Model Compiler Suite for Aries

Developers Guide

version 0.8.4

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0.2	December 1, 2021	Revised for v0.2

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1. Introduction

Mobilint® Model Compiler (i.e., Compiler) is a tool that converts models from deep learning frameworks (ONNX, PyTorch, Keras, TensorFlow, etc...) into Mobilint® Model eXeCUtable (i.e., MXQ), a format executable by Mobilint® Neural Processing Unit (NPU). This is the manual for the **qubee**, Mobilint's SDK. In this manual, you can learn how to use it, what frameworks it supports, etc. A set of functions you can use to interact with the SDK will be given below.

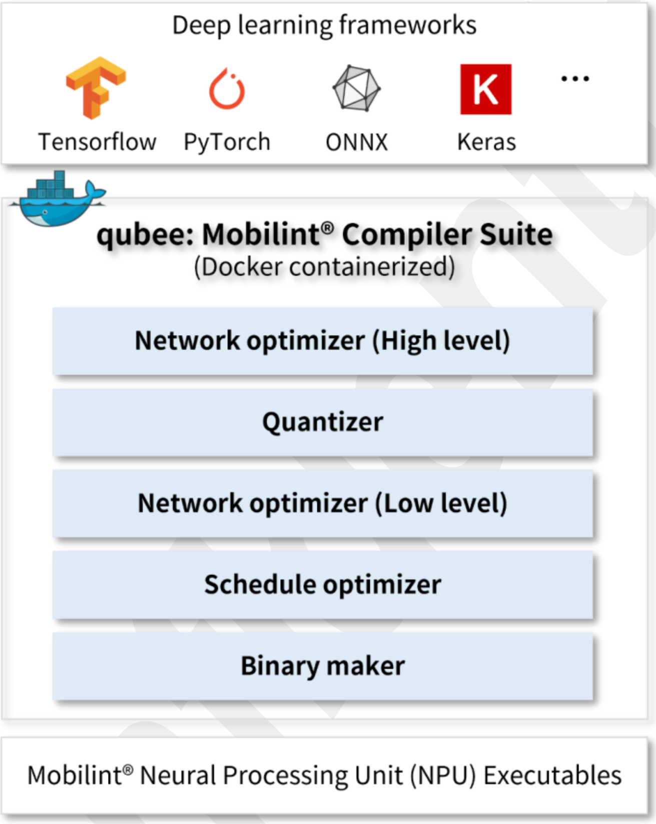

Figure 1-1. SDK Components

Inputs to qubee are a trained deep learning model, its input shape, and calibration data. It will return MXQ (compiled model) as an output.

Figure 1-2. Input and output of qubee

2. Changelog

2.1 qubee v0.8.4 (May 2024)

- API
    - TF backend connected to ONNX backend by TF2ONNX
- Support more operations

2.2 qubee v0.8.3 (March 2024)

- API
    - Support TF Lite backend

2.3 qubee v0.8.2 (February 2024)

2.4 qubee v0.8.1 (December 2023)

2.5 qubee v0.8.0 (November 2023)

- API
    - TVM backend deprecated

2.6 qubee v0.7.12 (September 2023)

2.7 qubee v0.7.11 (August 2023)

- API
    - Support TorchScript backend

2.8 qubee v0.7.10 (August 2023)

2.9 qubee v0.7.9 (August 2023)

2.10 qubee v0.7.8 (August 2023)

2.11 qubee v0.7.7 (June 2023)

- API
    - Improve CPU offloading (beta version)
- Improve CPU efficiency
- Support more operations
- Docker
    - torch: 1.10.1 -> 1.13.0
    - tensorflow: 2.3.0 -> 2.9.0
    - onnx:1.11.0 -> 1.12.0

2.12 qubee v0.7 (March 2023)

Multi-channel quantization

Support more operations

API

Improve calibration dataset processing

Support CPU offloading (beta version)

2.13 qubee v0.6 (August 2022)

Minor updates

2.14 qubee v0.5 (July 2022)

Docker

Conda -> Virtualenv

Python: 3.7.7 -> 3.8.10

torch: 1.8.1 -> 1.10.1

tensorflow: 1.15.0 -> 2.3.0

onnx:1.6.0 -> 1.11.0

Parser

Code refactoring

API

Enable saving sample inference results (inputs and outputs)

2.15 qubee v0.4 (February 2022)

Optimizer

Minor updates in fusing reshape

2.16 qubee v0.3 (February 2022)

Parser

Identify preprocess and postprocess of the model

Exclude preprocess and postprocess if they are unsupported by the NPU

API

Simulate integer inference in Python API

2.17 qubee v0.2 (December 2021)

First release

3. Installation

3.1 System requirements

We recommend to use NVIDIA GPU for faster compile wtih qubee, but it is not necessary. Currently, CPU version qubee is also supported.

3.1.1 Reference System

```
Ubuntu 22.04.4 LTS
NVIDIA Graphics Driver 545.29.06
```

3.1.2 Requirements and Recommended Packages

```
Ubuntu 20.04.6 LTS or Above
NVIDIA Graphics Driver 450.80.02 or Above
Docker
nvidia-docker
```

3.2 SDK Installation

We recommend installing qubee on the Mobilint docker container.

(Docker image: mobilint/qbcompiler:v0.8, https://hub.docker.com/r/mobilint/qbcompiler)

3.2.1 Building Docker Container

Run the following commands to build the docker container.

```
$ # Download Docker Image
$ docker pull mobilint/qbcompiler:v0.8
$ # mkdir {WORKING DIRCTORY} (if needed)
$ cd {WORKING DIRCTORY}
$ docker run -it --gpus all --ipc=host --name {YOUR_CONTAINER_NAME} -v
$(pwd):/workspace mobilint/qbcompiler:v0.8 /bin/bash
```

(Recommended) If the trained models and datasets are stored in different directories, you can mount them to the docker container as follows:

```
$ docker run -it --gpus all --ipc=host --name {YOUR_CONTAINER_NAME} -v
$(pwd):/workspace -v {PATH TO MODEL DIR}:/models -v {PATH TO DATASET DIR}:/datasets
mobilint/qbcompiler:v0.8 /bin/bash
```

(Optional) Build the docker image for CPU only version

```
$ # Download Docker Image
$ docker pull mobilint/qbcompiler:v0.8-cpu
$ cd {WORKING DIRCTORY}
$ docker run -it --ipc=host --name {YOUR_CONTAINER_NAME} -v $(pwd):/workspace
mobilint/qbcompiler:v0.8-cpu /bin/bash
```

(Optional, the latest version is not available yet) Build the docker image for WSL2

```
$ # Download Docker Image
$ docker pull mobilint/qbcompiler:v0.7-wsl
```

```
$ # Make a docker container
$ cd {WORKING DIRCTORY}
$ docker run -it --gpus all --ipc=host --name {YOUR_CONTAINER_NAME} -v $(pwd):/data
mobilint/qbcompiler:v0.7-wsl
```

3.2.2 Installation of qubee

qubee compiler packages are available in Mobilint® Software Development Kit (SDK).

