip bandwidth

IPU-Exchange™

11 TB/s all to all IPU-Exchange™
Non-blocking, any communication pattern

PCIe

PCI Gen4 x16
64 GB/s bidirectional bandwidth to host

IPU-Tiles™

1472 independent IPU-Tiles™ each with an IPU-Core™ and In-Processor-Memory™

IPU-Core™

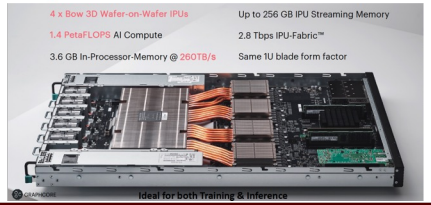
1472 independent IPU-Core™

8832 independent program threads executing in parallel

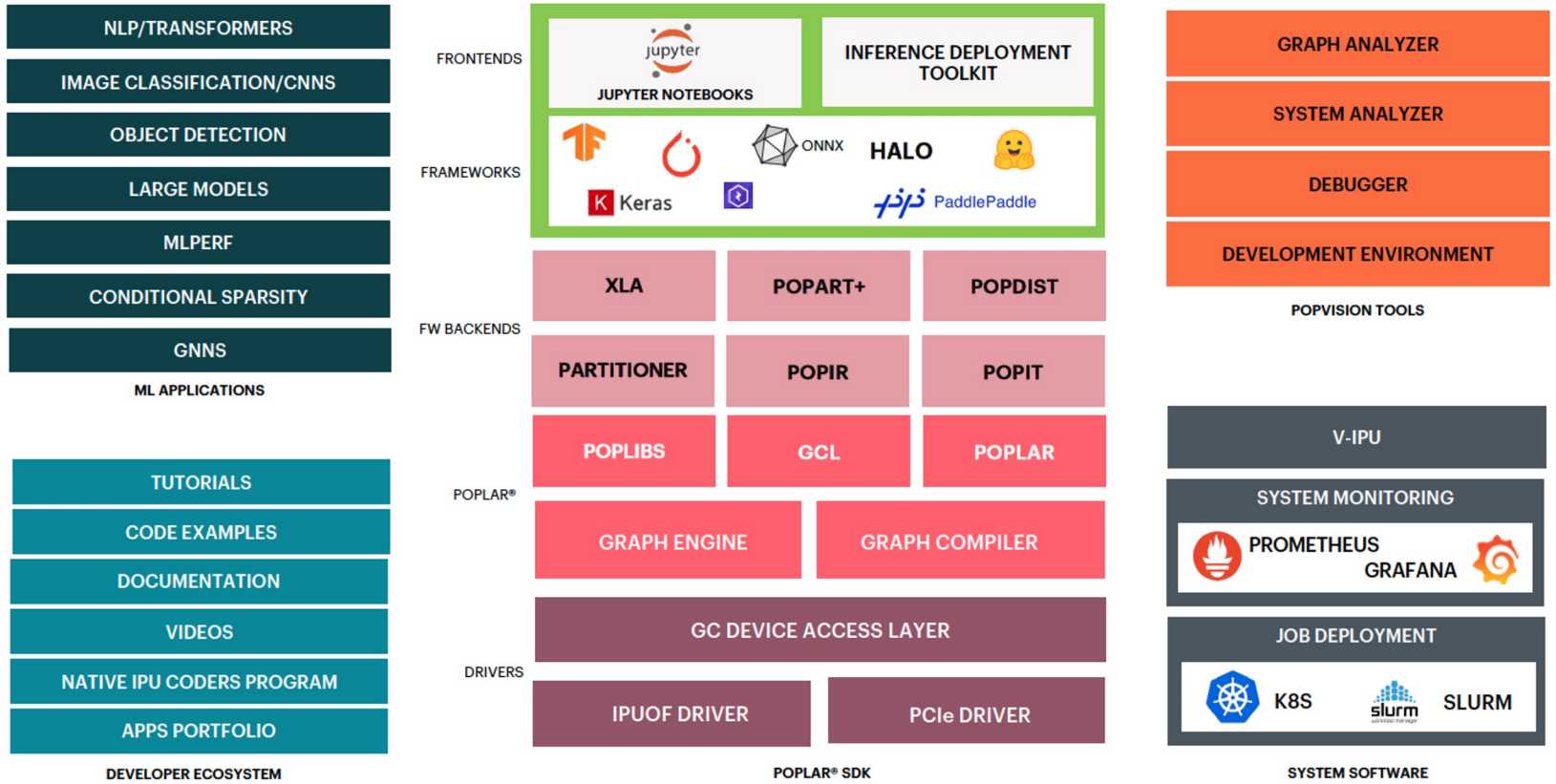
In-Processor-Memory™

900MB In-Processor-Memory™ per IPU

65.4TB/s memory bandwidth per IPU



Graphcore Software Stack



MODEL GARDEN COVERAGE

COMPUTER VISION

IMAGE CLASSIFICATION
- ResNet50 v1.5
- EfficientNet-B0
- EfficientNet-B4
- ResNeXt-101
- MobileNet v2
- MobileNet v3
- ViT
- DINO
- SWIN NEW
- MAE

