An Introduction to Torch-MLIR

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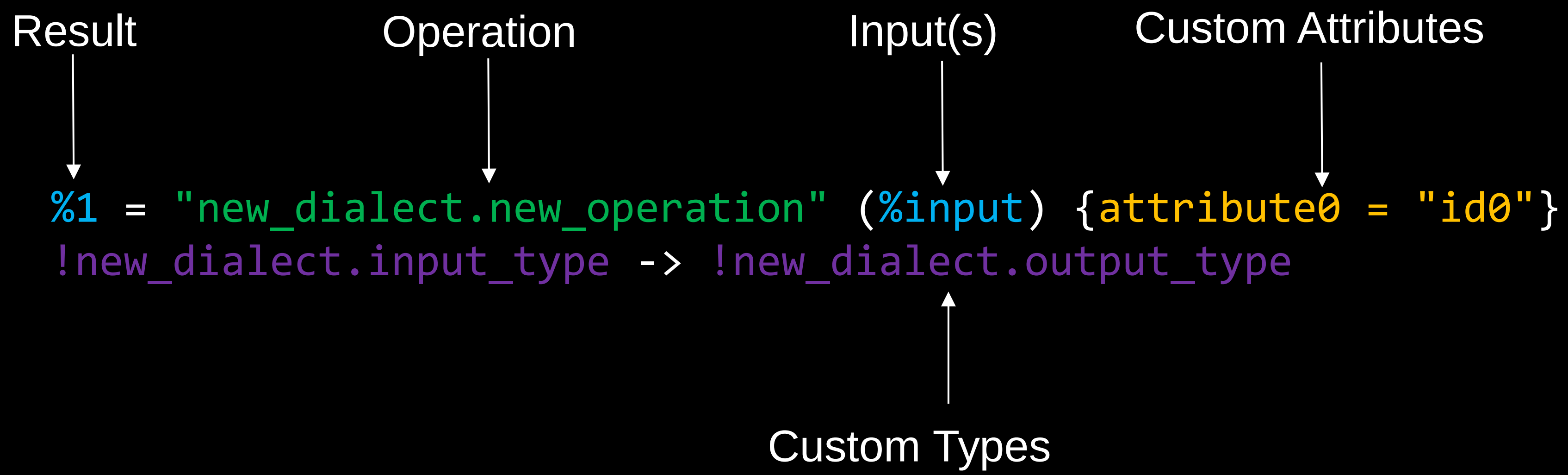
Outline

- 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)



Result

Operation

Input(s)

Custom Attributes

```
%1 = "new_dialect.new_operation" (%input) {attribute0 = "id0"}
!new_dialect.input_type -> !new_dialect.output_type
```

