An Introduction to Torch-MLIR

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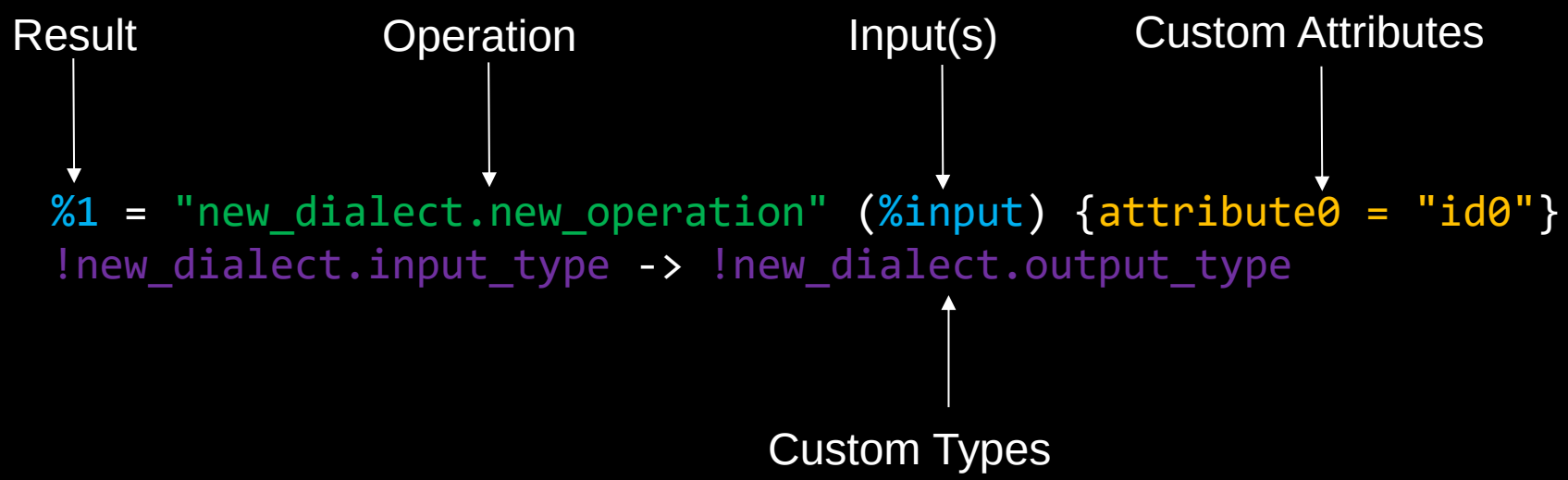
together we advance_

Outline

- What is MLIR?
- What is Torch-MLIR?
- The `torch` Dialect
- Building the Project
- Importing, Converting and Running Models
- How to Get Involved

What is MLIR?

- (Novel) Approach to build a reusable and extensible compiler infrastructure
- Provides an extensible intermediate representation (IR)

