NVIDIA TensorRT

Developer Guide | NVIDIA Docs

PG-08540-001_v8.2.0 Early Access (EA) | September 2021

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

NVIDIA® TensorRT™ is an SDK that facilitates high performance machine learning inference. It is designed to work in a complementary fashion with training frameworks such as TensorFlow, PyTorch, and MXNet. It focuses specifically on running an already-trained network quickly and efficiently on NVIDIA hardware.

Refer to the TensorRT Installation Guide for instructions on how to install TensorRT.

To get started with TensorRT, we recommend the TensorRT Quick Start Guide. The *TensorRT Quick Start Guide* is for users who want to try out TensorRT SDK; specifically, you'll learn how to quickly construct an application to run inference on a TensorRT engine.

1.1. Structure of this Guide

Chapter 1 provides information about how TensorRT is packaged and supported, and how it fits into the developer ecosystem.

Chapter 2 provides a broad overview of TensorRT capabilities.

Chapters 3 and 4 contain introductions to the C++ and Python APIs respectively.

Subsequent chapters provide more detail about advanced features.

The Appendix contains an operator reference and answers to Frequently Asked Questions.

1.2. Samples

The *TensorRT Sample Support Guide* illustrates many of the topics discussed in this guide. Additional samples focusing on embedded applications can be found here.

1.3. Complementary GPU Features

Multi-instance GPU, or MIG, is a feature of NVIDIA GPUs with Ampere or later architectures that enables user-directed partitioning of a single GPU into multiple smaller GPUs. The physical partitions provide dedicated compute and memory slices with QoS and independent execution of parallel workloads on fractions of the GPU. For TensorRT applications with low GPU utilization, MIG can produce higher throughput at small or no impact on latency. The optimal partitioning scheme is application-specific.

1.4. Complementary Software

The Triton Inference Server is a higher level library providing optimized inference across CPUs and GPUs. It provides capabilities for starting and managing multiple models, and REST and gRPC endpoints for serving inference.

DALI provides high performance primitives for preprocessing image, audio, and video data. TensorRT inference can be integrated as a custom operator in a DALI pipeline. A working example of TensorRT inference integrated as a part of DALI can be found here.

TF-TRT is an integration of TensorRT directly into TensorFlow. It selects subgraphs of TensorFlow graphs to be accelerated by TensorRT, while leaving the rest of the graph to be executed natively by TensorFlow. The result is still a TensorFlow graph that you can execute as usual. For TF-TRT examples, refer to Examples for TensorRT in TensorFlow (TF-TRT).

The PyTorch Quantization Toolkit provides facilities for training models at reduced precision, which can then be exported for optimization in TensorRT.

TensorRT is integrated with NVIDIA's profiling tools, NVIDIA Nsight Systems and NVIDIA Deep Learning Profiler (DLProf).

A restricted subset of TensorRT is certified for use in NVIDIA's DRIVE® product. Some APIs are marked for use only in NVIDIA DRIVE and are not supported for general use.

1.5. ONNX

TensorRT's primary means of importing a trained model from a framework is via the ONNX interchange format. TensorRT ships with an ONNX parser library to assist in importing models. Where possible, the parser is backward compatible up to opset 7; the ONNX Model Opset Version Converter can assist in resolving incompatibilities.

The GitHub version may support later opsets than the version shipped with TensorRT Refer to the ONNX-TensorRT operator support matrix for the latest information on the supported opset and operators.

The ONNX operator support list for TensorRT can be found here.

PyTorch natively supports ONNX export. For TensorFlow, the recommended method is tf2onnx.

1.6. API Versioning

TensorRT version number (MAJOR.MINOR.PATCH) follows Semantic Versioning 2.0.0 for its public APIs and library ABIs. Version numbers change as follows:

1. MAJOR version when making incompatible API or ABI changes changes
2. MINOR version when adding functionality in a backward-compatible manner
3. PATCH version when making backward-compatible bug fixes

Note that semantic versioning does not extend to serialized objects. To reuse plan files, and timing caches, version numbers must match across major, minor, patch, and build versions. Calibration caches can typically be reused within a major version but compatibility is not guaranteed.

1.7. Deprecation Policy

Deprecation is used to inform developers that some APIs and tools are no longer recommended for use. Beginning with version 8.0, TensorRT has the following deprecation policy:

- Deprecation notices are communicated in the release notes. Deprecated API elements are marked with the `TRT_DEPRECATED` macro where possible.
- TensorRT provides a 12-month migration period after the deprecation. For any APIs and tools deprecated in TensorRT 7.x, the 12-month migration period starts from the TensorRT 8.0 GA release date.
- APIs and tools continue to work during the migration period.
- After the migration period ends, APIs and tools are removed in a manner consistent with semantic versioning.

1.8. Support

Support, resources, and information about TensorRT can be found online at https://developer.nvidia.com/tensorrt. This includes blogs, samples, and more.

In addition, you can access the NVIDIA DevTalk TensorRT forum at https://devtalk.nvidia.com/default/board/304/tensorrt/ for all things related to TensorRT. This forum offers the possibility of finding answers, making connections, and getting involved in discussions with customers, developers, and TensorRT engineers.

1.9. How Do I Report A Bug?

We appreciate all types of feedback. If you encounter any issues, please report them by following these steps.

Procedure

1. Register for the NVIDIA Developer website.
2. Log in to the developer site.
3. Click on your name in the upper right corner.
4. Click **My account** > **My Bugs** and select **Submit a New Bug**.
5. Fill out the bug reporting page. Be descriptive and if possible, provide the steps that you are following to help reproduce the problem.
6. Click **Submit a bug**.

Chapter 2. TensorRT's Capabilities

This chapter provides an overview of what you can do with TensorRT™. It is intended to be useful to all TensorRT users.

2.1. C++ and Python APIs

TensorRT's API has language bindings for both C++ and Python, with nearly identical capabilities. The Python API facilitates interoperability with Python data processing toolkits and libraries like NumPy and SciPy. The C++ API can be more efficient, and may better meet some compliance requirements, for example in automotive applications.

Note: The Python API is not available for all platforms. For more information, refer to the TensorRT Support Matrix.

2.2. The Programming Model

TensorRT operates in two phases. In the first phase, usually performed offline, you provide TensorRT with a model definition, and TensorRT optimizes it for a target GPU. In the second phase, you use the optimized model to run inference.

2.2.1. The Build Phase

The highest-level interface for the build phase of TensorRT is the *`Builder`*(C++, Python). The builder is responsible for optimizing a model, and producing an *`Engine`*.

In order to build an engine, you need to:

- Create a network definition
- Specify a configuration for the builder
- Call the builder to create the engine

The *`NetworkDefinition`* interface (C++, Python) is used to define the model. The most common path to transfer a model to TensorRT is to export it from a framework in ONNX format, and use TensorRT's ONNX parser to populate the network definition. However, you can also construct the definition step by step using TensorRT's *`Layer`* (C++, Python) and *`Tensor`* (C++, Python) interfaces.

Whichever way you choose, you must also define which tensors are the inputs and outputs of the network. Tensors that are not marked as outputs are considered to be transient values that can be optimized away by the builder. Input and output tensors must be named, so that at runtime, TensorRT knows how to bind the input and output buffers to the model.

The *BuilderConfig* interface (C++, Python) is used to specify how TensorRT should optimize the model. Among the configuration options available, you can control TensorRT's ability to reduce the precision of calculations, control the tradeoff between memory and runtime execution speed, and constrain the choice of CUDA® kernels. Since the builder can take minutes or more to run, you can also control how the builder searches for kernels, and cached search results for use in subsequent runs.

Once you have a network definition and a builder configuration, you can call the builder to create the engine. The builder eliminates dead computations, folds constants, and reorders and combines operations to run more efficiently on the GPU. It can optionally reduce the precision of floating-point computations, either by simply running them in 16-bit floating point, or by quantizing floating point values so that calculations can be performed using 8-bit integers. It also times multiple implementations of operators with varying data layouts, then computes an optimal schedule to execute the model, minimizing the combined cost of kernel executions and layout transforms.

The builder creates the engine in a serialized form called a *plan*, which can be deserialized immediately, or saved to disk for later use.

Note:

- Engines created by TensorRT are specific to both the TensorRT version with which they were created and the GPU on which they were created.
- TensorRT's network definition does not deep-copy parameter arrays (such as the weights for a convolution). Therefore, you must not release the memory for those arrays until the build phase is complete. When importing a network using the ONNX parser, the parser owns the weights, so it must not be destroyed until the build phase is complete.
- The builder times algorithms to determine the fastest. Running the builder in parallel with other GPU work may perturb the timings, resulting in poor optimization.

2.2.2. The Runtime Phase

The highest-level interface for the execution phase of TensorRT is the *Runtime*

(C++, Python)

.

When using the runtime, you will typically carry out the following steps:

- Deserialize a plan to create an engine
- Create an execution context from the engine

Then, repeatedly:

- Populate input buffers for inference
- Call `enqueue()` or `execute()` on the execution context to run inference

The *Engine* interface (C++, Python) represents an optimized model. You can query an engine for information about the input and output tensors of the network - the expected dimensions, data type, data layout, etc.

The *ExecutionContext* interface (C++, Python), created from the engine, is the main interface for invoking inference. The execution context contains all of the state associated with a particular invocation - thus you can have multiple contexts associated with a single engine, and run them in parallel.

When invoking inference, you must set up the input and output buffers in the appropriate locations. Depending on the nature of the data this may be in either CPU or GPU memory. If not obvious based on your model, you can query the engine to determine in which memory space to provide the buffer.

Once the buffers are set up, inference can be invoked synchronously (`execute`) or asynchronously (`enqueue`). In the latter case, the required kernels are enqueued on a CUDA stream, and control is returned to the application as soon as possible. Some networks require multiple control transfers between CPU and GPU, so control may not return immediately. To wait for completion of asynchronous execution, synchronize on the stream using `cudaStreamSynchronize`.

2.3. Plugins

TensorRT has a *Plugin* interface to allow applications to provide implementations of operators that TensorRT does not support natively. Plugins that are created and registered with TensorRT's `PluginRegistry` can be found by the ONNX parser while translating the network.

TensorRT ships with a library of plugins, and source for many of these and some additional plugins can be found here.

Refer to the Extending TensorRT With Custom Layers chapter for more details.

2.4. Types and Precision

TensorRT supports computations using FP32, FP16, INT8, Bool, and INT32 data types.

When TensorRT chooses CUDA kernels to implement floating point operators in the network, it defaults to FP32 implementations. There are two ways to configure different levels of precision:

- To control precision at the model level, `BuilderFlag` options (C++, Python) can indicate to TensorRT that it may select lower-precision implementations when searching for the fastest (and because lower precision is generally faster, if allowed to, it typically will).

  Therefore, you can easily instruct TensorRT to use FP16 calculations for your entire model. For regularized models which have been and whose input dynamic range is approximately one, this typically produces significant speedups with negligible change in accuracy.

- For finer-grained control, where an operator must run at higher precision because part of the network is numerically sensitive or requires high dynamic range, arithmetic precision can be specified for that operator.

Refer to the Reduced Precision section for more details.

2.5. Quantization

TensorRT supports quantized floating point, where floating-point values are linearly compressed and rounded to 8-bit integers. This significantly increases arithmetic throughput while reducing storage requirements and memory bandwidth. When quantizing a floating-point tensor, TensorRT needs to know its dynamic range - that is, what range of values is important to represent - values outside this range are clamped when quantizing.

Dynamic range information can be calculated by the builder (this is called *calibration*) based on representative input data. Or you can perform quantization-aware training in a framework and import the model to TensorRT with the necessary dynamic range information.

Refer to the Working With INT8 chapter for more details.

2.6. Data Layout

When defining a network, TensorRT assumes that data is represented by multidimensional C-style arrays. Each operator has a specific interpretation of its inputs: for example, a 2D convolution will assume that the last three dimensions of its input are in CHW format - there is no option to use, for example an WHC format. Refer to the TensorRT Layers chapter for how each operator interprets its inputs.

While optimizing the network, TensorRT performs transformations internally (including to HWC, but also more complex formats) to use the fastest possible CUDA kernels. In general, layouts are chosen to optimize performance, and applications have no control over the choices. However, the underlying data formats are exposed at I/O boundaries (network input and output, and passing data to and from plugins) to allow applications to minimize unnecessary layout transformations.

Refer to the Reformat-free I/O section for more details.

2.7. Dynamic Shapes

By default, TensorRT optimizes the model based on the input shapes (batch size, image size, etc) at which it was defined. However, the builder can be configured to allow the input dimensions to be adjusted at runtime. In order to enable this, you specify one or more instances of `OptimizationProfile` (C++, Python) in the builder configuration, containing for each input a minimum and maximum shape, along with an optimization point within that range.

TensorRT creates an optimized engine for each profile, choosing CUDA kernels that work for all shapes within the (minimum, maximum) range and are fastest for the optimization point - typically different kernels for each profile. You can then select among profiles at runtime.

Refer to the Working With Dynamic Shapes chapter for more details.

2.8. DLA

TensorRT supports NVIDIA's Deep Learning Accelerator, a dedicated inference processor present on many NVIDIA SoCs which supports a subset of TensorRT's operators. TensorRT allows you to execute part of the network on the DLA and the rest on GPU; for operators which can be executed on either device, you can select the target device in the builder configuration on a per-operator basis.

Refer to the Working With DLA chapter for more details.

2.9. Updating Weights

When building an engine, you can specify that it may need to later have its weights updated. This can be useful if you are frequently updating the weights of the model without changing the structure, such as in reinforcement learning or when retraining a model while retaining the same structure. Weights updates are performed via the *`Refitter`* (C++, Python) interface.

Refer to the Refitting An Engine section for more details.

2.10. Polygraphy

Polygraphy is a toolkit designed to assist in running and debugging deep learning models in TensorRT and other frameworks. It includes aPython API anda command-line interface (CLI) built using this API.

Among other things, with Polygraphy you can:

- Run inference among multiple backends, like TensorRT and ONNX-Runtime, and compare results (for exampleAPI,CLI)
- Convert models to various formats, for example, TensorRT engines with post-training quantization (for exampleAPI,CLI)
- View information about various types of models (for exampleCLI)
- Modify ONNX models on the command-line:
  - Extract subgraphs (for exampleCLI)
  - Simplify and sanitize (for exampleCLI)
- Isolate faulty tactics in TensorRT (for exampleCLI)

For more details, refer to the Polygraphy repository.

Chapter 3. The C++ API

This chapter illustrates basic usage of the C++ API, assuming you are starting with an ONNX model. sampleOnnxMNIST illustrates this use case in more detail.

The C++ API can be accessed via the header `NvInfer.h`, and is in the `nvinfer1` namespace. For example, a simple application might begin with:

```
#include "NvInfer.h"

using namespace nvinfer1;
```

Interface classes in the TensorRT™ C++ API begin with the prefix `I`, for example `ILogger`, `IBuilder`, etc.

A CUDA context is automatically created the first time TensorRT makes a call to CUDA, if none exists prior to that point. It is generally preferable to create and configure the CUDA context yourself before the first call to TensoRT.

In order to illustrate object lifetimes, code in this chapter does not use smart pointers; however, their use is recommended with TensorRT interfaces.

3.1. The Build Phase

To create a builder, you first need to instantiate the `ILogger` interface. Here, we capture all warning messages but ignore informational messages:

```
class Logger : public ILogger
{
    void log(Severity severity, const char* msg) override
    {
        // suppress info-level messages
        if (severity <= Severity::kWARNING)
            std::cout << msg << std::endl;
    }
} logger;
```

You can then create an instance of the builder:

```
IBuilder* builder = createInferBuilder(logger);
```

3.1.1. Creating a Network Definition

Once the builder has been created, the first step in optimizing a model is to create a network definition:

```
uint32_t flag = 1U <<static_cast<uint32_t>
    (NetworkDefinitionCreationFlag::kEXPLICIT_BATCH)
```

```
INetworkDefinition* network = builder->createNetworkV2(flag);
```

The `kEXPLICIT_BATCH` flag is required in order to import models using the ONNX parser. Refer to the Explicit vs Implicit Batch section for more information.

3.1.2. Importing a Model using the ONNX Parser

Now, the network definition needs to be populated from the ONNX representation. The ONNX parser API is in the file `NvOnnxParser.h`, and the parser is in the `nvonnxparser` C++ namespace.

```
#include "NvOnnxParser.h"

Using namespace nvonnxparser;
```

You can create an ONNX parser to populate the network as follows:

```
IParser*  parser = createParser(*network, logger);
```

Then, read the model file and process any errors.

```
parser->parseFromFile(modelFile, ILogger::Severity::kWARNING);
for (int32_t i = 0; i < parser.getNbErrors(); ++i)
{
std::cout << parser->getError(i)->desc() << std::endl;
}
```

An important aspect of a TensorRT network definition is that it contains pointers to model weights, which are copied into the optimized engine by the builder. Since the network was created via the parser, the parser owns the memory occupied by the weights, and so the parser object should not be deleted until after the builder has run.

3.1.3. Building an Engine

The next step is to create a build configuration specifying how TensorRT should optimize the model.

```
IBuilderConfig* config = builder->createBuilderConfig();
```

This interface has many properties that you can set in order to control how TensorRT optimizes the network. One important property is the maximum workspace size. Layer implementations often require a temporary workspace, and this parameter limits the maximum size that any layer in the network can use. If insufficient workspace is provided, it is possible that TensorRT will not be able to find an implementation for a layer.

```
config->setMaxWorkspaceSize(1U << 20);
```

Once the configuration has been specified, the engine can be built.

```
IHostMemory*  serializedModel = builder->buildSerializedNetwork(*network, *config);
```

Since the serialized engine contains the necessary copies of the weights, the parser, network definition, builder configuration and builder are no longer necessary and may be safely deleted:

```
delete parser;
delete network;;
delete config;
delete builder;
```

The engine can then be saved to disk, and the buffer into which it was serialized can be deleted.

```
delete serializedModel
```

Note: Serialized engines are not portable across platforms or TensorRT versions. Engines are specific to the exact GPU model they were built on (in addition to the platform and the TensorRT version).

3.2. Deserializing a Plan

Assuming you have previously serialized an optimized model and wish to perform inference, you will need to create an instance of the `Runtime` interface. Like the builder, the runtime requires an instance of the logger:

```
IRuntime* runtime = createInferRuntime(logger);
```

Assuming you have read the model from into a buffer, you can then deserialize it to obtain an engine:

```
ICudaEngine* engine =
  runtime->deserializeCudaEngine(modelData, modelSize);
```

3.3. Performing Inference

The engine holds the optimized model, but to perform inference we will need to manage additional state for intermediate activations. This is done via the `ExecutionContext` interface:

```
IExecutionContext *context = engine->createExecutionContext();
```

An engine can have multiple execution contexts, allowing one set of weights to be used for multiple overlapping inference tasks.

To perform inference, you must pass TensorRT buffers for input and output, which TensorRT requires you to specify in an array of pointers. You can query the engine using the names you provided for input and output tensors to find the right positions in the array:

```
int32_t inputIndex = engine->getBindingIndex(INPUT_NAME);
int32_t outputIndex = engine->getBindingIndex(OUTPUT_NAME);
```

Using these indices, set up a buffer array pointing to the input and output buffers on the GPU:

```
void* buffers[2];
buffers[inputIndex] = inputBuffer;
buffers[outputIndex] = outputBuffer;
```

You can then call TensorRT's enqueue method to start inference asynchronously using a CUDA stream:

```
context->enqueueV2(buffers, stream, nullptr);
```

It is common to `enqueue` asynchronous `memcpy()` before and after the kernels to move data from the GPU if it is not already there. The final argument to `enqueueV2()` is an optional CUDA event that is signaled when the input buffers have been consumed, and their memory can be safely reused.

To determine when the kernel (and possibly `memcpy()`) are complete, use standard CUDA synchronization mechanisms such as events or waiting on the stream.

If you prefer synchronous inference, use the `executeV2` method instead of `enqueueV2`.

Chapter 4. The Python API

This chapter illustrates basic usage of the Python API, assuming you are starting with an ONNX model. The onnx_resnet50.py sample illustrates this use case in more detail.

The Python API can be accessed via the `tensorrt` module:

```
import tensorrt as trt
```

4.1. The Build Phase

To create a builder, you need to first create a logger. The Python bindings include a simple logger implementation that logs all messages above a certain severity to `stdout`.

```
logger = trt.Logger(trt.Logger.WARNING)
```

Alternatively, it is possible to define your own implementation of the logger by deriving from the `ILogger` class:

```
class MyLogger(trt.ILogger):
    def __init__(self):
       trt.ILogger.__init__(self)

    def log(self, severity, msg):
        pass # Your custom logging implementation here

logger = MyLogger()
```

You can then create a builder:

```
builder = trt.Builder(logger)
```

4.1.1. Creating a Network Definition in Python

Once the builder has been created, the first step in optimizing a model is to create a network definition:

```
network = builder.create_network(1 << int(trt.NetworkDefinitionCreationFlag.EXPLICIT_BATCH))
```

The `EXPLICIT_BATCH` flag is required in order to import models using the ONNX parser. Refer to the Explicit vs Implicit Batch section for more information.

4.1.2. Importing a Model using the ONNX Parser

Now, the network definition needs to be populated from the ONNX representation. You can create an ONNX parser to populate the network as follows:

```
parser = trt.OnnxParser(network, logger)
```

Then, read the model file and process any errors:

```
success = parser.parse_from_file(model_path)
for idx in range(parser.num_errors):
    print(parser.get_error(idx))

if not success:
    pass # Error handling code here
```

4.1.3. Building an Engine

The next step is to create a build configuration specifying how TensorRT should optimize the model:

```
config = builder.create_builder_config()
```

This interface has many properties that you can set in order to control how TensorRT optimizes the network. One important property is the maximum workspace size. Layer implementations often require a temporary workspace, and this parameter limits the maximum size that any layer in the network can use. If insufficient workspace is provided, it is possible that TensorRT will not be able to find an implementation for a layer:

```
config.max_workspace_size = 1 << 20 # 1 MiB
```

Once the configuration has been specified, the engine can be built and serialized with:

```
serialized_engine = builder.build_serialized_network(network, config)
```

It may be useful to save the engine to a file for future use. You can do that like so:

```
with open("sample.engine", "wb") as f:
    f.write(serialized_engine)
```

Note: Serialized engines are not portable across platforms or TensorRT versions. Engines are specific to the exact GPU model they were built on (in addition to the platform and the TensorRT version).