OBJECT DETECTION
- YOLO v3
- YOLO v4
- Faster RCNN
- EfficientDet

OBJECT SEGMENTATION
- Unet (Industrial)
- Unet (Medical)

GNN
- TGN NEW
- MPNN-GIN NEW
- GPS++ NEW
- Distr. KGE NEW
- Cluster-GCN NEW
- SchNet NEW
- NBFNet NEW

AI FOR SIMULATION
- DeepMD
- DeepDriveMD
- ET0
- CosmoFlow
- ABC Covid-19

REINFORCEMENT
- RL
  Reinforcement Learning

PROBABILISTIC
- MCMC
- VAE

NLP
- BERT-Base
- BERT-Large
- Group | Packing
- GPT2
- GPT-J NEW
- RoBERTa
- Deberta
- BART
- T5
- Hubert
- DistilBERT NEW

SPEECH

STT (ASR)
- RNN-T
- Conformer

TTS
- DeepVoice3
- FastSpeech2
- FastPitch

RECOMMENDER
- Autoencoder
- DIN
- DIEN

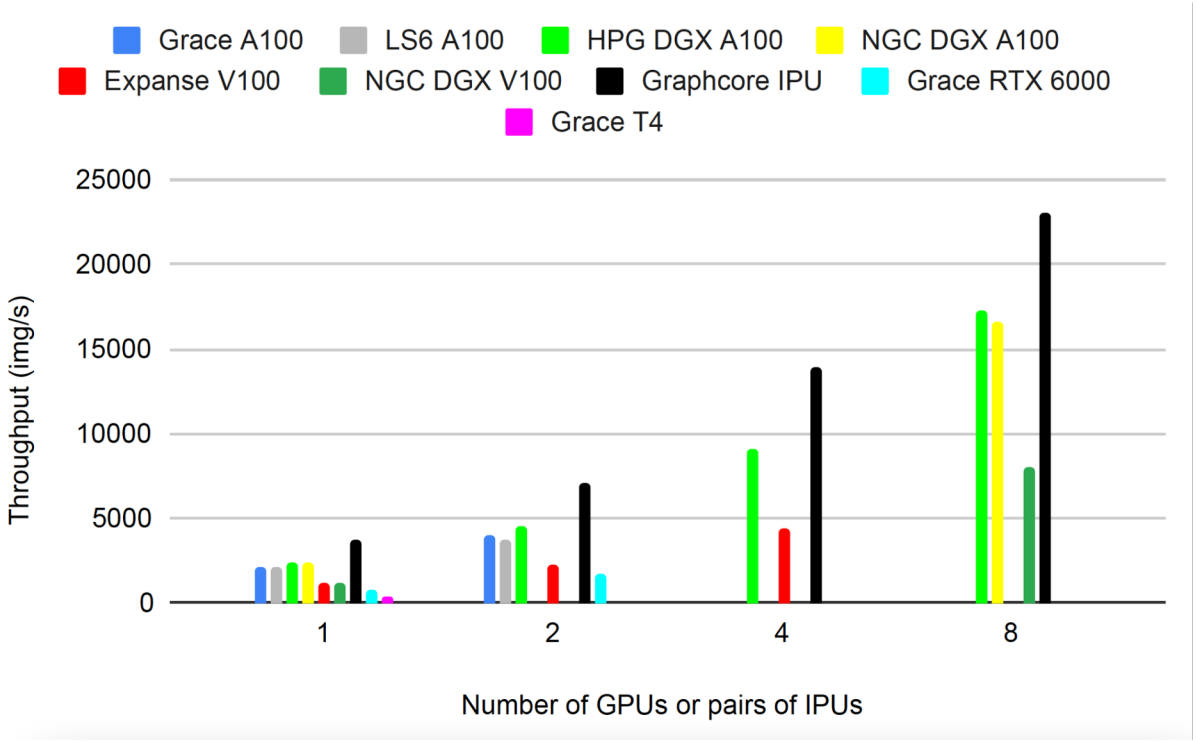
MULTIMODAL
- LXMERT
- CLIP
- Stable Diffusion NEW
- Mini DALL-E
- Frozen In Time NEW