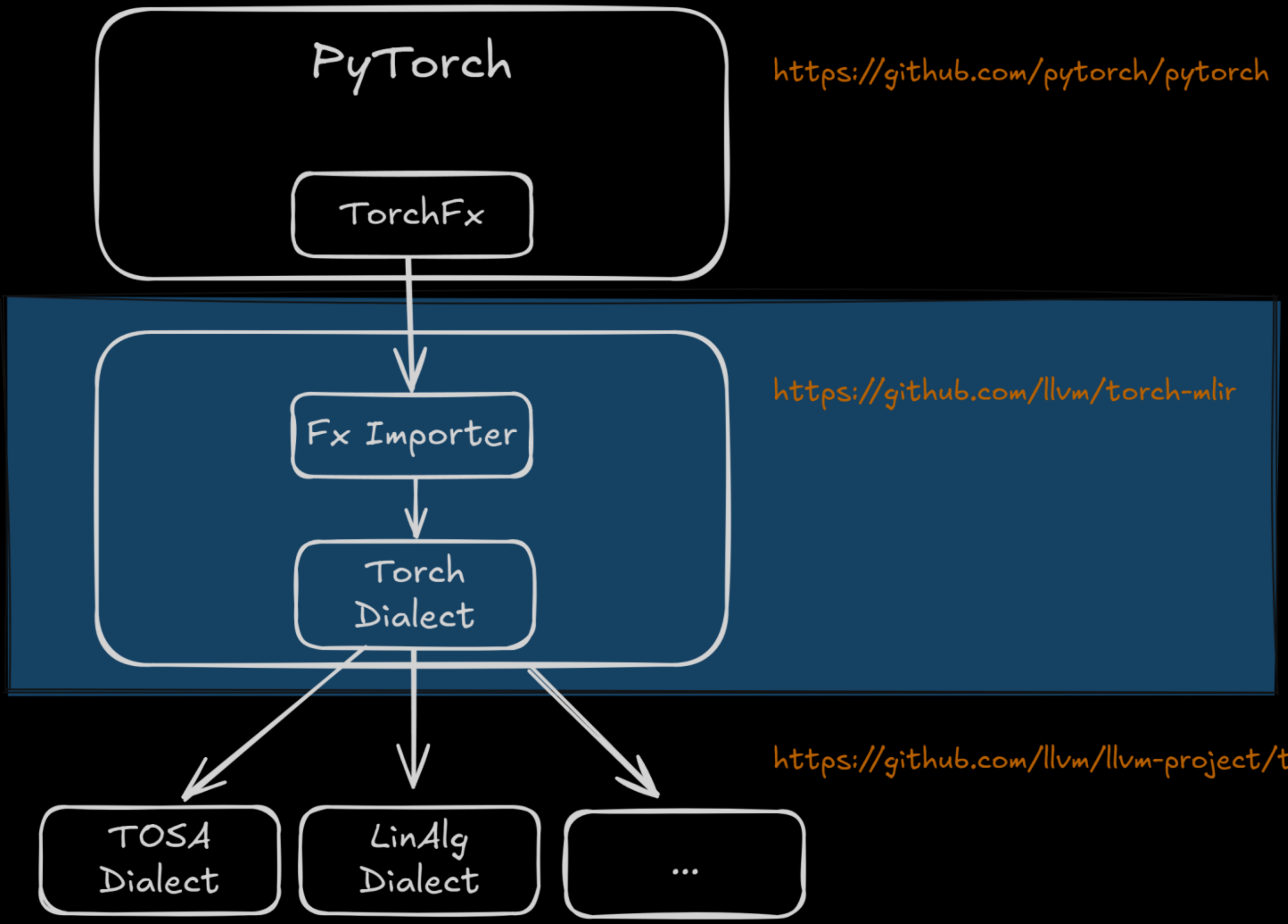
Custom Types

- 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?