4.2. Deserializing a Plan

To perform inference, you will first need to deserialize the engine using the `Runtime` interface. Like the builder, the runtime requires an instance of the logger.

```
runtime = trt.Runtime(logger)
```

You can then deserialize the engine from a memory buffer:

```
engine = runtime.deserialize_cuda_engine(serialized_engine)
```

If you need to first load the engine from a file, run:

```
with open("sample.engine", "rb") as f:
    serialized_engine = f.read()
```

4.3. Performing Inference

The engine holds the optimized model, but to perform inference we will need to manage an additional state for intermediate activations. This is done via the `IExecutionContext` interface:

```
context = engine.create_execution_context()
```

An engine can have multiple execution contexts, allowing one set of weights to be used for multiple overlapping inference tasks.

To perform inference, you must pass TensorRT buffers for inputs and outputs, which TensorRT requires you to specify in a list of GPU pointers. You can query the engine using the names you provided for input and output tensors to find the right positions in the array:

```
input_idx = engine[input_name]
output_idx = engine[output_name]
```

Using these indices, set up GPU buffers for each input and output. Several Python packages allow you to allocate memory on the GPU, including, but not limited to, PyTorch, the Polygraphy CUDA wrapper, and PyCUDA.

Then, create a list of GPU pointers. For example, for PyTorch CUDA tensors, you can access the GPU pointer using the `data_ptr()` method; for Polygraphy `DeviceArray`, use the `ptr` attribute:

```
buffers = [None] * 2 # Assuming 1 input and 1 output
buffers[input_idx] = input_ptr
buffers[output_idx] = output_ptr
```

After populating the input buffer, you can call TensorRT's `execute_async` method to start inference asynchronously using a CUDA stream.

First, create the CUDA stream. If you already have a CUDA stream, you can use a pointer to the existing stream. For example, for PyTorch CUDA streams, i.e. `torch.cuda.Stream()`, you can access the pointer using the `cuda_stream` property; for Polygraphy CUDA streams, use the `ptr` attribute.

Next, start inference:

```
context.execute_async_v2(buffers, stream_ptr)
```

It is common to enqueue asynchronous `memcpy()` before and after the kernels to move data from the GPU if it is not already there.

To determine when the kernel (and possibly `memcpy()`) are complete, use the standard CUDA synchronization mechanisms such as events or waiting on the stream. For example, with Polygraphy, use:

```
stream.synchronize()
```

If you prefer synchronous inference, use the `execute_v2` method instead of `execute_async_v2`.

Chapter 5. How TensorRT Works

This chapter provides more detail on how TensorRT™ works.

5.1. Object Lifetimes

TensorRT's API is class-based, with some classes acting as factories for other classes. For objects owned by the user, the lifetime of a factory object must span the lifetime of objects it creates. For example, the `NetworkDefinition` and `BuilderConfig` classes are created from the builder class, and objects of those classes should be destroyed before the builder factory object.

An important exception to this rule is creating an engine from a builder. Once you have created an engine, you may destroy the builder, network, parser and build config and continue using the engine.

5.2. Error Handling and Logging

When creating TensorRT top-level interfaces (builder, runtime or refitter), you must provide an implementation of the *`Logger`* (C++, Python) interface. The logger is used for diagnostics and informational messages; its verbosity level is configurable. Since the logger may be used to pass back information at any point in the lifetime of TensorRT, its lifetime must span any use of that interface in your application. The implementation must also be thread-safe, since TensorRT may use worker threads internally.

An API call to an object will use the logger associated with the corresponding top-level interface. For example, in a call to `ExecutionContext::enqueue()`, the execution context was created from an engine, which was created from a runtime, so TensorRT will use the logger associated with that runtime.

The primary method of error handling is the *`ErrorRecorde`* (C++, Python) interface. You can implement this interface, and attach it to an API object to receive errors associated with that object. The recorder for an object will also be passed to any others it creates - for example, if you attach an error recorder to an engine, and create an execution context from that engine, it will use the same recorder. If you then attach a new error recorder to the execution context, it will receive only errors coming from that context. If an error is generated but no error recorder is found, it will be emitted via the associated logger.

Note that CUDA errors are generally asynchronous - so when performing multiple inferences or other streams of CUDA work asynchronously in a single CUDA context, an asynchronous GPU error may be observed in a different execution context than the one which generated it.

5.3. Memory

TensorRT uses considerable amounts of device memory, i.e. memory directly accessible by the GPU, as opposed to the host memory attached to the CPU). Since device memory is often a constrained resource, it's important to understand how TensorRT uses it.

5.3.1. The Build Phase

During build, TensorRT allocates device memory for timing operator implementations. Some implementations can consume a lot of temporary memory, especially with large tensors. You can control the maximum amount of temporary memory through the builder's `maxWorkspace` attribute. This defaults to `0`, so that the builder does not use any temporary workspace. If the builder finds applicable kernels that could not be run because of insufficient workspace, it will emit a logging message indicating this, and how much workspace would be needed to succeed.

Even with relatively little workspace however, timing requires creating buffers for input, output, and weights. TensorRT is robust against the operating system returning out-of-memory for such allocations, but on some platforms the OS may successfully provide memory, and subsequently the out-of-memory killer process observes that the system is low on memory, and kills TensorRT. If this happens free up as much system memory as possible before retrying.

During the build phase, there will typically be at least two copies of the weights in hosty memory: those from the original network, and those included as part of the engine as it is built. In addition, when TensorRT combines weights (for example convolution with batch normalization) additional temporary weight tensors will be created.

5.3.2. The Runtime Phase

At runtime, TensorRT uses relatively little host memory, but can use considerable amounts of device memory.

An engine, on deserialization, allocates device memory to store the model weights. Since the serialized engine is almost all weights, its size is an excellent approximation to the amount of device memory the weights require.

An `ExecutionContext` uses two kinds of device memory:

- Persistent state, required by some operator implementations, lasts for the lifetime of an execution context.
- Scratch memory used to hold intermediate results while processing the network.

You may optionally create an execution context without scratch memory via `ICudaEngine::createExecutionContextWithoutDeviceMemory()` and provide that memory yourself for the duration of network execution. This allows you to share it between multiple contexts that are not running concurrently, or for other uses

while inference is not running. The amount of device memory required is returned by `ICudaEngine::getDeviceMemorySize()`.

Information about the amount of persistent state and scratch memory is emitted by the builder when building the network, at severity `kINFO`. Examining the log, the messages look similar to the following:

```
[08/12/2021-17:39:11] [I] [TRT] Total Host Persistent Memory: 106528
[08/12/2021-17:39:11] [I] [TRT] Total Device Persistent Memory: 29785600
[08/12/2021-17:39:11] [I] [TRT] Total Scratch Memory: 9970688
```

By default, TensorRT allocates device memory directly from CUDA. However, you can attach an implementation of TensorRT's *`IGpuAllocator`* (C++, Python) interface to the builder or runtime and manage device memory yourself. This is useful if your application wishes to control all GPU memory and sub-allocate to TensorRT instead of having TensorRT allocate directly from CUDA.

TensorRT's dependencies (cuDNN and cuBLAS) can occupy large amounts of device memory. TensorRT allows you to control whether these libraries are used for inference via the `TacticSources` (C++, Python) attribute in the builder configuration. Note that some operator implementations require these libraries, so that when they're excluded, the network may not compile.

The CUDA infrastructure and TensorRT's device code also consume device memory. The amount of memory varies by platform, device, and TensorRT version. You can use `cudaGetMemInfo` to determine the total amount of device memory in use.

Note: Since CUDA is not in control of memory on unified-memory devices, the results returned by `cudaGetMemInfo` may not be accurate on these platforms.

5.4. Threading

In general TensorRT objects are not thread-safe. The expected runtime concurrency model is that different threads will operate on different execution contexts. The context contains the state of the network (activation values etc) during execution, so using a context concurrently in different threads results in undefined behavior.

To support this model, the following operations are thread-safe:

- Non-modifying operations on a runtime or engine.
- Deserializing an engine from a TensorRT runtime.
- Creating an execution context from an engine.
- Registering and deregistering plugins.

5.5. Determinism

TensorRT builder uses timing to find the fastest kernel to implement a given operator. Timing kernels is subject to noise - other work running on the GPU, fluctuations in GPU clock speed,

etc. Timing noise means that on successive runs of the builder, the same implementation may not be selected.

The *`AlgorithmSelector`* (C++, Python) interface allows you to force the builder to pick a particular implementation for a given operator. You can use this to ensure that the same kernels are picked by the builder from run to run. For more information, refer to the Algorithm Selection and Reproducible Builds section.

Once an engine has been built it is deterministic: providing the same input in the same runtime environment will produce the same output.

5.6. CUDA Graphs

CUDA graphs are a way to represent a sequence (or more generally a graph) of kernels in a way that allows their scheduling to be optimized by CUDA.

TensorRT's `enqueuev2()` method supports CUDA graph capture (link) for models which require no CPU interaction mid-pipeline. Models for which graphs are not supported include those with loops or conditionals.

Graphs captured with TensorRT are specific to the input size for which they were captured, and also to the state of the execution context. Modifying the context from which the graph was captured will result in undefined behavior when executing the graph.

When capturing a graph, it's important to account for the two-phase execution strategy used in the presence of dynamic shapes.

1. Update internal state of the model to account for any changes in input size
2. Stream work to the GPU

For models where input size is fixed at build time, the first phase requires no per-invocation work. Otherwise, if the input sizes have changed since the last invocation, some work may be required to update derived properties.

The first phase of work is not designed to be captured, and even if the capture is successful may increase model execution time. Therefore, after changing the shapes of inputs or the values of shape tensors, call `enqueuev2()` once to flush deferred updates before capturing the graph.

5.7. Profiling TensorRT

TensorRT has a *`Profiler`* (C++, Python)interface, which you can implement in order to have TensorRT pass profiling information to your application.

The *Inspector* (C++, Python) interface allows you to query TensorRT to see the properties of each runtime layer.

At build time, you can control how much information is provided to the Inspector and DLProf by setting a `ProfilingVerbosity` (C++, Python) value in the builder configuration. This allows you to have rich profiling information while developing and debugging, while minimizing

the information observable in production deployment. The verbosity level also applies to information reported by NSight and DLProf.

Chapter 6. Advanced Topics

6.1. The Timing Cache

To reduce the builder time, TensorRT™ creates a layer timing cache to keep the layer profiling information during the builder phase. The information it contains is specific to the targeted builder devices, CUDA and TensorRT versions, and BuilderConfig parameters that can change the layer implementation such as `BuilderFlag::kTF32` or `BuilderFlag::kREFIT`.

If there are other layers with the same input/output tensor configuration and layer parameters, the TensorRT builder skips profiling and reuses the cached result for the repeated layers. If a timing query misses in the cache, the builder times the layer and updates the cache.

The timing cache can be serialized and deserialized. You can load a serialized cache from a buffer via `IBuilderConfig::createTimingCache`:

```
ITimingCache* cache =
 config->createTimingCache(cacheFile.data(), cacheFile.size());
```

Setting the buffer size to `0` creates a new empty timing cache.

You then attach the cache to a builder configuration before building.

```
config->setTimingCache(*cache, false);
```

During the build, the timing cache can be augmented with more information as a result of cache misses. After the build, it can be serialized for use with another builder.

```
IHostMemory* serializedCache = cache->serialize();
```

If there is no timing cache attached to a builder, the builder creates its own temporary local cache and destroys it when it is done.

The cache is incompatible with algorithm selection (refer to the Algorithm Selection and Reproducible Builds section). It can be disabled by setting the `BuilderFlag`.

```
config->setFlag(BuilderFlag::kDISABLE_TIMING_CACHE);
```

6.2. Refitting An Engine

TensorRT can *refit* an engine with new weights without having to rebuild it, however, the option to do so must be specified when building:

```
...
config->setFlag(BuilderFlag::kREFIT)
```

```
builder->buildSerializedNetwork(network, config);
```

Later, you can create a `Refitter` object:

```
ICudaEngine* engine = ...;
IRefitter* refitter = createInferRefitter(*engine,gLogger)
```

Then update the weights. For example, to update the kernel weights for a convolution layer named "MyLayer":

```
Weights newWeights = ...;
refitter->setWeights("MyLayer",WeightsRole::kKERNEL,
                     newWeights);
```

The new weights should have the same count as the original weights used to build the engine. `setWeights` returns false if something went wrong, such as a wrong layer name or role or a change in the weights count.

Because of the way the engine is optimized, if you change some weights, you might have to supply some other weights too. The interface can tell you what additional weights need to be supplied.

You can use `INetworkDefinition::setWeightsName()` to name weights at build time - the ONNX parser uses this API to associate the weights with the names used in the ONNX model. Then, later you can use `setNamedWeights` to update the weights:

```
Weights newWeights = ...;
refitter->setNamedWeights("MyWeights", newWeights);
```

`setNamedWeights` and `setWeights` can be used at the same time, i.e., you can update weights with names via `setNamedWeights` and update those unnamed weights via `setWeights`.

Because of the way the engine is optimized, if you change some weights, you might have to supply some other weights too. The interface can tell you what additional weights need to be supplied. This typically requires two calls to `IRefitter::getMissing`, first to get the number of weights objects that must be supplied, and second to get their layers and roles.

```
const int32_t n = refitter->getMissing(0, nullptr, nullptr);
std::vector<const char*> layerNames(n);
std::vector<WeightsRole> weightsRoles(n);
refitter->getMissing(n, layerNames.data(),
                        weightsRoles.data());
```

Alternatively, to get the names of all missing weights, run:

```
const int32_t n = refitter->getMissingWeights(0, nullptr);
std::vector<const char*> weightsNames(n);
refitter->getMissingWeights(n, weightsNames.data());
```

You can supply the missing weights, in any order:

```
for (int32_t i = 0; i < n; ++i)
    refitter->setWeights(layerNames[i], weightsRoles[i],
                         Weights{...});
```

The set of missing weights returned is complete, in the sense that supplying only the missing weights does not generate a need for any more weights.

Once all the weights have been provided, you can update the engine:

```
bool success = refitter->refitCudaEngine();
assert(success);
```

If refit returns false, check the log for a diagnostic, perhaps about weights that are still missing.

You can then delete the refitter:

```
delete refitter;
```

The updated engine behaves as if it had been built from a network updated with the new weights.

To view all refittable weights in an engine, use `refitter->getAll(...)` or `refitter->getAllWeights(...)`; similarly to how `getMissing` and `getMissingWeights` were used above.

6.3. Algorithm Selection and Reproducible Builds

The default behavior of TensorRT's optimizer is to choose the algorithms that globally minimize the execution time of the engine. It does this by timing each implementation, and sometimes, and when implementations have similar timings, it's possible that system noise will determine which will be chosen on any particular run of the builder. Different implementations will typically use different order of accumulation of floating point values, and two implementations may use different algorithms or even run at different precisions. Thus, different invocations of the builder will typically not result in engines which return bit-identical results.

Sometimes it's important to have a deterministic build, or to recreate the algorithm choices of an earlier build. By providing an implementation of the `IAlgorithmSelector` interface and attaching it to a builder configuration with `setAlgorithmSelector`, you can guide algorithm selection manually.

The method `IAlgorithmSelector::selectAlgorithms` receives an *`AlgorithmContext`* containing information about the algorithm requirements for a layer, and a set of *`Algorithm`* choices meeting those requirements. It returns the set of algorithms which TensorRT should consider for the layer.

The builder will select from these algorithms the one which minimizes the global runtime for the network. If no choice is returned and `BuilderFlag::kSTRICT_TYPES is unset`, TensorRT interprets this to mean that any algorithm may be used for this layer. To override this behavior and generate an error if an empty list is returned, set the `BuilderFlag::kSTRICT_TYPES` flag.

After TensorRT has finished optimizing the network for a given profile, it calls `reportAlgorithms`, which can be used to record the final choice made for each layer.

To build a TensorRT engine deterministically, return a single choice from `selectAlgorithms`. To replay choices from an earlier build, use `reportAlgorithms` to record the choices in that build, and return them in `selectAlgorithms`.

`sampleAlgorithmSelector` demonstrates how to use the algorithm selector to achieve determinism and reproducibility in the builder.

Note:

- The notion of a "layer" in algorithm selection is different from `ILayer` in `INetworkDefinition`. The "layer" in the former can be equivalent to a collection of multiple network layers due to fusion optimizations.
- Picking the fastest algorithm in `selectAlgorithms` may not produce the best performance for the overall network, as it may increase reformatting overhead.
- The timing of an `IAlgorithm` is `0` in `selectAlgorithms` if TensorRT found that layer to be a no-op.
- `reportAlgorithms` doesn't provide the timing and workspace information for an `IAlgorithm` that are provided to `selectAlgorithms`.

6.4. Creating A Network Definition From Scratch

6.4.1. C++

Instead of using a parser, you can also define the network directly to TensorRT via the Network Definition API. This scenario assumes that the per-layer weights are ready in host memory to pass to TensorRT during the network creation.

The following example creates a simple network with Input, Convolution, Pooling, FullyConnected, Activation, and SoftMax layers. To view the code in totality, refer to sampleMNISTAPI located in the `opensource/sampleMNISTAPI` directory in the GitHub repository.

Add the Input layer to the network, with the input dimensions, including dynamic batch. A network can have multiple inputs, although in this sample there is only one:

```
auto data = network->addInput(INPUT_BLOB_NAME, dt, Dims3{-1, 1, INPUT_H, INPUT_W});
```

Add the Convolution layer with hidden layer input nodes, strides and weights for filter and bias. In order to retrieve the tensor reference from the layer, we can use:

```
auto conv1 = network->addConvolution(
*data->getOutput(0), 20, DimsHW{5, 5}, weightMap["conv1filter"], weightMap["conv1bias"]);
conv1->setStride(DimsHW{1, 1});
```

Note: Weights passed to TensorRT layers are in host memory.

Add the Pooling layer:

```
auto pool1 = network->addPooling(*conv1->getOutput(0), PoolingType::kMAX, DimsHW{2, 2});
pool1->setStride(DimsHW{2, 2});
```

Add the FullyConnected and Activation layers:

```
auto ip1 = network->addFullyConnected(*pool1->getOutput(0), 500, weightMap["ip1filter"],
 weightMap["ip1bias"]);
auto relu1 = network->addActivation(*ip1->getOutput(0), ActivationType::kRELU);
```

Add the SoftMax layer to calculate the final probabilities and set it as the output:

```
auto prob = network->addSoftMax(*relu1->getOutput(0));
prob->getOutput(0)->setName(OUTPUT_BLOB_NAME);
```

Mark the output:

```
network->markOutput(*prob->getOutput(0));
```

6.4.2. Python

When creating a network, you must first define the engine and create a builder object for inference. The Python API is used to create a network and engine from the Network APIs. The network definition reference is used to add various layers to the network. For more information about using the Python API to create a network and engine, refer to the network_api_pytorch_mnist sample.

About this task

The following steps illustrate how to create a simple network with Input, Convolution, Pooling, FullyConnected, Activation, and SoftMax layers.

Procedure

1. Create the builder and network with `trt.Builder(TRT_LOGGER)` as builder and `builder.create_network()` as network.
   a). Configure the network layers based on the weights provided. In this case, the weights are imported from a Pytorch model.
   b). Add an input layer. The `name` is a string, `dtype` is a TensorRT dtype, and the `shape` can be provided as either a list or tuple.

   ```
   input_tensor = network.add_input(name=INPUT_NAME, dtype=trt.float32,
    shape=INPUT_SHAPE)
   ```

2. Add a convolution layer.

   ```
   conv1_w = weights['conv1.weight'].numpy()
    conv1_b = weights['conv1.bias'].numpy()
    conv1 = network.add_convolution(input=input_tensor, num_output_maps=20, kernel_shape=(5,
    5), kernel=conv1_w, bias=conv1_b)
    conv1.stride = (1, 1)

    pool1 = network.add_pooling(input=conv1.get_output(0), type=trt.PoolingType.MAX,
    window_size=(2, 2))
    pool1.stride = (2, 2)
    conv2_w = weights['conv2.weight'].numpy()
    conv2_b = weights['conv2.bias'].numpy()
    conv2 = network.add_convolution(pool1.get_output(0), 50, (5, 5), conv2_w, conv2_b)
    conv2.stride = (1, 1)

    pool2 = network.add_pooling(conv2.get_output(0), trt.PoolingType.MAX, (2, 2))
    pool2.stride = (2, 2)

    fc1_w = weights['fc1.weight'].numpy()
    fc1_b = weights['fc1.bias'].numpy()
    fc1 = network.add_fully_connected(input=pool2.get_output(0), num_outputs=500,
    kernel=fc1_w, bias=fc1_b)
   ```

```
relu1 = network.add_activation(fc1.get_output(0), trt.ActivationType.RELU)

fc2_w = weights['fc2.weight'].numpy()
fc2_b = weights['fc2.bias'].numpy()
fc2 = network.add_fully_connected(relu1.get_output(0), OUTPUT_SIZE, fc2_w, fc2_b)

fc2.get_output(0).name =OUTPUT_NAME
network.mark_output(fc2.get_output(0))
```

6.5. Reformat-free I/O

TensorRT optimizes a network using many different data formats. In order to allow efficient passing of data between TensorRT and a client application, these underlying data formats are exposed at network I/O boundaries, i.e. for Tensors marked as network input or output, and when passing data to and from plugins.

Note that this ability to specify tensor formats only applies at I/O boundaries - for other tensors, TensorRT picks the format that results in the fastest execution, and may insert reformats to improve performance.