OTHER
- Sales Forecast
- Neural Image Fields

PyG
PyTorch
TensorFlow
Hugging Face
Keras
PaddlePaddle
POPART

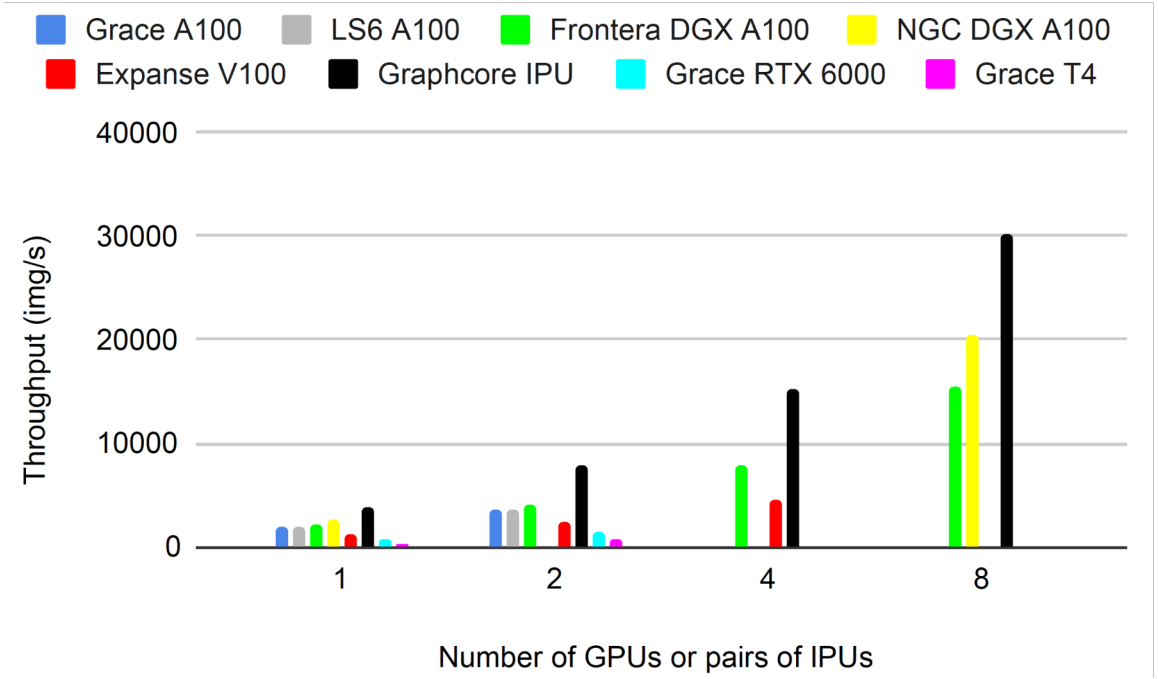
Paperspace

PyTorch ResNet50 - GPU vs IPU



Abhinand S. Nasari, Hieu T. Le, Richard Lawrence, Zhenhua He, Xin Yang, Mario M. Krell, Alex Tsyplikhin, Mahidhar Tatineni, Tim Cockerill, Lisa M. Perez, Dhruva K. Chakravorty and Honggao Liu. 2022. Benchmarking the Performance of Accelerators on National Cyberinfrastructure Resources for Artificial Intelligence / Machine Learning Workloads. In Practice and Experience in Advanced Research Computing (PEARC '22), July 10-14, 2022, Boston, MA, USA. ACM, New York, NY, USA, 13 Pages. https://doi.org/10.1145/3491418.3530772