https://github.com/pytorch/pytorch

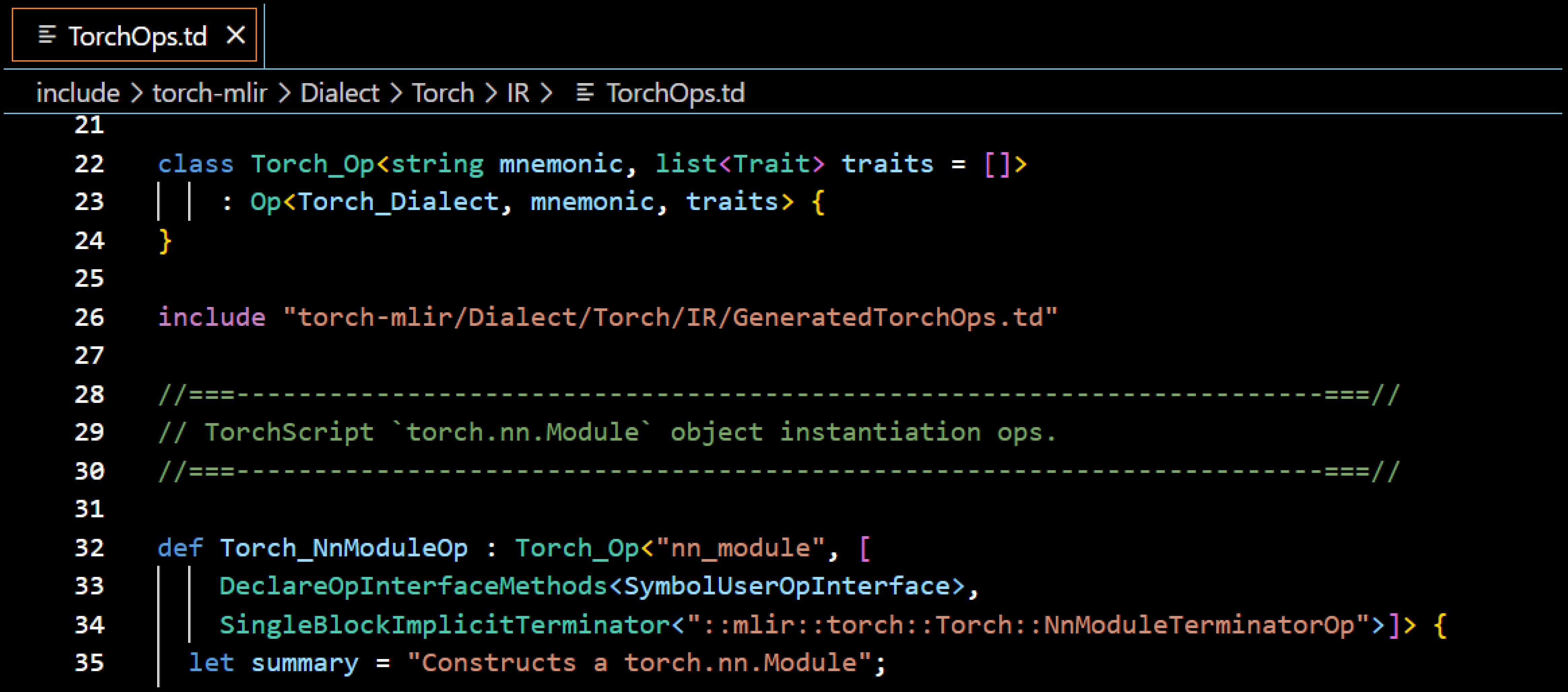
https://github.com/llvm/torch-mlir

https://github.com/llvm/llvm-project/tree/main/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`



```
class Torch_Op<string mnemonic, list<Trait> traits = []>
    : Op<Torch_Dialect, mnemonic, traits> {
}

include "torch-mlir/Dialect/Torch/IR/GeneratedTorchOps.td"

//===----------------------------------------------------------------------===//
// TorchScript `torch.nn.Module` object instantiation ops.
//===----------------------------------------------------------------------===//

def Torch_NnModuleOp : Torch_Op<"nn_module", [
    DeclareOpInterfaceMethods<SymbolUserOpInterface>,
    SingleBlockImplicitTerminator<"::mlir::torch::Torch::NnModuleTerminatorOp">]> {
  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

```python
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

```python
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
```