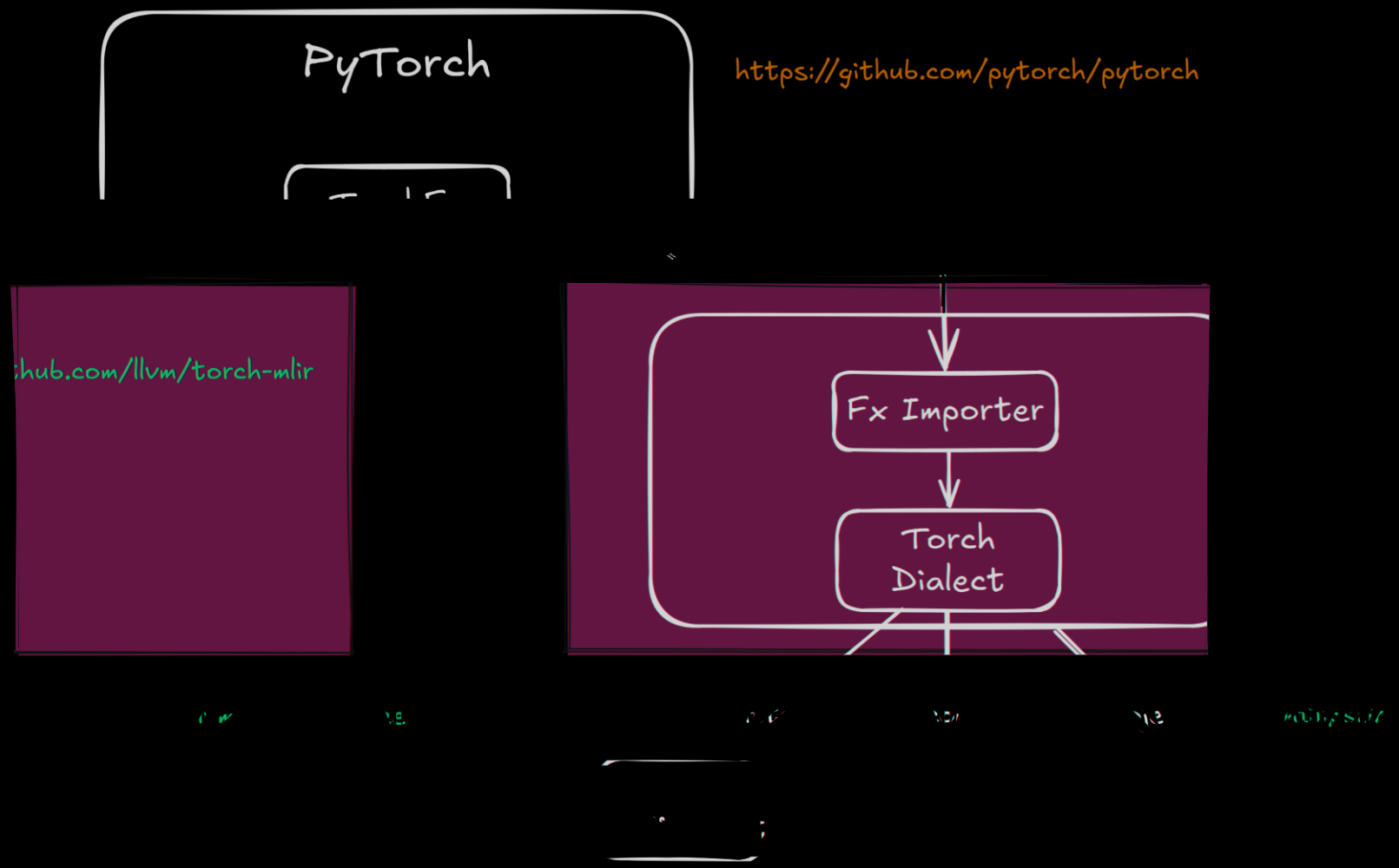


- MLIR is a project of the of the LLVM Foundation

What is Torch-MLIR?

- Aims to provide first class compiler support from the PyTorch ecosystem to the MLIR ecosystem
- Participating in the LLVM Incubator process
- Dual-Licensed under the Apache License 2.0 with LLVM Exceptions and a BSD-style License

What is Torch-MLIR?



The `torch` Dialect

- The central MLIR abstraction is the `torch` dialect
- Mostly auto-generated based on the PyTorch JIT IR operator registry
- Some manually implemented ops:
  - Used for modeling PyTorch IValue object graphs e.g. `torch.nn_module, torch.class_type`)
  - `torch.global_slot` and related ops to model an incremental lowering of the IValue object graphs
  - Ops supported in the JIT interpreter directly and therefore without a corresponding op in the registry
  - `torch.operator` to represent ops from the registry which haven't been auto-generated