Run the following commands to install qubee on the docker container.

```
$ # Download qubee-0.8.3-py3-none-any.whl file
$ # Copy qubee whl file to Docker
$ docker cp {Path to qubee-0.8.3-py3-none-any.whl} {YOUR_CONTAINER_NAME}:/
$ # Start Docker
$ docker start {YOUR_CONTAINER_NAME}
$ # Attach to Docker container
$ docker exec -it {YOUR_CONTAINER_NAME} /bin/bash
$ # Install qubee compiler
$ cd /
$ python -m pip install qubee-0.8.3-py3-none-any.whl
```

(Option, for WSL2) Run the following commands to install qubee on the docker container.

```
$ # Download qubee-0.8.1_wsl-py3-none-any.whl file
$ # Copy qubee whl file to Docker
$ docker cp {Path to qubee-0.8.1_wsl-py3-none-any.whl} {YOUR_CONTAINER_NAME}:/
$ # Start Docker
$ docker start {YOUR_CONTAINER_NAME}
$ # Attach to Docker container
$ docker exec -it {YOUR_CONTAINER_NAME} /bin/bash
$ # Install qubee
$ cd /
$ python -m pip install qubee-0.8.1_wsl-py3-none-any.whl
```

4. Tutorials

The tutorials below go through the steps for preparing the calibration dataset, model compiling, and inference.

4.1 Preparing Calibration Data

To compile the model, you should prepare the calibration dataset (the pre-processed inputs for the model) for quantization. There are three ways to make the calibration dataset as follows:

(i) Pre-process the raw calibration dataset and save it as numpy tensors.

(ii) Utilize a pre-processing configuration YAML file (only for images with **uniform format**).

(iii) Use a manually defined pre-processing function (only for images with **uniform format**).

(iv) Use Mobilint® Calibration GUI Tool

Important The process of making a calibration dataset may vary depending on whether you compile the model for CPU offloading or not. Currently, qubee compiles the model without CPU offloading by default. In this scenario, the pre-processed input shape should be in the format (H, W, C). On the other hand, when CPU offloading is employed, the pre-processed input shape should match the input shape that the original model takes.

4.1.1 Pre-process raw calibration dataset and save it as numpy tensors

You can save the pre-processed calibration dataset as numpy tensors with your custom pre-processing function and use them to compile the model.

An example code is shown below. The following code assumes that we have an image folder consisting of 1000 randomly selected JPEG image files from the ImageNet dataset for calibration prepared in directory `/datasets/imagenet/cali_1000`.

```
import os
import numpy as np
import cv2

def get_img_paths_from_dir(dir_path: str, img_ext = ["jpg", "jpeg", "png"]):
    assert os.path.exists(dir_path)
    candidates = os.listdir(dir_path)
    return [os.path.join(dir_path, y) for y in candidates if
any([y.lower().endswith(e) for e in
    img_ext])]

def pre_process(img_path: str, target_h: int, target_w: int):
    img = cv2.imread(img_path, cv2.IMREAD_COLOR)
    resized_img = cv2.resize(img, dsize=(target_w, target_h)).astype(np.float32)
    return resized_img

if __name__ == "__main__":
    img_dir = "/datasets/imagenet/cali_1000"
    save_dir = "/workspace/calibration/custom_single_input"
    target_h, target_w = 224, 224
    os.makedirs(save_dir, exist_ok=True)
    img_paths = get_img_paths_from_dir(img_dir)
    for i, img_path in enumerate(img_paths):
        fname = f"{i}".zfill(3) + ".npy"
```

```
        fpath = os.path.join(save_dir, fname)
        x = pre_process(img_path, target_h, target_w)
        np.save(fpath, x)
```

The above results are in a directory containing the pre-processed calibration dataset (numpy tensors of shape (224,224, 3)), located at `/workspace/calibration/custom_single_input`.

4.1.2 Use a pre-processing configuration YAML file

Image pre-processing techniques such as resizing, cropping, and normalization are often applied in machine vision tasks. Users can construct a pre-processing configuration using a YAML file and prepare the calibration dataset via the API provided by qubee, *make_calib*. Please be aware that this method can only be employed when the raw data is an image. An example code is shown below. The following code assumes that images for calibration are prepared in the directory `/workspace/cali_1000`.

```
from qubee import make_calib
make_calib(
    args_pre="/workspace/mobilenet_v2.yaml", # path to pre-processing configuration yaml file
    data_dir="/datasets/imagenet/cali_1000", # path to folder of original calibration data files such as images
    save_dir="/workspace/calibration/", # path to folder to save pre-proceessed calibration data files
    save_name="mobilenet_v2", # tag for the generated calibration dataset
    max_size=50 # Maximum number of data to use for calibration
)
```

```
# mobilenet_v2.yaml
Datatype: Image
GetImage:
    to_float32: false
    channel_order: RGB

Pre-Order: [ResizeTorch, CenterCrop, Normalize, SetOrder]
Pre-processing:
    ResizeTorch:
        size: [256, 256]
        interpolation: bilinear
    CenterCrop:
        size: [224, 224]
    Normalize:
        mean: [0.485, 0.456, 0.406]
        std: [0.229, 0.224, 0.225]
        to_float_div255: true
    SetOrder:
        shape: HWC
```

The above results are in a directory containing the pre-processed calibration dataset (numpy tensors), located at `/workspace/calibration/mobilenet_v2`. In addition, a calibration meta txt file containing the paths to the pre-processed numpy files is created, named `/workspace/calibration/mobilenet_v2.txt`.

Remark The sample dataset for calibration should be composed of images with the same format. If some are in color images and others are in grayscale images, the calibration dataset will not be created properly.

4.1.3 Use a manually defined pre-processing function

You can use your pre-processing function to make the calibration dataset via the API provided by qubee, *make_calib_man*. In this case, the pre-processing function should take the image path as input and return a numpy tensor. An example of the code is shown below. The following code assumes that images for calibration are prepared in the directory `/datasets/imagenet/cali_1000`.

```
import torch
import numpy as np
from PIL import Image
import torchvision.transforms.functional as F
from qubee import make_calib_man

def preprocess_resnet50(img_path: str):
    img = Image.open(img_path)
    resize_size=(232, 232)
    crop_size=(224, 224)
    mean=[0.485, 0.456, 0.406]
    std=[0.229, 0.224, 0.225]
    out = F.pil_to_tensor(img)
    out = F.resize(out, size=resize_size)
    out = F.center_crop(out, output_size=crop_size)
    out = out.to(torch.float, copy=False) / 255.
    out = F.normalize(out, mean, std)
    out = np.transpose(out.numpy(), axes=[1, 2, 0])
    return out

make_calib_man(
    pre_ftn=preprocess_resnet50, # callable function to pre-process the calibration
data
    data_dir="/datasets/imagenet/cali_1000", # path to folder of original
calibration data files such as images
    save_dir="/workspace/calibration/", # path to folder to save pre-proceessed
calibration data files
    save_name="resnet50", # tag for the generated calibration dataset
    max_size=50 # Maximum number of data to use for calibration
)
```

The above results are in a directory containing the pre-processed calibration dataset (numpy tensors), located at `/workspace/sample/calibration/resnet50`. In addition, a calibration meta txt file containing the paths to the pre-processed numpy files is created, named `/workspace/sample/calibration/resnet50.txt`.