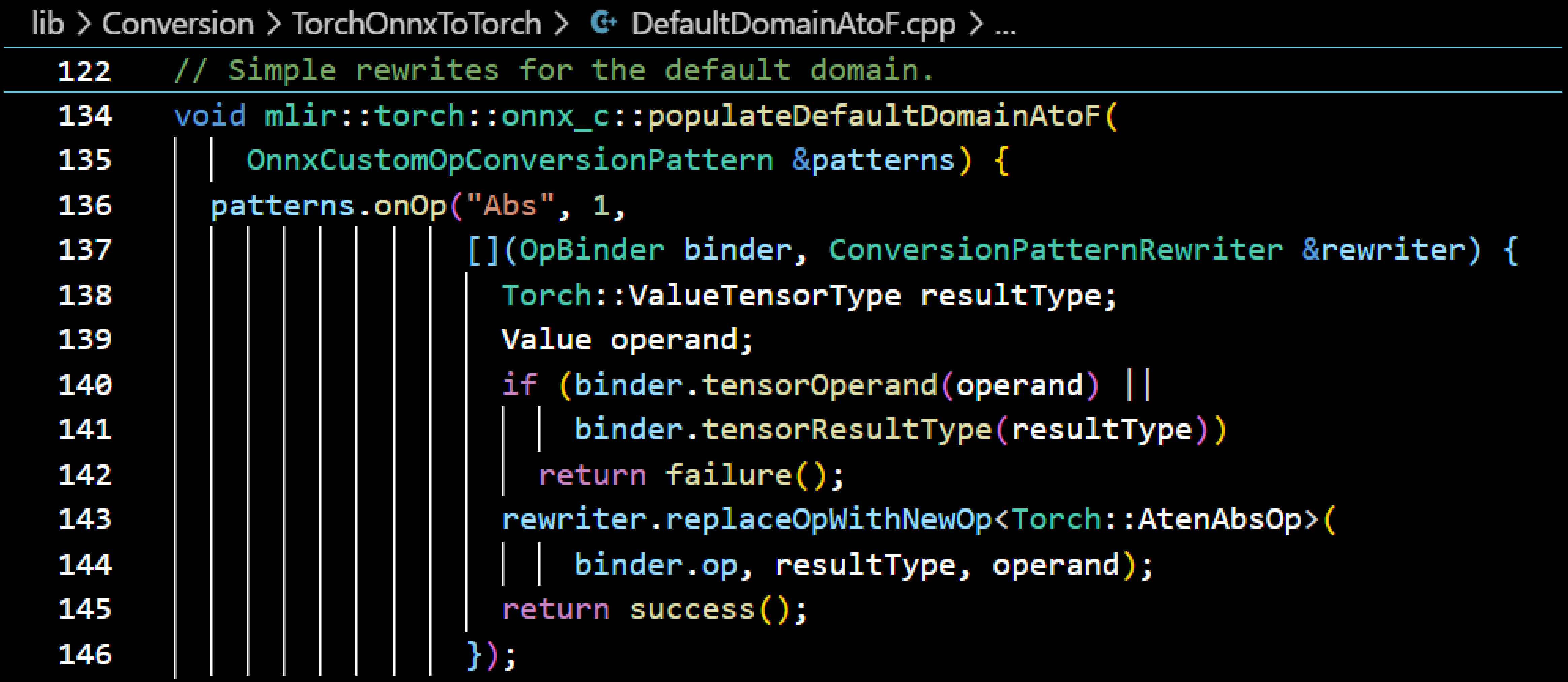
mnist.mlir (Snippet)

```
…

%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>

…
```

