Orchestrating a brighter world

NEC

SOL: Transparent Neural Network Acceleration on NEC SX-Aurora TSUBASA

Dr. Nicolas Weber (NEC Labs Europe)

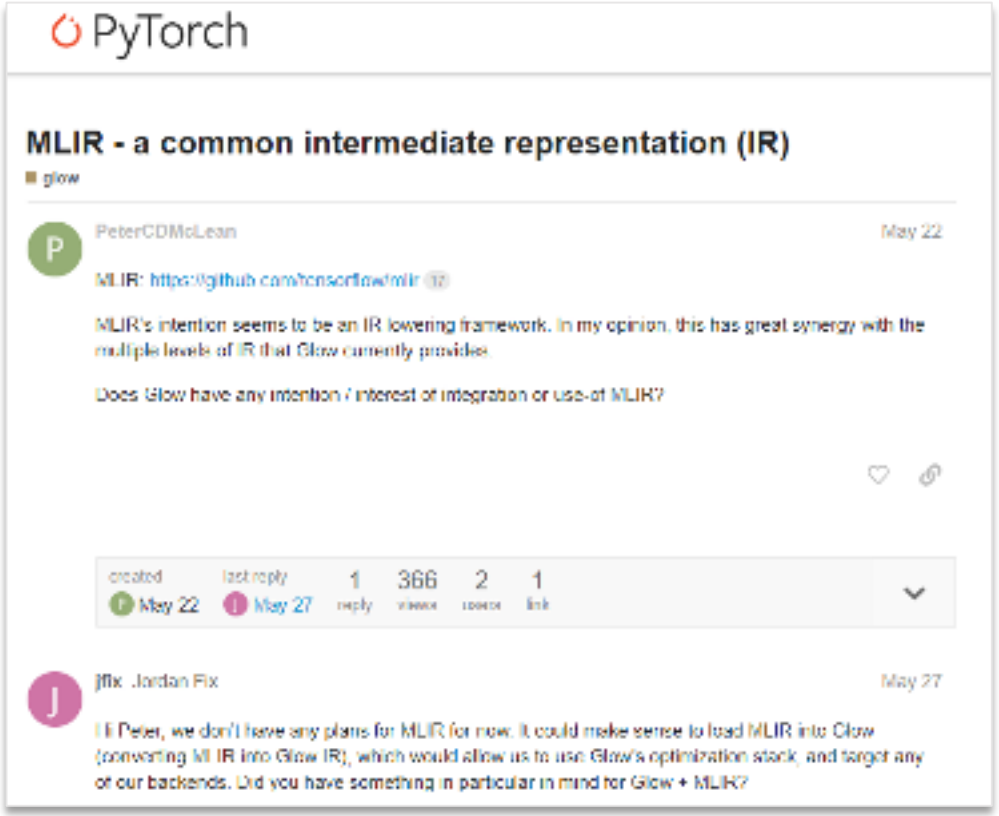
Where to start?

Integration into existing frameworks is expensive

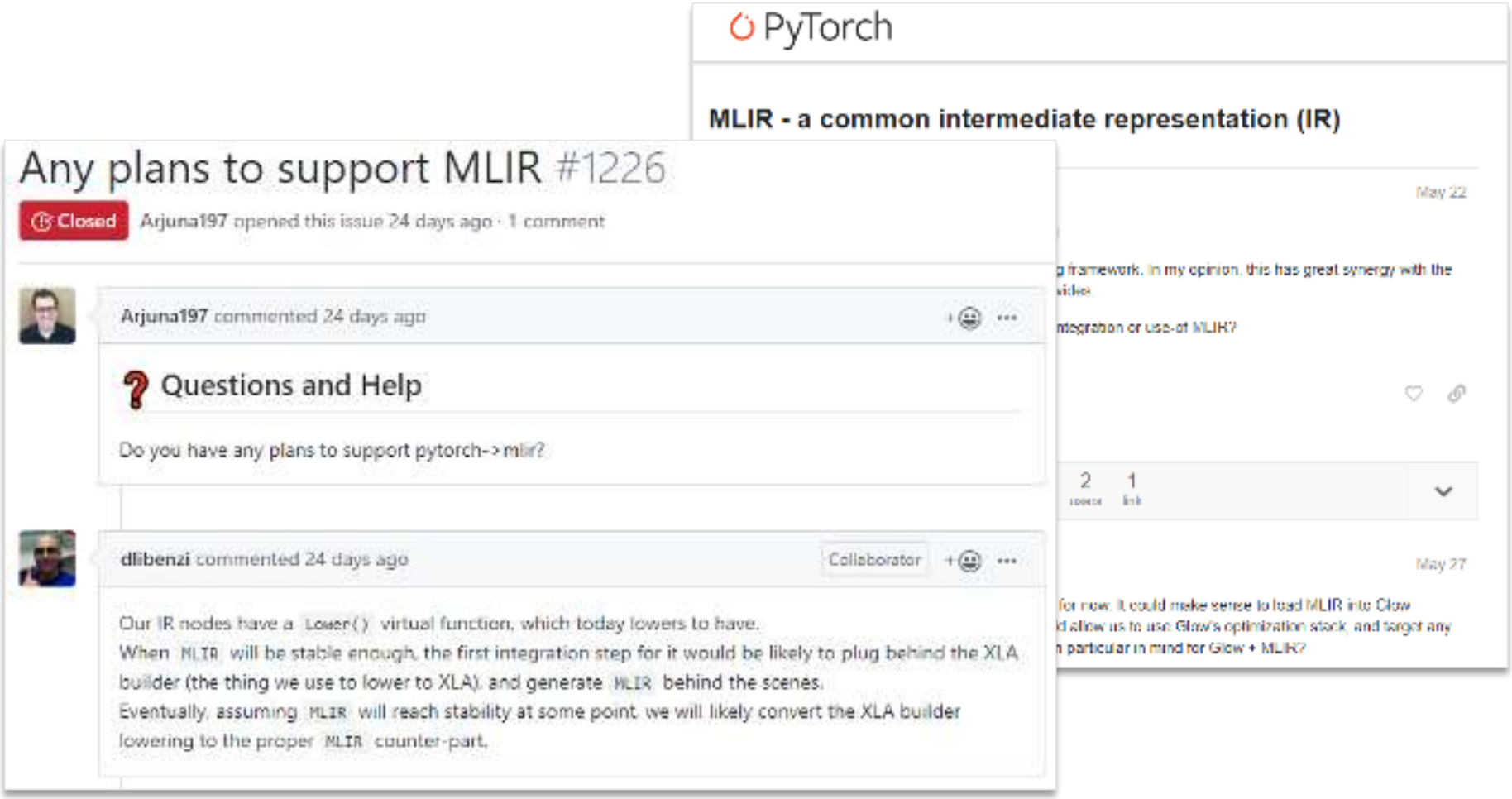
Each framework has its own internal and external APIs

- No common code base
- Approaches such as MLIR, ONNX, DLPack, … not widely adopted or very limited

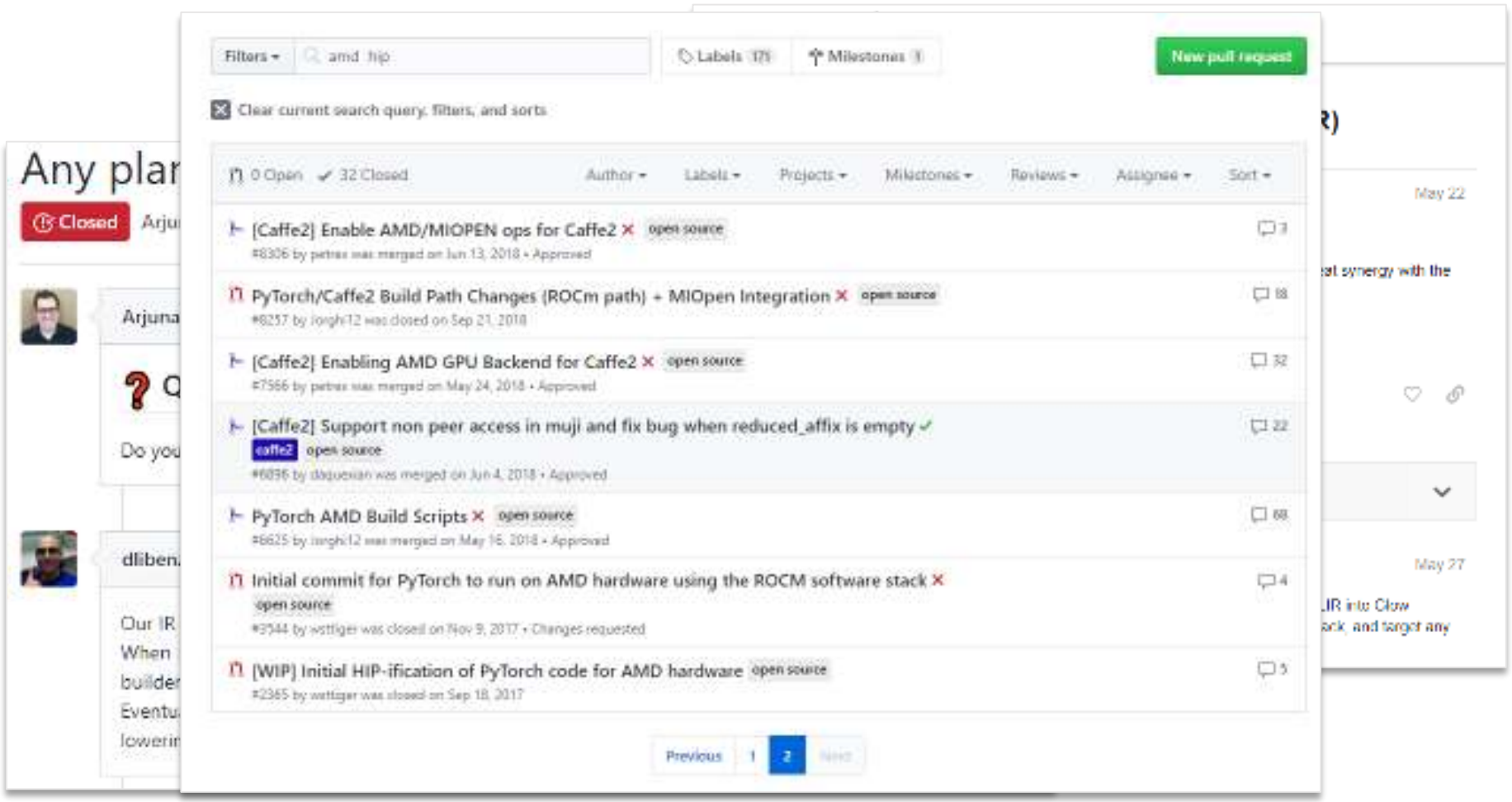
Integration into existing frameworks is expensive