Remark Unless the custom pre-processing function contains proper exception handling, the sample dataset for calibration should be composed of images with the same format. Like the previous method, the calibration dataset will not be created properly if some are in color images and others are in grayscale images.

4.1.4 Use Mobilint® Calibration GUI Tool

Mobilint® Calibration GUI is a tool that helps users to make the calibration dataset. With a prepared dataset of image files, users can easily generate a pre-processed calibration dataset of npy files. The tool provides pre-defined pre-processing functions for various deep learning models.

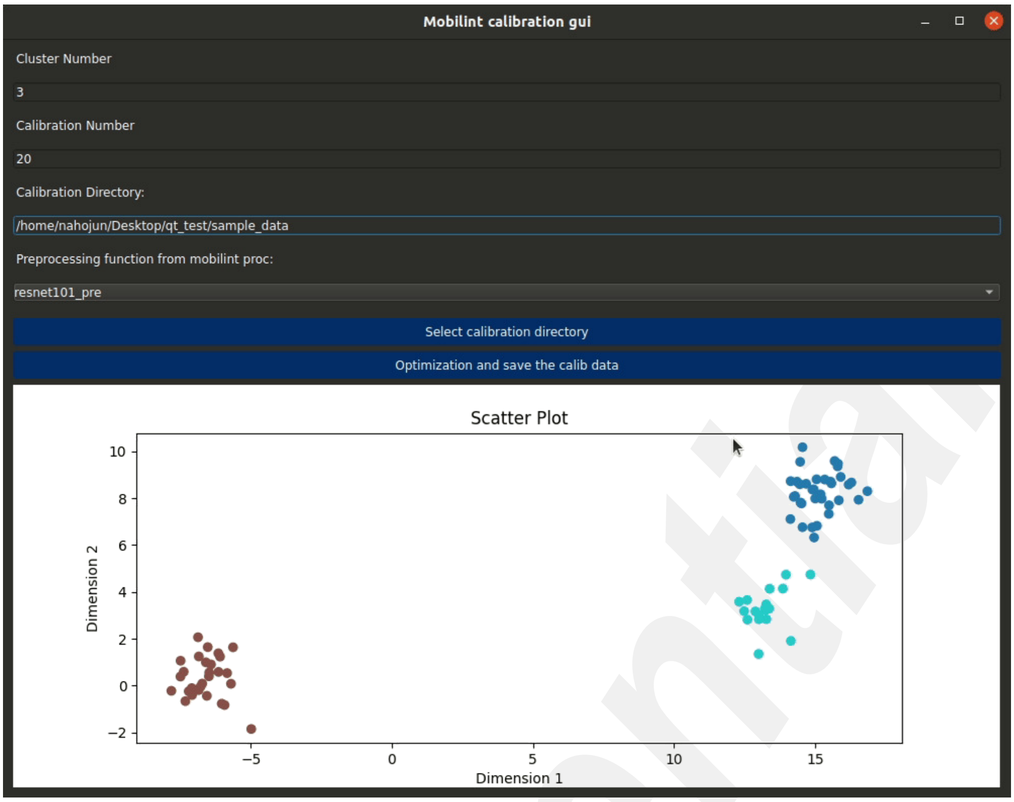

Figure 4-1. Mobilint® Calibration GUI

4.2 Compiling ONNX Models

ONNX is a recommended framework to be used for compiling the trained model. With simple code, the ONNX model can be directly parsed to obtain Mobilint IR. example code is shown below. The following code assumes that the calibration dataset and the model are prepared in the directory `/workspace/calibration/resnet50` and `/workspace/resnet50.onnx`, respectively.

```
""" Compile ONNX model"""
from qubee import mxq_compile
onnx_model_path = "/workspace/resnet50.onnx"
calib_data_path = "/workspace/calibration/resnet50"
# calib_data_path can be replaced with the path to the calibration meta file such as
"/workspace/calibration/resnet50.txt"

mxq_compile(
    model=onnx_model_path,
    calib_data_path=calib_data_path,
    save_path="resnet50.mxq",
    backend="onnx"
)
```

4.3 Compiling PyTorch Models

PyTorch models can be compiled in two different ways. The first approach is converting the PyTorch model into the ONNX model with [`torch.onnx`] namespace, and compiling the converted model with the ONNX backend. The second approach is directly plugging the model into the Mobilint IR. Once the model is converted to Mobilint IR, then it is compiled into MXQ. The example code is shown below. The following codes assume that the calibration dataset is prepared in the directory `/workspace/calibration/resnet50`.

```python
""" Compile PyTorch model"""
from qubee import mxq_compile
### get resnet50 from torchvision
import torchvision
import torch
calib_data_path = "/workspace/calibration/resnet50"
# A calibration meta file such as "/workspace/calibration/resnet50.txt" can be used
instead.

### get resnet50 from torchvision and convert it to torchscript
torch_model = torchvision.models.resnet50(pretrained=True)
torchscript_model_path = "/workspace/resnet50.pt"

example_input = torch.rand(1, 3, 224, 224)
scripted_model = torch.jit.script(torch_model, example_input)
torch.jit.save(scripted_model, torchscript_model_path)

mxq_compile(
    model=torchscript_model_path,
    calib_data_path=calib_data_path,
    backend="torchscript",
    save_path="resnet50.mxq",
    example_input=example_input
)
```

4.4 Compiling TensorFlow/Keras Models

Since Keras works as an interface for TensorFlow, models on the Keras framework can be converted to Mobilint IR via TensorFlow. Currently, the qubee compiler supports TensorFlow models saved in the format of the SavedModel or frozen graph. For the SavedModel format, which includes the serialized model ending with `.pb`, the model can be directly compiled. For the frozen graph, the compiler requires the input node name and the output node name, which can be viewed by Netron. The following codes assume the calibration dataset is prepared in the directory `/workspace/calibration/resnet50`.

```python
""" Compile Keras/TensorFlow model in SavedModel format """
from qubee import mxq_compile
import tensorflow as tf

keras_model = tf.keras.applications.resnet50.ResNet50() # Load a Keras model
calib_data_path = "/workspace/calibration/resnet50"
# A calibration metadata file such as "/workspace/calibration/resnet50.txt" can be
used instead.

keras_model_save_path = "/workspace/tf_models/resnet50" # directory to save the
model
keras_model.save(keras_model_save_path) # Save the model in the format of the frozen
graph. saved_model.pb file will be created in the directory.

mxq_compile(
    model=keras_model_save_path,
    calib_data_path=calib_data_path,
    backend="tf",
    save_path="resnet50.mxq",
)
```

To test the model in the format of the frozen graph, download `MobileNet_v2_1.0_224` from the TensorFlow Model Garden and save it in the directory `/workspace/tf_models/mobilenet_v2`. The following code assumes the calibration dataset is prepared in the directory `/workspace/calibration/resnet50`, which contains the calibration data that is compatible with the model `MobileNet`.