TensorFlow ResNet50 - GPU vs IPU



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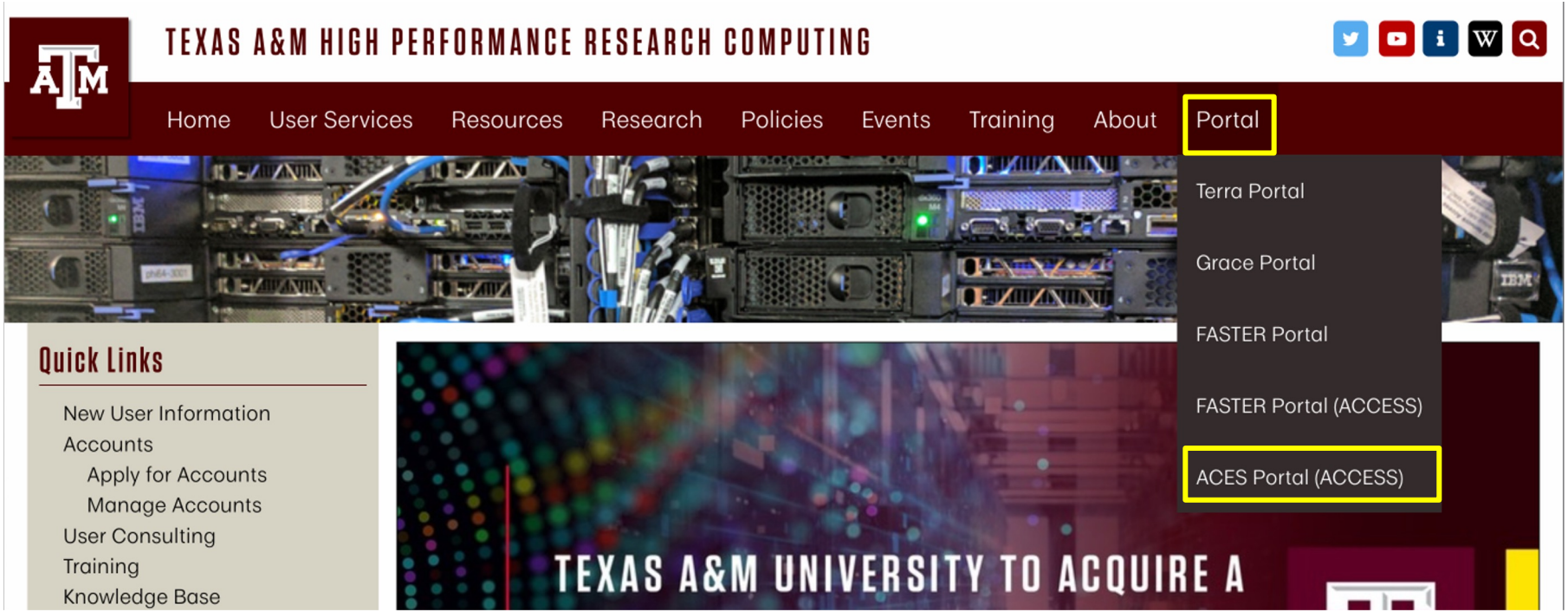
Section II. Demo on ACES