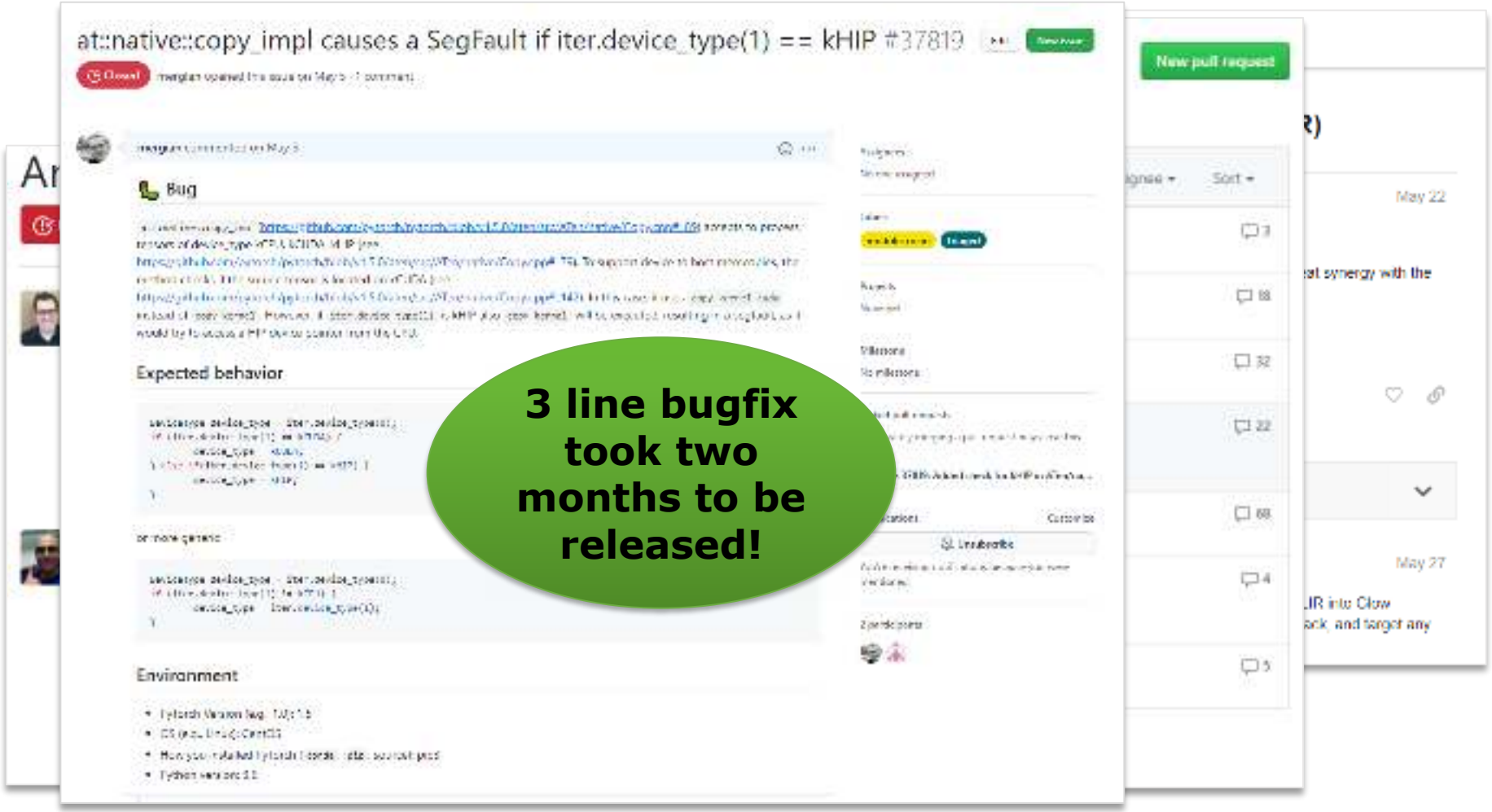
Integration into existing frameworks is expensive



Integration into existing frameworks is expensive



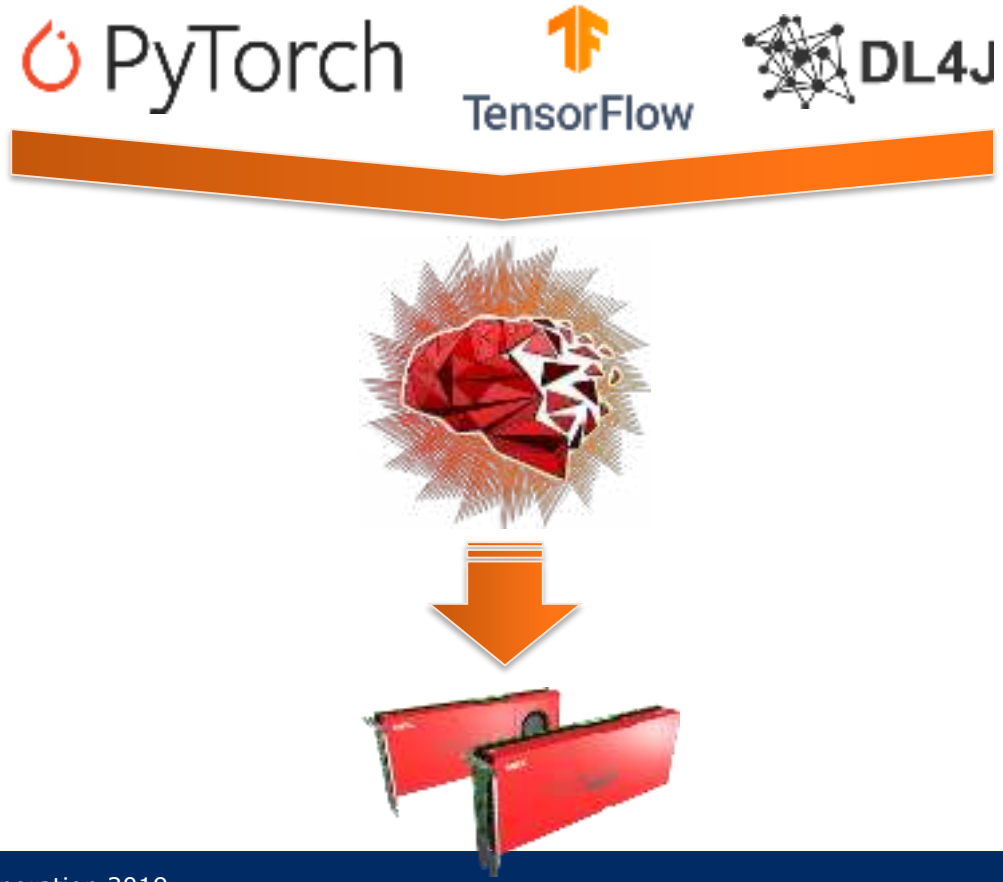
Integration into existing frameworks is expensive



The SOL-Project

SOL is a full stack AI acceleration middleware

- Add-on to AI frameworks that does not require any code changes to the framework
- Optimizations range from mathematical/algorithmic down to actual implementations/code generation



SOL in a nutshell

What data scientists see:

```
x = Conv(x, kernel=1x1, bias=True)
x = ReLU(x)
x = AvgPooling(x, kernel=13x13)
```

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SOL in a nutshell

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```
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x = ReLU(x)
x = AvgPooling(x, kernel=13x13)
```

What HPC people see:

```
function(Conv):
    for(Batch, OutChannel, Y, X):
        for(InChannel, KernelY, KernelX):
            output[…] += input[…] * weight[…]
        output[…] += bias[…]

function(ReLU):
    for(Batch, OutChannel, Y, X):
        output[…] = max(0, input[…])

function(AvgPooling):
    for(Batch, OutChannel, Y, X):
        for(KernelY, KernelX):
            output[…] += input[…] / (13*13)
```

SOL in a nutshell (continued)

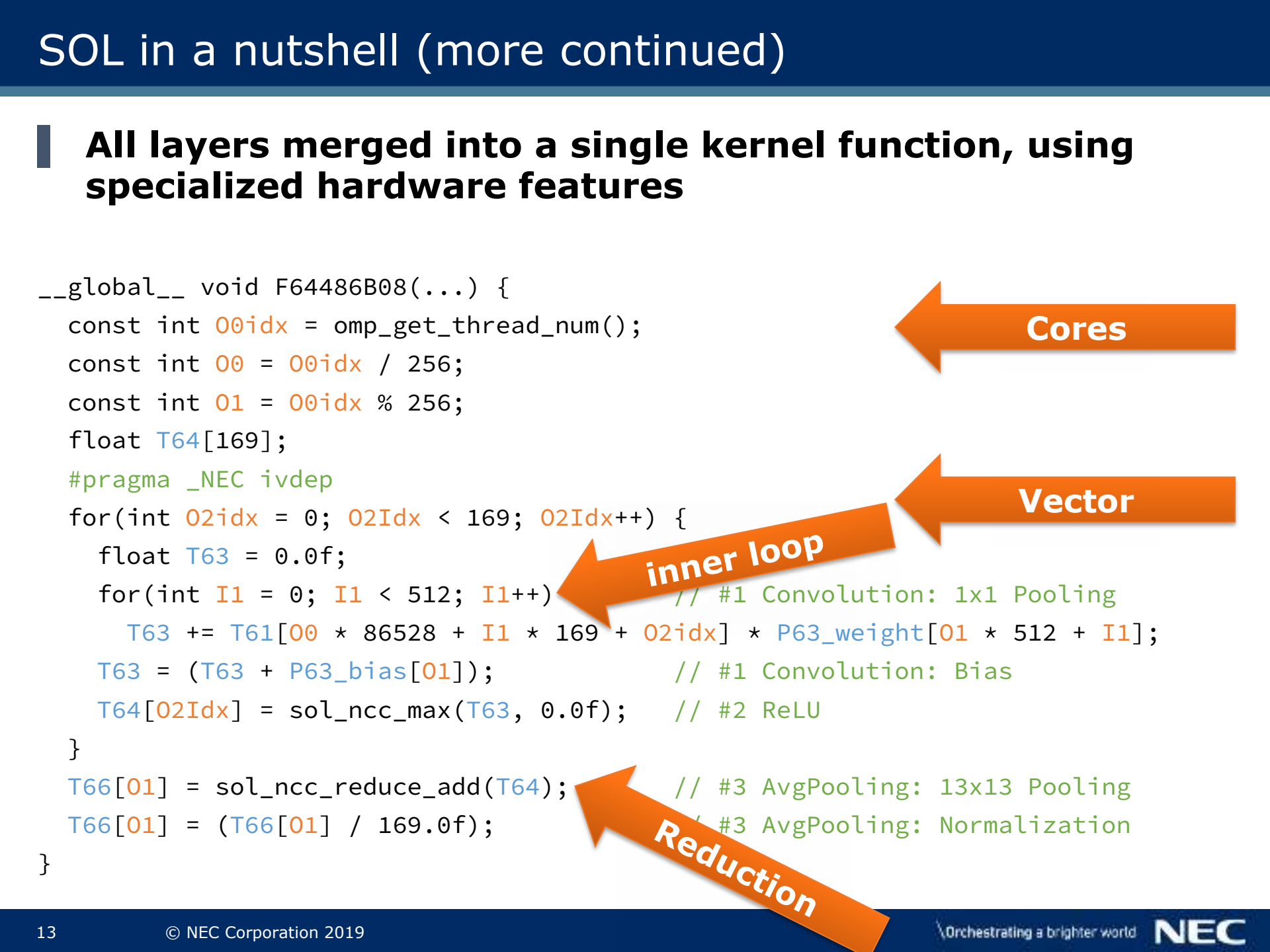
What we actually want:

```
function(FusedNetwork):
  for(Batch, OutChannel):
    float N[…]
    for(Y, X):
        for(InChannel, KernelY, KernelX):
            N[…] += input[…] * weight[…]
        N[…] += bias[…]
        N[…] = max(0, X)
    for(Y, X):
        for(KernelY, KernelX):
            output[…] += N[…] / (13*13)
```

SOL in a nutshell (more continued)

All layers merged into a single kernel function, using specialized hardware features

```
__global__ void F64486B08(...) {
  const int O0idx = omp_get_thread_num();
  const int O0 = O0idx / 256;
  const int O1 = O0idx % 256;
  float T64[169];
  #pragma _NEC ivdep
  for(int O2idx = 0; O2Idx < 169; O2Idx++) {
    float T63 = 0.0f;
    for(int I1 = 0; I1 < 512; I1++)
      T63 += T61[O0 * 86528 + I1 * 169 + O2idx] * P63_weight[O1 * 512 + I1];
    T63 = (T63 + P63_bias[O1]);              // #1 Convolution: Bias
    T64[O2Idx] = sol_ncc_max(T63, 0.0f);     // #2 ReLU
  }
  T66[O1] = sol_ncc_reduce_add(T64);         // #3 AvgPooling: 13x13 Pooling
  T66[O1] = (T66[O1] / 169.0f);              // #3 AvgPooling: Normalization
}
```



SOL Usage (PyTorch)

```
import torch
from torchvision import models


py_model  = models.__dict__[“…”]()
input     = torch.rand(1, 32, 224, 224)

output    = py_model(input)
```

SOL Usage (PyTorch)

```
import torch
from torchvision import models
import sol.pytorch as sol

py_model  = models.__dict__["…"]()
input     = torch.rand(1, 32, 224, 224)
sol_model = sol.optimize(py_model, input)
output    = sol_model(input)
```

How SOL integrates into the frameworks?

- SOL injects its optimized code as custom model into the framework

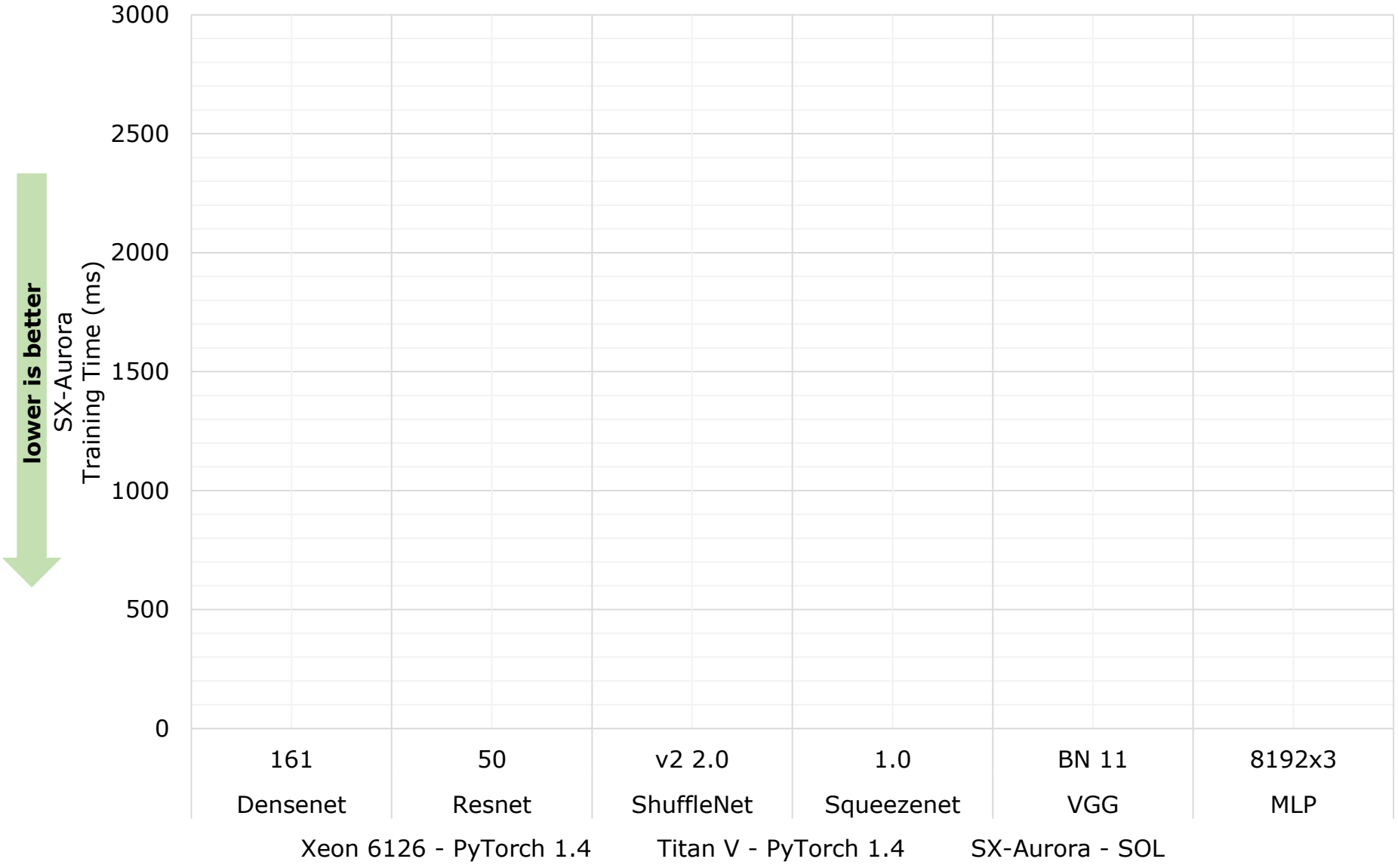
```
class SolLayer(torch.nn.Module):
      def  __init__(self):
            self.ParamA = …
            self.ParamB = …