To define your preferred tensor formats, you specify one or more formats that you would prefer TensorRT use, in the form of a bitfield.

C++

```
auto formats = 1U << TensorFormat::kHWC8;
network->getInput(i)->setAllowedFormats(formats);
```

Python

```
formats = 1 << int(tensorrt.TensorFormat.HWC8)
network.get_input(i).allowed_formats = formats
```

In order to force TensorRT to pick the preferred formats, set the `STRICT_TYPES` flag in the builder configuration. If this flag is not set, and there exists a faster implementation including reformats, then TensorRT will pick the faster path.

It's possible that in some cases no operator implementation is found which obeys the constraints, in which case TensorRT emits a warning, and picks a format that results in the fastest execution path as normal.

sampleReformatFreeIO illustrates the use of reformat-free I/O using C++.

The following table shows the supported combinations of data type and layout.

Table 1. Supported combination of data type and layout

Memory Layout \ Data Type	kINT32	kFLOAT	kHALF	kINT8
kLINEAR	Only for GPU	Supported	Supported	Supported
kCHW2	N/A	N/A	Only for GPU	N/A
kCHW4	N/A	N/A	Supported	Supported
kHWC8	N/A	N/A	Only for GPU	N/A
kCHW16	N/A	N/A	Supported	N/A
kCHW32	N/A	Only for GPU	Only for GPU	Supported

Memory Layout \ Data Type	kINT32	kFLOAT	kHALF	kINT8
kDHWC8	N/A	N/A	Only for GPU	N/A
kCDHW32	N/A	N/A	Only for GPU	Only for GPU
kHWC	N/A	Only for GPU	N/A	N/A
kDLA_LINEAR	N/A	N/A	Only for DLA	Only for DLA
kDLA_HWC4	N/A	N/A	Only for DLA	Only for DLA
kHWC16	N/A	N/A	Only for NVIDIA Ampere GPUs and later	N/A

6.6. Reduced Precision

6.6.1. Network-level Control of Precision

By default, TensorRT works in 32-bit precision, but can also execute operations using 16-bit floating point, and 8-bit quantized floating point. Using lower precision requires less memory and enables faster computation.

Reduced precision support depends on your hardware (refer to the Hardware And Precision section in the *TensorRT Support Matrix*). You can query the builder to check the supported precision support on a platform:

C++

```
if (builder->platformHasFastFp16()) { … };
```

Python

```
if builder.platform_has_fp16:
```

Setting flags in the builder configuration informs TensorRT that it may select lower-precision implementations:

C++

```
config->setFlag(BuilderFlag::kFP16);
```

Python

```
config.set_flag(trt.BuilderFlag.FP16)
```

There are three precision flags: FP16, INT8, and TF32, and they may be enabled independently. Note that TensorRT will still choose a higher-precision kernel if it results in overall lower runtime, or if no low-precision implementation exists.

When TensorRT chooses a precision for a layer, it automatically converts weights as necessary to run the layer.

sampleGoogleNet and sampleMNIST provide examples of using these flags.

While using FP16 and TF32 precisions is relatively straightforward, there is additional complexity when working with INT8. Refer to the Working With INT8 chapter for more details.

6.6.2. Layer-level Control of Precision

The builder-flags provide permissive, coarse-grained control. However, sometimes part of a network requires higher dynamic range or is sensitive to numerical precision. You can constrain the input and output types per layer:

C++

```
layer->setPrecision(DataType::kFP16)
```

Python

```
layer.precision = trt.fp16
```

This provides a *preferred type* (here, `DataType::kFP16`) for the inputs and outputs.

You may further set preferred types for the layer's outputs:

C++

```
layer->setOutputType(out_tensor_index, DataType::kFLOAT)
```

Python

```
layer.set_output_type(out_tensor_index, trt.fp16)
```

The computation will use the same floating-point type as is preferred for the inputs. Most TensorRT implementations have the same floating-point types for input and output; however, Convolution, Deconvolution, and FullyConnected can support quantized INT8 input and unquantized FP16 or FP32 output, as sometimes working with higher-precision outputs from quantized inputs is necessary to preserve accuracy.

Setting the precision constraint hints to TensorRT that it should select a layer implementation whose inputs and outputs match the preferred types, inserting reformat operations if the outputs of the previous layer and the inputs to the next layer do not match the requested types.

By default, TensorRT chooses such an implementation only if it results in a higher-performance network. If another implementation is faster, TensorRT uses it and issues a warning. You can override this behavior by making the type constraints *strict* in the builder configuration.

C++

```
config->setFlag(BuilderFlag::kSTRICT_TYPES)
```

Python

```
config.set_flag(trt.BuilderFlag.STRICT_TYPES)
```

If the constraints are strict, TensorRT obeys them unless there is no implementation with the preferred precision constraints, in which case it issues a warning and uses the fastest available implementation.

sampleINT8API illustrates the use of reduced precision with these APIs.

6.6.3. Enabling TF32 Inference Using C++

TensorRT allows the use of TF32 Tensor Cores by default. When computing inner products, such as during convolution or matrix multiplication, TF32 execution does the following:

- Rounds the FP32 multiplicands to FP16 precision but keeps the FP32 dynamic range.
- Computes an exact product of the rounded multiplicands.
- Accumulates the products in an FP32 sum.

TF32 Tensor Cores can speed up networks using FP32, typically with no loss of accuracy. It is more robust than FP16 for models which require a high dynamic range for weights or activations.

There is no guarantee that TF32 Tensor Cores are actually used, and there's no way to force the implementation to use them - TensorRT can fall back to FP32 at any time and always falls back if the platform does not support TF32. However you can disable their use by clearing the TF32 builder flag.

Setting the environment variable `NVIDIA_TF32_OVERRIDE=0` when building an engine disables the use of TF32, despite setting `BuilderFlag::kTF32`. This environment variable, when set to `0`, overrides any defaults or programmatic configuration of NVIDIA libraries, so they never accelerate FP32 computations with TF32 Tensor Cores. This is meant to be a debugging tool only, and no code outside NVIDIA libraries should change the behavior based on this environment variable. Any other setting besides `0` is reserved for future use.

WARNING: Setting the environment variable `NVIDIA_TF32_OVERRIDE` to a different value when the engine is run can cause unpredictable precision/performance effects. It is best left unset when an engine is run.

Note: Unless your application requires the higher dynamic range provided by TF32, FP16 will be a better solution since it almost always yields faster performance.

6.7. Compatibility of Serialized Engines

Serialized engines are only guaranteed to work correctly when used with the same operating systems, CPU architectures, GPU models, and TensorRT versions used to serialize the engines.

TensorRT checks the following attributes of the engine and will fail to deserialize if they do not match the environment in which the engine was serialized:

- major, minor, patch, and build versions of TensorRT
- SM major and minor versions

This ensures that kernels selected during the build phase are present and can run. In addition, the APIs that TensorRT uses to select and configure kernels from cuDNN and cuBLAS do not support cross-device compatibility, so disable the use of these tactic sources in the builder configuration.

TensorRT additionally checks the following properties and will issue a warning if they do not match:

- CUDA compute capability
- Global memory bus width
- L2 cache size
- Maximum shared memory per block and per multiprocessor

- Texture alignment requirement
- Number of multiprocessors
- Whether the GPU device is integrated or discrete

If GPU clock speeds differ between engine serialization and runtime systems, the chosen tactics from the serialization system may not be optimal for the runtime system and may incur some performance degradation.

If the device memory available during deserialization is smaller than the amount during serialization, deserialization may fail due to memory allocation failures.

When building small models on large devices, TensorRT may choose kernels which are less efficient but scale better across the available resources. Thus if optimizing a single TensorRT engine for use on multiple devices in the same architecture, the best approach is to run the builder on the smallest device.

6.8. Explicit vs Implicit Batch

TensorRT supports two modes for specifying a network: explicit batch and implicit batch.

In *implicit batch* mode, every tensor has an implicit batch dimension and all other dimensions must have constant length. This mode was used by early versions of TensoRT, and continues to be supported for backwards compatibility.

In *explicit batch* mode, all dimensions are explicit and can be dynamic, that is their length can change at execution time. Many new features, such as dynamic shapes and loops, are available only in this mode. It is also required by the ONNX parser.

For example, consider a network that processes N images of size HxW with 3 channels, in NCHW format. At runtime, the input tensor has dimensions [N,3,H,W]. The two modes differ in how the `INetworkDefinition` specifies the tensor's dimensions:

- In explicit batch mode, the network specifies [N,3,H,W].
- In implicit batch mode, the network specifies only [3,H,W]. The batch dimension N is implicit.

Operations that "talk across a batch" are impossible to express in implicit batch mode because there is no way to specify the batch dimension in the network. Examples of inexpressible operations in implicit batch mode:

- reducing across the batch dimension
- reshaping the batch dimension
- transposing the batch dimension with another dimension

The exception is that a tensor can be *broadcast* across the entire batch, via method `ITensor::setBroadcastAcrossBatch` for network inputs, and implicit broadcasting for other tensors.

Explicit batch mode erases the limitations - the batch axis is axis 0. A more accurate term for explicit batch would be "batch oblivious", because in this mode, TensorRT attaches no special semantic meaning to the leading axis,except as required by specific operations. Indeed

in explicit batch mode there might not even be a batch dimension (such as a network that handles only a single image) or there might be multiple batch dimensions of unrelated lengths (such as comparison of all possible pairs drawn from two batches).

The choice of explicit vs. implicit batch must be specified when creating the INetworkDefinition, via a flag. Here's the code for explicit batch mode:

```
IBuilder* builder = ...;
INetworkDefinition* network = builder->createNetworkV2(1U <<
 static_cast<uint32_t>(NetworkDefinitionCreationFlag::kEXPLICIT_BATCH))
```

For implicit batch, use `createNetwork` or pass a 0 to `createNetworkV2`.

Chapter 7. Working With INT8

7.1. Introduction to Quantization

TensorRT supports the use of 8-bit integers to represent quantized floating point values. The quantization scheme is *symmetric uniform* quantization - quantized values are represented in signed INT8, and the transformation from quantized to unquantized values is simply a multiplication. In the reverse direction, quantization uses the reciprocal scale, followed by rounding and clamping.

To enable the use of any quantized operations, the INT8 flag must be set in the builder configuration.

7.1.1. Quantization Workflows

There are two workflows for creating quantized networks:

Post-training quantization (PTQ) derives scale factors after the network has been trained. TensorRT provides a workflow for PTQ, called *calibration*, where it measures the distribution of activations within each activation tensor as the network executes on representative input data, then uses that distribution to estimate a scale value for the tensor.

Quantization-aware training (QAT) computes scale factors during training. This allows the training process to compensate for the effects of the quantization and dequantization operations.

TensorRT's Quantization Toolkit is a PyTorch library that helps produce QAT models that can be optimized by TensorRT. You can also utilize the toolkit's PTQ recipe to perform PTQ in PyTorch and export to ONNX.

7.1.2. The C++ API

Quantized networks can be represented in two ways:

In *implicitly quantized* networks, each quantized tensor has an associated scale. When reading and writing the tensor, the scale is used to implicitly quantize and dequantize values.

When processing implicitly quantized networks, TensorRT treats the model as a floating-point model when applying the graph optimizations, and uses INT8 opportunistically to optimize layer execution time. If a layer runs faster in INT8, then it executes in INT8. Otherwise, FP32 or FP16 are used. In this mode, TensorRT is optimizing for performance only, and you have

little control over where INT8 is used - even if you explicitly set the precision of a layer at the API level, TensorRT may fuse that layer with another during graph optimization, and lose the information that it must execute in INT8. TensorRT's PTQ capability generates an implicitly quantized network.

In *explicitly quantized* networks, the scaling operations to transform between the quantized and unquantized values are represented explicitly by `IQuantizeLayer` (C++, Python) and `IDequantizeLayer` (C++, Python) nodes in the graph - these will henceforth be referred to as Q/DQ nodes. By contrast with implicit quantization, the explicit form specifies exactly where conversion to and from INT8 is performed, and the optimizer will perform only precision conversions that are dictated by the semantics of the model, even if:

- adding extra conversions could increase layer precision (for example, choosing an FP16 kernel implementation over an INT8 implementation)
- adding extra conversions results in an engine that executes faster (for example, choosing an INT8 kernel implementation to execute a layer specified as having float precision or vice versa)

ONNX uses an explicitly quantized representation - when a model in PyTorch or TensorFlow is exported to ONNX, each fake-quantization operation in the framework's graph is exported as Q followed by DQ. Since TensorRT preserves the semantics of these operators, you can expect results very close to those seen in the framework. While optimizations preserve the placement of quantization and dequantization, they may change the order of floating-point operations in the model, so results will not be bitwise identical.

Note that by contrast with TensorRT's PTQ, performing either QAT or PTQ in a framework and then exporting to ONNX will result in an explicitly quantized model.

Table 2. Implicit vs Explicit Quantization

	Implicit Quantization	Explicit Quantization
User control over precision	Little control: INT8 is used in all kernels for which it accelerates performance.	Full control over quantization/ dequantization boundaries.
Optimization criterion	Optimize for performance.	Optimize for performance while maintaining arithmetic precision (accuracy).
API	▶ Model + Scales (dynamic range API) ▶ Model + Calibration data	Model with Q/DQ layers.
Quantization scales	Weights: ▶ Set by TensorRT (internal) ▶ Range `[-127, 127]` Activations: ▶ Set by calibration or specified by the user	Weights and activations: ▶ Specified using Q/DQ ONNX operators ▶ Range `[-128, 127]`

	Implicit Quantization	Explicit Quantization
	▶ Range `[-128, 127]`	

For more background on quantization, refer to the Integer Quantization for Deep Learning Inference: Principles and Empirical Evaluation paper.

7.2. Setting Dynamic Range

TensorRT provides APIs to set *dynamic range* (the range that must be represented by the quantized tensor) directly, to support implicit quantization where these values have been calculated outside TensorRT.

The API allows you to set the dynamic range for a tensor using minimum and maximum values. Since TensorRT currently supports only symmetric range, the scale is calculated using `max(abs(min_float), abs(max_float))`.

Dynamic range is needed for all floating-point inputs and outputs of an operation that will execute in INT8.

You can set the dynamic range for a tensor as follows:

C++

```
tensor->setDynamicRange(min_float, max_float);
```

Python

```
tensor.dynamic_range = (min_float, max_float)
```

sampleINT8API illustrates the use of these APIs in C++.

7.3. Post-Training Quantization using Calibration

In post-training quantization, TensorRT computes a scale value for each tensor in the network. This process, called *calibration*, requires you to supply representative input data on which TensorRT runs the network to collect statistics for each activation tensor.

The amount of input data required is application-dependent, but experiments indicate that about 500 images are sufficient for calibrating ImageNet classification networks.

Given the statistics for an activation tensor, deciding on the best scale value is not an exact science - it requires balancing two sources of error in the quantized representation: *discretization error* (which increases as the range represented by each quantized value becomes larger) and *truncation error* (where values are clamped to the limits of the representable range.) Thus, TensorRT provides multiple different calibrators which calculate the scale in different ways. Older calibrators also performed layer fusion to optimize away unneeded Tensors before performing calibration, which can be problematic when using DLA.

`EntropyCalibratorV2`

This is the recommended calibrator and is required for DLA. Calibration happens before Layer fusion by default. This is recommended for CNN-based networks.

MinMaxCalibrator
This calibrator seems to work better for NLP tasks. Calibration happens before Layer fusion by default. This is recommended for networks such as NVIDIA BERT (an optimized version of Google's official implementation).

EntropyCalibrator
This is the legacy entropy calibrator. This is less complicated than a legacy calibrator and produces better results. Calibration happens after Layer fusion by default. Refer to `kCALIBRATION_BEFORE_FUSION` for enabling calibration before fusion.

LegacyCalibrator
This calibrator is for compatibility with TensorRT 2.0 EA. This calibrator requires user parameterization and is provided as a fallback option if the other calibrators yield poor results. Calibration happens after Layer fusion by default. Refer to `kCALIBRATION_BEFORE_FUSION` for enabling calibration before fusion. You can customize this calibrator to implement percentile max, for example, 99.99% percentile max is proved to have best accuracy for NVIDIA BERT.

When building an INT8 engine, the builder performs the following steps:

1. Build a 32-bit engine, run it on the calibration set, and record a histogram for each tensor of the distribution of activation values.
2. Build from the histograms a calibration table providing a scale value for each tensor.
3. Build the INT8 engine from the calibration table and the network definition.

Calibration can be slow; therefore the output of step 2 (the calibration table) can be cached and reused. This is useful when building the same network multiple times, for example, on multiple platforms - in particular, it can simplify workflow to build the calibration table on a machine with a discrete GPU and then reuse it on an embedded platform.

Before running calibration, TensorRT queries the calibrator implementation to see if it has access to a cached table. If so, it proceeds directly to step 3 above. Cached data is passed as a pointer and length.

As well as quantizing activations, TensorRT must also quantize weights. It uses symmetric quantization with a quantization scale calculated using the maximum absolute values found in the weight tensor. For convolution and deconvolution weights, scales are per-channel.

Note: When the builder is configured to use INT8 I/O, TensorRT still expects calibration data to be in FP32. You can create FP32 calibration data bycasting INT8 I/O calibration data to FP32 precision. You should also ensure that FP32 cast calibration data is in the range `[-128.0f, 127.0f]` and so can be converted to INT8 data without any precision loss.

INT8 calibration can be used along with the dynamic range APIs. Setting the dynamic range manually overrides the dynamic range generated from INT8 calibration.

7.3.1. INT8 Calibration Using C++

To provide calibration data to TensorRT, implement the `IInt8Calibrator` interface.

About this task

The builder invokes the calibrator as follows:

- First, it queries the interface for the batch size and calls `getBatchSize()` to determine the size of the input batch to expect.
- Then, it repeatedly calls `getBatch()` to obtain batches of input. Batches should be exactly the batch size by `getBatchSize()`. When there are no more batches, `getBatch()` should return `false`.

After you have implemented the calibrator, you can configure the builder to use it:

```
config->setInt8Calibrator(calibrator.get());
```

To cache the calibration table, implement the `writeCalibrationCache()` and `readCalibrationCache()` methods.

For more information about configuring INT8 Calibrator objects, see sampleINT8.

7.3.2. Calibration Using Python

The following steps illustrate how to create an INT8 Calibrator object using the Python API.

Procedure

1. Import TensorRT:
   ```
   import tensorrt as trt
   ```
2. Similar to test/validation files, use a set of input files as a calibration files dataset. Make sure the calibration files are representative of the overall inference data files. For TensorRT to use the calibration files, you must create a `batchstream` object. A `batchstream` object is used to configure the calibrator.
   ```
   NUM_IMAGES_PER_BATCH = 5
   batchstream = ImageBatchStream(NUM_IMAGES_PER_BATCH, calibration_files)
   ```
3. Create an `Int8_calibrator` object with input nodes names and batch stream:
   ```
   Int8_calibrator = EntropyCalibrator(["input_node_name"], batchstream)
   ```
4. Set INT8 mode and INT8 calibrator:
   ```
   config.set_flag(trt.BuilderFlag.INT8)
   config.int8_calibrator = Int8_calibrator
   ```

7.4. Explicit Quantization

When TensorRT detects the presence of Q/DQ layers in a network, it builds an engine using explicit-precision processing logic.

A Q/DQ network must be built with the INT8-precision builder flag enabled:

```
config->setFlag(BuilderFlag::kINT8);
```

In explicit-quantization, network changes of representation to and from INT8 are explicit, therefore, INT8 should not be used as a type constraint.

7.4.1. Quantization Scale

There are two common quantization scale granularities:

- *Per-tensor quantization*: in which a single scale value (scalar) is used to scale the entire tensor.
- *Per-channel quantization*: in which a scale tensor is broadcast along the given axis - for convolutional neural networks, this is typically the channel axis.

With explicit quantization, weights can be quantized using per-tensor quantization or they can be quantized using per-channel quantization. In either case, the scale precision is FP32. Activations can only be quantized using per-tensor quantization.

When using per-channel quantization, the axis of quantization must be the output-channel axis. For example, when the weights of 2D convolution are described using `KCRS` notation, `K` is the output-channel axis, and the weights quantization can be described as:

```
For each k in K:
    For each c in C:
        For each r in R:
            For each s in S:
                output[k,c,r,s] := clamp(round(input[k,c,r,s] / scale[k]))
```

The scale is a vector of coefficients and must have the same size as the quantization axis. The quantization scale must consist of all positive float coefficients. The rounding method is rounding-to-nearest ties-to-even and clamping is in the range `[-128, 127]`.

Dequantization is performed similarly except for the pointwise operation which is defined as:

```
output[k,c,r,s] := input[k,c,r,s] * scale[k]
```

7.4.2. Quantized Weights

Weights of Q/DQ models must be specified using FP32 data type. The weights are quantized by TensorRT using the scale of the `IQuantizeLayer` that operates on the weights. The quantized weights are stored in the `Engine` file. Pre-quantized weights can also be used but must be specified using FP32 data-type. The scale of the Q node should be set to `1.0f`, but for the DQ node should be the real scale value.

7.4.3. ONNX Support

When a model trained in PyTorch or TensorFlow using Quantization Aware Training (QAT) is exported to ONNX, each fake-quantization operation in the framework's graph is exported as a pair of `QuantizeLinear`and `DequantizeLinear`ONNX operators.

When TensorRT imports ONNX models, the ONNX `QuantizeLinear` operator is imported as an `IQuantizeLayer` instance, and the ONNX `DequantizeLinear` operator is imported as an `IDequantizeLayer` instance. ONNX using opset 10 introduced support for QuantizeLinear/DequantizeLinear, and a quantization-axis attribute was added in opset 13 (required for per-channel quantization). PyTorch 1.8 introduced support for exporting PyTorch models to ONNX using opset 13.