Remark Compiling the model in the frozen graph format requires the input and output node name. When the input tensor name is `input`, it is recommended to set the input node name as `input:0`. In the case that the input tensor shape is unknown, the input shape should be set as `input:0[-1,224,224,3]`, where -1 indicates the batch dimension, and `[224,224,3]` is the input shape. The output argument should be set in the same way.

```
""" Compile TensorFlow model in frozen graph format """
from qubee import mxq_compile
import tensorflow as tf

calib_data_path = "/workspace/calibration/resnet50"
# A calibration metadata file such as "/workspace/calibration/resnet50.txt" can be
used instead.

tf_model_save_path =
"/workspace/tf_models/mobilenet_v2/mobilenet_v2_1.0_224_frozen.pb" # directory to
save the model
feed_dict = {"input": ["input:0[-1,224,224,3]"], "output":
["MobilenetV2/Predictions/Softmax:0"]}

mxq_compile(
    model=tf_model_save_path,
    calib_data_path=calib_data_path,
    backend="tf",
    save_path="mobilenet_v2.mxq",
    feed_dict=feed_dict
)
```

4.5 Compiling TensorFlow Lite Models

The qubee compiler supports TensorFlow Lite models. With the given TensorFlow Lite model, the calibration dataset, and the backend, the model can be compiled into Mobilint IR. The following code assumes the calibration dataset is prepared in the directory `/workspace/calibration/resnet50`.

```
""" Compile Tensorflow Lite model """
from qubee import mxq_compile
import tensorflow as tf

keras_model = tf.keras.applications.resnet50.ResNet50() # Load a pre-trained Keras
model
input_shape = (224, 224, 3)
calib_data_path = "/workspace/calibration/resnet50"
# A calibration metadata file such as "/workspace/calibration/resnet50.txt" can be
used instead.

keras_model_save_path = "/workspace/tf_models/resnet50" # directory to save the
Tensorflow model
keras_model.save(keras_model_save_path) # Save the model in the format of the frozen
graph. saved_model.pb file will be created in the directory.

tflite_model =
tf.lite.TFLiteConverter.from_saved_model(keras_model_save_path).convert() # Convert
the model to TFLite format
with open('/workspace/tf_models/resnet50.tflite', 'wb') as f:
    f.write(tflite_model)

mxq_compile(
```

```
    model=keras_model_save_path+".tflite",
    calib_data_path=calib_data_path,
    backend="tflite",
    save_path="resnet50.mxq",
)
```

4.6 Compling Models with Custom Input(ONNX/Torch/TensorFlow Frameworks)

When the model lacks input shape information, qubee may generate the following error:

```
ValueError: Input node <node name> has more than one unknown shape. Please enter the
numpy input array to infer the input shape.
```

If you encounter this error, you should provide numpy input arrays along with the model during compilation. Ensure the folder structure is as follows:

```
- <folder name>
|- <input node name 1>.npy // only for input node whose shape is unknown.
|- ...
|- <input node name n>.npy
```

For example, if your model has three inputs named `<input1, input2, input3>` and the shape of `input2` and `input3` are unknown, then you should prepare the numpy array for `input2` and `input3` with the following folder structure.

```
- custom_input_array
|- input2.npy
|- input3.npy
```

With the above array, you can compile the model as follows:

```
# compile_test.py
import argparse

from qubee import mxq_compile
from qubee.utils.utils_model_dict import parse_custom_input_info

onnx_model_path = "/workspace/deeplabv3_mobilenet_v3_large_torchvision.onnx"
calib_data_path = "/workspace/calibration/deeplabv3"

parser = argparse.ArgumentParser(description="Compile arguments")
parser.add_argument("--input_shape_path", dest="custom_input_shape_dict",
action=parse_custom_input_info)


mxq_compile(
    model=onnx_model_path,
    calib_data_path=calib_data_path,
    save_path="deeplabv3.mxq",
    input_shape_dict=args.custom_input_shape_dict
    backend="onnx"
)
```

Then, you can compile the model with the following command:

```
python compile_test.py --input_shape_path /workspace/custom_input_array
```

5. CPU Offloading (Beta Version)

Remark To proceed inference with CPU offloading, it requires a runtime library that supports the MXQ file that is compiled for CPU offloading.

From qubee v0.7, we provide a Beta version of CPU offloading for mxq compile. CPU offloading makes it easier for users to compile their models by automatically offloading the computation that Mobilint NPU does not support to the CPU. For example, if a pre-processing or post-processing included in the model involves operations that the NPU does not support, the user would have to implement them manually after compiling, but CPU offloading covers most of these operations and eliminates the need for additional work.

When CPU offloading is employed, the procedures for preparing the calibration dataset and compiling the model vary slightly as follows:

(i) The pre-processed input shape should match the original model's input shape, whereas the pre-processed input shape should be in the format (H, W, C) to compile the model without CPU offloading.

(ii) Set the argument *cpu_offload* of function *mxq_compile* True to enable CPU offloading.

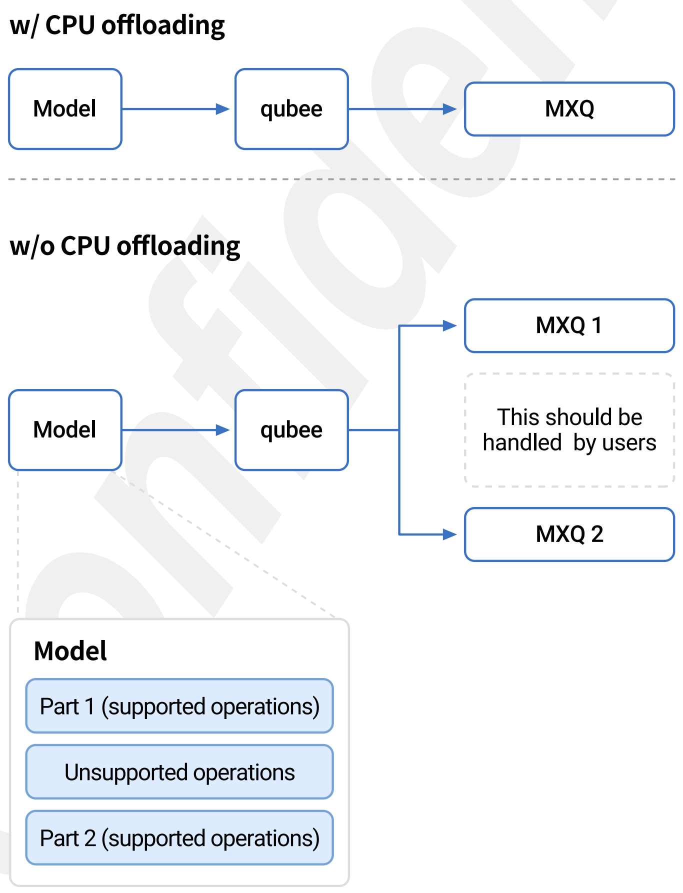

Figure 5-1. SDK CPU Offloading

6. Supported Frameworks

We support almost all the commonly used Machine Learning frameworks & libraries such as ONNX, PyTorch, Keras, TensorFlow, and TensorFlow Lite.