      def forward(self, X):
            return sol.run(X, self.ParamA, self.ParamB)
```

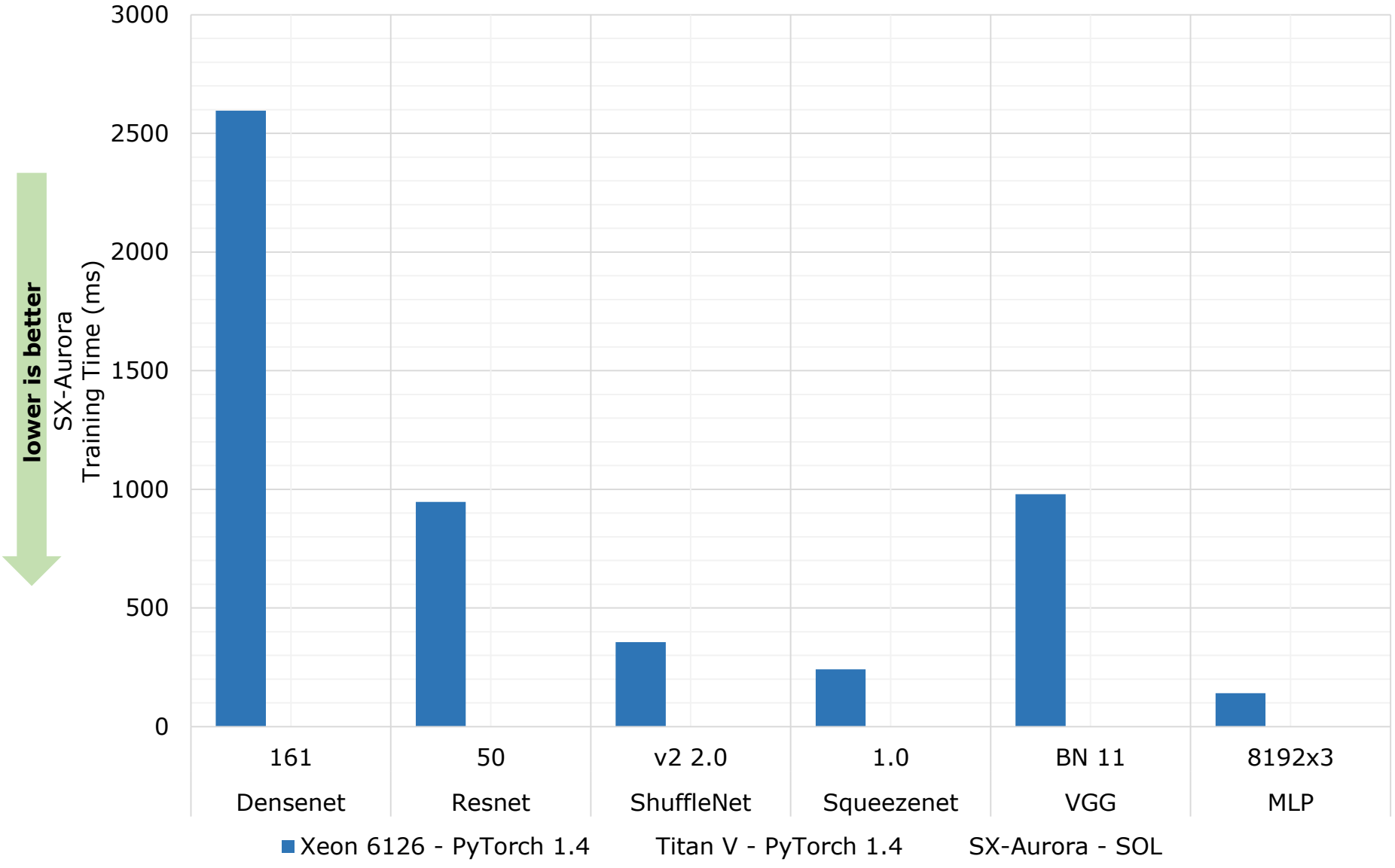
framework handles model parameters!

SOL handles execution

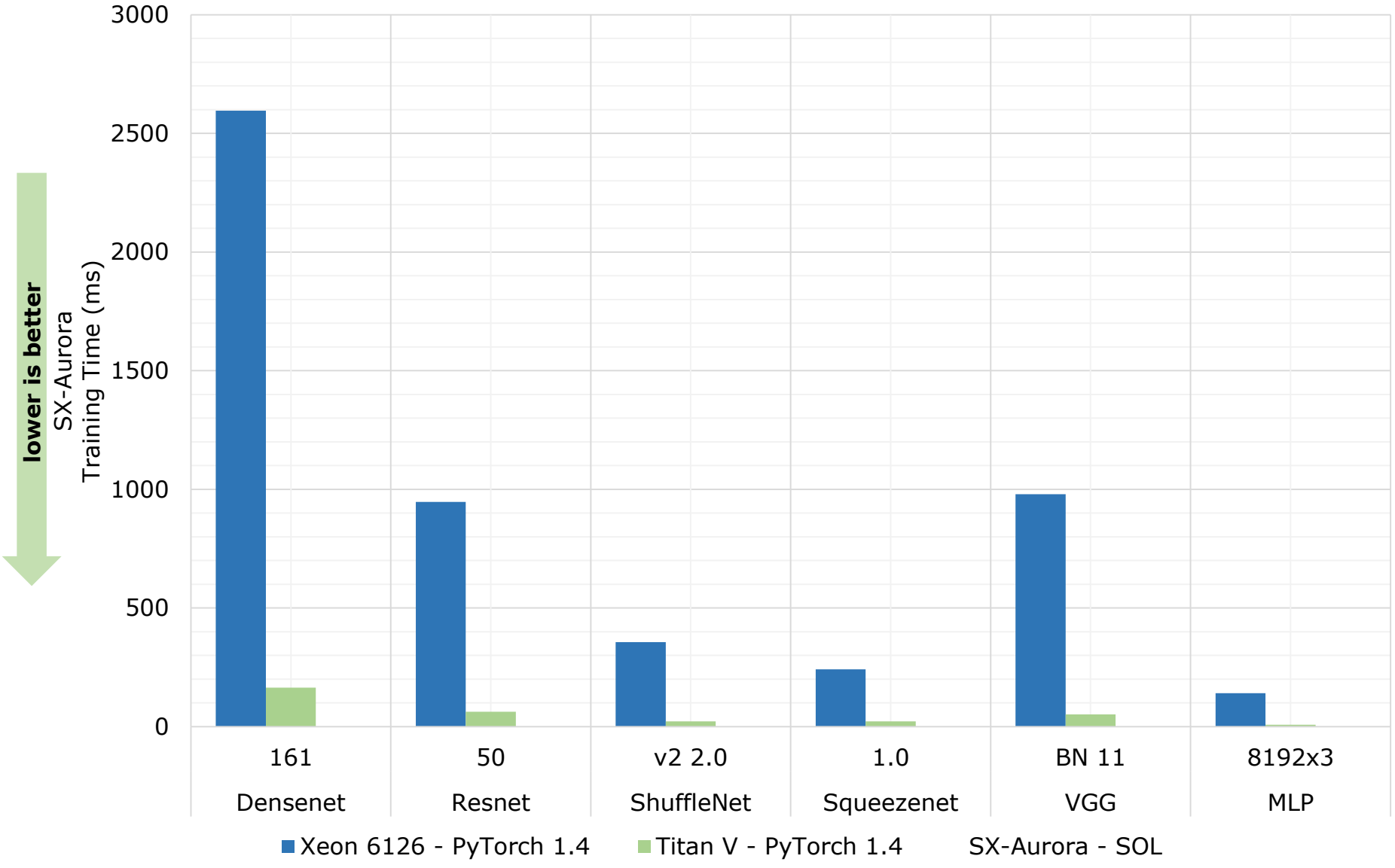
Training Performance (CNN BS=16, MLP BS=64, FP32)



Training Performance (CNN BS=16, MLP BS=64, FP32)

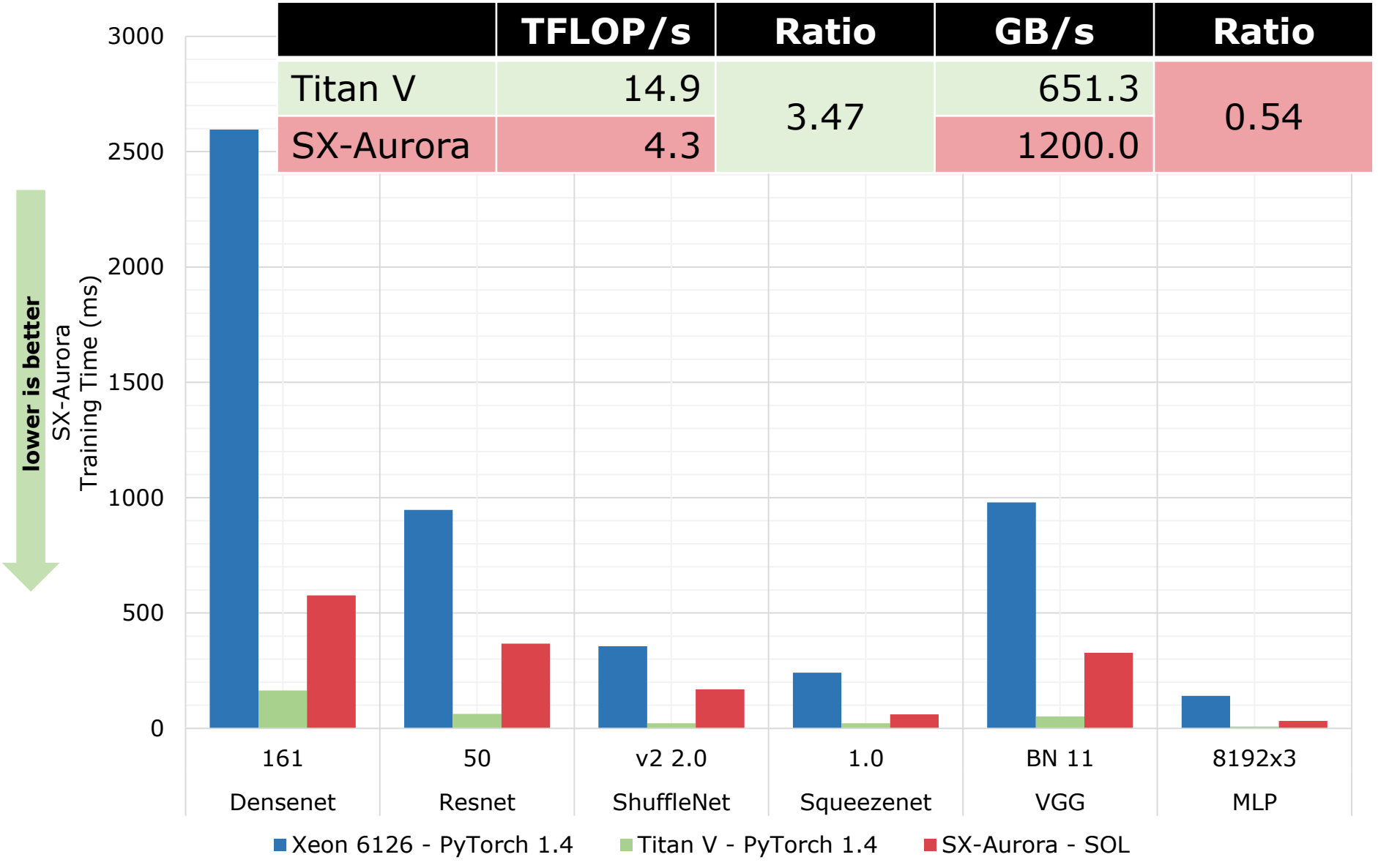


Training Performance (CNN BS=16, MLP BS=64, FP32)

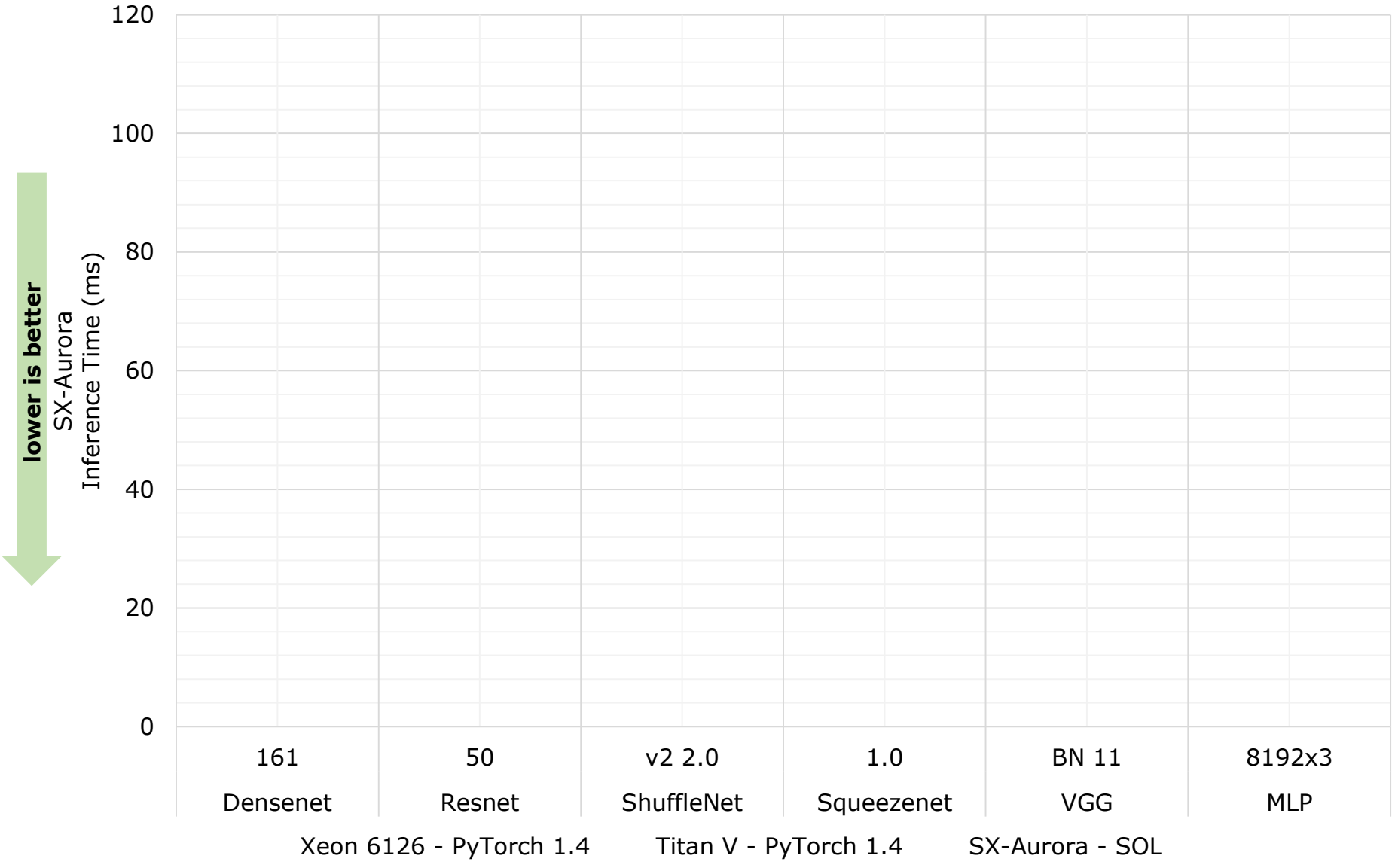


Training Performance (CNN BS=16, MLP BS=64, FP32)

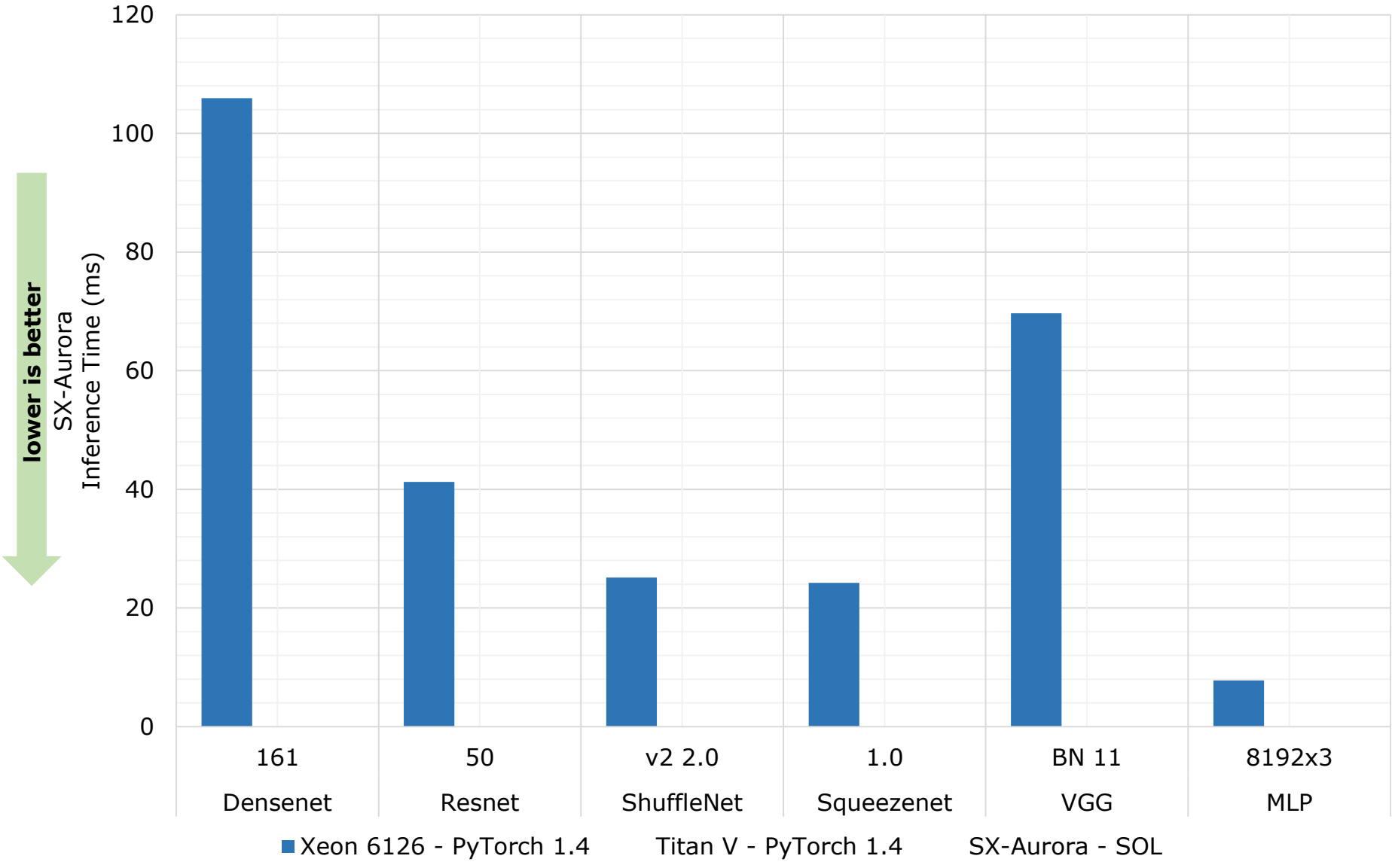
	TFLOP/s	Ratio	GB/s	Ratio
Titan V	14.9	3.47	651.3	0.54