The `torch` Dialect - `TorchOps.td`

TorchOps.td

include > torch-mlir > Dialect > Torch > IR > TorchOps.td

```
21
22  class Torch_Op<string mnemonic, list<Trait> traits = []>
23      : Op<Torch_Dialect, mnemonic, traits> {
24  }
25
26  include "torch-mlir/Dialect/Torch/IR/GeneratedTorchOps.td"
27
28  //===----------------------------------------------------------------------===//
29  // TorchScript `torch.nn.Module` object instantiation ops.
30  //===----------------------------------------------------------------------===//
31
32  def Torch_NnModuleOp : Torch_Op<"nn_module", [
33      DeclareOpInterfaceMethods<SymbolUserOpInterface>,
34      SingleBlockImplicitTerminator<"::mlir::torch::Torch::NnModuleTerminatorOp">]> {
35    let summary = "Constructs a torch.nn.Module";
```

Setup the Project

```
# Clone the project and initialize the submodules

git clone https://github.com/llvm/torch-mlir
cd torch-mlir
git submodule update --init --progress --depth=1



# Create a virtual environment and install dependencies


python3 -m venv mlir_venv
source mlir_venv/bin/activate

python -m pip install --upgrade pip

python -m pip install -r requirements.txt
python -m pip install -r torchvision-requirements.txt
```

Build the Project – Monolithic Build

```
cmake -GNinja -Bbuild-external \
  externals/llvm-project/llvm \
  -DCMAKE_BUILD_TYPE=Release \
  -DCMAKE_C_COMPILER=clang -DCMAKE_CXX_COMPILER=clang++ \
  -DCMAKE_LINKER_TYPE=LLD \
  -DCMAKE_C_COMPILER_LAUNCHER=ccache -DCMAKE_CXX_COMPILER_LAUNCHER=ccache \
  -DLLVM_ENABLE_ASSERTIONS=ON -DPython3_FIND_VIRTUALENV=ONLY \
  -DLLVM_ENABLE_PROJECTS=mlir \
  -DMLIR_ENABLE_BINDINGS_PYTHON=ON -DLLVM_TARGETS_TO_BUILD=host \
  -DLLVM_EXTERNAL_PROJECTS="torch-mlir" \
  -DLLVM_EXTERNAL_TORCH_MLIR_SOURCE_DIR="$PWD" \
  -DLIBTORCH_CACHE=ON -DLIBTORCH_SRC_BUILD=ON -DLIBTORCH_VARIANT=shared \
  -DTORCH_MLIR_ENABLE_PYTORCH_EXTENSIONS=ON \
  -DTORCH_MLIR_ENABLE_JIT_IR_IMPORTER=ON

cmake --build build-external/ --target check-torch-mlir
```

Build the Project – Component Build (1)

```
# Build and install MLIR
export LLVM_INSTALL_DIR="`realpath install-llvm/`"

cmake -GNinja -Bbuild-llvm \
  externals/llvm-project/llvm \
  -DCMAKE_BUILD_TYPE=Release \
  -DCMAKE_C_COMPILER=clang -DCMAKE_CXX_COMPILER=clang++ \
  -DCMAKE_LINKER_TYPE=LLD \
  -DCMAKE_C_COMPILER_LAUNCHER=ccache -DCMAKE_CXX_COMPILER_LAUNCHER=ccache \
  -DLLVM_ENABLE_ASSERTIONS=ON -DPython3_FIND_VIRTUALENV=ONLY \
  -DLLVM_ENABLE_PROJECTS=mlir \
  -DMLIR_ENABLE_BINDINGS_PYTHON=ON -DLLVM_TARGETS_TO_BUILD=host \
  -DLLVM_INSTALL_UTILS=ON \
  -DCMAKE_INSTALL_PREFIX="${LLVM_INSTALL_DIR}"

cmake --build build-llvm/ --target install
```