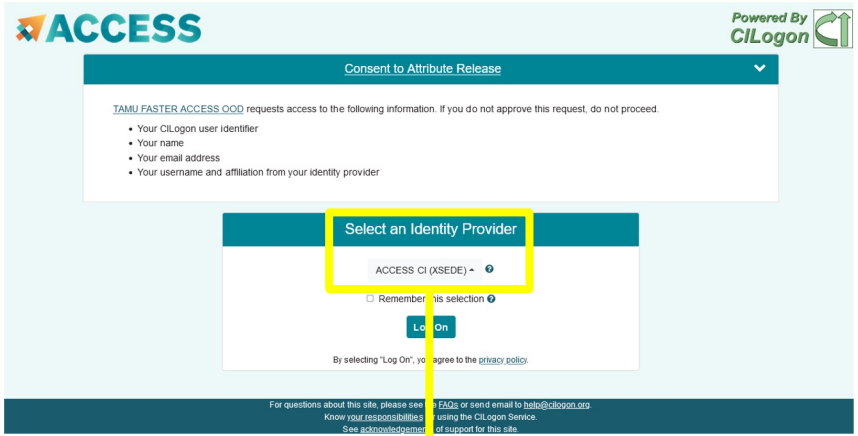
Log into ACES Using the HPRC Portal

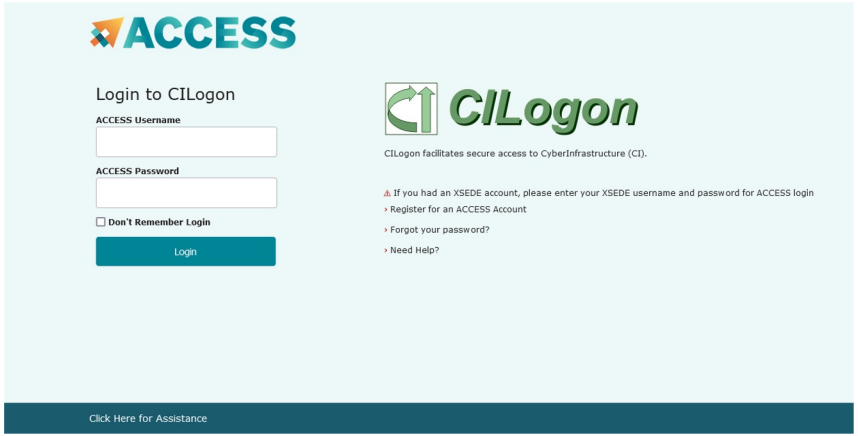
- HPRC webpage: https://hprc.tamu.edu/, Portal dropdown menu

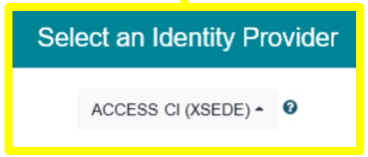


Accessing ACES via the ACES Portal (ACCESS)

Log-in using your ACCESS credentials.







Select the Identity Provider appropriate for your account.

Shell access via the HPRC Portal

Access through (most) web browsers

–Top Banner Menu “Clusters” -> “Shell Access”

ACES

ACCELERATING COMPUTING
FOR EMERGING SCIENCES

Training Materials

- From the ACES login node, ssh into the poplar2 (BOW Pod16) IPU system

```
ssh poplar2
```

- Change to your scratch directory:

```
cd $SCRATCH
```

- Copy the **example** materials to your scratch directory:

```
git clone https://github.com/graphcore/examples.git
```

- Copy the hands-on **exercise** materials to your scratch directory:

```
git clone https://github.com/happidence1/IPU-Training.git
```

Poplar SDK setup

```
source /opt/gc/poplar/poplar_sdk-ubuntu_20_04-3.3.0+1403-
208993bbb7/poplar-ubuntu_20_04-3.3.0+7857-
b67b751185/enable.sh

source /opt/gc/poplar/poplar_sdk-ubuntu_20_04-3.3.0+1403-
208993bbb7/popart-ubuntu_20_04-3.3.0+7857-
b67b751185/enable.sh

mkdir -p $SCRATCH/tmp
export TF_POPLAR_FLAGS=--executable_cache_path=$SCRATCH/tmp
export POPTORCH_CACHE_DIR=$SCRATCH/tmp
```

Run a TensorFlow (TF) model on IPU

TF Virtual Environment Setup

```
virtualenv -p python3 venv_tf2

source venv_tf2/bin/activate

python -m pip install -U pip

python -m pip install /opt/gc/poplar/poplar_sdk-
ubuntu_20_04-3.3.0+1403-208993bbb7/tensorflow-
2.6.3+gc3.3.0+251582+08d96978c7f+intel_skylake512-cp38-
cp38-linux_x86_64.whl
```