Figure 6-1. Supported deep-learning frameworks

6.1 Supported Operations (ONNX)

Table 6-1. ONNX Supported Operations

API Name	Comments
Add	Broadcast only for specific cases of constant addition: Adding scalar, Adding channel-size vector.
And	
ArgMax	
AveragePool	Only dilation=1, count_include_pad=1.
BatchNormalization	Only training_mode=0.
Cast	
Ceil	
Clip	
Concat	Only along channel axis.
Constant	
ConstantOfShape	
Conv	
ConvTranspose	
DepthToSpace	
Div	Only constant division. Support broadcast same as Add.
Elu	
Equal	
Erf	
Exp	
Expand	
Flatten	Only axis=1 and before fully connected layer or Conv w/ 1x1 kernel.
Floor	
Gather	

API Name	Comments
GatherND	
Gemm	Only transA=0. Only for the following specific case: Input A is a flatten activation and input B is 2D tensor.
GlobalAveragePool	
Greater	
HardSigmoid	
HardSwish	
Identity	
InstanceNormalization	
LayerNormalization	
LeakyRelu	
Less	
Loop	
MatMul	Only for the following specific case: Input A is a flatten activation and input B is 2D tensor or vice-versa.
Max	
MaxPool	Only dilation=1.
Min	
Mod	
Mul	Only constant multiplication. Support broadcast same as Add.
NonMaxSuppression	
NonZero	
Not	
Or	
Pad	Constant, reflect, edge modes are supported
Pow	
PRelu	
Range	
Reciprocal	
ReduceMax	Only along height and width.
ReduceMean	Only along height and width.
ReduceMin	Only along height and width.
ReduceProd	Only along height and width.
ReduceSum	Only along height and width.
Relu	Only scalar slope.
Reshape	Only channel-wise flatten and before fully connected layer or Conv w/ 1x1 kernel. Only allowzero=0.
Resize	Only for the following specific case:

API Name	Comments
	Only mode = "nearest" and coordinate_transformation_mode = "half_pixel" or "pytorch_half_pixel", Only mode = "linear" and coordinate_transformation_mode = "half_pixel" or "pytorch_half_pixel", Attributes axes, antialias, keep_aspect_ratio_policy nearest_mode are not supported.
ScatterND	
Shape	
Sigmoid	
Slice	Only channel-wise slice.
Softmax	
Softplus	
Split	
Sqrt	
Squeeze	Only when resulting tensor has 2D shape. Squeeze along batch axis is unsupported.
Sub	Support broadcast same as Add.
Tanh	
Tile	Batch-wise tile is unsupported.
TopK	
Transpose	Only for the following specific case: Transpose-Flatten-Linear.
Unsqueeze	
Upsample	Only mode "nearest" and "linear".
Xor	

6.2 Supported operations (PyTorch)

Remark Since the Torchscript backend framework is based on Torchscript-Based-ONNX-Exporter, even if the operation is not listed below, it may be supported if it has corresponding ONNX operation, which is supported by qubee.

Table 6-2. PyTorch Supported Operations

API Name	Comments
ADD	Only alpha=1. See supported operations (ONNX): Add
AMAX	See supported operations (ONNX): ReduceMax
AMIN	See supported operations (ONNX): ReduceMin
ARGMAX	See supported operations (ONNX): ArgMax
CAT	Only along channel axis. See supported operations (ONNX): Concat
CEIL	See supported operaitons (ONNX): Ceil
CLAMP	See supported operations (ONNX): Clip

API Name	Comments
DIV	Only constant division. See supported operations (ONNX): Div
EQ	See supported operations (ONNX): Equal
ERF	See supported operations (ONNX): Erf
EXP	See supported operations (ONNX): Exp
FLOOR	See supported operations (ONNX): Floor
FMOD	See supported operations (ONNX): Mod
GATHER	See supported operations (ONNX): GatherND
GT	See supported operations (ONNX): Greater
LOGICAL_AND	See supported operations (ONNX): And
LOGICAL_NOT	See supported operations (ONNX): Not
LOGICAL_OR	See supported operations (ONNX): Or
LOGICAL_XOR	See supported operations (ONNX): Xor
LT	See supported operations (ONNX): Less
MATMUL	See supported operations (ONNX): MatMul
MAX	See supported operations (ONNX): Max
MEAN	See supported operations (ONNX): ReduceMean
MIN	See supported operations (ONNX): Min
MUL	Only constant multiplication. See supported operations (ONNX): Mul
ADAPTIVEAVGPOOL2D	See supported operations (ONNX): AveragePool
ADAPTIVEMAXPOOL2D	See supported operations (ONNX): MaxPool
AVGPOOL2D	Only dilation=1, count_include_pad=1. See supported operations (ONNX): AveragePool
BATCHNORM2D	See supported operations (ONNX): BatchNormalization
CONV2D	See supported operations (ONNX): Conv
CONVTRANSPOSE2D	See supported operations (ONNX): ConvTranspose
ELU	See supported operations (ONNX): Elu
FLATTEN	Only channel-wise flatten and before fully connected layer or Conv w/ 1x1 kernel. See supported operations (ONNX): Flatten
INTERPOLATE	See supported operations (ONNX): Resize.
PAD	See supported operations (ONNX): Pad
HARDSIGMOID	See supported operations (ONNX): HardSigmoid
HARDSWISH	See supported operations (ONNX): HardSwish
IDENTITY	See supported operations (ONNX): Identity
INSTANCENORM2D	See supported operations (ONNX): InstanceNormalization
LEAKYRELU	See supported operations (ONNX): LeakyRelu
LINEAR	See supported operations (ONNX): Gemm
MAXPOOL2D	Only dilation=1. See supported operations (ONNX): MaxPool

API Name	Comments
PRELU	See supported operations (ONNX): PRelu
RELU	See supported operations (ONNX): Relu
SIGMOID	See supported operations (ONNX): Sigmoid
SOFTMAX	See supported operations (ONNX): Softmax
SOFTPLUS	Only beta=1. See supported operations (ONNX): Softplus
TANH	See supported operations (ONNX): Tanh
UPSAMPLE	Only mode "nearest" and "linear". Only scales=[2,2]. See supported operations (ONNX): Upsample
PERMUTE	See supported operations (ONNX): Transpose
POW	See supported operations (ONNX): Pow
PROD	See supported operations (ONNX): ReduceProd
RECIPROCAL	See supported operations (ONNX): Reciprocal
RESHAPE	Only channel-wise flatten and before fully connected layer or Conv w/ 1x1 kernel. See supported operations (ONNX): Reshape
SCATTER	See supported operaitons (ONNX): ScatterND
SPLIT	See supported operations (ONNX): Split
SQRT	See supported operations (ONNX): Sqrt
SQUEEZE	Only when resulting tensor has 2D shape. Squeeze along batch axis is unsupported. See supported operations (ONNX): Squeeze
SUB	Only alpha=1. See supported operations (ONNX): Sub
TENSOR	See supported operations (ONNX): Constant
TILE	Batch-wise tile is unsupported. See supported operations (ONNX): Tile
TOPK	See supported operations (ONNX): TopK
TRANSPOSE	Only before fully connected layer. See supported operations (ONNX): Transpose
UNSQUEEZE	See supported operations (ONNX): Unsqueeze

6.3 Supported operations (TensorFlow/Keras/TensorFlow Lite)

As mentioned in the previous section, Keras works as an interface for TensorFlow 2, and they save the model in the same format as the frozen graph, which ends with `.pb`. Therefore, the TensorFlow/Keras/TensorflowLite operation is supported if it can be described by the TensorFlow raw operations listed below when the model is saved in the format of the frozen graph.