Build the Project – Component Build (2)

```
# Build Torch-MLIR
export LLVM_BUILD_DIR="`realpath build-llvm/`"

cmake -GNinja -Bbuild-component \
  -DCMAKE_BUILD_TYPE=Release \
  -DCMAKE_C_COMPILER=clang -DCMAKE_CXX_COMPILER=clang++ \
  -DCMAKE_LINKER_TYPE=LLD \
  -DCMAKE_C_COMPILER_LAUNCHER=ccache -DCMAKE_CXX_COMPILER_LAUNCHER=ccache \
  -DLLVM_ENABLE_ASSERTIONS=ON -DPython3_FIND_VIRTUALENV=ONLY \
  -DMLIR_DIR="${LLVM_INSTALL_DIR}/lib/cmake/mlir/" \
  -DLLVM_DIR="${LLVM_INSTALL_DIR}/lib/cmake/llvm/" \
  -DLLVM_EXTERNAL_LIT="${LLVM_BUILD_DIR}/bin/llvm-lit"
  -DMLIR_ENABLE_BINDINGS_PYTHON=ON -DLLVM_TARGETS_TO_BUILD=host \
  -DLIBTORCH_CACHE=ON -DLIBTORCH_SRC_BUILD=ON -DLIBTORCH_VARIANT=shared \
  -DTORCH_MLIR_ENABLE_PYTORCH_EXTENSIONS=ON \
  -DTORCH_MLIR_ENABLE_JIT_IR_IMPORTER=ON

cmake --build build-external/ --target check-torch-mlir
```

Alternative: Install Python Wheels

```
# Install PyTorch
pip install --index-url https://download.pytorch.org/whl/nightly/cpu --pre \
 torch==2.7.0.dev20250120

# Install ONNX
pip install onnx

# Install Torch-MLIR
pip install --find-links https://github.com/llvm/torch-mlir-
release/releases/expanded_assets/dev-wheels torch-mlir
```

A Simple Torch Model

```
from pathlib import Path
import torch

class SimpleNN(torch.nn.Module):
    def __init__(self):
        super().__init__()
        self.linear = torch.nn.Linear(16, 10, bias=False)
        self.linear.weight = torch.nn.Parameter(torch.ones(10, 16))
        self.relu = torch.nn.ReLU()
        self.train(False)

    def forward(self, input):
        return self.relu(self.linear(input))

input = torch.randn(2, 16)
model = SimpleNN()
```

A Simple Torch Model Imported to MLIR

```
from pathlib import Path
import torch

class SimpleNN(torch.nn.Module):
    def __init__(self):
        super().__init__()
        self.linear = torch.nn.Linear(16, 10, bias=False)
        self.linear.weight = torch.nn.Parameter(torch.ones(10, 16))
        self.relu = torch.nn.ReLU()
        self.train(False)

    def forward(self, input):
        return self.relu(self.linear(input))

input = torch.randn(2, 16)
model = SimpleNN()

from torch_mlir.fx import export_and_import
mlir_module = export_and_import(model, input, output_type="torch")
```

Importing an ONNX Model

```
# Download an ONNX model
wget https://github.com/onnx/models/raw/main/validated/vision/classification/mnist/model/mnist-12.onnx

# Import the model
torch-mlir-import-onnx mnist-12.onnx --opset-version 17 -o mnist.mlir
```

mnist.mlir (Snippet)

…

```
%9 = torch.operator "onnx.Add"(%8, %3) : (!torch.vtensor<[1,8,28,28],f32>,
!torch.vtensor<[8,1,1],f32>) -> !torch.vtensor<[1,8,28,28],f32>
%10 = torch.operator "onnx.Relu"(%9) : (!torch.vtensor<[1,8,28,28],f32>) ->
!torch.vtensor<[1,8,28,28],f32>
%11 = torch.operator "onnx.MaxPool"(%10) {torch.onnx.auto_pad = "NOTSET",
torch.onnx.kernel_shape = [2 : si64, 2 : si64], torch.onnx.pads = [0 : si64, 0
: si64, 0 : si64, 0 : si64], torch.onnx.strides = [2 : si64, 2 : si64]} :
(!torch.vtensor<[1,8,28,28],f32>) -> !torch.vtensor<[1,8,14,14],f32>
```