SX-Aurora	4.3		1200.0	



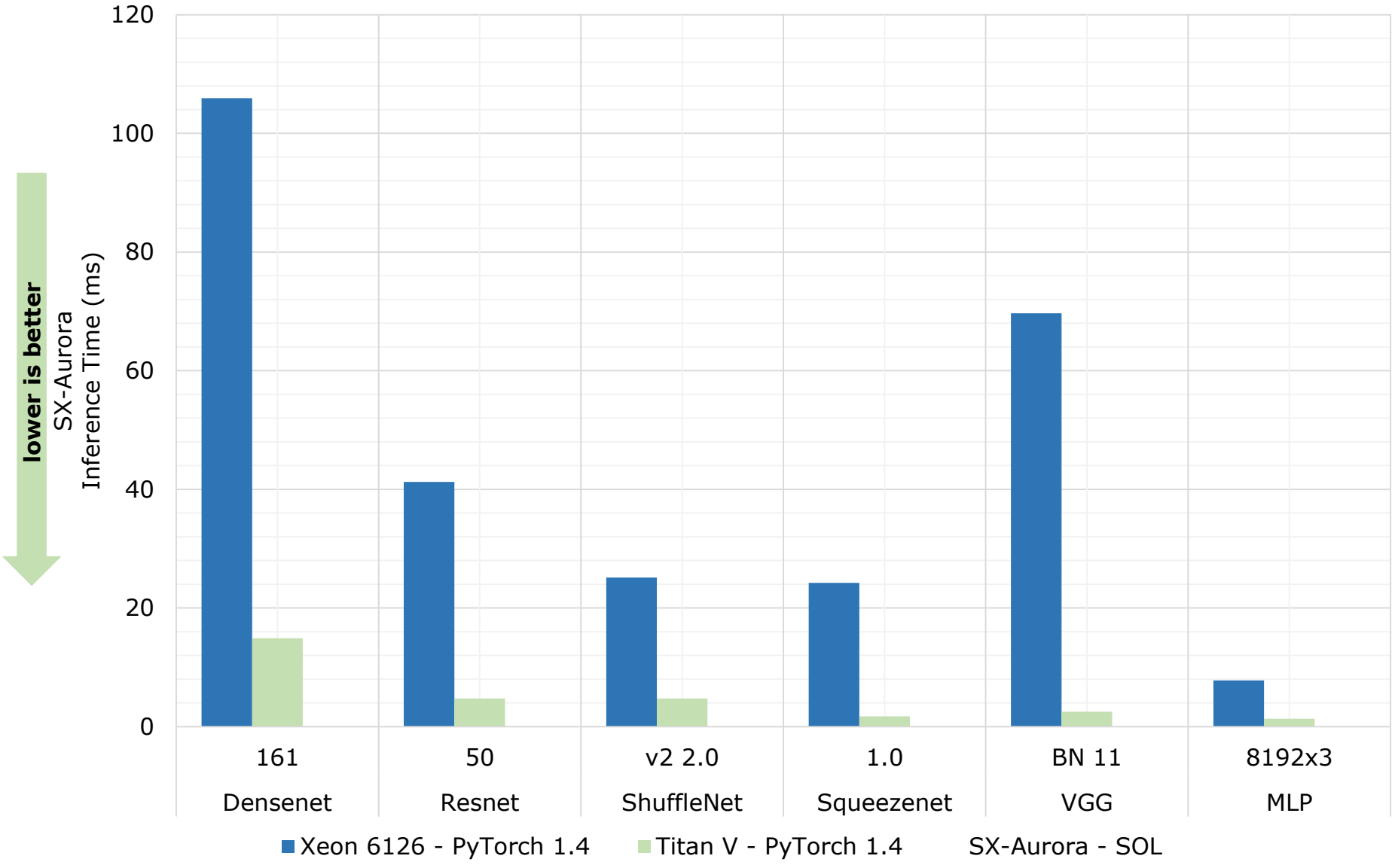
Inference Performance (BS=1, FP32)



Inference Performance (BS=1, FP32)



Inference Performance (BS=1, FP32)



Inference Performance (BS=1, FP32)

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Titan V	14.9	3.47	651.3	0.54
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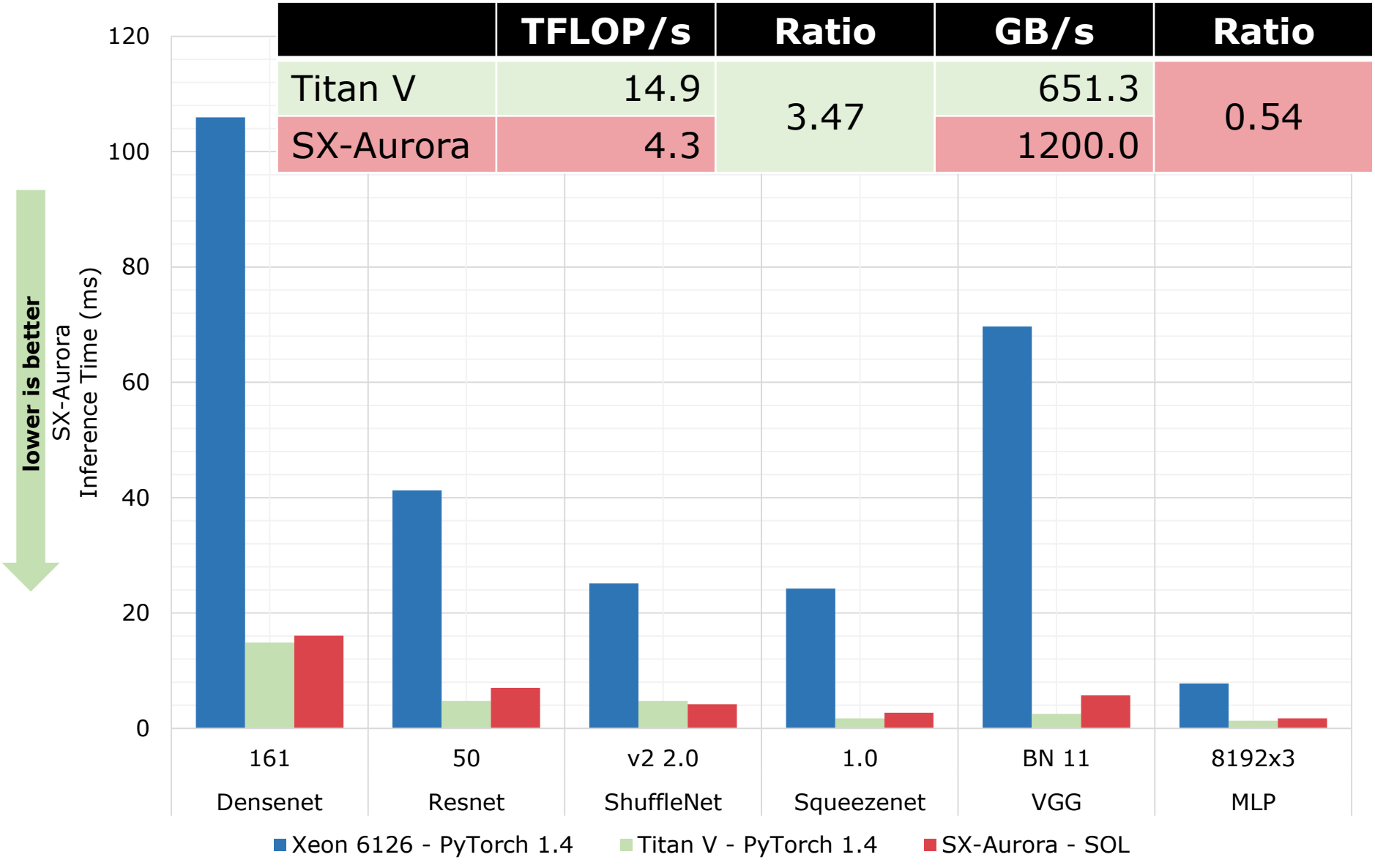

How to use DNN in my own software?

Again, dozen of available tools…

- TF-Lite
- LibTorch
- ONNXRuntime
- OpenVino (only Intel)
- NGraph
- TVM
- TensorRT (only NVIDIA)
- SOL
- …

How to use DNN in my own software?