WARNING: The ONNX GEMM operator is an example that can be quantized per channel. PyTorch `torch.nn.Linear` layers are exported as an ONNX GEMM operator with `(K, C)` weights layout and with the `transB` GEMM attribute enabled (this transposes the weights before performing the GEMM operation). TensorFlow, on the other hand, pre-transposes the weights `(C, K)` before ONNX export:

- **PyTorch:** $y = xW^T$

- **TensorFlow:** `y = xW`

PyTorch weights are therefore transposed by TensorRT. The weights are quantized by TensorRT before they are transposed, so GEMM layers originating from ONNX QAT models that were exported from PyTorch use dimension `0` for per-channel quantization (axis `K = 0`); while models originating from TensorFlow use dimension `1` (axis `K = 1`).

TensorRT does not support pre-quantized ONNX models that use INT8 tensors or quantized operators. Specifically, the following ONNX quantized operators are *not* supported and generates an import error if they are encountered when TensorRT imports the ONNX model:

- `QLinearConv`/`QLinearMatmul`
- `ConvInteger`/`MatmulInteger`

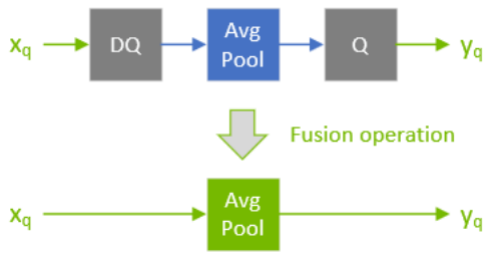
7.4.4. TensorRT Processing Of Q/DQ Networks

When TensorRT optimizes a network in Q/DQ-mode, the optimization process is limited to optimizations that do not change the arithmetic correctness of the network. Bit-level accuracy is rarely possible since the order of floating-point operations can produce different results (for example, rewriting `a * s + b * s` as `(a + b) * s` is a valid optimization). Allowing these differences is fundamental to back-end optimization in general, and this also applies to converting a graph with Q/DQ layers to use INT8 computation.

Q/DQ layers control the compute and data precision of a network. An `IQuantizeLayer` instance converts an FP32 tensor to an INT8 tensor by employing quantization, and an `IDequantizeLayer` instance converts an INT8 tensor to an FP32 tensor by means of dequantization. TensorRT expects a Q/DQ layer pair on each of the inputs of quantizable-layers. Quantizable-layers are deep-learning layers that can be converted to quantized layers by fusing with `IQuantizeLayer` and `IDequantizeLayer` instances. When TensorRT performs these fusions, it replaces the quantizable-layers with quantized layers that actually operate on INT8 data using INT8 compute operations.

For the diagrams used in this chapter, green designates INT8 precision and blue designates floating-point precision. Arrows represent network activation tensors and squares represent network layers.

Figure 1. A quantizable `AveragePool` layer (in blue) is fused with a DQ layer and a Q layer. All three layers are replaced by a quantized `AveragePool` layer (in green).



During network optimization, TensorRT moves Q/DQ layers in a process called Q/DQ propagation. The goal in propagation is to maximize the proportion of the graph that can be processed at low precision. Thus, TensorRT propagates Q nodes backwards (so that quantization happens as early as possible) and DQ nodes forward (so that dequantization happens as late as possible). Q-layers can swap places with layers that commute-with-Quantization and DQ-layers can swap places with layers that commute-with-Dequantization.

A layer `Op` commutes with quantization if:

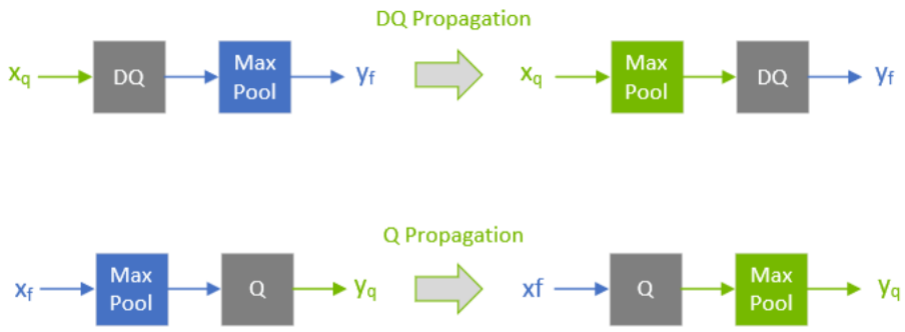
```
Q(Op(x)) == Op(Q(x))
```

Similarly, a layer `Op` commutes with dequantization if:

```
Op(DQ(x)) == DQ(Op(x))
```

The following diagram illustrates DQ forward-propagation and Q backward-propagation. These are legal rewrites of the model because Max Pooling has an INT8 implementation and because Max Pooling commutes with DQ and with Q.

Figure 2. An illustration depicting a DQ forward-propagation and Q backward-propagation.



Note:

To understand Max Pooling commutation, let's look at the output of the maximum-pooling operation applied to some arbitrary input. Max Pooling is applied to groups of input coefficients and outputs the coefficient with the maximum value. For group `i` composed of coefficients: $\{x_0..x_m\}$:

$$\text{output}_i := \max(\{x_0, x_1, \ldots x_m\}) = \max(\{\max(\{\max(\{x_0, x_1\}), x_2\}), \ldots x_m\})$$

It is therefore enough to look at two arbitrary coefficients without loss of generality (WLOG):

$$x_j = \max(\{x_j, x_k\}) \text{ for } x_j >= x_k$$

For quantization function $Q(a, \text{scale}, x_{\max}, x_{\min}) := \text{truncate}(\text{round}(a/\text{scale}), x_{\max}, x_{\min})$, with `scale > 0`, note that (without providing proof, and using simplified notation):

$$Q(x_j, \text{scale}) >= Q(x_k, \text{scale}) \text{ for } x_j >= x_k$$

Therefore:

$$\max(\{Q(x_j, \text{scale}), Q(x_k, \text{scale})\}) = Q(x_j, \text{scale}) \text{ for } x_j >= x_k$$

However, by definition:

$$Q(\max(\{x_j, x_k\}), \text{scale}) = Q(x_j, \text{scale}) \text{ for } x_j >= x_k$$

Function `max` commutes-with-quantization and so does Max Pooling.

Similarly for dequantization, function `DQ(a, scale) := a * scale` with `scale > 0` we can show that:

$$\max(\{DQ(x_j, \text{scale}), DQ(x_k, \text{scale})\}) = DQ(x_j, \text{scale}) = DQ(\max(\{x_j, x_k\}), \text{scale}) \text{ for } x_j >= x_k$$

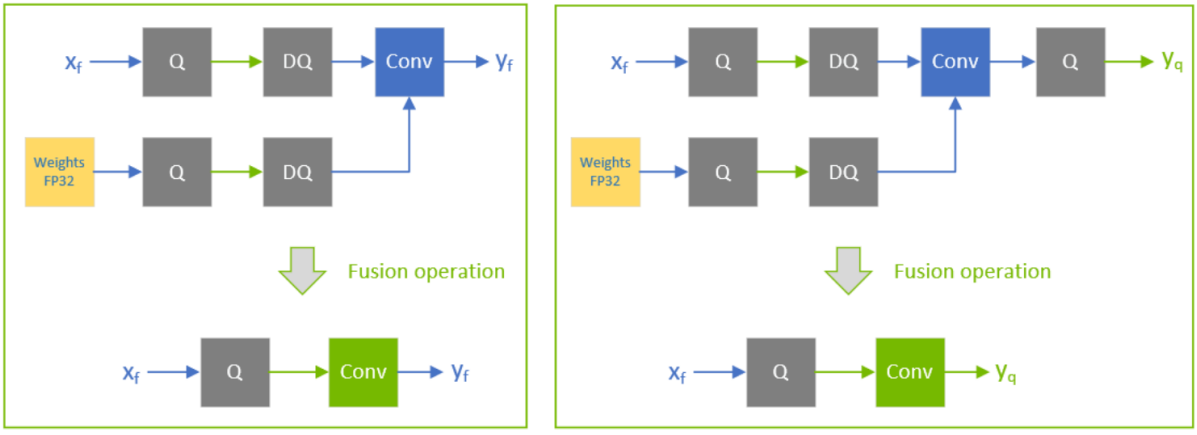
There is a distinction between how quantizable-layers and commuting-layers are processed. Both types of layers can compute in INT8, but quantizable-layers also fuse with DQ input layers and a Q output layer. For example, an `AveragePooling` layer (quantizable) does not commute with either Q or DQ, so it is quantized using Q/DQ fusion as illustrated in the first diagram. This is in contrast to how Max Pooling (commuting) is quantized.

7.4.5. Q/DQ Layer-Placement Recommendations

The placement of Q/DQ layers in a network affects performance and accuracy. Aggressive quantization can lead to degradation in model accuracy because of the error introduced by quantization. But quantization also enables latency reductions. Listed here are some recommendations for placing Q/DQ layers in your network.

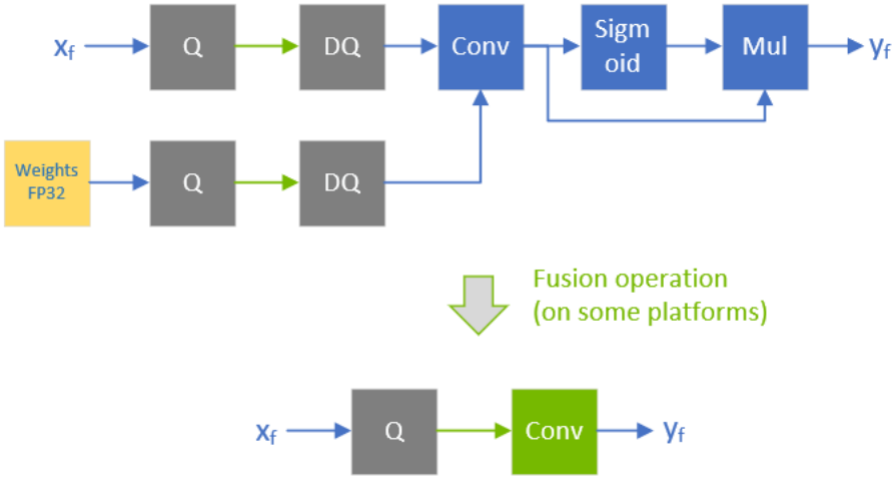
Quantize all inputs of weighted-operations (Convolution, Transposed Convolution and GEMM). Quantization of the weights and activations reduces bandwidth requirements and also enables INT8 computation to accelerate bandwidth-limited and compute-limited layers.

Figure 3. Two examples of how TensorRT fuses convolutional layers. On the left, only the inputs are quantized. On the right, both inputs and output are quantized.



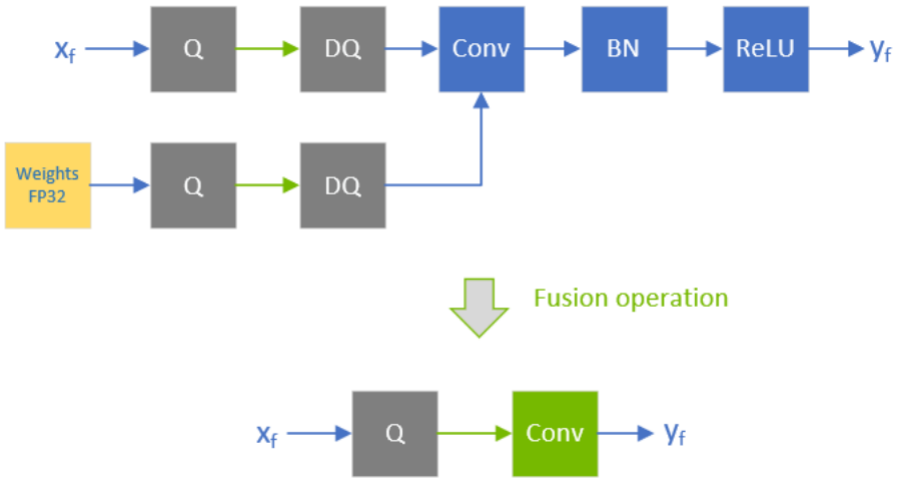
By default, don't quantize the outputs of weighted-operations. It's sometimes useful to preserve the higher-precision dequantized output. For example, if the linear operation is followed by an activation function (SiLU, in the following diagram) that requires higher precision input to produce acceptable accuracy.

Figure 4. Example of a linear operation followed by an activation function.



Don't simulate batch-normalization and ReLU fusions in the training framework because TensorRT optimizations guarantee to preserve the arithmetic semantics of these operations.

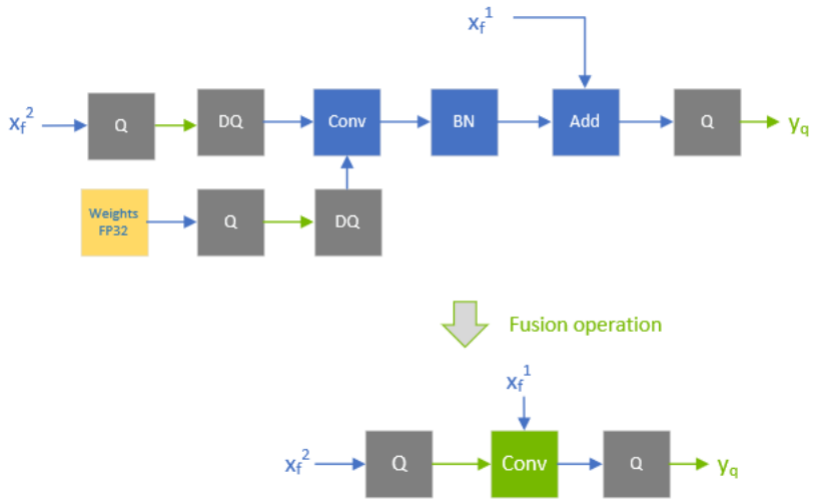
Figure 5. Batch normalization is fused with convolution and ReLU while keeping the same execution order as defined in the pre-fusion network. There is no need to simulate BN-folding in the training network.



TensorRT can fuse element-wise addition following weighted layers, which is useful for models with skip connections like ResNet and EfficientNet. The precision of the first input to the element-wise addition layer determines the precision of the output of the fusion.

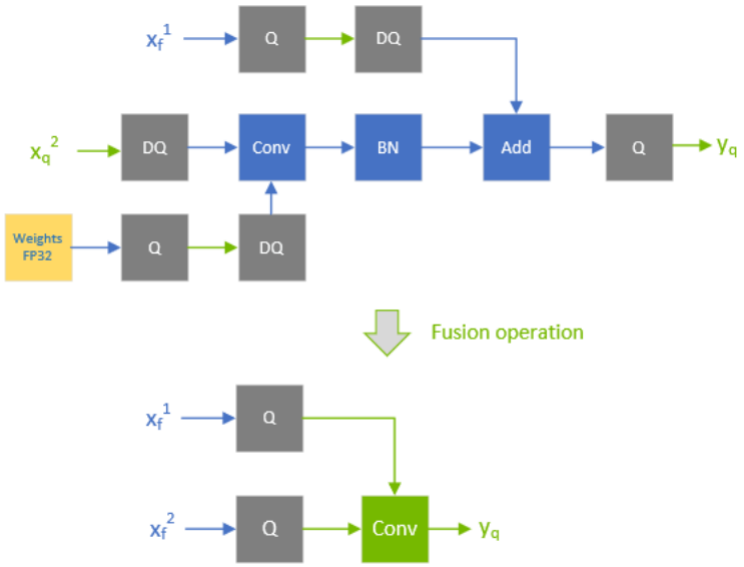
For example, in the following diagram, the precision of xf1 is floating-point, so the output of the fused convolution is limited to floating-point, and the trailing Q-layer cannot be fused with the convolution.

Figure 6. The precision of x_f^1 is floating-point, so the output of the fused convolution is limited to floating-point, and the trailing Q-layer cannot be fused with the convolution.



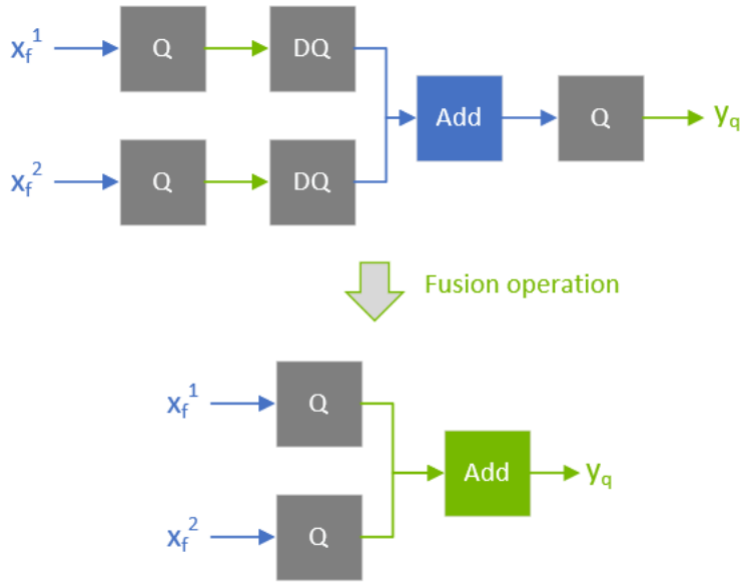
In contrast, when x_f^1 is quantized to INT8, as depicted in the following diagram, the output of the fused convolution is also INT8, and the trailing Q-layer is fused with the convolution.

Figure 7. When x_f^1 is quantized to INT8, the output of the fused convolution is also INT8, and the trailing Q-layer is fused with the convolution.



For extra performance, **try quantizing layers that do not commute with Q/DQ**. Currently, non-weighted layers that have INT8 inputs also require INT8 outputs, so quantize both inputs and outputs.

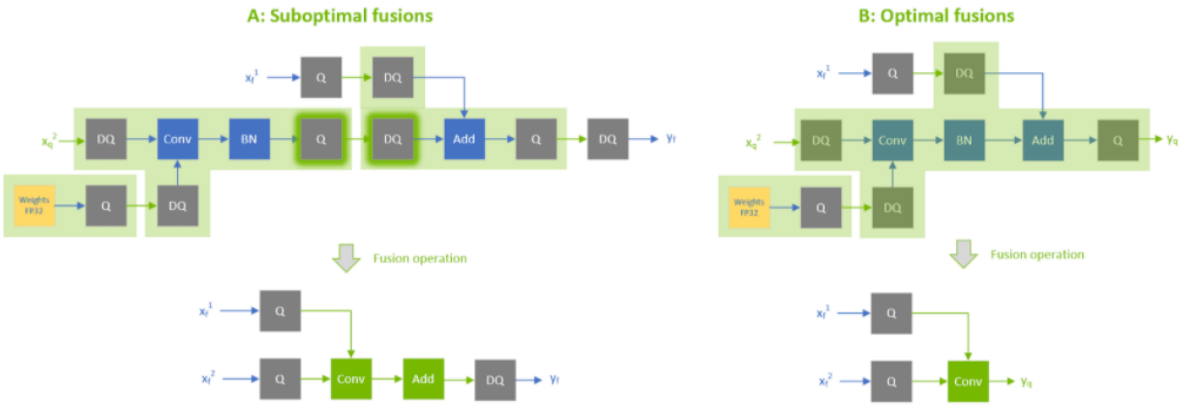
Figure 8. An example of quantizing a quantizable-operator. An element-wise addition operator is fused with the input DQ operators and the output Q operator.



Performance can decrease if TensorRT cannot fuse the operations with the surrounding Q/DQ layers, so **be conservative when adding Q/DQ nodes and experiment with accuracy and TensorRT performance** in mind.

The following figure is an example of suboptimal fusions (the highlighted light green background rectangles) that can result from extra Q/DQ operators. Contrast the following figure with Figure 7, which shows a more performant configuration. The convolution operator is fused separately from the element-wise addition operator because each of them is surrounded by Q/DQ operator pairs. The fusion of the element-wise addition operator is shown in Figure 8.

Figure 9. An example of suboptimal quantization fusions: contrast the suboptimal fusion in A and the optimal fusion in B. The extra pair of Q/DQ operators (highlighted with a glowing-green border) forces the separation of the convolution operator from the element-wise addition operator.



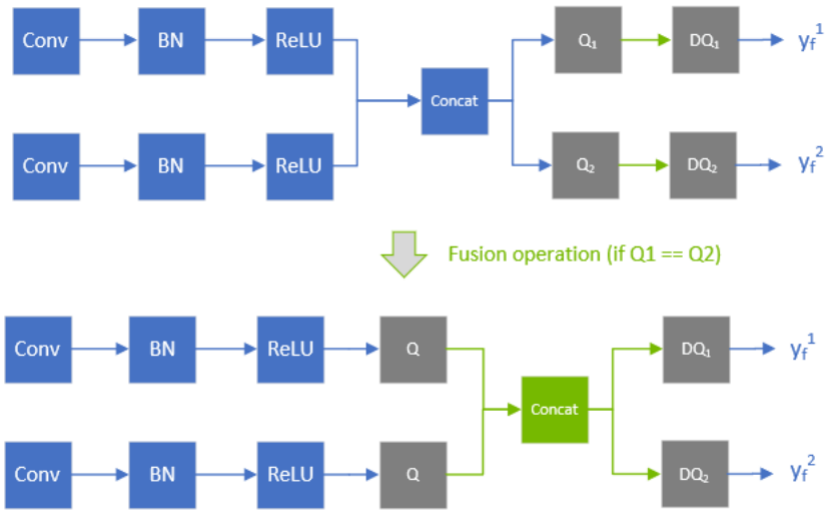
Use per-tensor quantization for activations; and per-channel quantization for weights.This configuration has been demonstrated empirically to lead to the best quantization accuracy.

You can further optimize engine latency by enabling FP16. TensorRT attempts to use FP16 instead of FP32 whenever possible (this is not currently supported for all layer types).