Table 6-3. TensorFlow Supported Operations

API Name	Comments
Placeholder	According to the official document, this operation will fail with an error if it is executed.

API Name	Comments
PlaceholderWithDefault	
Floor	
Identity	
Const	
IdentityN	
Pad	
PadV2	
Conv2D	
DepthwiseConv2dNative	
Conv2DBackpropInput	
MatMul	
FusedBatchNormV3	
FusedBatchNorm	
MaxPool	
AvgPool	
Mean	Only along height, width, and channel.
ResizeNearestNeighbor	
ResizeBilinear	
ConcatV2	Only along channel axis.
Add	
AddV2	
Mul	Only constant multiplication.
Sub	
RealDiv	Only constant division.
AddN	
BiasAdd	
Relu	
Sigmoid	
Softplus	
Exp	
Tanh	
Neg	
LeakyRelu	
Relu6	
Softmax	
ArgMax	
Switch	
Merge	
Shape	
Reshape	Only channel-wise flatten and before fully connected layer or Conv w/

API Name	Comments
	1x1 kernel.
Transpose	Only before fully connected layer.
ExpandDims	
Squeeze	Only when resulting tensor has 2D shape. Squeeze along batch axis is unsupported.
StridedSlice	ellipsis_mask, new_axis_mask, shrink_axis_mask are unsupported.
Slice	
Pack	
Split	
SplitV	
Range	
Fill	
Tile	Batch-wise tile is unsupported.
Cast	
TensorArrayV3	
Maximum	
Sqrt	
Rsqrt	
Rint	
Greater	
LogicalAnd	
Equal	
GreaterEqual	
RandomUniform	
NoOp	
Assert	
ReadFile	
DecodeJpeg	

7. API Reference

7.1 Function: mxq_compile

Compile a given model directly without creating an instance of "Model_Dict".

Table 7-1. mxq_compile

Parameter	Type	Description
model	string or model instance	Model path or model instance. Model should be instance for the following cases: When using backend="onnx", it should be the path to ONNX model file When using backend="torchscript", it should be the path to PyTorch model file When using backend="tf", it should be the path to the folder saving TensorFlow PB graph and assets. When using backend="tflite", it should be the path to TF Lite model file.
calib_data_path	string	A path to the calibration dataset. It can be either of a path to the text (or json) file containing the paths to the pre-processed numpy files or a directory containing the pre-processed numpy files.
model_nickname	string (optional)	Model nickname used in qubee. It is used in qubee to facilitate quicker recompilation of the same models. Qubee stores prior optimization information under this nickname, enabling it to locate and utilize the previously compiled results for faster processing. It is auto-generated from the model's base name, if not provided. For instance, a model "/workspace/onnx/resnet50.onnx" results in "resnet50". If not derivable, "temporary" is the default nickname.
save_path	string (optional)	Filename of the resulting .mxq. If it is None, then it is set to "model_nickname".mxq Defaults to None.
input_shape	tuple or list (optional)	Input shape in HWC. Required only for using PyTorch model and backend="torchscript".
backend	string (optional)	Which framework to use to get the Mobilint IR. It must be one of "onnx", "tf1", "tf2", and "torchscript". They correspond to deep learning frameworks as follows: "onnx": ONNX, "tf": TensorFlow, "tflite": TensorFlow Lite, "torchscript": PyTorch Defaults to "onnx".
device	string (optional)	Device to be used for compile and inerence. Either "cpu" or "gpu".

Parameter	Type	Description
		Defaults to "cpu".
quantize_method	string (optional)	Quantization method to determine the scale parameter in the quantization. Currently, "Max", "Percentile", "MaxPercentile" and "KL" are supported. Defaults to "Percentile".
quantize_percentile	float (optional)	Percentile used for the quantization method "Percentile" and "MaxPercentile". This should be between 0 and 1. (Ex. 0.999, 0.9999) Defaults to 0.99995.
topk_ratio	float (optional)	It is used for quantization method "maxpercentile". Defaults to 0. The larger this value is, the more data is used for calibration. This should be between 0 and 1, but using a value of 0.01 or less is recommended.
smooth_factor	float (optional)	Smooth factor for Gaussian kernel construction, which is required on KL divergence estimation. Defaults to 1.6.
is_quant_ch	bool (optional)	Use multi-channel quantization if True. Defaults to False.
optimization	bool (optional)	If True, it compiles the model with optimization process. If false, qubee uses previous optimization information when stored in previous compiling. (Nickname should be the same.) It must be set to True on the first compile. Defaults to True.
optimization_level	int (optional)	Optimization level in the compiler. If optimization level is high, NPU inference could be faster, but it takes more time for compiling. (Recommend: 3~6) Defaults to 5.
save_sample	bool (optional)	If True, create the "sampleInOut" folder in the current directory and store the input and output binary files in it. Defaults to False.
use_random_calib	bool (optional)	If True, it compiles the given model with random calibration data. This is just used to check if the model is compilable without making a calibration data. Defaults to False.
cpu_offload	bool (optional)	Use CPU offloading for NPU inference if True. Defaults to False.
quant_output	string (optional)	Quantization method that applied to the output layer. "layer", "ch" and "sigmoid" options are available. If "layer", per-layer quantization is applied to the output layer. If is_quant_ch is true, then the computed quantization scale for each channel of the output layer will be merged into single value. If "ch", per-channel quantization is applied to the output layer.

Parameter	Type	Description
		This option is valid only when is_quant_ch is true. If "sigmoid", assign quantization scale that computed with sigmoid function. Defaults to "layer".
adaq_useadaquant	bool (optional)	If True, enable the finetuning with AdaQuant after quantization. Defaults to False.
adaq_weightDeltaLR	float (optional)	Learning rate for finetuning weight delta(weight update) of AdaQuant. (Recommend: 1e-6 ~ 5e-5) Defaults to 0.
adaq_biasDeltaLR	float (optional)	Learning rate for finetuning bias delta(bias update) of AdaQuant. (Recommend: weightDeltaLR/10 ~ weightDeltaLR/2) Defaults to 0.
adaq_weightScaleLR	float (optional)	Learning rate for finetuning weight quantization scale of AdaQuant. Defaults to 0.
adaq_biasScaleLR	float (optional)	Learning rate for finetuning bias quantization scale of AdaQuant. Defaults to 0.
adaq_actScaleLR	float (optional)	Learning rate for finetuning activation quantization scale of AdaQuant. Defaults to 0.
adaq_batchSize	int (optional)	Batch size for running AdaQuant. Defaults to 16.
adaq_epoch	int (optional)	Epochs for repeating AdaQuant update. Defaults to 10.

7.1.1 Tips for choosing quantization methods

"Percentile" and "MaxPercentile" quantization methods each take a hyperparameter called *percentile*. An increase in this value corresponds to a broader quantization interval. To elaborate further, a higher *percentile* results in reduced overflow, albeit at the expense of accuracy.