Run a TensorFlow model on IPU

```
cd examples/tutorials/tutorials/tensorflow2/keras/completed_demos/

python completed_demo_ipu.py
```

- Deactivate the virtual environment after the model finishes running.

```
deactivate
```

Monitor the IPU usage with gc-monitor command

```
watch -n 2
gc-monitor
```

```
Every 2.0s: gc-monitor                                  poplar2: Thu Jul  6 10:33:31 2023

+---------------+-----------------------------------------------------------------------------+
|  gc-monitor   |              Partition: p17 [active] has 16 reconfigurable IPUs             |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|    IPU-M    |       Serial      |IPU-M SW|Server version|  ICU FW  | Type  | ID | IPU# |Routing|
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|  10.5.5.1   | 0019.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 0  |  3   |  DNC  |
|  10.5.5.1   | 0019.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 1  |  2   |  DNC  |
|  10.5.5.1   | 0019.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 2  |  1   |  DNC  |
|  10.5.5.1   | 0019.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 3  |  0   |  DNC  |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|  10.5.5.2   | 0021.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 4  |  3   |  DNC  |
|  10.5.5.2   | 0021.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 5  |  2   |  DNC  |
|  10.5.5.2   | 0021.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 6  |  1   |  DNC  |
|  10.5.5.2   | 0021.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 7  |  0   |  DNC  |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|  10.5.5.3   | 0013.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 8  |  3   |  DNC  |
|  10.5.5.3   | 0013.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 9  |  2   |  DNC  |
|  10.5.5.3   | 0013.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 10 |  1   |  DNC  |
|  10.5.5.3   | 0013.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 11 |  0   |  DNC  |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|  10.5.5.4   | 0016.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 12 |  3   |  DNC  |
|  10.5.5.4   | 0016.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 13 |  2   |  DNC  |
|  10.5.5.4   | 0016.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 14 |  1   |  DNC  |
|  10.5.5.4   | 0016.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 15 |  0   |  DNC  |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+

+-------------------------------------------------------+----------------------+-----------------+
|          Attached processes in partition p17          |         IPU          |      Board      |
+---------+-------------------------+--------+----------+----+----------+--------+--------+--------+
|  PID    |         Command         |  Time  |   User   | ID |  Clock   |  Temp  |  Temp  | Power  |
+---------+-------------------------+--------+----------+----+----------+--------+--------+--------+
| 902631  |         python          |  50s   | u.zh108696 | 0  | 1500MHz  | 23.5 C | 21.9 C | 90.3 W |
+---------+-------------------------+--------+----------+----+----------+--------+--------+--------+
```

Run a PyTorch (PopTorch) model on IPU

PopTorch Virtual Environment Setup

```
cd $SCRATCH

virtualenv -p python3 poptorch_test

source poptorch_test/bin/activate

python -m pip install -U pip

python -m pip install /opt/gc/poplar/poplar_sdk-
ubuntu_20_04-3.3.0+1403-208993bbb7/poptorch-
3.3.0+113432_960e9c294b_ubuntu_20_04-cp38-cp38-
linux_x86_64.whl
```

Run a PopTorch model on IPU

```
cd $SCRATCH/examples/tutorials/simple_applications/pytorch/mnist/

pip install -r requirements.txt

python mnist_poptorch.py
```

- Deactivate the virtual environment after the model finishes running.

```
deactivate
```