7.4.6. Q/DQ Limitations

A few of the Q/DQ graph-rewrite optimizations that TensorRT performs compare the values of quantization scales between two or more Q/DQ layers and only perform the graph-rewrite if the compared quantization scales are equal. When a refittable TensorRT engine is refitted, the scales of Q/DQ nodes can be assigned new values. During the refitting operation of Q/DQ engines, TensorRT checks if Q/DQ layers that participated in scale-dependent optimizations are assigned new values that break the rewrite optimizations and throws an exception if true.

Figure 10. *An example showing scales of Q1 and Q2 are compared for equality, and if equal, they are allowed to propagate backward. If the engine is refitted with new values for Q1 and Q2 such that `Q1 != Q2`, then an exception aborts the refitting process.*



7.4.7. QAT Networks Using TensorFlow

TensorFlow QAT models place Q/DQ on the outputs of weighted-operations (in contrast with the TensorRT Quantization Toolkit for PyTorch) and can produce suboptimal models. TensorRT is not validated on TensorFlow and can show a lower quality of service.

As TensorRT only supports symmetric quantization for both activations and weights, a training graph must be created using `symmetric=True`.

Tensorflow 1.15 supports Quantization Aware Training (QAT) for creating symmetrically quantized models using tf.contrib.quantize.experimental_create_training_graph API. By default, the TensorFlow training graph would create `per-tensor` weights and activation dynamic range, meaning (min, max). To generate `per-channel` dynamic range for weights, the QAT scripts would need to be updated.

After QAT, you can create a frozen inference graph using the following commands. (This example uses TensorFlow models repo for training and creating an inference graph.)

```
python models/research/slim/export_inference_graph.py \
     --model_name<model> \
     --output_file=quantized_symm_eval.pb \
     --quantize \
     --symmetric
```

Freeze the graph with checkpoints:

```
python tensorflow/tensorflow/python/tools/freeze_graph.py \
 --input_graph=eval.pb \
 --input_checkpoint=model.ckpt-0000 \
 --input_binary=true \
 --output_graph=quantized_symm_frozen.pb \
 --output_node_names=<OutputNode>
```

7.4.7.1. Converting TensorFlow To ONNX Quantized Models

TensorFlow quantized model with `tensorflow::ops::FakeQuantWithMinMaxVars` or `tensorflow::ops::FakeQuantWithMinMaxVarsPerChannel` nodes can be converted to sequence of `QuantizeLinear` and `DequantizeLinear` nodes (Q/DQ nodes).

Dynamic range with, meaning `[min, max]`, values are converted to `scale` and `zero-point`, where `scale = max(abs(min, max))/127` and `zero_point = 0`.

You can use the tf2onnx converter to convert a quantized frozen model to a quantized ONNX model.

```
python -m tf2onnx.convert \
--input quantized_symm_frozen.pb \
--output quantized.onnx \
--inputs <InputNode> \
--outputs <OutputNode> \
--opset 10 \
--fold_const \
--inputs-as-nchw <InputNode>
```

7.4.8. QAT Networks Using PyTorch

PyTorch 1.8.0 supports QuantizeLinear/DequantizeLinear that support per channel scales. You can use pytorch-quantization to do INT8 calibration, run quantization aware fine-tuning, generate ONNX and finally use TensorRT to run inference on this ONNX model. More detail can be found in PyTorch-Quantization Toolkit User Guide.

7.5. INT8 Rounding Modes

Backend	Compute Kernel Quantization (FP32 to INT8)	Weights Quantization (FP32 to INT8)	
		Quantized Network (QAT)	Dynamic Range API / Calibration
GPU	`round-to-nearest-with-ties-to-even`	`round-to-nearest-with-ties-to-even`	`round-to-nearest-with-ties-to-positive-infinity`
DLA	`round-to-nearest-with-ties-away-from-zero`	N/A	`round-to-nearest-with-ties-away-from-zero`

Chapter 8. Working With Dynamic Shapes

Dynamic shapes are the ability to defer specifying some or all tensor dimensions until runtime. Dynamic shapes can be used via both the C++ and Python interfaces.

The following sections provide greater detail; however, here's an overview of the steps for building an engine with dynamic shapes:

1. The network definition must not have an implicit batch dimension.
   C++
   Create the `INetworkDefinition` by calling
   ```
   IBuilder::createNetworkV2(1U <<
           static_cast<int>(NetworkDefinitionCreationFlag::kEXPLICIT_BATCH))
   ```
   Python
   Create the `tensorrt.INetworkDefinition` by calling
   ```
   create_network(1 <<
           int(tensorrt.NetworkDefinitionCreationFlag.EXPLICIT_BATCH))
   ```
   These calls request that the network not have an implicit batch dimension.
2. Specify each runtime dimension of an input tensor by using `-1` as a placeholder for the dimension.
3. Specify one or more *optimization profiles* at build time that specify the permitted range of dimensions for inputs with runtime dimensions, and the dimensions for which the auto-tuner should optimize. For more information, refer to Optimization Profiles.
4. To use the engine:
   a). Create an execution context from the engine, the same as without dynamic shapes.
   b). Specify one of the optimization profiles from step 3 that covers the input dimensions.
   c). Specify the input dimensions for the execution context. After setting input dimensions, you can get the output dimensions that TensorRT computes for the given input dimensions.
   d). Enqueue work.

To change the runtime dimensions, repeat steps 4b and 4c, which do not have to be repeated until the input dimensions change.

8.1. Specifying Runtime Dimensions

When building a network, use `-1` to denote a runtime dimension for an input tensor. For example, to create a 3D input tensor named `foo` where the last two dimensions are specified at runtime, and the first dimension is fixed at build time, issue the following.

C++

```
networkDefinition.addInput("foo", DataType::kFLOAT, Dims3(3, -1, -1))
```

Python

```
network_definition.add_input("foo", trt.float32,(3, -1, -1))
```

At run time, you'll need to set the input dimensions after choosing an optimization profile (refer to Optimization Profiles). Let the `bindingIndex` of input `foo` be `0`, and the input have dimensions `[3,150,250]`. After setting an optimization profile for the previous example, you would call:

C++

```
context.setBindingDimensions(0, Dims3(3, 150, 250))
```

Python

```
context.set_binding_shape(0, (3, 150, 250))
```

At runtime, asking the engine for binding dimensions returns the same dimensions used to build the network, meaning, you get a `-1` for each runtime dimension. For example:

C++

`engine.getBindingDimensions(0)` returns a `Dims` with dimensions `{3, -1, -1}`.

Python

`engine.get_binding_shape(0)` returns `(3, -1, -1)`.

To get the actual dimensions, which are specific to each execution context, query the execution context:

C++

`context.getBindingDimensions(0)` returns a `Dims` with dimensions `{3, 150, 250}`.

Python

`context.get_binding_shape(0)` returns `(3, 150, 250)`.

Note: The return value of `setBindingDimensions` for an input only indicates consistency with respect to the optimization profile set for that input. After all input binding dimensions are specified, you can check whether the entire network is consistent with respect to the dynamic input shapes by querying the dimensions of the output bindings of the network.

```
nvinfer1::Dims out_dim = context->getBindingDimensions(out_index);

if (out_dim.nbDims == -1) {
gLogError << "Invalid network output, this might be caused by inconsistent input
 shapes." << std::endl;
// abort inference
}
```

8.2. Optimization Profiles

An *optimization profile* describes a range of dimensions for each network input and the dimensions that the auto-tuner should use for optimization. When using runtime dimensions, you must create at least one optimization profile at build time. Two profiles can specify disjoint or overlapping ranges.

For example, one profile might specify a minimum size of `[3,100,200]`, a maximum size of `[3,200,300]`, and optimization dimensions of `[3,150,250]` while another profile might specify min, max and optimization dimensions of `[3,200,100]`, `[3,300,400]`, and `[3,250,250]`.

To create an optimization profile, first construct an `IOptimizationProfile`. Then set the min, optimization, and max dimensions, and add it to the network configuration. The shapes defined by the optimization profile must define valid input shapes for the network. Here are the calls for the first profile mentioned previously for an input `foo`:

C++

```
IOptimizationProfile* profile = builder.createOptimizationProfile();
profile->setDimensions("foo", OptProfileSelector::kMIN, Dims3(3,100,200);
profile->setDimensions("foo", OptProfileSelector::kOPT, Dims3(3,150,250);
profile->setDimensions("foo", OptProfileSelector::kMAX, Dims3(3,200,300);

config->addOptimizationProfile(profile)
```

Python

```
profile = builder.create_optimization_profile();
profile.set_shape("foo", (3, 100, 200), (3, 150, 250), (3, 200, 300))
config.add_optimization_profile(profile)
```

At runtime, you need to set an optimization profile before setting input dimensions. Profiles are numbered in the order they were added, starting at `0`. To choose the first optimization profile in the example, use:

C++

call `context.setOptimizationProfileAsync(0, stream)`

where `stream` is the CUDA stream that is used for the subsequent `enqueue()` or `enqueueV2()` invocation in this context.

Python

set `context.set_optimization_profile_async(0, stream)`

If the associated CUDA engine has dynamic inputs, the optimization profile must be set at least once with a unique profile index that is not used by other execution contexts that are not destroyed. For the first execution context that is created for an engine, profile 0 is chosen implicitly.

`setOptimizationProfileAsync()` can be called to switch between profiles. It must be called after any `enqueue()` or `enqueueV2()` operations finish in the current context. When multiple execution contexts run concurrently, it is allowed to switch to a profile that was formerly used but already released by another execution context with different dynamic input dimensions.

`setOptimizationProfileAsync()` function replaces the now deprecated version of the API `setOptimizationProfile()`. Using `setOptimizationProfile()` to switch between optimization profiles can cause GPU memory copy operations in the subsequent

`enqueue()` or `enqueueV2()` operations operation. To avoid these calls during enqueue, use `setOptimizationProfileAsync()` API instead.

In an engine built from multiple profiles, there are separate binding indices for each profile. The names of input/output tensors for the *K*th profile have `[profile K]` appended to them, with *K* written in decimal. For example, if the `INetworkDefinition` had the name "`foo`", and `bindingIndex` refers to that tensor in the optimization profile with index `3`, `engine.getBindingName(bindingIndex)` returns "`foo [profile 3]`".

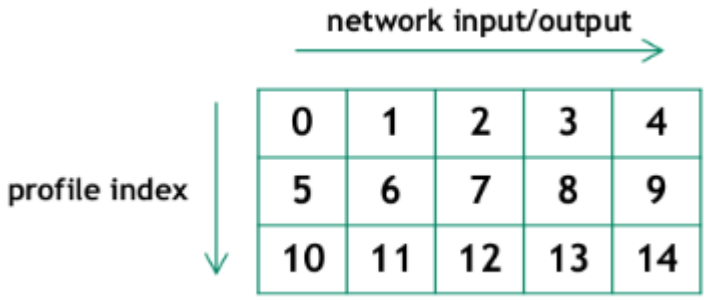
Likewise, if using `ICudaEngine::getBindingIndex(name)` to get the index for a profile *K* beyond the first profile (*K=0*), append "`[profile K]`" to the name used in the `INetworkDefinition`. For example, if the tensor was called "`foo`" in the `INetworkDefinition`, then `engine.getBindingIndex("foo [profile 3]")` returns the binding index of Tensor "`foo`" in optimization profile `3`.

Always omit the suffix for *K=0*.

8.2.1. Bindings For Multiple Optimization Profiles

TensorRT 7.1 is stricter about binding indices than its predecessors. Previously, binding indices for the wrong profile were tolerated. Consider a network with four inputs, one output, with three optimization profiles in the `IBuilderConfig`. The engine has 15 bindings, five for each optimization profile, conceptually organized as a table:

Figure 11. Optimization profile



Each row is a profile. Numbers in the table denote binding indices. The first profile has binding indices 0..4, the second has 5..9, and the third has 10..14. Prior to version 7.1, where a profile index was specified or implied, TensorRT accepted binding numbers for the wrong profile, using the binding index only to determine the column. In TensorRT 7.1, the binding index must be correct; otherwise, refer to an API check failure that mentions `bindingIndexBelongsToProfile`.

For the sake of backward semi-compatibility, the interfaces have an "auto-correct" for the case that the binding belongs to the *first* profile, but another profile was specified. In that case, TensorRT warns about the mistake and then chooses the correct binding index from the same column.

For the sake of backward semi-compatibility, the interfaces have an "auto-correct" in the scenario where the binding belongs to the *first* profile, but another profile was specified. In this

case, TensorRT warns about the mistake and then chooses the correct binding index from the same column.

8.3. Layer Extensions For Dynamic Shapes

Some layers have optional inputs that allow specifying dynamic shape information, and there is a new layer `IShapeLayer` for accessing the shape of a tensor at runtime. Furthermore, some layers allow calculating new shapes. The next section goes into semantic details and restrictions. Here is a summary of what you might find useful in conjunction with dynamic shapes.

`IShapeLayer` outputs a 1D tensor containing the dimensions of the input tensor. For example, if the input tensor has dimensions `[2,3,5,7]`, the output tensor is a four-element 1D tensor containing `{2,3,5,7}`. If the input tensor is a scalar, it has dimensions `[]`, and the output tensor is a zero-element 1D tensor containing `{}`.

`IResizeLayer` accepts an optional second input containing the desired dimensions of the output.

`IShuffleLayer` accepts an optional second input containing the reshape dimensions before the second transpose is applied. For example, the following network reshapes a tensor `Y` to have the same dimensions as `X`:

C++

```
auto* reshape = networkDefinition.addShuffle(Y);
reshape.setInput(1, networkDefintion.addShape(X)->getOutput(0));
```

Python

```
reshape = network_definition.add_shuffle(y)
reshape.set_input(1, network_definition.add_shape(X)->get_output(0))
```

Shuffle operations that are equivalent to identity operations on the underlying data is omitted if the input tensor is only used in the shuffle layer and the input and output tensors of this layer are not input and output tensors of the network. TensorRT no longer executes additional kernels or memory copies for such operations.

`ISliceLayer` accepts an optional second, third, and fourth inputs containing the start, size, and stride.

```
IConcatenationLayer, IElementWiseLayer, IGatherLayer, IIdentityLayer, and
        IReduceLayer
```

can be used to do calculations on shapes and create new shape tensors.

8.4. Restrictions For Dynamic Shapes

The following layer restrictions arise because the layer's weights have a fixed size:

- `IConvolutionLayer` and `IDeconvolutionLayer` require that the channel dimension be a build-time constant.
- `IFullyConnectedLayer` requires that the last three dimensions be build-time constants.
- `Int8` requires that the channel dimension be a build-time constant.

- Layers accepting additional shape inputs (`IResizeLayer`, `IShuffleLayer`, `ISliceLayer`) require that the additional shape inputs be compatible with the dimensions of the minimum and maximum optimization profiles as well as with the dimensions of the runtime data input; otherwise, it can lead to either a build-time or runtime error.

Values that must be build-time constants don't have to be constants at the API level. TensorRT's shape analyzer does element-by-element constant propagation through layers that do shape calculations. It's sufficient that the constant propagation discovers that a value is a build-time constant.

8.5. Execution Tensors vs. Shape Tensors

Engines using dynamic shapes employ a two-phase execution strategy.

1. Compute the shapes of all tensors
2. Stream work to the GPU.

Phase 1 is implicit and driven by demand, such as when output dimensions are requested. Phase 2 is the same as in prior versions of TensorRT. The two-phase execution puts some limits on dynamism that are important to understand.

The key limits are:

- The rank of a tensor must be determinable at build time.
- A tensor is either an *execution tensor*, *shape tensor*, or both. Tensors classified as shape tensors are subject to limits.

An *execution tensor* is a traditional TensorRT tensor. A *shape tensor* is a tensor that is related to shape calculations. It must be 0D or 1D, have type `Int32` or `Bool`, and its shape must be determinable at build time. For example, there is an `IShapeLayer` whose output is a 1D tensor containing the dimensions of the input tensor. The output is a shape tensor. `IShuffleLayer` accepts an optional second input that can specify reshaping dimensions. The second input must be a shape tensor.

Some layers are "polymorphic" with respect to the kinds of tensors they handle. For example, `IElementWiseLayer` can sum two Int32 execution tensors or sum two Int32 shape tensors. The type of tensor depends on its ultimate use. If the sum is used to reshape another tensor, then it is a "shape tensor."

8.5.1. Formal Inference Rules

The formal inference rules used by TensorRT for classifying tensors are based on a type-inference algebra. Let `E` denote an execution tensor and `S` denote a shape tensor.

`IActivationLayer` has the signature:

```
IActivationLayer: E → E
```

since it takes an execution tensor as an input and an execution tensor as an output. `IElementWiseLayer` is polymorphic in this respect, with two signatures:

```
IElementWiseLayer: S × S → S, E × E → E
```

For brevity, let's adopt the convention that t is a variable denoting either class of tensor, and all t in a signature refers to the same class of tensor. Then, the two previous signatures can be written as a single polymorphic signature:

IElementWiseLayer: t × t → t

The two-input `IShuffleLayer` has a shape tensor as the second input and is polymorphic with respect to the first input:

IShuffleLayer (two inputs): t × S → t

`IConstantLayer` has no inputs, but can produce a tensor of either kind, so its signature is:

IConstantLayer: → t

The signature for `IShapeLayer` allows all four possible combinations `E→E`, `E→S`, `S→E`, and `S→S`, so it can be written with two independent variables:

IShapeLayer: $t_1 \rightarrow t_2$

Here is the complete set of rules, which also serves as a reference for which layers can be used to manipulate shape tensors:

```
IConcatenationLayer: t × t × ...→ t
IConstantLayer: → t
IElementWiseLayer: t × t → t
IGatherLayer: t × t → t
IIdentityLayer: t → t
IReduceLayer: t → t
IResizeLayer (one input): E → E
IResizeLayer (two inputs): E × S → E
ISelectLayer: t × t × t → t
IShapeLayer: t1 → t2
IShuffleLayer (one input): t → t
IShuffleLayer (two inputs): t × S → t
ISliceLayer (one input): t → t
ISliceLayer (two inputs): t × S → t
ISliceLayer (three inputs): t × S × S → t
ISliceLayer (four inputs): t × S × S × S → t
all other layers: E × ... → E × ...
```

Because an output can be the input of more than one subsequent layer, the inferred "types" are not exclusive. For example, an `IConstantLayer` might feed into one use that requires an execution tensor and another use that requires a shape tensor. The output of `IConstantLayer` is classified as both and can be used in both phase 1 and phase 2 of the two-phase execution.

The requirement that the rank of a shape tensor be known at build time limits how `ISliceLayer` can be used to manipulate a shape tensor. Specifically, if the third parameter, which specifies the size of the result, is not a build-time constant, the length of the resulting shape tensor would no longer be known at build time, breaking the restriction of shape tensors to build-time shapes. Worse, it might be used to reshape another tensor, breaking the restriction that tensor ranks must be known at build time.

TensorRT's inferences can be inspected via methods `ITensor::isShapeTensor()`, which returns true for a shape tensor, and `ITensor::isExecutionTensor()`, which returns true for an execution tensor. Build the entire network first before calling these methods because their answer can change depending on what uses of the tensor have been added.

For example, if a partially built network sums two tensors, *T1* and *T2,* to create tensor *T3*, and none are yet needed as shape tensors, `isShapeTensor()` returns false for all three tensors. Setting the second input of `IShuffleLayer` to *T3* would cause all three tensors to become

shape tensors because `IShuffleLayer` requires that its second optional input be a shape tensor, and if the output of `IElementWiseLayer` is a shape tensor, its inputs are too.

8.6. Shape Tensor I/O (Advanced)

Sometimes the need arises to do shape tensor I/O for a network. For example, consider a network consisting solely of an `IShuffleLayer`. TensorRT infers that the second input is a shape tensor. `ITensor::isShapeTensor` returns true for it. Because it is an input shape tensor, TensorRT requires two things for it:

- At build time: the optimization profile *values* of the shape tensor.
- At run time: the *values* of the shape tensor.

The shape of an input shape tensor is always known at build time. It's the values that need to be described since they can be used to specify the dimensions of execution tensors.

The optimization profile values can be set using `IOptimizationProfile::setShapeValues`. Analogous to how min, max, and optimization dimensions must be supplied for execution tensors with runtime dimensions, min, max and optimization values must be provided for shape tensors at build time.

The corresponding runtime method is `IExecutionContext::setInputShapeBinding`, which sets the values of the shape tensor at runtime.

Because the inference of "execution tensor" vs "shape tensor" is based on ultimate use, TensorRT cannot infer whether a network output is a shape tensor. You must to tell it via the method `INetworkDefinition::markOutputForShapes`.

Besides letting you output shape information for debugging, this feature is useful for composing engines. For example, consider building three engines, one each for sub-networks A, B, C, where a connection from A to B or B to C might involve a shape tensor. Build the networks in reverse order: C, B, and A. After constructing network C, you can use `ITensor::isShapeTensor` to determine if an input is a shape tensor, and use `INetworkDefinition::markOutputForShapes` to mark the corresponding output tensor in network B. Then check which inputs of B are shape tensors and mark the corresponding output tensor in network A.

Shape tensors at network boundaries must have type `Int32`. They cannot have type `Bool`.

8.7. INT8 Calibration With Dynamic Shapes

To run INT8 calibration for a network with dynamic shapes, a calibration optimization profile must be set. Calibration is performed using kOPT values of the profile. Calibration input data size must match this profile.

To create a calibration optimization profile, first, construct an `IOptimizationProfile` the same way as it is done for a general optimization profile. Then set the profile to the configuration:

C++

```
config->setCalibrationProfile(profile)
```

Python

```
config.set_calibration_profile(profile)
```

The calibration profile must be valid or be `nullptr`. `kMIN` and `kMAX` values are overwritten by `kOPT`. To check the current calibration profile, use`IBuilderConfig::getCalibrationProfile`.

This method returns a pointer to the current calibration profile or nullptr if the calibration profile is unset. `getBatchSize()` calibrator method must return `1` when running calibration for a network with dynamic shapes.

Note: If the calibration optimization profile is not set, the first network optimization profile are used as a calibration optimization profile.