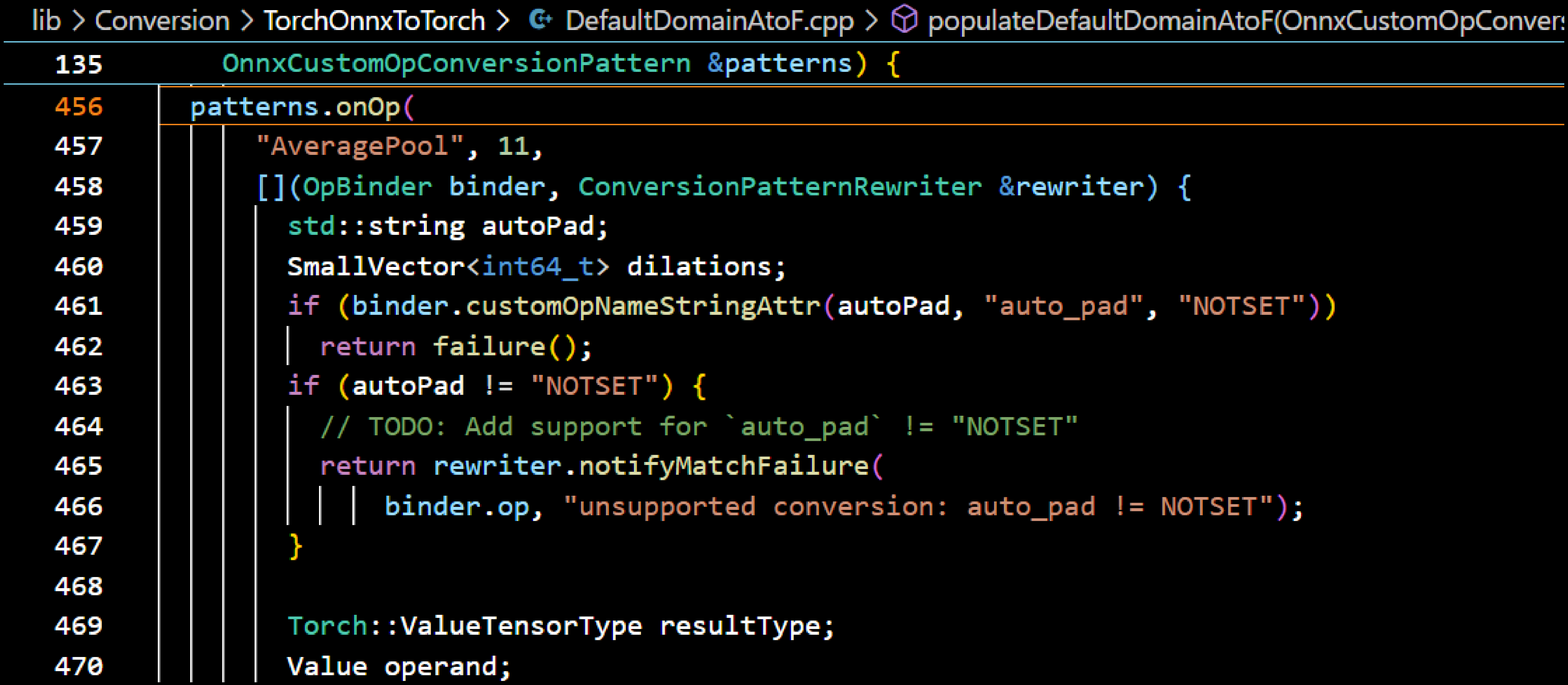
TorchOnnxToTorch - Abs



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

```
// Simple rewrites for the default domain.
void mlir::torch::onnx_c::populateDefaultDomainAtoF(
    OnnxCustomOpConversionPattern &patterns) {
  patterns.onOp("Abs", 1,
                [](OpBinder binder, ConversionPatternRewriter &rewriter) {
                  Torch::ValueTensorType resultType;
                  Value operand;
                  if (binder.tensorOperand(operand) ||
                      binder.tensorResultType(resultType))
                    return failure();
                  rewriter.replaceOpWithNewOp<Torch::AtenAbsOp>(
                      binder.op, resultType, operand);
                  return success();
                });
```