```
sol.deploy(trained_model, [input],
target=sol.deployment.shared_lib, device=sol.device.ve,
lib_name="MyNetwork", func_name="predict", …)
```

```
#ifndef __MyNetwork__
#define __MyNetwork__

#ifdef __cplusplus
extern "C" {
#endif

void predict_init(const int deviceIdx);
int  predict_seed(const int seed);
void predict     (void* ctx, const float* input, float** output);

#ifdef __cplusplus
}
#endif
#endif
```

SOL RoadMap

Status Quo:

- PyTorch and ONNX
- CNN, MLP, Transformer, …
- Training, Inference, Deployment
- …

SOL RoadMap: Tested Neural Networks

Convolutional Neural Networks

- Alexnet
- SqueezeNet (1.0, 1.1)
- VGG + BN (11, 13, 16, 19)
- Resnet (18, 34, 50, 101, 152)
- Densenet (121, 161, 169, 201)
- Inception V3
- GoogleNet
- MobileNet (v1, v2)
- MNasNet (0.5, 0.75, 1.0, 1.3)
- ShuffleNet V2 (0.5, 1.0, 1.5, 2.0)
- ResNext (50, 101)
- WideResNet (50, 101)

Multi Layer Perceptron (MLP)

Linear/Logistic Regression

Natural Language Processing

- BERT (PyTorchic + HuggingFace implemenations)
- *GPT-2 (in upcoming v0.3.0 release)*
- *LSTM+GRU (coming in Q4 2020)*

SOL RoadMap

Status Quo:

- PyTorch and ONNX
- CNN, MLP, Transformer, …
- Training, Inference, Deployment
- …

2020:

- DL4J (October)
- TensorFlow v2 (December)
- Recurrent Neural Networks (LSTM, GRU)
- torch.nn.DataParallel support for PyTorch

2021:

- Adjustable memory consumption during training (trading memory vs performance)
- User defined Custom Layers
- Algorithmic and internal code optimizations to improve performance
- NumPY support

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Frovedis

presented by Dr. Erich Focht, NEC-D

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Basics on SOL

How to install

`pip3 install sol-0.2.7.2-py3-none-any.whl`

- enforces installation of dependencies

Coming in v0.3.0

- `pip3 install sol-0.3.0-py3-none-any.whl[torch, onnx]`
  - optional installation of dependencies (i.e. if you do not need support for all frameworks, etc.)

SOL Vocabular

Rest of the World	SOL
Layer	Layer
Tensor	Tensor
Model/Neural Network	Model
Fused Layers	Cluster
Framework	Frontend
Device	Device
Compute Library/Compiler	Backend

SOL Interface

Importing SOL:

- `import sol.pytorch as sol`

SOL Devices

- `sol.devices()`

```
################################################################################

SOL Device Dump:
    X86 CPUs
       *[x86:0] Intel(R) Xeon(R) Gold 6126 CPU @ 2.60GHz, 12 cores
    NEC SX-Aurora Vector Engine
       *[ve:0] NEC SX-Aurora Tsubasa VE10l, Firmware: 5399, 8 cores

################################################################################
```

```
################################################################################

SOL Device Dump:
    X86 CPUs
       *[x86:0] Intel(R) Xeon(R) Gold 6126 CPU @ 2.60GHz, 12 cores
    NEC SX-Aurora Vector Engine
       *[ve:0] NEC SX-Aurora Tsubasa VE10l, Firmware: 5399, 8 cores, 24B/48.00G

################################################################################
```

star indicates default device

activated device

currently used memory

SOL Versions

`sol.versions()`

```
################################################################################

SOL Version Dump:
    AVEO          0.9.12
    DNNL          1.6.0
    GraphVIZ      2.30.1
    ISPC          1.14.1
    Linux         CentOS Linux 7 (Core), 3.10.0-1127.13.1.el7.x86_64
    MKL           2020.0.1
    NEC NAR       2.26.20160125
    NEC NC++      3.0.28
    NEC NLD       2.26.20160125
    NNPACK        bundled
    OneTBB        2020_U3
    PyTorch       1.6.0
    Python        3.6.9
    SOL           0.3.0, Betelgeuse
    SQLite        3.32.3
    VEASL         2.1.0
    VEBLAS        2.1.0
    VEDA          linked: 0.9.3, loaded: 0.9.3
    VEDNN         bundled
    VEOS          2.5.0
    X86 GCC AR    2.30
    X86 GCC G++   8.3.1
    X86 GCC GCC   8.3.1
    X86 GCC LD    2.30

################################################################################
```

SOL Seed

Print Seeds:

- `sol.seeds()`

```
################################################################################

SOL Seed Dump: (0x5F71BC4C / 1601289292)
    X86 CPUs (0x5F71BC4C / 1601289292)
    [x86:0]  0x00000000 / 0
    NEC SX-Aurora Vector Engine (0x5F71BC4C / 1601289292)
    [ve:0]  0x5F71BC4C / 1601289292

################################################################################
```

3 Types of Seeds:

- Global (all devices)
- DeviceType (all devices of same type)
- Device (a specific device)

Get seed:

- `sol.seed(deviceType=None, deviceIdx=None)`
- `sol.seed(deviceType=sol.device.ve, deviceIdx=None)`
- `sol.seed(deviceType=sol.device.ve, deviceIdx=0)`

Set seed:

- `sol.set_seed(seed, deviceType=None, deviceIdx=None)`
- `sol.set_seed(seed, deviceType=sol.device.ve, deviceIdx=None)`
- `sol.set_seed(seed, deviceType=sol.device.ve, deviceIdx=0)`

Debugging

```
sol.config[“compiler::name”] = “Prefix Used for Debugging Output”
```

C/C++ device code generated in .sol/ve/source

- Might not be obvious to read