Chapter 9. Extending TensorRT With Custom Layers

NVIDIA® TensorRT™ supports many types of layers and its functionality is continually extended; however, there can be cases in which the layers supported do not cater to the specific needs of a model.

You can extend TensorRT by implementing custom layers, often referred to as plugins.

9.1. Adding Custom Layers Using The C++ API

You can implement a custom layer by deriving from one of TensorRT's plugin base classes.

Table 3. Base classes, ordered from least expressive to most expressive

	Introduced in TensorRT version?	Mixed input/output formats/types	Dynamic shapes?
`IPluginV2Ext`	5.1	Limited	No
`IPluginV2IOExt`	6.0.1	General	No
`IPluginV2DynamicExt`	6.0.1	General	Yes

In order to use a plugin in a network, you must first register it with TensorRT's `PluginRegistry` (C++, Python). Rather than registering the plugin directly, you register an instance of a factory class for the plugin, derived from `PluginCreator` (C++, Python). The plugin creator class also provides other information about the plugin: its name, version, and plugin field parameters.

You must derive your plugin class from one of the base classes for plugins. They have varying expressive power with respect to supporting inputs/outputs with different types/formats or networks with dynamic shapes. The following table summarizes the base classes, ordered from least expressive to most expressive.

Note: If a plugin is intended for general use, provide an FP32 implementation in order to allow it to properly operate with any network.

TensorRT provides a macro `REGISTER_TENSORRT_PLUGIN` that statically registers the plugin creator with the registry.

TensorRT library contains plugins that can be loaded into your application. The version of all these plugins is set to `1`. For a list of open-sourced plugins, refer to GitHub: TensorRT plugins.

Note:

- To use TensorRT plugins in your application, the `libnvinfer_plugin.so` library must be loaded, and all plugins must be registered by calling `initLibNvInferPlugins` in your application code.
- If you have your own plugin library, you can include a similar entry point to register all plugins in the registry under a unique namespace. This ensures there are no plugin name collisions during build time across different plugin libraries.

For more information about these plugins, refer to the NvInferPlugin.h file for reference.

Calling `IPluginCreator::createPlugin()` returns a plugin object of type `IPluginV2`. You can add a plugin to the TensorRT network using `addPluginV2()` which creates a network layer with the given plugin.

For example, you can add a plugin layer to your network as follows:

```
// Look up the plugin in the registry
auto creator = getPluginRegistry()->getPluginCreator(pluginName, pluginVersion);
const PluginFieldCollection* pluginFC = creator->getFieldNames();
//populate the fields parameters for the plugin layer
PluginFieldCollection *pluginData = parseAndFillFields(pluginFC, layerFields);
//create the plugin object using the layerName and the plugin meta data
IPluginV2 *pluginObj = creator->createPlugin(layerName, pluginData);
//add the plugin to the TensorRT network
auto layer = network.addPluginV2(&inputs[0], int(inputs.size()), pluginObj);
… (build rest of the network and serialize engine)
pluginObj->destroy() // Destroy the plugin object
… (destroy network, engine, builder)
… (free allocated pluginData)
```

Note:

- `pluginData` should allocate the `PluginField` entries on the heap before passing to `createPlugin`.
- The `createPlugin` method described previously creates a new plugin object on the heap and returns a pointer to it. Ensure you destroy the `pluginObj`, as shown previously, to avoid a memory leak.

During serialization, the TensorRT engine internally stores the plugin type, plugin version, and namespace (if it exists) for all `IPluginV2` type plugins. During deserialization, TensorRT looks up the Plugin Creator from the Plugin Registry and calls `IPluginCreator::deserializePlugin()`. The plugin object created during deserialization is destroyed internally by the TensorRT engine by calling `IPluginV2::destroy()` method.

During serialization, the TensorRT engine internally stores the plugin type, plugin version, and namespace (if it exists) for all `IPluginV2` type plugins. During deserialization, TensorRT looks up the Plugin Creator from the Plugin Registry and calls `IPluginCreator::deserializePlugin()`. The plugin object created during deserialization is destroyed internally by the TensorRT engine by calling the `IPluginV2::destroy()` method.

9.1.1. Example: Adding A Custom Layer With Dynamic Shape Support Using C++

To support dynamic shapes, your plugin must be derived from `IPluginV2DynamicExt`.

About this task

`BarPlugin` is a plugin with two inputs and two outputs where:

- The first output is a copy of the second input
- The second output is the concatenation of both inputs, along the first dimension, and all types/formats must be the same and be linear formats

`BarPlugin` needs to be derived as follows:

```
class BarPlugin : public IPluginV2DynamicExt
{
 ...override virtual methods inherited from IPluginV2DynamicExt.
};
```

The inherited methods are all pure virtual methods, so the compiler reminds you if you forget one.

The four methods that are affected by dynamic shapes are:

- `getOutputDimensions`
- `supportsFormatCombination`
- `configurePlugin`
- `enqueue`

The override for `getOutputDimensions` returns symbolic *expressions* for the output dimensions in terms of the input dimensions. You can build the expressions from the expressions for the inputs, using the `IExprBuilder` passed into `getOutputDimensions`. In the example, no new expression has to be built for case 1 because the dimensions of the second output are the same as the dimensions of the first input.

```
DimsExprs BarPlugin::getOutputDimensions(int outputIndex,
    const DimsExprs* inputs, int nbInputs,
    IExprBuilder& exprBuilder)
{
    switch (outputIndex)
    {
    case 0:
    {
        // First dimension of output is sum of input
        // first dimensions.
        DimsExprs output(inputs[0]);
        output.d[0] =
            exprBuilder.operation(DimensionOperation::kSUM,
                inputs[0].d[0], inputs[1].d[0]);
    return output;
    }
    case 1:
        return inputs[0];
    default:
         throw std::invalid_argument("invalid output");
```

```
}
```

The override for `supportsFormatCombination` must indicate whether a format combination is allowed. The interface indexes the inputs/outputs uniformly as "connections", starting at 0 for the first input, then the rest of the inputs in order, followed by numbering the outputs. In the example, the inputs are connections 0 and 1, and the outputs are connections 2 and 3.

TensorRT uses `supportsFormatCombination` to ask whether a given combination of formats/types are okay for a connection, given formats/types for lesser indexed connections. So the override can assume that lesser indexed connections have already been vetted and focus on the connection with index `pos`.

```
bool BarPlugin::supportsFormatCombination(int pos, const PluginTensorDesc* inOut, int
 nbInputs, int nbOutputs) override
{
    assert(0 <= pos && pos < 4);
    const auto* in = inOut;
    const auto* out = inOut + nbInputs;
    switch (pos)
    {
    case 0: in[0].format == TensorFormat::kLINEAR;
    case 1: return in[1].type == in[0].type &&
                   in[0].format == TensorFormat::kLINEAR;
    case 2: return out[0].type == in[0].type &&
                   out[0].format == TensorFormat::kLINEAR;
    case 3: return out[1].type == in[0].type &&
                   out[1].format == TensorFormat::kLINEAR;
    }
    throw std::invalid_argument("invalid connection number");
}
```

The local variables in and `out` here allow inspecting `inOut` by input or output number instead of connection number.

Important: The override inspects the format/type for a connection with an index less than `pos`, but must never inspect the format/type for a connection with an index greater than `pos`. The example uses `case 3` to check connection 3 against connection 0, and not use `case 0` to check connection 0 against connection 3.

TensorRT uses `configurePlugin` to set up a plugin at runtime. This plugin doesn't need `configurePlugin` to do anything, so it's a no-op:

```
void BarPlugin::configurePlugin(
    const DynamicPluginTensorDesc* in, int nbInputs,
    const DynamicPluginTensorDesc* out, int nbOutputs) override
{
}
```

If the plugin needed to know the minimum or maximum dimensions it might encounter, it can inspect the field `DynamicPluginTensorDesc::min` or `DynamicPluginTensorDesc::max` for any input or output. Format and build-time dimension information can be found in `DynamicPluginTensorDesc::desc`. Any runtime dimensions appear as -1. The actual dimension is supplied to `BarPlugin::enqueue`.

Finally, the override `BarPlugin::enqueue` has to do the work. Since shapes are dynamic, enqueue is handed a `PluginTensorDesc` that describes the actual dimensions, type, and format of each input and output.

9.1.2. Example: Adding A Custom Layer With INT8 I/O Support Using C++

`PoolPlugin` is a plugin to demonstrate how to extend INT8 I/O for the custom pooling layer. The derivation is as follows:

```
class PoolPlugin : public IPluginV2IOExt
{
    ...override virtual methods inherited from IPluginV2IOExt.
};
```

Most of the pure virtual methods are common to plugins. The main methods that affect INT8 I/O are:

- `supportsFormatCombination`
- `configurePlugin`
- `enqueue`

The override for `supportsFormatCombination` must indicate which INT8 I/O combination is allowed. The usage of this interface is similar to Adding A Custom Layer With Dynamic Shape Support Using C++. In this example, the supported I/O tensor format is linear CHW while INT32 is excluded, but the I/O tensor must have the same data type.

```
bool PoolPlugin::supportsFormatCombination(int pos, const PluginTensorDesc* inOut, int
 nbInputs, int nbOutputs) const override
{
    assert(nbInputs == 1 && nbOutputs == 1 && pos < nbInputs + nbOutputs);
    bool condition = inOut[pos].format == TensorFormat::kLINEAR;
    condition &= inOut[pos].type != DataType::kINT32;
    condition &= inOut[pos].type == inOut[0].type;
    return condition;
}
```

Important:

- If INT8 calibration must be used with a network with INT8 I/O plugins, the plugin must support FP32 I/O as it is used by the FP32 calibration graph.
- If the FP32 I/O variant is not supported or INT8 calibration is not used, all required INT8 I/O tensors scales must be set explicitly.
- Calibration can't determine the dynamic range of a plugin's internal tensors. Plugins that operate on quantized data must calculate their own dynamic range for internal tensors.

TensorRT invokes `configurePlugin` method to pass the information to the plugin through `PluginTensorDesc`, which are stored as member variables, serialized and deserialized.

```
void PoolPlugin::configurePlugin(const PluginTensorDesc* in, int nbInput, const
 PluginTensorDesc* out, int nbOutput)
{
    ...
    mPoolingParams.mC = mInputDims.d[0];
    mPoolingParams.mH = mInputDims.d[1];
    mPoolingParams.mW = mInputDims.d[2];
    mPoolingParams.mP = mOutputDims.d[1];
    mPoolingParams.mQ = mOutputDims.d[2];
    mInHostScale = in[0].scale >= 0.0f ? in[0].scale : -1.0f;
    mOutHostScale = out[0].scale >= 0.0f ? out[0].scale : -1.0f;
}
```

Where INT8 I/O scales per tensor can be obtained from `PluginTensorDesc::scale`.

Finally, the override `UffPoolPluginV2::enqueue` has to do the work. It includes a collection of core algorithms to execute the custom layer at runtime by using the actual batch size, inputs, outputs, cuDNN stream, and the information configured.

```
int PoolPlugin::enqueue(int batchSize, const void* const* inputs, void** outputs, void*
 workspace, cudaStream_t stream)
{
    ...
    CHECK(cudnnPoolingForward(mCudnn, mPoolingDesc, &kONE, mSrcDescriptor, input, &kZERO,
 mDstDescriptor, output));
    ...
    return 0;
}
```

9.2. Adding Custom Layers Using The Python API

Although the C++ API is the preferred language to implement custom layers, due to accessing libraries like CUDA and cuDNN, you can also work with custom layers in Python applications.

You can use the C++ API to create a custom layer, package the layer using `pybind11` in Python, then load the plugin into a Python application. For more information, refer to Creating a Network Definition in Python.

The same custom layer implementation can be used for both C++ and Python.

9.2.1. Example: Adding A Custom Layer To A TensorRT Network Using Python

Custom layers can be added to any TensorRT network in Python using plugin nodes.

The Python API has a function called `add_plugin_v2` that enables you to add a plugin node to a network. The following example illustrates this. It creates a simple TensorRT network and adds a Leaky ReLU plugin node by looking up TensorRT Plugin Registry.

```
import tensorrt as trt
import numpy as np

TRT_LOGGER = trt.Logger()

trt.init_libnvinfer_plugins(TRT_LOGGER, '')
PLUGIN_CREATORS = trt.get_plugin_registry().plugin_creator_list

def get_trt_plugin(plugin_name):
        plugin = None
        for plugin_creator in PLUGIN_CREATORS:
            if plugin_creator.name == plugin_name:
                lrelu_slope_field = trt.PluginField("neg_slope", np.array([0.1],
 dtype=np.float32), trt.PluginFieldType.FLOAT32)
                field_collection = trt.PluginFieldCollection([lrelu_slope_field])
                plugin = plugin_creator.create_plugin(name=plugin_name,
 field_collection=field_collection)
        return plugin

def main():
    builder = trt.Builder(TRT_LOGGER)
```

```
    network = builder.create_network()
    config = builder.create_builder_config()
    config.max_workspace_size = 2**20
    input_layer = network.add_input(name="input_layer", dtype=trt.float32, shape=(1, 1))
    lrelu = network.add_plugin_v2(inputs=[input_layer], plugin=get_trt_plugin("LReLU_TRT"))
    lrelu.get_output(0).name = "outputs"
    network.mark_output(lrelu.get_output(0))
```

9.3. Using Custom Layers When Importing A Model With A Parser

The ONNX parser automatically attempts to import unrecognized nodes as plugins. If a plugin with the same `op_type` as the node is found in the plugin registry, the parser forwards the attributes of the node to the plugin creator as plugin field parameters in order to create the plugin. By default, the parser uses "`1`" as the plugin version and "" as the plugin namespace. This behavior can be overridden by setting a `plugin_version` and/or `plugin_namespace` string attribute in the corresponding ONNX node.

In some cases, you might want to modify an ONNX graph prior to importing it into TensorRT. For example, to replace a set of ops with a plugin node. To accomplish this, you can use the ONNX GraphSurgeon utility. For details on how to use ONNX-GraphSurgeon to replace a subgraph, refer to this example.

For more examples, refer to the onnx_packnet sample.

9.4. Plugin API Description

All new plugins should derive classes from both `IPluginCreator` and one of the plugin base classes described in Adding Custom Layers Using The C++ API. In addition, new plugins should also call the `REGISTER_TENSORRT_PLUGIN(...)` macro to register the plugin with the TensorRT Plugin Registry or create an `init` function equivalent to `initLibNvInferPlugins()`.

9.4.1. Migrating Plugins From TensorRT 6.x Or 7.x To TensorRT 8.x.x

`IPluginV2` and `IPluginV2Ext` are still supported for backward compatibility with TensorRT 5.1 and 6.0.x respectively. However, new plugins should target the `IPluginV2DynamicExt` or `IPluginV2IOExt` interfaces, and old ones refactored to use these interfaces.

The new features in `IPluginV2DynamicExt` are as follows:

```
virtual DimsExprs getOutputDimensions(int outputIndex, const DimsExprs* inputs, int nbInputs,
 IExprBuilder& exprBuilder) = 0;

virtual bool supportsFormatCombination(int pos, const PluginTensorDesc* inOut, int nbInputs,
 int nbOutputs) = 0;

virtual void configurePlugin(const DynamicPluginTensorDesc* in, int nbInputs, const
 DynamicPluginTensorDesc* out, int nbOutputs) = 0;
```

```
virtual size_t getWorkspaceSize(const PluginTensorDesc* inputs, int nbInputs, const
 PluginTensorDesc* outputs, int nbOutputs) const = 0;

virtual int enqueue(const PluginTensorDesc* inputDesc, const PluginTensorDesc* outputDesc,
 const void* const* inputs, void* const* outputs, void* workspace, cudaStream_t stream) = 0;
```

The new features in `IPluginV2IOExt` are as follows:

```
virtual void configurePlugin(const PluginTensorDesc* in, int nbInput, const PluginTensorDesc*
 out, int nbOutput) = 0;

virtual bool supportsFormatCombination(int pos, const PluginTensorDesc* inOut, int nbInputs,
 int nbOutputs) const = 0;
```

Guidelines for migration to `IPluginV2DynamicExt` or `IPluginV2IOExt`:

- `getOutputDimensions` implements the expression for output tensor dimensions given the inputs.
- `supportsFormatCombination` checks if the plugin supports the format and datatype for the specified input/output.
- `configurePlugin` mimics the behavior of equivalent `configurePlugin` in `IPluginV2Ext` but accepts tensor descriptors.
- `getWorkspaceSize` and `enqueue` mimic the behavior of equivalent APIs in `IPluginV2Ext` but accept tensor descriptors.

Refer to the API description in IPluginV2 API Description for more details about the API.

9.4.2. `IPluginV2` API Description

The following section describes the functions of the `IPluginV2` class. To connect a plugin layer to neighboring layers and set up input and output data structures, the builder checks for the number of outputs and their dimensions by calling the following plugins methods.

`getNbOutputs`

Used to specify the number of output tensors.

`getOutputDimensions`

Used to specify the dimensions of output as a function of the input dimensions.

`supportsFormat`

Used to check if a plugin supports a given data format.

`getOutputDataType`

Used to get the data type of the output at a given index. The returned data type must have a format that is supported by the plugin.

Plugin layers can support four data formats and layouts, for example:

- `NCHW` single (FP32), half-precision (FP16), and integer (INT32) tensors
- `NC/2HW2` and `NHWC8` half-precision (FP16) tensors

The formats are enumerated by `PluginFormatType`.

Plugins that do not compute all data in place and need memory space in addition to input and output tensors can specify the additional memory requirements with the `getWorkspaceSize` method, which is called by the builder to determine and pre-allocate scratch space.

During both build and inference time, the plugin layer is configured and executed, possibly multiple times. At build time, to discover optimal configurations, the layer is configured, initialized, executed, and terminated. After the optimal format is selected for a plugin, the plugin is once again configured, then it is initialized once and executed as many times as needed for the lifetime of the inference application, and finally terminated when the engine is destroyed. These steps are controlled by the builder and the engine using the following plugin methods:

configurePlugin

Communicates the number of inputs and outputs, dimensions and datatypes of all inputs and outputs, broadcast information for all inputs and outputs, the chosen plugin format, and maximum batch size. At this point, the plugin sets up its internal state and selects the most appropriate algorithm and data structures for the given configuration.

initialize

The configuration is known at this time, and the inference engine is being created, so the plugin can set up its internal data structures and prepare for execution.

enqueue

Encapsulates the actual algorithm and kernel calls of the plugin and provides the runtime batch size, pointers to input, output, and scratch space, and the CUDA stream to be used for kernel execution.

terminate

The engine context is destroyed, and all the resources held by the plugin should be released.

clone

This is called every time a new builder, network, or engine is created that includes this plugin layer. It should return a new plugin object with the correct parameters.

destroy

Used to destroy the plugin object and/or other memory allocated each time a new plugin object is created. It is called whenever the builder or network or engine is destroyed.

set/getPluginNamespace

This method is used to set the library namespace that this plugin object belongs to (default can be ""). All plugin objects from the same plugin library should have the same namespace.

`IPluginV2Ext` supports plugins that can handle broadcast inputs and outputs. The following methods need to be implemented for this feature:

canBroadcastInputAcrossBatch

This method is called for each input whose tensor is semantically broadcast across a batch. If `canBroadcastInputAcrossBatch` returns `true` (meaning the plugin can support broadcast), TensorRT does not replicate the input tensor. There is a single copy that the plugin should share across the batch. If it returns `false`, TensorRT replicates the input tensor so that it appears like a non-broadcasted tensor.

isOutputBroadcastAcrossBatch

This is called for each output index. The plugin should return true the output at the given index and is broadcast across the batch.

IPluginV2IOExt

This is called by the builder prior to `initialize()`. It provides an opportunity for the layer to make algorithm choices on the basis of I/O PluginTensorDesc and the maximum batch size.

9.4.3. `IPluginCreator` API Description

The following methods in the `IPluginCreator` class are used to find and create the appropriate plugin from the Plugin Registry.

getPluginName

This returns the plugin name and should match the return value of `IPluginExt::getPluginType`.

getPluginVersion

Returns the plugin version. For all internal TensorRT plugins, this defaults to `1`.

getFieldNames

To successfully create a plugin, it is necessary to know all the field parameters of the plugin. This method returns the `PluginFieldCollection` struct with the `PluginField` entries populated to reflect the field name and `PluginFieldType` (the data should point to `nullptr`).

createPlugin

This method is used to create the plugin using the `PluginFieldCollection` argument. The data field of the `PluginField` entries should be populated to point to the actual data for each plugin field entry.

deserializePlugin

This method is called internally by the TensorRT engine based on the plugin name and version. It should return the plugin object to be used for inference.

set/getPluginNamespace

This method is used to set the namespace that this creator instance belongs to (default can be "").

9.4.4. Persistent LSTM Plugin

The following section describes the new `Persistent LSTM` plugin. The `Persistent LSTM` plugin supports half-precision persistent LSTM. To create a `Persistent LSTM` plugin in the network, you need to call:

```
auto creator = getPluginRegistry()->getPluginCreator("CgPersistentLSTMPlugin_TRT", "1")

IPluginV2* cgPersistentLSTMPlugin = creator->createPlugin("CgPersistentLSTMPlugin_TRT", &fc);
```

`fc` is a `PluginField` array that consists of four parameters:

- `hiddenSize`: This is an INT32 parameter that specifies the hidden size of LSTM.

- `numLayers`: This is an INT32 parameter that specifies the number of layers in LSTM.
- `bidirectionFactor`: This is an INT32 parameter that indicates whether LSTM is bidirectional. If LSTM is bidirectional, the value should be set to `2`; otherwise, the value is set to `1`.
- `setInitialStates`: This is an INT32 parameter that indicates whether LSTM has initial state and cell values as inputs. If it is set to `0`, the initial state and cell values are zero. It is recommended to use this flag instead of providing zero state and cell values as inputs for better performance.