TorchOnnxToTorch - AveragePool

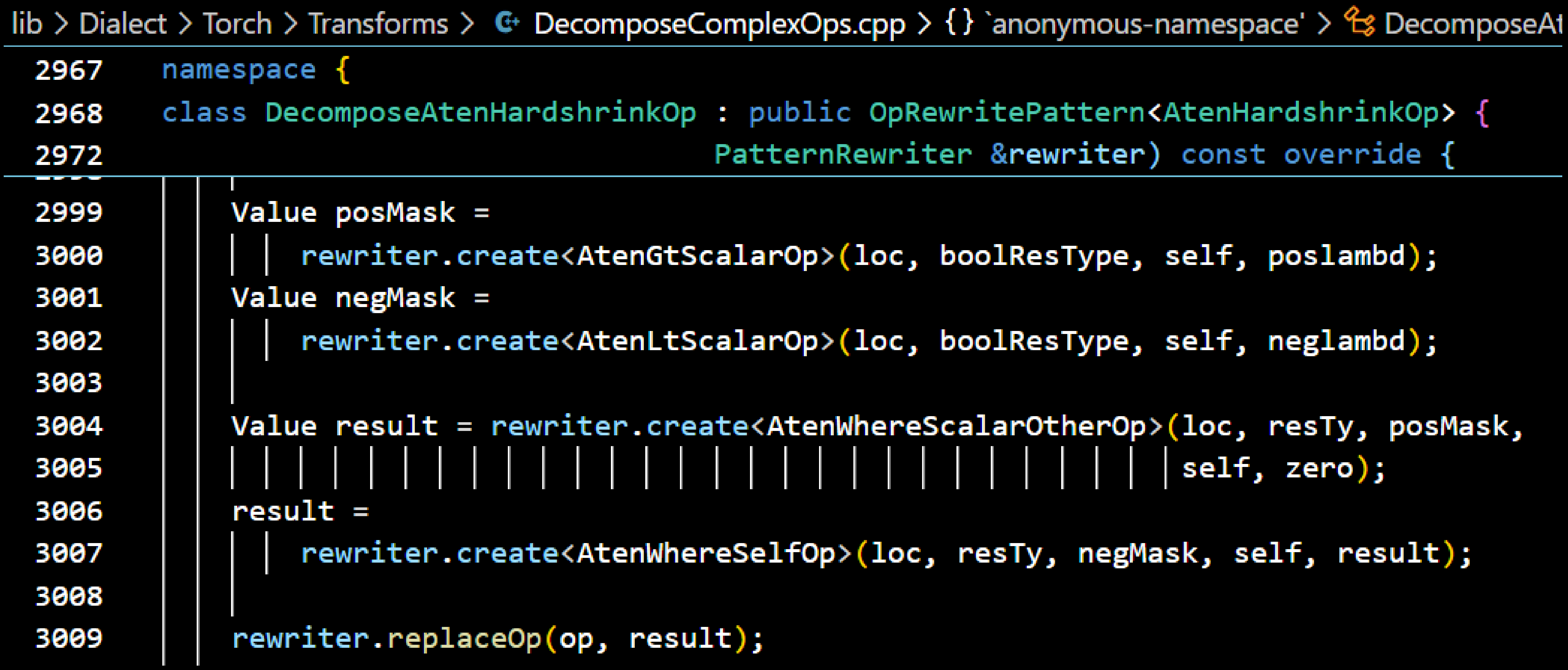


lib > Conversion > TorchOnnxToTorch > DefaultDomainAtoF.cpp > populateDefaultDomainAtoF(OnnxCustomOpConver

```
    OnnxCustomOpConversionPattern &patterns) {
  patterns.onOp(
      "AveragePool", 11,
      [](OpBinder binder, ConversionPatternRewriter &rewriter) {
        std::string autoPad;
        SmallVector<int64_t> dilations;
        if (binder.customOpNameStringAttr(autoPad, "auto_pad", "NOTSET"))
          return failure();
        if (autoPad != "NOTSET") {
          // TODO: Add support for `auto_pad` != "NOTSET"
          return rewriter.notifyMatchFailure(
              binder.op, "unsupported conversion: auto_pad != NOTSET");
        }

        Torch::ValueTensorType resultType;
        Value operand;
```

DecomposeComplexOps



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

```
namespace {
class DecomposeAtenHardshrinkOp : public OpRewritePattern<AtenHardshrinkOp> {
                                PatternRewriter &rewriter) const override {
    Value posMask =
        rewriter.create<AtenGtScalarOp>(loc, boolResType, self, poslambd);
    Value negMask =
        rewriter.create<AtenLtScalarOp>(loc, boolResType, self, neglambd);

    Value result = rewriter.create<AtenWhereScalarOtherOp>(loc, resTy, posMask,
                                                            self, zero);
    result =
        rewriter.create<AtenWhereSelfOp>(loc, resTy, negMask, self, result);

    rewriter.replaceOp(op, result);
```

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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
- …

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