The "MaxPercentile" method determines the percentile value from data that has been filtered once. As a result, a lower *percentile* is needed for "MaxPercentile" compared to the "Percentile" method. For instance, for the "Percentile" method, we suggest using a value of 0.9999 to 0.999999. For the "MaxPercentile" method, we recommend *percentile* between 0.9 and 0.9999.

The "is_quant_ch" argument enables channel-wise quantization. When set to True, the quantization is performed on a per-channel basis. This method is particularly useful for models, in which activations vary significantly across channels. However, it may take a longer time to compile the model.

The "quant_output" argument is used to determine the quantization method for the output layer. When the original model's output is various across the channels, it is recommended to set "ch" to keep channel-wise quantization. Otherwise, set "layer" to quantize the output layer as a whole.

7.2 Class: Model_Dict

This class serves two main functions:

1. Compile
2. Inference (Note that this inference is only for testing and done by CPU or GPU.)

Table 7-2. Model_Dict Class

Attributes	Type	Description
model_dict	ONNX_Model_Dict, TF_Model_Dict, TFLITE_Model_Dict	Mobilint IR, which holds information of layers in the model.
model_from	string	Backend for holding information of the model.
output_name_list	List[string]	List of the keys (in model_dict) corresponding to the output layer of the model. (It could be different from the original model, because qubee parses deep learning related operations only.)
model_from	string	Deep learning framework where the input model comes from.
c_model	qubee.mmc.Compiler	Low-level compiler. (defined in C++ code). It compiles Mobilint IR into MXQ format.
p_model	qubee.model_dict.Model	Model restored from Mobilint IR. This enables full-precision inference for testing.
is_compiled	bool	Indicates whether the model is compiled.
device	string	Device to be used for compile and inerence. Either CPU or GPU.
has_c_model	bool	Indicates whether the c_model is prepared.
has_p_model	bool	Indicates whether the p_model is prepared.

7.2.1 Methods

Table 7-3. Model_Dict Methods

Methods	Description
__init__	Constructor of Mobilint IR model.
compile	Compile the given model into MXQ format.
inference	Floating inference with the Mobilint IR. This can be used to check the built IR returns the same output as the model.
inference_int8	Integer inference with the compiled and quantized model. The model must be compiled before executing this function.
inference_int8_input_dict	Same as "inference_int8", but get a dictionary input which has a form of {node name: node input} instead. This can be used for models with multiple inputs.
cal_ops	Return the number of add/multiplication operations in the build Mobilint IR. This can be reduced in later optimization steps.
to	Set the operating device (CPU or GPU).

7.2.2 Method Details

Table 7-4. Model_Dict.__init__

Parameter	Type	Description
model	string or model class of the corresponding framework	Model path or model instance. The following cases are supported: When using backend="onnx", it should be the path to ONNX model file When using backend="torchscript", it should be the path to PyTorch model file When using backend="tf", it should be the path to the folder saving TensorFlow PB graph and assets. When using backend="tflite", it should be the path to TF Lite model file.
backend	string (optional)	Which framework to use to get the Mobilint IR. It must be one of "onnx", "tf", "tflite", or "torchscript". They correspond to deep learning frameworks as follows: "onnx": ONNX, "tf": TensorFlow, "tflite": TensorFlow Lite, "torchscript": PyTorch Defaults to "onnx".
input_shape	tuple or list (optional)	Input shape in HWC. Required only for using PyTorch model.
device	string (optional)	Device to be used for compile and inerence. Either "cpu" or "gpu". Defaults to "cpu".

Table 7-5. Model_Dict.compile

Parameter	Type	Description
calib_data_path	string	A path to the calibration dataset. It can be either of a path to the text (or json) file containing the paths to the pre-processed numpy files or a directory containing the pre-processed numpy files.
save_path	string	Filename of the resulting .mxq.
model_nickname	string (optional)	Model nickname used in qubee. It is used in qubee to facilitate quicker recompilation of the same models. Qubee stores prior optimization information under this nickname, enabling it to locate and utilize the previously compiled results for faster processing. It is auto-generated from the model's base name, if not provided. For instance, a model "/workspace/onnx/resnet50.onnx" results in "resnet50". If not derivable, "temporary" is the default nickname.
quantize_method	string (optional)	Quantization method to determine the scale parameter in the quantization. Currently, "Max", "Percentile", "MaxPercentile" and "KL" are supported. Defaults to "Percentile".
quantize_percentile	float (optional)	Percentile used for the quantization method "Percentile" and "MaxPercentile".

Parameter	Type	Description
		This should be between 0 and 1. (Ex. 0.999, 0.9999). Defaults to 0.9999.
topk_ratio	float (optional)	It is used for quantization method "maxpercentile". Defaults to 0. The larger this value is, the more data is used for calibration. This should be between 0 and 1, but using a value of 0.01 or less is recommended.
smooth_facto r	float (optional)	Smoothing factor that is required for Gaussian kernel construction on KL divergence estimation. Defaults to 1.6.
is_quant_ch	bool (optional)	Use multi-channel quantization if True. Defaults to False.
optimization	bool (optional)	If True, it compiles the model with optimization process. If False, qubee uses previous optimization information when stored in previous compiling. (Nickname should be the same.) It must be set to True on the first compile. Defaults to True.
optimization_l evel	int (optional)	Optimization level in the compiler. If optimization level is high, NPU inference could be faster, but it takes more time for compiling. (Recommend: 3~6.) Defaults to 5.
save_sample	bool (optional)	If True, create the "sampleInOut" folder in the current directory and store the input and output binary files in it. Defaults to False.
use_random_ calib	bool (optional)	If True, it compiles the given model with random calibration data. This is just used to check if the model is compilable without making a calibration data. Defaults to False.
cpu_offload	bool (optional)	Use CPU offloading for NPU inference if True. Defaults to False.
quant_output	string (optional)	Quantization method that applied to the output layer. "layer", "ch" and "sigmoid" options are available. If "layer", per-layer quantization is applied to the output layer. If is_quant_ch is true, then the computed quantization scale for each channel of the output layer will be merged into single value. If "ch", per-channel quantization is applied to the output layer. This option is valid only when is_quant_ch is true. If "sigmoid", assign quantization scale that computed with sigmoid function. Defaults to "layer".
adaq_useada quant	bool (optional)	If True, enable the finetuning with AdaQuant after quantization. Defaults to False.
adaq_weight	float (optional)	Learning rate for finetuning weight delta(weight update) of

Parameter	Type	Description
DeltaLR		AdaQuant. (Recommend: 1e-6 ~ 5e-5) Defaults to 0.
adaq_biasDeltaLR	float (optional)	Learning rate for finetuning bias delta(bias update) of AdaQuant. (Recommend: weightDeltaLR/10 ~ weightDeltaLR/2) Defaults to 0.
adaq_weightScaleLR	float (optional)	Learning rate for finetuning weight quantization scale of AdaQuant. Defaults to 0.
adaq_biasScaleLR	float (optional)	Learning rate for finetuning bias quantization scale of AdaQuant. Defaults to 0.
adaq_actScaleLR	float (optional)	Learning rate for finetuning activation quantization scale of AdaQuant. Defaults to 0.
adaq_batchSize	int (optional)	Batch size for running AdaQuant. Defaults to 16.
adaq_epoch	int (optional)	Epochs for repeating AdaQuant update. Defaults to 10.