The plugin can be added to the network by calling:

```
auto lstmLayer = network->addPluginV2(&inputs[0], 6, *cgPersistentLSTMPlugin);
```

`inputs` is a vector of `ITensor` pointers with six elements in the following order:

1. `input`: These are the input sequences to the LSTM.
2. `seqLenTensor`: This is the sequence length vector that stores the effective length of each sequence.
3. `weight`: This tensor consists of all weights needed for LSTM. Even though this tensor is 1D, it can be viewed with the following 3D indexing `[isW, layerNb, gateType]`. `isW` starts from `false` to `true` suggesting that the first half of weight is recurrent weight and the second half is input weight. `layerNb` starts from 0 to `numLayers*bidirectionFactor` such that the first layer is the forward direction of the actual layer and the second layer is the backward direction. The `gateType` follows this order: `input, cell, forget` and `output`.
4. `bias`: Similar to weight, this tensor consists of all biases needed for LSTM. Even though this tensor is 1D, it can be viewed with the following 3D indexing `[layerNb, isW, gateType]`. Notice the slight difference between bias and weight.
5. `initial hidden state`: The pointer should be set to `null` if `setInitialStates` is `0`. Otherwise, the tensor should consist of the initial hidden state values with the following coordinates `[batch index, layerNb, hidden index]`. The `batch index` indicates the index within a batch, and the `hidden index` is the index to vectors of `hiddenSize` length.
6. `initial cell state`: The pointer should be set to null if `setInitialStates` is `0`. Otherwise, the tensor should consist of the initial hidden state values with the following coordinates `[batch index, layerNb, hidden index]`.

9.5. Best Practices For Custom Layers Plugin

Converting User-Defined Layers

To create a custom layer implementation as a TensorRT plugin, you need to implement the `IPluginV2Ext` class and the `IPluginCreator` class for your plugin.

For more information about both API classes, refer to Plugin API Description.

Debugging Custom Layer Issues

Memory allocated in the plugin must be freed to ensure no memory leak. If resources are acquired in the `initialize()` function, they need to be released in the `terminate()` function. All other memory allocations should be freed, preferably in the plugin class destructor or in the `destroy()` method. Adding Custom Layers Using The C++ API outlines this in detail and also provides some notes for best practices when using plugins.

Chapter 10. Working With Empty Tensors

NVIDIA® TensorRT™ supports empty tensors. A tensor is an empty tensor if it has one or more dimensions with length zero. Zero-length dimensions usually get no special treatment. If a rule works for a dimension of length `L` for an arbitrary positive value of `L`, it usually works for `L=0` too.

For example, when concatenating two tensors with dimensions `[x,y,z]` and `[x,y,w]` along the last axis, the result has dimensions `[x,y,z+w]`, regardless of whether `x`, `y`, `z`, or `w` is zero.

Implicit broadcast rules remain unchanged since only unit-length dimensions are special for broadcast. For example, given two tensors with dimensions `[1,y,z]` and `[x,1,z]`, their sum computed by `IElementWiseLayer` has dimensions `[x,y,z]`, regardless of whether `x`, `y`, or `z` is zero.

Note that if an engine binding is an empty tensor, at least one byte of memory still needs to be allocated for it.

10.1. `IReduceLayer` And Empty Tensors

If all inputs to a layer are empty, the output is usually empty, but there are exceptions. The exceptions arise from how reduction over an empty set is defined in mathematics: Reduction over an empty set yields the identity element for the operation.

The following table shows cases relevant to TensorRT:

Reduction Operation	`kFLOAT` & `kHALF`	`kINT32`	`kINT8`
`kSUM`	0	0	0
`kPROD`	1	1	1
`kMAX`	∞	`INT_MAX`	-128
`kMIN`	-∞	`INT_MIN`	127
`kAVG`	NaN	0	-128

The average empty set is mathematically ill-defined. The obvious definition (sum of elements)/(number of elements) yields 0/0. It's represented by "Not a Number" (NaN) for floating-point. The 0 for `kAVG` over an empty set of `kINT32` has no mathematical justification and was chosen for compatibility with TensorFlow.

TensorRT usually performs reduction for `kINT8` via `kFLOAT` or `kHALF`. The kINT8 values show the quantized *representations* of the floating-point values, not their dequantized values.

10.2. `IMatrixMultiplyLayer`, `IFullyConnectedLayer`, And Empty Tensors

Multiplying matrices with dimensions `[m,0]` and `[0,n]` results in a matrix of zeros with dimensions `[m,n]`. It's zeros because each element of the result is the sum over an empty set of products.

`IFullyConnectedLayer` is fundamentally a matrix multiplication, so similar rules apply.

10.3. Plugins And Empty Tensors

Plugins that need to handle empty tensors must be written with `IPluginV2Ext`, `IPluginV2IOExt`, or `IPluginV2DynamicExt`.

WARNING: Empty tensors can have properties not seen for non-empty tensors:

- **a volume of zero**
- **one or more strides equal to zero**

The volume of zero can break kernel launching logic since a common approach is to set the number of CUDA blocks proportional to the volume being processed. CUDA reports an error for launching a kernel with zero blocks. Hence plugins should be careful about avoiding such launches.

Strides should be calculated the same as for non-empty tensors. For example, given a tensor with dimensions [N,C,H,W], the stride of the memory representation corresponding to an increment along the C axis is H*W. It doesn't matter if H or W is zero. Though make sure that your code does not divide by a stride or dimension that could be zero. For example, the assertion in the following fragment risks dividing by zero in both divisions:

```
int volume = N*C*H*W;
int cStride = H*W;
...
assert(C == volume/N/cStride);
```

For some plugins, an effective strategy is to make the plugin's method `enqueue` return early if all outputs are empty, and thereby not complicate the rest of the logic with consideration of zero-length dimensions.

10.4. `IRNNv2Layer` And Empty Tensors

`IRNNv2Layer` works for empty tensors but was deprecated in TensorRT 7.2.1 and removed in TensorRT 9.0. Use a loop to synthesize a recurrent sub-network as discussed in the Working With Loops section.

`IRNNLayer` has been deprecated since TensorRT 4.0 and was removed in TensorRT 8.0.

10.5. `IShuffleLayer` And Empty Tensors

By default, `IShuffleLayer` treats a `0` in the reshape dimensions as a special placeholder, and *not meaning zero.* The placeholder means "copy the corresponding input dimension." This default behavior has been kept for compatibility with earlier versions of TensorRT but is hazardous when working with empty tensors.

If you are reshaping to dimensions that might include a zero-length dimension, disable the placeholder treatment of zero with the `IShuffleLayer::setZeroIsPlaceholder` method.

```
IShuffleLayer* s = ...;
s->setZeroIsPlaceholder(false);
```

For example, consider the following code that intends to reshape a tensor input to dimensions specified by shape tensor `reshapeDims`.

```
IShuffleLayer* s = network.addShuffle(input);
s->setInput(1, reshapeDims);
#if CORRECT
s->setZeroIsPlaceholder(false);
#endif
output = *s->getOutput(0);
```

Suppose at runtime, the input has dimensions `[3,0]`, and the second input `reshapeDims` contains `[0,0]`. If the engine was built with `CORRECT==0`, the zeros in `reshapeDims` are interpreted as placeholders for input dimensions, and the output has dimensions `[3,0]`, not `[0,0]` as intended. Building the fragment with `CORRECT==1` ensures that the `IShuffleLayer` treats zero as zero. Unless you know that you need the placeholder feature, it is recommended that it be turned off with `setZeroIsPlaceholder(false)`.

Empty tensors also introduce the possibility of a new kind of error when using the `-1` wildcard in reshape dimensions. The wildcard denotes an unknown dimension *x* that TensorRT solves using the equation:

```
x *  (volume of other reshape dimension) = volume(input
    tensor)
```

If the volume of the other reshape dimensions is zero, one of two errors occur:

- The volume of the input tensor is zero. Then `x` is indeterminate.
- The volume of the input tensor is nonzero. Then `x` has no solution.

TensorRT reports an error in either case, possibly at build time or run time.

10.6. `ISliceLayer` And Empty Tensors

The behavior of `ISliceLayer` for empty tensors follows a strict interpretation of its semantics. Specifically, consider slicing a dimension of length `L` with parameters `start`, `size`, and `stride`.

Constructing the output tensor requires subscripting the half-open interval `[0,L)` with generated indices of the form `start+i*stride` for all `i`, such that `0 ≤ i < size`. All the generated indices must be in bounds. However, with `size=0`, no indices are generated, and thus no bounds checking applies. So for `size=0`, the `start` and `stride` parameters do not matter and can be any values.

Conversely, if `L=0` and `size≠0`, then TensorRT reports an error since the half-open interval `[0,L)` becomes empty, and the generated indices are inherently out of bounds.

10.7. `IConvolutionLayer` And Empty Tensors

Convolution with zero input channels (for example, `[n, 0, h, w]`) results in a tensor of zeros with dimensions `[n, k, p, q]`, before adding the bias, because each element of the result is a sum over an empty set of products.

Chapter 11. Working With Loops

NVIDIA® TensorRT™ supports loop-like constructs, which can be useful for recurrent networks. TensorRT loops support scanning over input tensors, recurrent definitions of tensors, and both "scan outputs" and "last value" outputs.

11.1. Defining A Loop

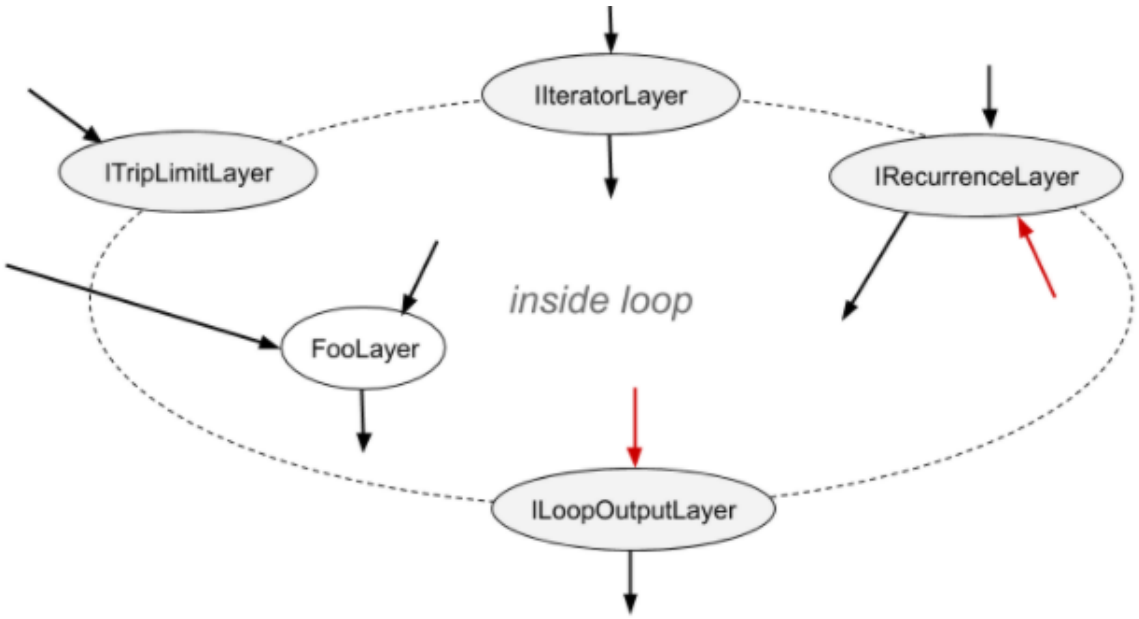
A loop is defined by *loop boundary layers*.

- `ITripLimitLayer` specifies how many times the loop iterates.
- `IIteratorLayer` enables a loop to iterate over a tensor.
- `IRecurrenceLayer` specifies a recurrent definition.
- `ILoopOutputLayer` specifies an output from the loop.

Each of the boundary layers inherits from class `ILoopBoundaryLayer`, which has a method `getLoop()` for getting its associated `ILoop`. The `ILoop` object identifies the loop. All loop boundary layers with the same `ILoop` belong to that loop.

Figure 12 depicts the structure of a loop and data flow at the boundary. Loop-invariant tensors can be used inside the loop directly, such as shown for FooLayer.

Figure 12. A TensorRT loop is set by loop boundary layers. Dataflow can leave the loop only via `ILoopOutputLayer`. The only back edges allowed are the second input to `IRecurrenceLayer`.



A loop can have multiple `IIteratorLayer`, `IRecurrenceLayer`, and `ILoopOutputLayer`, and at most two `ITripLimitLayers` as explained later. A loop with no `ILoopOutputLayer` has no output and is optimized away by TensorRT.

The interior of the loop can have the following kinds of layers:

- `IActivationLayer` if the operation is one of:
  - `kRELU`
  - `kSIGMOID`
  - `kTANH`
  - `kELU`
- `IConcatenationLayer`
- `IConstantLayer`
- `IIdentityLayer`
- `IFullyConnectedLayer`
- `IMatrixMultiplyLayer`
- `IElementWiseLayer`
- `IPluginV2Layer`
- `IScaleLayer`
- `ISliceLayer`
- `ISelectLayer`

- IShuffleLayer
- ISoftMaxLayer
- IUnaryLayer if the operation is one of:
  - kABS
  - kCEIL
  - kEXP
  - kFLOOR
  - kLOG
  - kNEG
  - kNOT
  - kRECIP
  - kSQRT

Interior layers are free to use tensors defined inside or outside the loop. The interior can contain other loops (refer to Nested Loops).

To define a loop, first, create an ILoop object with the method INetworkDefinition::addLoop. Then add the boundary and interior layers. The rest of this section describes the features of the boundary layers, using *loop* to denote the ILoop* returned by INetworkDefinition::addLoop.

ITripLimitLayer supports both counted loops and while-loops.

- *loop*->addTripLimit(*t*,TripLimit::kCOUNT) creates an ITripLimitLayer whose input *t* is a 0D Int32 tensor that specifies the number of loop iterations.
- *loop*->addTripLimit(*t*,TripLimit::kWHILE) creates an ITripLimitLayer whose input *t* is a 0D Bool tensor that specifies whether an iteration should occur. Typically *t* is either the output of an IRecurrenceLayer or a calculation based on said output.

A loop can have at most one of each kind of limit.

IIteratorLayer supports iterating forwards or backward over any axis.

- *loop*->addIterator(*t*) adds an IIteratorLayer that iterates over axis 0 of tensor *t*. For example, if the input is the matrix:
  ```
  2 3 5
  4 6 8
  ```
  the output is the 1D tensor {2, 3, 5} on the first iteration and {4, 6, 8} for the second iteration. It's invalid to iterate beyond the tensor's bounds.
- *loop*->addIterator(*t*,*axis*) is similar, but the layer iterates over the given axis. For example, if axis=1 and the input is a matrix, each iteration delivers a column of the matrix.
- *loop*->addIterator(*t*,*axis*,*reverse*) is similar, but the layer produces its output in reverse order if *reverse*=true.

ILoopOutputLayer supports three forms of loop output:

- *loop*->addLoopOutput(*t*,LoopOutput::kLAST_VALUE) outputs the last value of *t*, where t must be the output of a IRecurrenceLayer.

- *loop*->addLoopOutput(*t*,LoopOutput::kCONCATENATE,*axis*) outputs the concatenation of each iteration's input to *t*. For example, if the input is a 1D tensor, with value {a,b,c} on the first iteration and {d,e,f} on the second iteration, and *axis*=0, the output is the matrix:

  ```
  a b c
  d e f
  ```

  If *axis*=1, the output is:

  ```
  a d
  b e
  c f
  ```

- *loop*->addLoopOutput(*t*,LoopOutput::kREVERSE,*axis*) is similar, but reverses the order.

Both the kCONCATENATE and kREVERSE forms of ILoopOutputLayer require a 2nd input, which is a 0D INT32 shape tensor specifying the length of the new output dimension. When the length is greater than the number of iterations, the extra elements contain arbitrary values. The second input, for example *u*, should be set using ILoopOutputLayer::setInput(1,*u*).

Finally, there is IRecurrenceLayer. Its first input specifies the initial output value, and its second input specifies the next output value. The first input must come from outside the loop; the second input usually comes from inside the loop. For example, the TensorRT analog of this C++ fragment:

```
for (int32_t i = j; ...; i += k) ...
```

could be created by these calls, where j and k are ITensor*.

```
ILoop* loop = n.addLoop();
IRecurrenceLayer* iRec = loop->addRecurrence(j);
ITensor* i = iRec->getOutput(0);
ITensor* iNext = addElementWise(*i, *k,
    ElementWiseOperation::kADD)->getOutput(0);
iRec->setInput(1, *iNext);
```

The second input to IRecurrenceLayer is the only case where TensorRT allows a back edge. If such inputs are removed, the remaining network must be acyclic.

11.2. Formal Semantics

TensorRT has applicative semantics, meaning there are no visible side effects other than engine inputs and outputs. Because there are no side effects, intuitions about loops from imperative languages do not always work. This section defines formal semantics for TensorRT's loop constructs.

The formal semantics is based on *lazy sequences* of tensors. Each iteration of a loop corresponds to an element in the sequence. The sequence for a tensor *X* inside the loop is denoted #*X*0, *X*1, *X*2, ...#. Elements of the sequence are evaluated lazily, meaning, as needed.

The output from IIteratorLayer(X) is #X[0], X[1], X[2], ...# where X[i] denotes subscripting on the axis specified for the IIteratorLayer.

The output from IRecurrenceLayer(X,Y)is #X, Y0, Y1, Y2, ...#.

The input and output from an ILoopOutputLayer depend on the kind of LoopOutput.

- `kLAST_VALUE`: Input is a single tensor `X`, and output is X_n for an n-trip loop.
- `kCONCATENATE`: The first input is a tensor `X`, and the second input is a scalar shape tensor `Y`. The result is the concatenation of `X0, X1, X2, ... Xn-1` with post padding, if necessary, to the length specified by `Y`. It is a runtime error if `Y < n`. `Y` is a build-time constant. Note the inverse relationship with `IIteratorLayer`. `IIteratorLayer` maps a tensor to a sequence of subtensors; `ILoopOutputLayer` with `kCONCATENATE` maps a sequence of sub-tensors to a tensor.
- `kREVERSE`: Similar to `kCONCATENATE`, but the output is in the reverse direction.

The value of `n` in the definitions for the output of `ILoopOutputLayer` is determined by the `ITripLimitLayer` for the loop:

- For counted loops, it's the iteration count, meaning the input to the `ITripLimitLayer`.
- For while loops, it's the least n such that X_n is false, where `X` is the sequence for the `ITripLimitLayer`'s input tensor.

The output from a non-loop layer is a sequence-wise application of the layer's function. For example, for a two-input non-loop layer `F(X,Y) = #f(`X_0`,`Y_0`), f(`X_1`,`Y_1`), f(`X_2`,`Y_2`)...#`. If a tensor comes from outside the loop, i.e. is loop-invariant, then the sequence for it is created by replicating the tensor.

11.3. Nested Loops

TensorRT infers the nesting of the loops from the data flow. For instance, if loop B uses values defined *inside* loop A, then B is considered to be nested inside of A.

TensorRT rejects networks where the loops are not cleanly nested, such as if loop A uses values defined in the interior of loop B and vice versa.

11.4. Limitations

A loop that refers to more than one dynamic dimension can take an unexpected amount of memory.

In a loop, memory is allocated as if all dynamic dimensions take on the maximum value of any of those dimensions. For example, if a loop refers to two tensors with dimensions `[4,x,y]` and `[6,y]`, memory allocation for those tensors are as if their dimensions were `[4,max(x,y),max(x,y)]` and `[6,max(x,y)]`.

The input to a `LoopOutputLayer` with `kLAST_VALUE` must be the output from an `IRecurrenceLayer`.

The loop API supports only FP32 and FP16 precision.

11.5. Replacing `IRNNv2Layer` With Loops

`IRNNv2Layer` was deprecated in TensorRT 7.2.1 and will be removed in TensorRT 9.0. Use the loop API to synthesize a recurrent sub-network. For an example, refer to `sampleCharRNN`, method `SampleCharRNNLoop::addLSTMCell`. The loop API lets you express general recurrent networks instead of being limited to the prefabricated cells in `IRNNLayer` and `IRNNv2Layer`.

Chapter 12. Working With DLA

NVIDIA® DLA™ (Deep Learning Accelerator) is a fixed-function accelerator engine targeted for deep learning operations. DLA is designed to do full hardware acceleration of convolutional neural networks. DLA supports various layers such as convolution, deconvolution, fully-connected, activation, pooling, batch normalization, etc. DLA does not support Explicit Quantization.

For more information about DLA support in NVIDIA® TensorRT™ layers, refer to DLA Supported Layers. The `trtexec` tool has additional arguments to run networks on DLA, refer to trtexec.

To run the AlexNet network on DLA using `trtexec` in FP16 mode, issue:

```
./trtexec --deploy=data/AlexNet/AlexNet_N2.prototxt --output=prob --useDLACore=1 --fp16 --allowGPUFallback
```

To run the AlexNet network on DLA using `trtexec` in INT8 mode, issue:

```
./trtexec --deploy=data/AlexNet/AlexNet_N2.prototxt --output=prob --useDLACore=1 --int8 --allowGPUFallback
```

12.1. Running On DLA During TensorRT Inference

The TensorRT builder can be configured to enable inference on DLA. DLA support is currently limited to networks running in either FP16 or INT8 mode. The `DeviceType` enumeration is used to specify the device that the network or layer executes on. The following API functions in the `IBuilderConfig` class can be used to configure the network to use DLA,

`setDeviceType(ILayer* layer, DeviceType deviceType)`

This function can be used to set the `deviceType` that the layer must execute on.

`getDeviceType(const ILayer* layer)`

This function can be used to return the `deviceType` that this layer executes on. If the layer is executing on the GPU, this returns `DeviceType::kGPU`.

`canRunOnDLA(const ILayer* layer)`

This function can be used to check if a layer can run on DLA.

`setDefaultDeviceType(DeviceType deviceType)`

This function sets the default `deviceType` to be used by the builder. It ensures that all the layers that can run on DLA runs on DLA unless `setDeviceType` is used to override the `deviceType` for a layer.