```
sol.config[“compiler::debug”] = True
```

- Compiles with debug symbols
- Prints execution times of fused layers
- Outputs visualized NN in .sol/debug/ subfolder
- Requires: GraphViz (Dot)

Debugging

`sol.config["compiler::debug"] = True`

- Prints execution times of fused layers

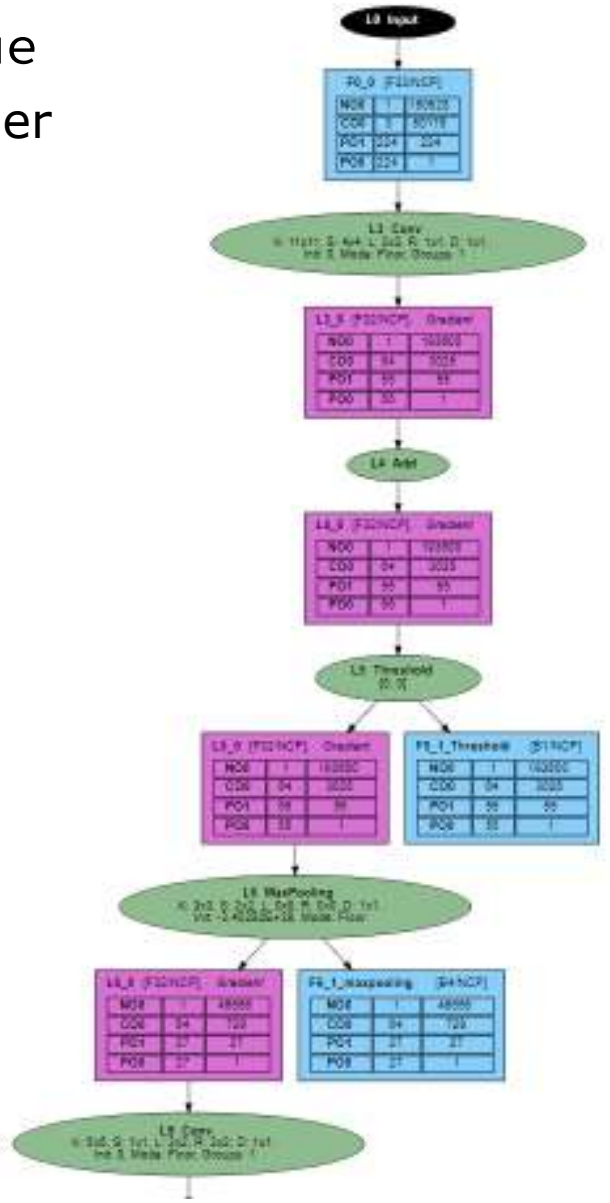
```
ve_0EAE7ED7_vednn_FI_385          76.912 us
ve_0EAE7ED7_ncc_FI_38B             0.500 us
ve_0EAE7ED7_vednn_FI_38E           0.029 us
ve_0EAE7ED7_ncc_FI_394             0.020 us
ve_0EAE7ED7_vednn_FI_3A0           0.039 us
ve_0EAE7ED7_ncc_FI_481             0.036 us
ve_0EAE7ED7_vednn_FI_397           0.025 us
ve_0EAE7ED7_ncc_FI_47E             0.037 us
ve_0EAE7ED7_vednn_FI_3A9           0.033 us
ve_0EAE7ED7_ncc_FI_3AF             0.019 us
ve_0EAE7ED7_vednn_FI_3BB           0.038 us
ve_0EAE7ED7_ncc_FI_487             0.036 us
ve_0EAE7ED7_vednn_FI_3B2           0.023 us
ve_0EAE7ED7_ncc_FI_404             0.037 us
ve_0EAE7ED7_ncc_FI_3C4             0.038 us
ve_0EAE7ED7_vednn_FI_3C7           0.022 us
ve_0EAE7ED7_ncc_FI_3CD             0.017 us
ve_0EAE7ED7_vednn_FI_3D9           0.037 us
ve_0EAE7ED7_ncc_FI_48D             0.025 us
ve_0EAE7ED7_vednn_FI_3D0           0.022 us
ve_0EAE7ED7_ncc_FI_48A             0.025 us
ve_0EAE7ED7_vednn_FI_3E2           0.026 us
ve_0EAE7ED7_ncc_FI_3E8             0.017 us
ve_0EAE7ED7_vednn_FI_3F4           0.035 us
ve_0EAE7ED7_ncc_FI_493             0.025 us
ve_0EAE7ED7_vednn_FI_3EB           0.023 us
ve_0EAE7ED7_ncc_FI_490             0.025 us
ve_0EAE7ED7_ncc_FI_3FD             0.021 us
ve_0EAE7ED7_vednn_FI_400           0.024 us
ve_0EAE7ED7_ncc_FI_406             0.015 us
ve_0EAE7ED7_vednn_FI_412           0.032 us
ve_0EAE7ED7_ncc_FI_499             0.018 us
ve_0EAE7ED7_vednn_FI_409           0.022 us
ve_0EAE7ED7_ncc_FI_496             0.018 us
ve_0EAE7ED7_vednn_FI_41B           0.024 us
ve_0EAE7ED7_ncc_FI_421             0.015 us
ve_0EAE7ED7_vednn_FI_42D           0.032 us
```

Index of /v0.2.7.2/.sol/ve/src/

../		
ve_0EAE7ED7.h	28-Sep-2020 12:57	2763
ve_0EAE7ED7_BT.cpp	28-Sep-2020 12:57	20K
ve_0EAE7ED7_BT.o	28-Sep-2020 12:57	81K
ve_0EAE7ED7_FI.cpp	28-Sep-2020 12:57	14K
ve_0EAE7ED7_FI.o	28-Sep-2020 12:57	75K
ve_0EAE7ED7_FT.cpp	28-Sep-2020 12:57	14K
ve_0EAE7ED7_FT.o	28-Sep-2020 12:57	76K
ve_0EAE7ED7_ve.cpp	28-Sep-2020 12:57	1054
ve_0EAE7ED7_ve.o	28-Sep-2020 12:57	26K
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_38D.cpp	28-Sep-2020 12:57	2511
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_38D.o	28-Sep-2020 12:57	52K
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_396.cpp	28-Sep-2020 12:57	1889
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_396.o	28-Sep-2020 12:57	44K
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3B1.cpp	28-Sep-2020 12:57	1912
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3B1.o	28-Sep-2020 12:57	44K
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3C6.cpp	28-Sep-2020 12:57	1454
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3C6.o	28-Sep-2020 12:57	41K
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3CF.cpp	28-Sep-2020 12:57	1910
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3CF.o	28-Sep-2020 12:57	44K
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3EA.cpp	28-Sep-2020 12:57	1910
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3EA.o	28-Sep-2020 12:57	44K
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3FF.cpp	28-Sep-2020 12:57	1453
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_3FF.o	28-Sep-2020 12:57	41K
ve_0EAE7ED7_ve_0EAE7ED7_ncc_BT_408.cpp	28-Sep-2020 12:57	1880

Debugging

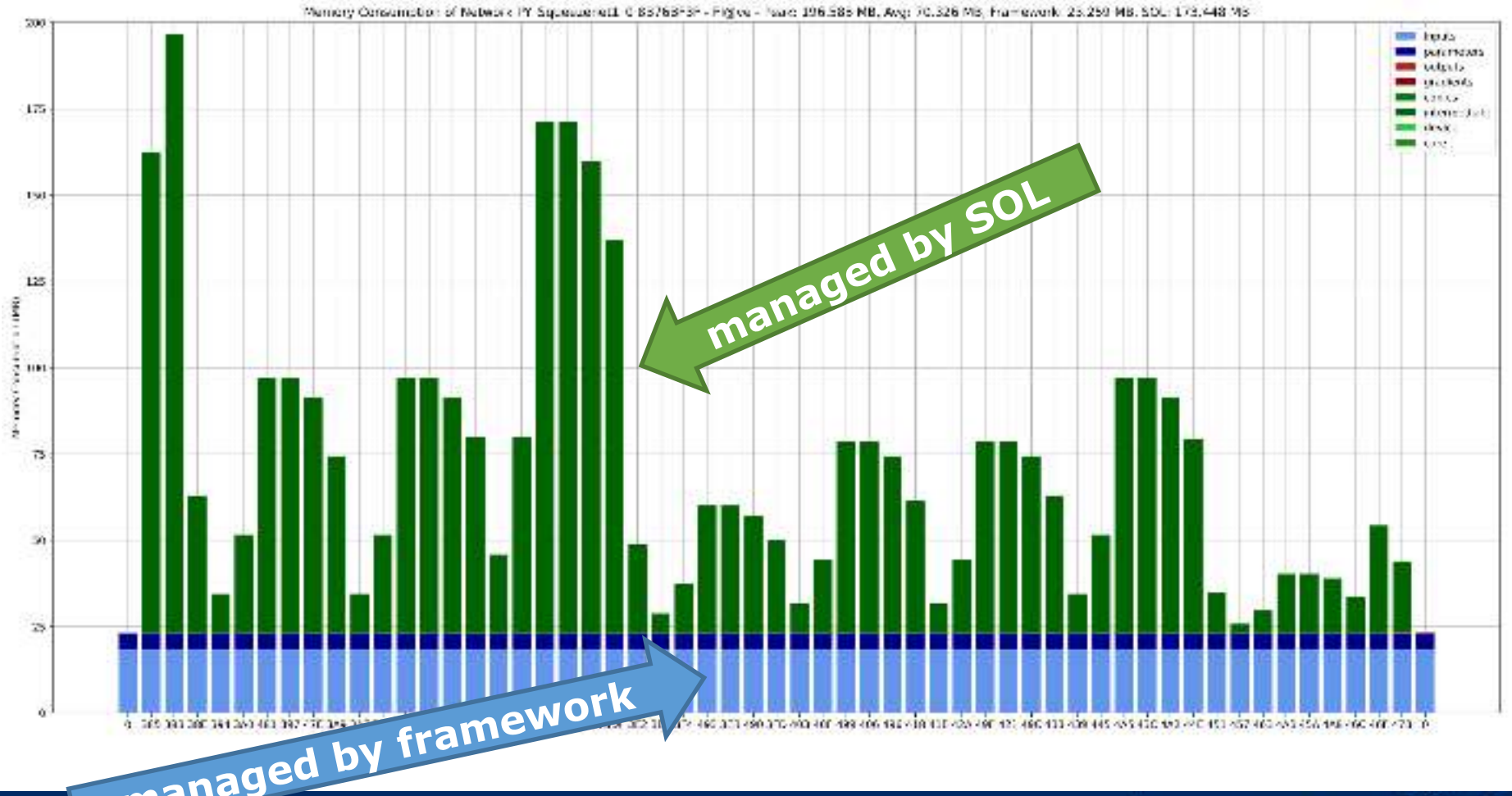
- `sol.config[“compiler::debug”] = True`
  - Outputs visualized NN in .sol/debug/ subfolder



Debugging

```
sol.config["compiler::debug_memory_consumption"]=True
```

- Outputs memory consumption plots
- Requires: matplotlib



Debugging

- `sol.config["compiler::name"] = "Prefix Used for Debugging Output"`

- C/C++ device code generated in .sol/ve/source
  - Might not be obvious to read

- `sol.config["compiler::debug"] = True`
  - Compiles with debug symbols
  - Prints execution times of fused layers
  - Outputs visualized NN in .sol/debug/ subfolder
  - Outputs memory consumption plots
  - Requires: matplotlib, GraphViz (Dot)

- Activate tracing:
  - `sol.config["log::level"] = sol.log.[error, info, warn, debug, trace]`
  - `SOL_LOG=TRACE python3 mySolScript.py`

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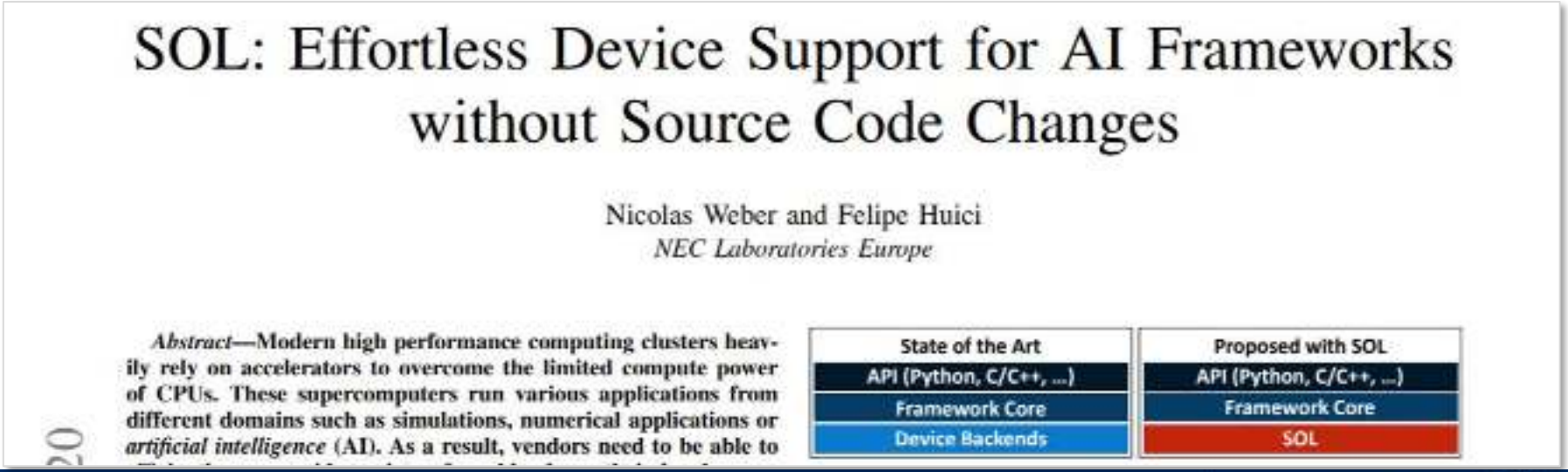
SOL's VE integration into PyTorch

SOL's VE integration into PyTorch

- **PyTorch does not come with support for storing data on VE devices.**
- **SOL adds this support into PyTorch automatically when loaded.**
- **We misuse the HIP-device for the VE's as we can't add new device types without recompiling PyTorch:**
  - see https://arxiv.org/abs/2003.10688 for details



SOL: Effortless Device Support for AI Frameworks without Source Code Changes

Nicolas Weber and Felipe Huici
NEC Laboratories Europe

Abstract—Modern high performance computing clusters heavily rely on accelerators to overcome the limited compute power of CPUs. These supercomputers run various applications from different domains such as simulations, numerical applications or *artificial intelligence* (AI). As a result, vendors need to be able to

SOL's VE integration into PyTorch

Identical to how CUDA is used in PyTorch, just with 'hip'

Copy data to VE: `tensor_ve = tensor_cpu.to('hip:0')`

Copy data to CPU: `tensor_cpu = tensor_ve.cpu()` or `.to('cpu')`

Copy model to VE: `model.to('hip:0')`

Unfortunately `tensor.hip()` **does not work :(**

Synchronize VE execution:

- `torch.hip.synchronize()`

Selection of VE's in Server

- `export VEDA_VISIBLE_DEVICES=0,1,2`
- `export VEDA_VISIBLE_DEVICES=$VE_NODE_NUMBER`

Known Issues

`torch.concat()` on CPU can produce wrong results when SOL4VE is loaded

- Submitted bugfix to PyTorch, was released in PyTorch v1.6.0. SOL v0.3.0 will support PyTorch v1.6.0.

Only minimal number of functions implemented

- A + B, A – B, print(A), …
- Otherwise you will get a message like: “Function X not implemented for HipTensorId”.
- Workaround:
  - `A.cpu().notImplemented().to('hip:0')`
- CAN ONLY OCCUR OUTSIDE OF YOUR NEURAL NETWORK!!!

`print(tensor)` always shows scientific notation.

We finally want to use it!!!

SOL Execution Modes

- PyTorch supports four execution modes, SOL only two:

	model.eval()	**model.training()**
torch.no_grad()	SOL Inference	N/A
~~**torch.no_grad()**~~	N/A	SOL Training

Optimizing a model