Monitor the IPU usage with gc-monitor command

```
watch -n 2
gc-monitor
```

```
Every 2.0s: gc-monitor                                          poplar2: Thu Jul  6 10:55:55 2023

+-------------+-----------------------------------------------------------------------------------+
|  gc-monitor |                Partition: p17 [active] has 16 reconfigurable IPUs                 |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|    IPU-M    |       Serial      |IPU-M SW|Server version|  ICU FW  | Type  | ID | IPU# |Routing|
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|  10.5.5.1   | 0019.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 0  |  3   |  DNC  |
|  10.5.5.1   | 0019.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 1  |  2   |  DNC  |
|  10.5.5.1   | 0019.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 2  |  1   |  DNC  |
|  10.5.5.1   | 0019.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 3  |  0   |  DNC  |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|  10.5.5.2   | 0021.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 4  |  3   |  DNC  |
|  10.5.5.2   | 0021.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 5  |  2   |  DNC  |
|  10.5.5.2   | 0021.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 6  |  1   |  DNC  |
|  10.5.5.2   | 0021.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 7  |  0   |  DNC  |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|  10.5.5.3   | 0013.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 8  |  3   |  DNC  |
|  10.5.5.3   | 0013.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 9  |  2   |  DNC  |
|  10.5.5.3   | 0013.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 10 |  1   |  DNC  |
|  10.5.5.3   | 0013.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 11 |  0   |  DNC  |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+
|  10.5.5.4   | 0016.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 12 |  3   |  DNC  |
|  10.5.5.4   | 0016.0002.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 13 |  2   |  DNC  |
|  10.5.5.4   | 0016.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 14 |  1   |  DNC  |
|  10.5.5.4   | 0016.0001.8222521 | 2.6.0  |    1.11.0   |  2.5.9   | M2000 | 15 |  0   |  DNC  |
+-------------+-------------------+--------+-------------+----------+-------+----+------+-------+

+-----------------------------------------------------+-----------------+-----------------+
|          Attached processes in partition p17        |       IPU       |      Board      |
+---------+-----------------------+--------+----------+----+---------+---------+--------+---------+
|  PID    |        Command        |  Time  |   User   | ID |  Clock  |  Temp   |  Temp  |  Power  |
+---------+-----------------------+--------+----------+----+---------+---------+--------+---------+
| 907530  |        python         |  17s   | u.zh108696 | 0  | 1500MHz | 23.5 C | 22.0 C | 90.8 W |
+---------+-----------------------+--------+----------+----+---------+---------+--------+---------+
```

Hands-On Session 1

- Please access ACES and poplar2 now.
- Copy the tutorial materials to your scratch directory.
- Run the TensorFlow and PyTorch (PopTorch) example models on IPU

Section III. Porting TensorFlow Code to IPU

1. Import the TensorFlow IPU module

Add the following import statement to the beginning of your script:

```
from tensorflow.python import ipu
```

2. Preparing the dataset

- Make sure the sizes of the datasets are divisible by the batch size

```
def make_divisible(number, divisor):
    return number - number % divisor
```

- Adjust dataset lengths

```
(x_train, y_train), (x_test, y_test) = load_data()
train_data_len = x_train.shape[0]
train_data_len = make_divisible(train_data_len, batch_size)
x_train, y_train = x_train[:train_data_len], y_train[:train_data_len]
test_data_len = x_test.shape[0]
test_data_len = make_divisible(test_data_len, batch_size)
x_test, y_test = x_test[:test_data_len], y_test[:test_data_len]
```

3. Add IPU configuration

To use the IPU, you must create an IPU session configuration:

```
ipu_config = ipu.config.IPUConfig()
ipu_config.auto_select_ipus = 1
ipu_config.configure_ipu_system()
```

A full list of configuration options is available in the API documentation.

4. Specify IPU strategy

```
strategy = ipu.ipu_strategy.IPUStrategy()
```

The `tf.distribute.Strategy` is an API to distribute training and inference across multiple devices. `IPUStrategy` is a subclass which targets a system with one or more IPUs attached.

5. Wrap the model within the IPU strategy scope

- Creating variables and Keras models within the scope of the `IPUStrategy` object will ensure that they are placed on the IPU.
- To do this, we create a `strategy.scope()` context manager and move all the model code inside it.

Hands-on Session 2

- Activate the TF virtual environment

  cd $SCRATCH

  source venv_tf2/bin/activate

- Change directory to Keras

  cd IPU-Training/Keras

- Complete the **#Todo**s in the mnist-ipu-todo.py file.
- Run it in the **venv_tf2** virtual environment.

  python mnist-ipu-todo.py

- After finishing the job, you can deactivate the virtual environment

  deactivate

Section IV. Porting PyTorch Code to IPU

PopTorch

- PopTorch is a set of extensions for PyTorch released by Graphcore to enable PyTorch models to run on Graphcore's IPU hardware.