…

TorchOnnxToTorch - Abs

lib > Conversion > TorchOnnxToTorch > DefaultDomainAtoF.cpp > ...

```
122   // Simple rewrites for the default domain.
134   void mlir::torch::onnx_c::populateDefaultDomainAtoF(
135       OnnxCustomOpConversionPattern &patterns) {
136     patterns.onOp("Abs", 1,
137                   [](OpBinder binder, ConversionPatternRewriter &rewriter) {
138       Torch::ValueTensorType resultType;
139       Value operand;
140       if (binder.tensorOperand(operand) ||
141           binder.tensorResultType(resultType))
142         return failure();
143       rewriter.replaceOpWithNewOp<Torch::AtenAbsOp>(
144           binder.op, resultType, operand);
145       return success();
146     });
```

TorchOnnxToTorch - AveragePool

lib > Conversion > TorchOnnxToTorch > DefaultDomainAtoF.cpp > populateDefaultDomainAtoF(OnnxCustomOpConver

```
135        OnnxCustomOpConversionPattern &patterns) {
456    patterns.onOp(
457        "AveragePool", 11,
458        [](OpBinder binder, ConversionPatternRewriter &rewriter) {
459          std::string autoPad;
460          SmallVector<int64_t> dilations;
461          if (binder.customOpNameStringAttr(autoPad, "auto_pad", "NOTSET"))
462            return failure();
463          if (autoPad != "NOTSET") {
464            // TODO: Add support for `auto_pad` != "NOTSET"
465            return rewriter.notifyMatchFailure(
466                binder.op, "unsupported conversion: auto_pad != NOTSET");
467          }
468
469          Torch::ValueTensorType resultType;
470          Value operand;
```

DecomposeComplexOps

lib > Dialect > Torch > Transforms > DecomposeComplexOps.cpp > {} `anonymous-namespace' > DecomposeAt

```
2967    namespace {
2968    class DecomposeAtenHardshrinkOp : public OpRewritePattern<AtenHardshrinkOp> {
2972                                      PatternRewriter &rewriter) const override {
2999      Value posMask =
3000          rewriter.create<AtenGtScalarOp>(loc, boolResType, self, poslambd);
3001      Value negMask =
3002          rewriter.create<AtenLtScalarOp>(loc, boolResType, self, neglambd);
3003
3004      Value result = rewriter.create<AtenWhereScalarOtherOp>(loc, resTy, posMask,
3005                                                             self, zero);
3006      result =
3007          rewriter.create<AtenWhereSelfOp>(loc, resTy, negMask, self, result);
3008
3009      rewriter.replaceOp(op, result);
```

Pipelines

- torch-backend-to-linalg-on-tensors-backend-pipeline
- torch-backend-to-stablehlo-backend-pipeline
- torch-backend-to-tosa-backend-pipeline
- torch-function-to-torch-backend-pipeline
- torch-onnx-to-torch-backend-pipeline
- torch-shape-refinement-pipeline
- torch-simplification-pipeline
- torchdynamo-export-to-torch-backend-pipeline
- torchscript-module-to-torch-backend-pipeline

RefBackend

```
# See pt1/examples/fximporter_resnet18.py


from torch_mlir_e2e_test.linalg_on_tensors_backends import refbackend
from torch_mlir_e2e_test.configs.utils import (
    recursively_convert_to_numpy,
)


resnet18 = models.resnet18(pretrained=True).eval()
module = fx.export_and_import(
    resnet18,
    torch.ones(1, 3, 224, 224),
    output_type="linalg-on-tensors",
    func_name=resnet18.__class__.__name__,
)
backend = refbackend.RefBackendLinalgOnTensorsBackend()
compiled = backend.compile(module)
fx_module = backend.load(compiled)
```

How To Get Involved

- Try to import and lower a model by using `torch-mlir-opt`
- Fill issues @ https://github.com/llvm/torch-mlir
- Join discussions @ #torch-mlir (LLVM Discord)
- Implement support for attributes of ONNX operators
- …

Disclaimer

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