```
sol_model = sol.optimize(model, input0, input1, input2, …, batch_size=32)
```

`model` = any `torch.nn.Module`

`inputX`

- `torch.Tensor`
- any primitive datatype `(int, float, …)`
- `sol.input([0, 3, 224, 224], requires_grad=False, dtype=torch.float)`
  - Size of 0 is a wildcard (only in first dimension!)

`batch_size` → needs to be set if wildcard is used, otherwise ignored. Is used by SOL in its heuristics.

Model Preparation

```
import torch
import sol.pytorch as sol

class Model(torch.nn.Module):
    def forward(self, A, B):
        return A + B

py_model = Model()
sol.config[…] = … # always set BEFORE sol.optimize
sol_model = sol.optimize(py_model, sol.input([0, 50]),
sol.input([0, 50]), batch_size=32)
sol_model.load_state_dict(py_model.state_dict())
sol_model.to('hip:0')
```

Inference

```
# generate random input
A_cpu = torch.rand(5, 50)
B_cpu = torch.rand(5, 50)

# copy to VE
A_ve, B_ve = A_cpu.to('hip:0'), B_cpu.to('hip:0')

# activate inference mode
sol_model.eval()
with torch.no_grad():
    # run model
    C_ve = sol_model(A_ve, B_ve)
    # print result
    print(C_ve)
```

Training

```
sol_model.training()
for epoch in range(epochs):
    for batch in train_dataloader:
        # get batch and copy to VE
        A_cpu, B_cpu = *batch
        A_ve, B_ve = A_cpu.to('hip:0'), B_cpu.to('hip:0')

        # run forward pass
        C_ve = sol_model(A_ve, B_ve)

        # compute loss on CPU
        C_cpu = C_ve.cpu()
        loss = loss_function(C_cpu)

        # run backward pass
        loss.backward()

        # Optional: wait for VE to complete this iteration
        torch.hip.synchronize()
```

Known Issues/Pitfalls

"SQLITE Error UNIQUE CONSTRAINT …"

- SOL cache got corrupted. Either:
  - run: `rm –r .sol`
  - or call `sol.cache.clear()` before `sol.optimize(…)`

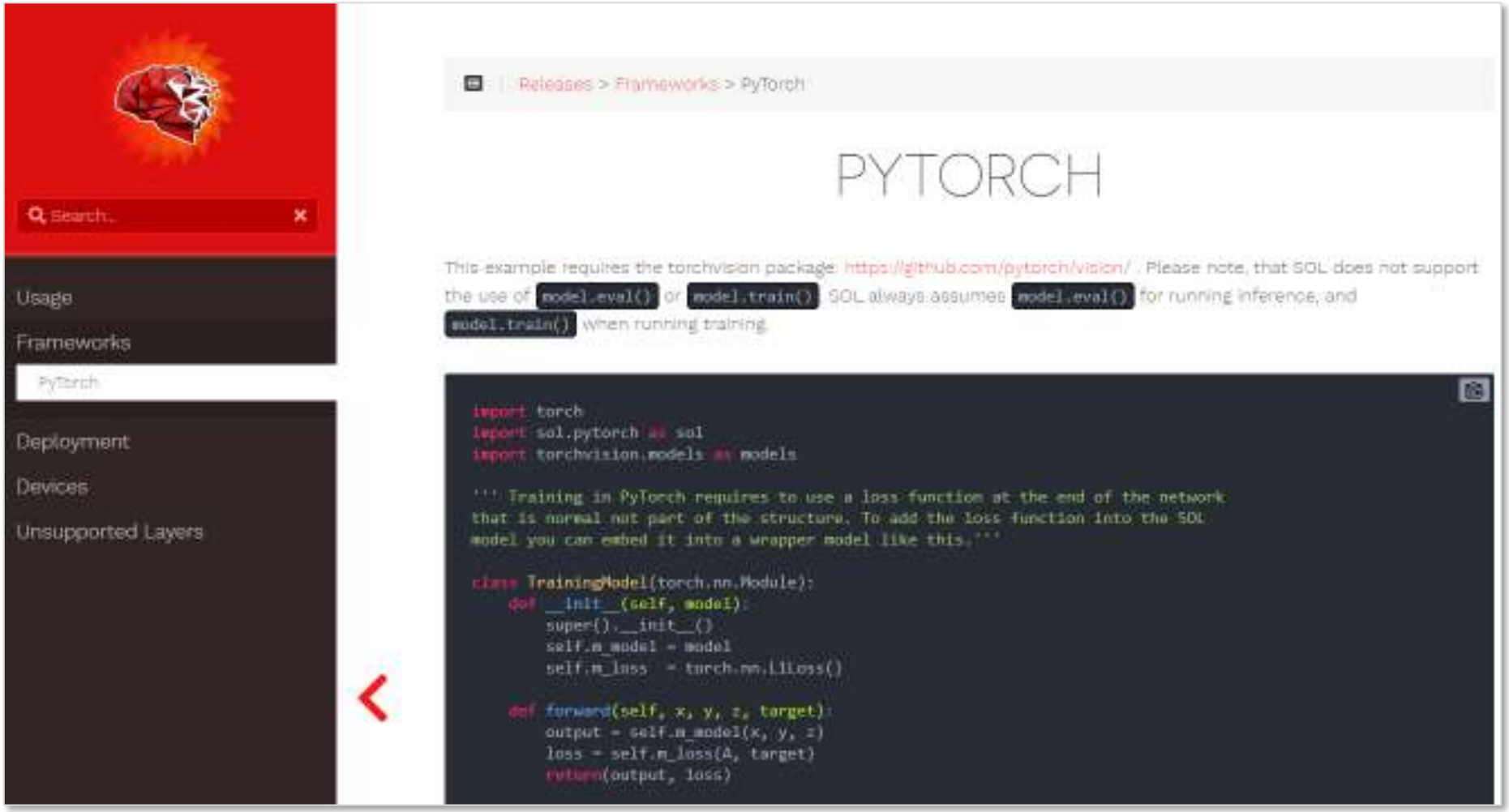
SOL does not complain when the model and the input data are not located on the same device:

- fixed in v0.3.0

sol.deploy(…) not fully working in v0.2.7.2. Would need some manual fixing in generated code.

- fixed in v0.3.0

More information in the SOL docs



How to get started on ICM

```
# login to server
ssh hpc.icm.edu.pl
...

# install and activate virtualenv
pip3 install --user virtualenv
virtualenv sol
source sol/bin/activate

# install sol
pip3 install /apps/nec/sol/sol-0.2.7.2-py3-none-any.whl
pip3 install torchvision==0.6.1

# test sol
mkdir tmp
cd tmp
VEDA_VISIBLE_DEVICES=0 python3 /apps/nec/sol/test.py
```

How to get started on ICM

```
(scl) kdmark20@pharan ~/scl/tmp $ VEDA_VISIBLE_DEVICES=0 python3 test.py
[INFO ][  0.00][core] Log (90):
[INFO ][  0.00][core] Log (91):
[INFO ][  0.00][core] Log (92):
[INFO ][  0.00][core] Log (93):
[INFO ][  0.00][core] Log (94):
[INFO ][  0.00][core] Log (95):
[INFO ][  0.00][core] Log (96):
[INFO ][  0.00][core] Log (97):
[INFO ][  0.00][core] Log (98):
[INFO ][  0.00][core] Log (99):
[INFO ][  0.00][core] Log (100):
[INFO ][  0.00][core] Log (101):
[INFO ][  0.00][core] Log (102):
[INFO ][  0.00][core] Log (103):
[WARN ][  0.52][jit-dot] Dot (13):
[INFO ][  0.55][core] NetworkBuilder (281):
[VE] ERROR: getsym_handler() dlerror: ./scl/ve/69FF6BA9.vso: undefined symbol: ve_69FF6BA9_FT
[VE] ERROR: getsym_handler() dlerror: ./scl/ve/69FF6BA9.vso: undefined symbol: ve_69FF6BA9_BT
CPU tensor([[1.6391, 0.8292, 1.0491, 1.4602, 0.1955],
        [1.2085, 0.8560, 1.2459, 1.1432, 0.4776],
        [1.1108, 0.8073, 1.0278, 1.3681, 0.7307],
        [1.3812, 1.3908, 0.5743, 0.5613, 0.7339],
        [0.9672, 0.2896, 0.6323, 1.2249, 0.8866]])
VE tensor([[1.6391e+00, 8.2516e-01, 1.0491e+00, 1.4602e+00, 1.9546e-01],
        [1.2085e+00, 8.5602e-01, 1.2459e+00, 1.1432e+00, 4.7764e-01],
        [1.1108e+00, 8.0732e-01, 1.0278e+00, 1.3681e+00, 7.3071e-01],
        [1.3812e+00, 1.3908e+00, 5.7426e-01, 5.6132e-01, 7.3390e-01],
        [9.6719e-01, 2.8963e-01, 6.3231e-01, 1.2249e+00, 8.8658e-01]],
       device='hip:0')
```

```
##############################################################################

  Scl v0.2.7.2 Altair
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  Europe and is only allowed for demonstration purposes. Any redistribution
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##############################################################################

Unable to find dot in path. Please add dot to your $PATH variable!
Using cached network Unknown (0x69FF6BA9)
```

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Dr. Nicolas Weber
Intelligent Software Systems Group
Senior Software Engineer
NEC Laboratories Europe
nicolas.weber@neclab.eu

www.sol-project.org