- PopTorch will use PopART to parallelise the model over the given number of IPUs. Additional parallelism can be expressed via a replication factor, which enables you to data-parallelise the model over more IPUs.

Training a model on IPU

- Import the packages

```
import torch
import poptorch
import torchvision
import torch.nn as nn
import matplotlib.pyplot as plt
from tqdm import tqdm
from sklearn.metrics import accuracy_score
```

Load the data

PopTorch offers an extension of `torch.utils.data.DataLoader` class with its `poptorch.DataLoader` class, specialized for the way the underlying PopART framework handles batching of data.

Build the model

```
class ClassificationModel(nn.Module):
    def __init__(self):
        super().__init__()
        self.conv1 = nn.Conv2d(1, 5, 3)
        self.pool = nn.MaxPool2d(2, 2)
        self.conv2 = nn.Conv2d(5, 12, 5)
        self.norm = nn.GroupNorm(3, 12)
        self.fc1 = nn.Linear(972, 100)
        self.relu = nn.ReLU()
        self.fc2 = nn.Linear(100, 10)
        self.log_softmax = nn.LogSoftmax(dim=1)
        self.loss = nn.NLLLoss()
```

```
def forward(self, x, labels=None):
        x = self.pool(self.relu(self.conv1(x)))
        x = self.norm(self.relu(self.conv2(x)))
        x = torch.flatten(x, start_dim=1)
        x = self.relu(self.fc1(x))
        x = self.log_softmax(self.fc2(x))
        # The model is responsible for the
calculation of the loss when using an IPU. We do
it this way:
        if self.training:
            return x, self.loss(x, labels)
        return x


model = ClassificationModel()
model.train()
```

Prepare training for IPUs

The compilation and execution on the IPU can be controlled using `poptorch.Options`. These options are used by PopTorch's wrappers such as `poptorch.DataLoader` and `poptorch.trainingModel`.

```
opts = poptorch.Options()
train_dataloader = poptorch.DataLoader(
    opts, train_dataset, batch_size=16, shuffle=True, num_workers=20
)
```

Train the model

```
optimizer = poptorch.optim.SGD(model.parameters(), lr=0.001, momentum=0.9)

poptorch_model = poptorch.trainingModel(model, options=opts,
optimizer=optimizer)

epochs = 30
for epoch in tqdm(range(epochs), desc="epochs"):
    total_loss = 0.0
    for data, labels in tqdm(train_dataloader, desc="batches", leave=False):
        output, loss = poptorch_model(data, labels)
        total_loss += loss

poptorch_model.detachFromDevice()

torch.save(model.state_dict(), "classifier.pth")
```

Evaluate the model

```
model = model.eval()

poptorch_model_inf = poptorch.inferenceModel(model, options=opts)

test_dataloader = poptorch.DataLoader(opts, test_dataset, batch_size=32,
num_workers=10)

predictions, labels = [], []
for data, label in test_dataloader:
    predictions += poptorch_model_inf(data).data.max(dim=1).indices
    labels += label

poptorch_model_inf.detachFromDevice()

print(f"Eval accuracy: {100 * accuracy_score(labels,
predictions):.2f}%")
```

Hands-on Session 3

- Activate the TF virtual environment

  cd $SCRATCH

  source poptorch_test/bin/activate

- Change directory to PyTorch

  cd IPU-Training/PyTorch

- Complete the **#Todo**s in the fashion-mnist-pytorch-ipu-todo.py file.
- Run it in the **poptorch_test** virtual environment.

  pip install scikit-learn

  python fashion-mnist-pytorch-ipu-todo.py

- After finishing the job, you can deactivate the virtual environment

  deactivate

References

- https://www.graphcore.ai/
- https://github.com/graphcore/examples/tree/v3.2.0/tutorials/tutorials/tensorflow2/keras
- https://github.com/graphcore/examples/tree/v3.2.0/tutorials/tutorials/pytorch/basics
- https://hprc.tamu.edu/wiki/Main_Page

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Help us help you. Please include details in your request for support, such as, Cluster (ACES, Faster, Grace, Terra, ViDaL), Job information (Job id(s), Location of your jobfile, input/output files, Application, Module(s) loaded, Error messages, etc), and Steps you have taken, so we can reproduce the problem.