Table 7-6. Model_Dict.inference

Parameter	Type	Description
input_tensor	numpy.array torch.Tensor Dict[string, numpy.array or torch.Tensor] List[numpy.array or torch.Tensor]	Input tensor with layout BCHW.
cast_cpu	bool (optional)	If True, enable CPU casting on full precision inference. Defaults to False.

Table 7-7. Model_Dict.inference_int8

Parameter	Type	Description
input_tensor	torch.Tensor or np.ndarray	Input tensor with layout BCHW.

Table 7-8. Model_Dict.inference_int8_input_dict

Parameter	Type	Description
input_dict	Dict[str, torch.Tensor or np.ndarray]	Dictionary that contains input information such as {input node name: input tensor}.

Table 7-9. Model_Dict.to

Parameter	Type	Description
device	string	Target device to use, which must be one of "cpu", "gpu", "cuda".

7.3 Function: make_calib

From the given images and preprocessing configuration, create the preprocessed numpy files and a txt file containing their paths.

Table 7-10. make_calib

Parameter	Type	Description
args_pre	string or Dict	Path to a Yaml file or dictionary containing preprocessing configuration information. Refer to 7.4. for details.
data_dir	string	Directory of data to be used for calibration.
save_dir	string	Directory to save the pre-processed numpy files and txt file which contains their paths.
save_name	string (optional)	Name for resulting files. Numpy files will be saved under {save_dir}/{save_name}_npy directory. Text file will be saved in {save_dir}/{save_name}.txt. If it is not provided, it is set to the basename of data_dir.
anno_json	string (optional)	Path to an annotation json file for COCO format. When provided, make_calib function randomly selects samples considering class balance. Defaults to None.
file_format	string (optional)	Filename format using image_idx. Defaults to '%012d.jpg'.
max_size	int (optional)	Maximum size of the resulting calibration data. Defaults to -1, which means no limit on the number of the calibration data.
remove_npy	bool (optional)	If True, remove pre-existing numpy files. Defaults to False.
seed	int (optional)	Random seed. Defaults to 2023.
save_calib_msg	bool (optional)	If True, save calibration data dictionary as MSGpack file. Defaults to False.
msg_path	string (optional)	Path to save MSGpack file If not provided, it automatically generate the path with dataname and number of calibration data. Defaults to None.

7.4 Fuction: make_calib_man

From given images and manually written function that takes an image path as input, create the preprocessed numpy files and a txt file containing their paths.

Table 7-11. make_calib_man

Parameter	Type	Description
pre_ftn	Callable	Pre-processing function that takes an image path as input.
data_dir	string	Directory of data to be used for calibration.
save_dir	string	Directory to save the pre-processed numpy files and txt file which contains their paths.
save_name	string (optional)	Name for resulting files. Numpy files will be saved under {save_dir}/{save_name}_npy directory. Text file will be saved in {save_dir}/{save_name}.txt. If it is not provided, it is set to the basename of data_dir.
anno_json	string (optional)	Path to an annotation json file for COCO format. When provided, make_calib function randomly selects samples considering class balance. Defaults to None.
file_format	string (optional)	Filename format using image_idx. Defaults to '%012d.jpg'.
max_size	int (optional)	Maximum size of the resulting calibration data. Defaults to -1, which means no limit on the number of the calibration data.
remove_npy	bool (optional)	If True, remove pre-existing numpy files. Defaults to False.
seed	int (optional)	Random seed. Defaults to 2023.
save_calib_msg	bool (optional)	If True, save calibration data dictionary as MSGpack file. Defaults to False.
msg_path	string (optional)	Path to save MSGpack file If not provided, it automatically generate the path with dataname and number of calibration data. Defaults to None.

Example codes for using these functions are provided in the ## Preparing Calibration Data section.

7.5 Pre-processing Configurations

qubee supports the following pre-processing functions to make calibration data.

Table 7-12. Pre-processing function API

Pre-processing Type	Description
GetImage	Get image tensor from image path using cv2 backend or image tensor. Note that this should be at the top of the list.
Pad	Pad image tensor.
Normalize	Normalize image tensor.
ResizeTorch	Resize the input image to the given size using torchvision.transforms.functional.resize
Resize	Resize image tensor to the given size using cv2.resize.
CenterCrop	Center crop the image tensor.

Pre-processing Type	Description
SetOrder	Set the order of axes of the given image tensor. Note that this should be at the very end.

You can write a yaml file as follows:

```
[Pre-processing Type]
    [Parameter]: [Argument]
    ...
```

```
# Example
GetImage:
    to_float32: false
    channel_order: RGB
ResizeTorch:
    size: [256, 256]
    interpolation: blinear
CenterCrop:
    size: [224, 224]
Normalize:
    mean: [0.485, 0.456, 0.406]
    std: [0.229, 0.224, 0.225]
    to_float: true
SetOrder:
    shape: HWC
```

7.5.1 Pre-processing Parameters

Table 7-13. GetImage

Parameter	Type	Description
to_float32	bool (optional)	If True, set dtype as float32. Defaults to False.
channel_order	string (optional)	Channel order to load. Upper cases will be converted into lower cases. Defaults to "bgr".

Table 7-14. Pad

Parameter	Type	Description
shape	Tuple[int] (optional)	Expected padding shape (h, w). Defaults to None.
size_divisor	int (optional)	Pad images so that the the resulting image's width and height are divisible by size_divisor. Defaults to None.
pad_val	float (optional)	Values to be filled in padding areas when padding_mode is 'constant'. Defaults to 0.
right_bottom	bool (optional)	If True, it only pads to right and bottom. Defaults to False.

Table 7-15. Normalize

Parameter	Type	Description
mean	List[float] or np.ndarray	Normalization mean.
std	List[float] or np.ndarray	Normalization standard deviation.
to_float	bool (optional)	Normalize image between [0, 255] into [0, 1] by dividing by 255 before normalizing with the mean and std. Defaults to False.

Table 7-16. ResizeTorch

Parameter	Type	Description
size	List[int]	Desired output size, i.e., height and width.
interpolation	string	Interpolation method, accepted values are "nearest", "bilinear", "bicubic", "box", "hamming", "lanczos".

Table 7-17. Resize

Parameter	Type	Description
img_scale	float or Tuple[int, int]	The scaling factor or maximum size (h, w). If it is a float number, then the image will be rescaled by this factor, else if it is a tuple of 2 integers, then the image will be rescaled as large as possible within the scale.
keep_ratio	bool	Whether to keep the aspect ratio when resizing the image. Defaults to False.
interpolation	string	Interpolation method, accepted values are "nearest", "bilinear", "bicubic", "area", "lanczos".

Table 7-18. CenterCrop

Parameter	Type	Description
size	List[int]	Desired output height and width.

Table 7-19. SetOrder

Parameter	Type	Description
shape	string	Desired data layout format, accepted values are "HWC", "CHW", "BHWC", "BCHW". Defaults to "HWC".

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