`getDefaultDeviceType()`

This function returns the default `deviceType` which was set by `setDefaultDeviceType`.

`isDeviceTypeSet(const ILayer* layer)`

This function checks whether the `deviceType` has been explicitly set for this layer.

`resetDeviceType(ILayer* layer)`

This function resets the `deviceType` for this layer. The value is reset to the `deviceType` that is specified by `setDefaultDeviceType` or `DeviceType::kGPU` if none is specified.

`allowGPUFallback(bool setFallBackMode)`

This function notifies the builder to use GPU if a layer that was supposed to run on DLA cannot run on DLA. For more information, refer to GPU Fallback Mode.

`reset()`

This function can be used to reset the `IBuilderConfig` state, which sets the `deviceType` for all layers to be `DeviceType::kGPU`. After reset, the builder can be re-used to build another network with a different DLA config.

The following API functions in `IBuilder` class can be used to help configure the network for using the DLA:

`getMaxDLABatchSize()`

This function returns the maximum batch size DLA can support.

Note: For any tensor, the total volume of index dimensions combined with the requested batch size should not exceed the value returned by this function.

`getNbDLACores()`

This function returns the number of DLA cores available to the user.

If the builder is not accessible, such as in the case where a plan file is being loaded online in an inference application, then the DLA to be utilized can be specified differently by using DLA extensions to the `IRuntime`. The following API functions in the `IRuntime` class can be used to configure the network to use DLA:

`getNbDLACores()`

This function returns the number of DLA cores that are accessible to the user.

`setDLACore(int dlaCore)`

The DLA core to execute on. Where `dlaCore` is a value between `0` and `getNbDLACores() - 1`. The default value is `0`.

`getDLACore()`

The DLA core the runtime execution is assigned to. The default value is 0.

12.1.1. Example: sampleMNIST With DLA

This section provides details on how to run a TensorRT sample with DLA enabled.

sampleMNIST located in the GitHub repository demonstrates how to import a trained model, build the TensorRT engine, serialize and deserialize the engine and finally use the engine to perform inference.

The sample first creates the builder:

```
auto builder = SampleUniquePtr<nvinfer1::IBuilder>(nvinfer1::createInferBuilder(gLogger));
if (!builder) return false;
builder->setMaxBatchSize(batchSize);
config->setMaxWorkspaceSize(16_MB);
```

Then, enable `GPUFallback` mode:

```
config->setFlag(BuilderFlag::kGPU_FALLBACK);
config->setFlag(BuilderFlag::kFP16); or config->setFlag(BuilderFlag::kINT8);
```

Enable execution on DLA, where `dlaCore` specifies the DLA core to execute on:

```
config->setDefaultDeviceType(DeviceType::kDLA);
config->setDLACore(dlaCore);
```

With these additional changes, sampleMNIST is ready to execute on DLA. To run sampleMNIST with DLA Core 1, use the following command:

```
./sample_mnist --useDLACore=1 [--int8|--fp16]
```

12.1.2. Example: Enable DLA Mode For A Layer During Network Creation

In this example, let's create a simple network with input, convolution and output.

About this task

Procedure

1. Create the builder, builder configuration, and the network:

   ```
   IBuilder* builder = createInferBuilder(gLogger);
   IBuilderConfig* config = builder.createBuilderConfig();
   INetworkDefinition* network = builder->createNetworkV2(0U);
   ```

2. Add the Input layer to the network, with the input dimensions.

   ```
   auto data = network->addInput(INPUT_BLOB_NAME, dt, Dims3{1, INPUT_H, INPUT_W});
   ```

3. Add the convolution layer with hidden layer input nodes, strides, and weights for filter and bias.

   ```
   auto conv1 = network->addConvolution(*data->getOutput(0), 20, DimsHW{5, 5},
    weightMap["conv1filter"], weightMap["conv1bias"]);
   conv1->setStride(DimsHW{1, 1});
   ```

4. Set the convolution layer to run on DLA:

   ```
   if(canRunOnDLA(conv1))
   {
   config->setFlag(BuilderFlag::kFP16); or config->setFlag(BuilderFlag::kINT8);
   builder->setDeviceType(conv1, DeviceType::kDLA);

   }
   ```

5. Mark the output:

   ```
   network->markOutput(*conv1->getOutput(0));
   ```

6. Set the DLA core to execute on:

   ```
   config>setDLACore(0)
   ```

12.2. DLA Supported Layers

This section lists the layers supported by DLA along with the constraints associated with each layer.

Generic restrictions while running on DLA (applicable to all layers)

- Max batch size supported is 32.
- The dimensions used for building must be used at runtime.
- The maximum size of weights supported by DLA is 512 MB.
- A DLA network can only support up to 1 GB of intermediate tensor data. Tensors that are the input and output to the DLA graph are not counted against this limit. TensorRT rejects networks that exceed this limit that are built without GPU fallback enabled.
- DLA supports wildcard dimensions on the leftmost dimension as long as the `min`, `max`, and `opt` values of the profile are equal.
- TensorRT can split a DLA network into multiple sections if any restriction is violated and `GpuFallback` is enabled. Otherwise, TensorRT can emit an error and fallback. For more information, refer to GPU Fallback Mode.
- At most, four DLA loadables can be in use concurrently due to hardware and software memory limitations.

Note: Batch size for DLA is the product of all index dimensions except the `CHW` dimensions. For example, if input dimensions are `NPQRS`, the effective batch size is `N*P`.

Layer specific restrictions

Convolution and Fully Connected layers

- Only two spatial dimension operations are supported.
- Both FP16 and INT8 are supported.
- Each dimension of the kernel must be in the range `[1, 32]`.
- Padding must be in the range `[0, 31]`.
- Dimensions of padding must be less than the corresponding kernel dimension.
- Dimensions of stride must be in the range `[1, 8]`.
- Number of output maps must be in the range `[1, 8192]`.
- Number of groups must be in the range `[1, 8192]` for operations using the formats `TensorFormat::kLINEAR`, `TensorFormat::kCHW16`, and `TensorFormat::kCHW32`.
- Number of groups must be in the range `[1, 4]` for operations using the formats `TensorFormat::kCHW4`.
- Dilated convolution must be in the range `[1, 32]`.

Deconvolution layer

- Only two spatial dimension operations are supported.
- Both FP16 and INT8 are supported.
- Dimensions of the kernel must be in the range `[1, 32]`, in addition to `1x[64, 96, 128]` and `[64, 96, 128]x1`.
- TensorRT has disabled deconvolution square kernels and strides in the range `[23 – 32]` on DLA as they significantly slow down compilation.
- The stride must be the same in each dimension as the kernel dimensions.
- Padding must be `0`.
- Grouped deconvolution must be `1`.
- Dilated deconvolutions must be `1`.
- Number of input channels must be in the range `[1, 8192]`.
- Number of output channels must be in the range `[1, 8192]`.

Pooling layer

- Only two spatial dimension operations are supported.
- Both FP16 and INT8 are supported.
- Operations supported: `kMAX`, `kAVERAGE`.
- Dimensions of the window must be in the range `[1, 8]`.
- Dimensions of padding must be in the range `[0, 7]`.
- Dimensions of stride must be in the range `[1, 16]`.
- Exclusive padding with `kAVERAGE` pooling is not supported.
- With INT8 mode, input and output tensor scales must be the same.

Activation layer

- Only two spatial dimension operations are supported.
- Both FP16 and INT8 are supported.
- Functions supported: `ReLU`, `Sigmoid`, `TanH` and `Clipped ReLU`.
  - Negative slope is not supported for `ReLU`.
  - `Clipped ReLU` only supports values in the range `[1, 127]`.
- `TanH`, `Sigmoid` INT8 support is supported by auto-upgrading to FP16.

ElementWise layer

- Only two spatial dimension operations are supported.
- Both FP16 and INT8 are supported.
- Operations supported: `Sum`, `Sub`, `Product`, `Max`, and `Min`.

- Only `Sum` operation is supported in INT8.

Note: TensorRT concatenates a DLA Scale layer and a DLA ElementWise layer with the operation `Sum` to support the `Sub` operation, which is not supported by a single DLA ElementWise layer.

Scale layer

- Only two spatial dimension operations are supported.
- Both FP16 and INT8 are supported.
- Mode supported: `Uniform`, `Per-Channel`, and `ElementWise`.
- Only `scale` and `shift` operations are supported.

LRN (Local Response Normalization) layer

- Allowed window sizes are `3`, `5`, `7`, or `9`.
- Normalization region supported is `ACROSS_CHANNELS`.
- `LRN` INT8 is supported by auto-upgrading to FP16.

Concatenation layer

- DLA supports concatenation only along the channel axis.
- Concat must have at least two inputs.

Note: When running INT8 networks on the DLA using TensorRT, operations are recommended to be added to the same subgraph to reduce quantization errors across the subgraph of the network running on the DLA by allowing them to fuse and retain higher precision for intermediate results. Breaking apart the subgraph in order to inspect intermediate results by setting the tensors as Network output tensors can result in different levels of quantization errors due to these optimizations being disabled.

12.3. GPU Fallback Mode

The `GPUFallbackMode` sets the builder to use GPU if a layer that was marked to run on DLA could not run on DLA.

A layer cannot run on DLA due to the following reasons:

1. The `layer` operation is not supported on DLA.
2. The parameters specified are out of the supported range for DLA.
3. The given batch size exceeds the maximum permissible DLA batch size. For more information, refer to DLA Supported Layers.
4. A combination of layers in the network causes the internal state to exceed what the DLA is capable of supporting.
5. There are no DLA engines available on the platform.

If the GPUFallbackMode is set to false, a layer set to execute on DLA that couldn't run on DLA results in an error. However, with GPUFallbackMode set to true, it continues to execute on the GPU instead, after reporting a warning.

Similarly, if defaultDeviceType is set to DeviceType::kDLA and GPUFallbackMode is set to false, it results in an error if any of the layers can't run on DLA. With GPUFallbackMode set to true, it reports a warning and continue executing on the GPU.

If a combination of layers in the network cannot run on DLA, all layers in the combination executes on the GPU.

12.4. Restrictions With DLA

DLA supports formats that are unique to the device and have constraints on their layout due to vector width byte requirements.

For DLA input, kDLA_LINEAR(FP16, INT8), kDLA_HWC4(FP16, INT8), kCHW16(FP16), and kCHW32(INT8) are supported. For DLA output, only kDLA_LINEAR(FP16, INT8), kCHW16(FP16), and kCHW32(INT8) are supported. For kCHW16 and kCHW32 formats, the C channel count is recommended to be equivalent to a positive integer multiple of the vector size. If C is not an integer multiple, then it must be padded to the next 32-byte boundary.

For kDLA_LINEAR format, the stride along the W dimension must be padded up to 64 bytes. The memory layout is equivalent to a C array with dimensions [N][C][H][roundUp(W, 64/elementSize)] where elementSize is 2 for FP16 and 1 for Int8, with the tensor coordinates (n, c, h, w) mapping to array subscript [n][c][h][w].

For kDLA_HWC4 format, the stride along the W dimension must be a multiple of 32 bytes.

- When C == 1, TensorRT maps the format to the native grayscale image format.
- When C == 3 or C == 4, it maps to the native color image format. If C == 3, the stride for stepping along the W axis needs to be padded to 4 in elements.

  In this case, the padded channel is located at the 4th-index. Ideally, the padding value doesn't matter because the 4th channel in the weights is padded to zero by the DLA compiler; however, it is safe for the application to allocate a zero-filled buffer of four channels and populate three valid channels.
- When C is {1, 3, 4}, then padded C' is {1, 4, 4} respectively, the memory layout is equivalent to a C array with dimensions [N][H][roundUp(W, 32/C'/elementSize)][C'] where elementSize is 2 for FP16 and 1 for Int8. The tensor coordinates (n, c, h, w) mapping to array subscript [n][h][w][c], roundUp calculates the smallest multiple of 64/elementSize greater than or equal to W.

When using kDLA_HWC4 as DLA input format, it has the following requirements:

- C must be 1, 3, or 4
- The first layer must be convolution.
- The convolution parameters must meet DLA requirements, refer to DLA Supported Layers.

When the EngineCapability is EngineCapability::kDEFAULT and TensorRT cannot generate a reformat free network for the given input/output formats, the unsupported DLA

formats can be automatically converted into supported DLA format. For example, if the layers connected to the network inputs or outputs cannot run on DLA or if the network does not meet other DLA requirements, reformat operations are inserted to satisfy constraints. In all cases, the strides that TensorRT expects data to be formatted with can be obtained by querying `IExecutionContext::getStrides`.

Q: What is the best practice to use reformat-free network I/O tensors for DLA? A: First, you have to check if your network can run entirely on DLA, then try to build the network by specifying `kDLA_LINEAR`, `kDLA_HWC4` or `kCHW16/32` format as allowed I/O formats. If multiple formats can work, you can profile them and choose the fastest I/O format combination. If your network indeed performs better with `kDLA_HWC4`, but it doesn't work, you have to check which requirement listed in the previous section is unsatisfied.

12.5. DLA Standalone Mode

If you are using a separate DLA runtime component, you can use `EngineCapability::kDLA_STANDALONE` to generate a DLA loadable. See the documentation for the DLA runtime component in question for how to use the loadable.

When using `kDLA_STANDALONE`, TensorRT generates a reformat free network for the given input/output formats. For DLA input, `kLINEAR`(`FP16`, `INT8`), `kCHW4`(`FP16`, `INT8`), `kCHW16`(`FP16`), and `kCHW32`(`INT8`) are supported. While for DLA output, only `kLINEAR`(`FP16`, `INT8`), `kCHW16`(`FP16`), and `kCHW32`(`INT8`) are supported. For `kCHW16` and `kCHW32` formats, the `C` channel count is recommended to be equivalent to a positive integer multiple of the vector size. If `C` is not an integer multiple, then it must be padded to the next 32-byte boundary.

Chapter 13. Troubleshooting

The following sections help answer the most commonly asked questions regarding typical use cases with NVIDIA® TensorRT™.

13.1. FAQs

This section is to help troubleshoot the problem and answer our most asked questions.

Q: How do I create an engine that is optimized for several different batch sizes?

A: While TensorRT allows an engine optimized for a given batch size to run at any smaller size, the performance for those smaller sizes can not be as well-optimized. To optimize for multiple different batch sizes, create optimization profiles at the dimensions that are assigned to `OptProfilerSelector::kOPT`.

Q: Are engines and calibration tables portable across TensorRT versions?

A: No. Internal implementations and formats are continually optimized and can change between versions. For this reason, engines and calibration tables are not guaranteed to be binary compatible with different versions of TensorRT. Applications should build new engines and INT8 calibration tables when using a new version of TensorRT.

Q: How do I choose the optimal workspace size?

A: Some TensorRT algorithms require additional workspace on the GPU. The method `IBuilderConfig::setMaxWorkspaceSize()` controls the maximum amount of workspace that can be allocated and prevents algorithms that require more workspace from being considered by the builder. At runtime, the space is allocated automatically when creating an `IExecutionContext`. The amount allocated is no more than is required, even if the amount set in `IBuilderConfig::setMaxWorkspaceSize()` is much higher. Applications should therefore allow the TensorRT builder as much workspace as they can afford; at runtime, TensorRT allocates no more than this and typically less.

Q: How do I use TensorRT on multiple GPUs?

A: Each `ICudaEngine` object is bound to a specific GPU when it is instantiated, either by the builder or on deserialization. To select the GPU, use `cudaSetDevice()` before calling the builder or deserializing the engine. Each `IExecutionContext` is bound to the same GPU as the engine from which it was created. When calling `execute()` or `enqueue()`, ensure that the thread is associated with the correct device by calling `cudaSetDevice()` if necessary.

Q: How do I get the version of TensorRT from the library file?

A: There is a symbol in the symbol table named `tensorrt_version_#_#_#_#` which contains the TensorRT version number. One possible way to read this symbol on Linux is to use the `nm` command like in the following example:

```
$ nm -D libnvinfer.so.7 | grep tensorrt_version
000000002564741c B tensorrt_version_7_2_2_3
```

Q: What can I do if my network is producing the wrong answer?

A: There are several reasons why your network can be generating incorrect answers. Here are some troubleshooting approaches which can help diagnose the problem:

- Turn on `INFO` level messages from the log stream and check what TensorRT is reporting.
- Check that your input preprocessing is generating exactly the input format required by the network.
- If you're using reduced precision, run the network in FP32. If it produces the correct result, it is possible that lower precision has an insufficient dynamic range for the network.
- Try marking intermediate tensors in the network as outputs, and verify if they match what you are expecting.

> **Note:** Marking tensors as outputs can inhibit optimizations, and therefore, can change the results.

Q: How do I implement batch normalization in TensorRT?

A: Batch normalization can be implemented using a sequence of `IElementWiseLayer` in TensorRT. More specifically:

```
adjustedScale = scale / sqrt(variance + epsilon)
batchNorm = (input + bias - (adjustedScale * mean)) * adjustedScale
```

Q: Why does my network run slower when using DLA compared to without DLA?

A: DLA was designed to maximize energy efficiency. Depending on the features supported by DLA and the features supported by the GPU, either implementation can be more performant. Which implementation to use depends on your latency or throughput requirements and your power budget. Since all DLA engines are independent of the GPU and each other, you could

also use both implementations at the same time to further increase the throughput of your network.

Q: Is INT4 quantization or INT16 quantization supported by TensorRT?

A: Neither INT4 nor INT16 quantization is supported by TensorRT at this time.

Q: When will TensorRT support layer XYZ required by my network in the UFF parser?

A: UFF is deprecated. We recommend users switch their workflows to ONNX. The TensorRT ONNX parser is an open source project.

Q: Can I use multiple TensorRT builders to compile on different targets?

A: TensorRT assumes that all resources for the device it is building on are available for optimization purposes. Concurrent use of multiple TensorRT builders (for example, multiple `trtexec` instances) to compile on different targets (DLA0, DLA1 and GPU) can oversubscribe system resources causing undefined behavior (meaning, inefficient plans, builder failure, or system instability).

It is recommended to use `trtexec` with the `--saveEngine` argument to compile for different targets (DLA and GPU) separately and save their plan files. Such plan files can then be reused for loading (using `trtexec` with the `--loadEngine` argument) and submitting multiple inference jobs on the respective targets (DLA0, DLA1, GPU). This two-step process alleviates over-subscription of system resources during the build phase while also allowing execution of the plan file to proceed without interference by the builder.

13.2. Understanding Error Messages

If an error is encountered during execution, TensorRT reports an error message that is intended to help in debugging the problem. Some common error messages that can be encountered by developers are discussed in the following sections.

UFF Parser Error Messages

The following table captures the common UFF parser error messages.

Error Message	Description
`The input to the Scale Layer is required to have a minimum of 3 dimensions.`	This error message can occur due to incorrect input dimensions. In UFF, input dimensions should always be specified with the implicit batch dimension *not* included in the specification.
`Invalid scale mode, nbWeights: <X>`	
`kernel weights has count <X> but <Y> was expected`	

Error Message	Description
`<NODE> Axis node has op <OP>, expected Const. The axis must be specified as a Const node.`	As indicated by the error message, the axis must be a build-time constant in order for UFF to parse the node correctly.

ONNX Parser Error Messages

The parser can issue error messages if a constant input is used with a layer that does not support constant inputs. Consider using a tensor input instead.

TensorRT Core Library Error Messages

The following table captures the common TensorRT core library error messages.

	Error Message	Description
Installation Errors	`Cuda initialization failure with error <code>. Please check cuda installation: http://docs.nvidia.com/cuda/cuda-installation-guide-linux/index.html.`	This error message can occur if the CUDA or NVIDIA driver installation is corrupt. Refer to the URL for instructions on installing CUDA and the NVIDIA driver on your operating system.
Builder Errors	`Internal error: could not find any implementation for node <name>. Try increasing the workspace size with IBuilderConfig::setMaxWorkspaceSize().`	This error message occurs because there is no layer implementation for the given node in the network that can operate with the given workspace size. This usually occurs because the workspace size is insufficient but could also indicate a bug. If increasing the workspace size as suggested doesn't help, report a bug (refer to How Do I Report A Bug?).
	`<layer-name>: (kernel|bias) weights has non-zero count but null values` `<layer-name>: (kernel|bias) weights has zero count but non-null values`	This error message occurs when there is a mismatch between the values and count fields in a Weights data structure passed to the builder. If the count is 0, then the values field should contain a null pointer; otherwise, the count must be non-zero, and values should contain a device pointer.

	Error Message	Description
	`Builder was created on device different from current device.`	This error message can show up if you: 1. Created an IBuilder targeting one GPU, then 2. Called `cudaSetDevice()` to target a different GPU, then 3. Attempted to use the IBuilder to create an engine. Ensure you only use the `IBuilder` when targeting the GPU that was used to create the `IBuilder`.
	You can encounter error messages indicating that the tensor dimensions do not match the semantics of the given layer. Carefully read the documentation on NvInfer.h on the usage of each layer and the expected dimensions of the tensor inputs and outputs to the layer.	
INT8 Calibration Errors	`Tensor <X> is uniformly zero.`	This warning occurs and should be treated as an error when data distribution for a tensor is uniformly zero. In a network, the output tensor distribution can be uniformly zero under the following scenarios: 1. Constant tensor with all zero values; not an error. 2. Activation (ReLU) output with all negative inputs: not an error. 3. Data distribution is forced to all zero due to computation error in the previous layer; emit a warning here.[1] 4. User does not provide any calibration images; emit a warning here.[1]

[1] **It is recommended to evaluate the calibration input or validate the previous layer outputs.**

	Error Message	Description
	`Could not find scales for tensor <X>.`	This error message indicates that a calibration failure occurred with no scaling factors detected. This could be due to no INT8 calibrator or insufficient custom scales for network layers. For more information, refer to sampleINT8 located in the `/opensource/sampleINT8` directory in the GitHub repository to set up calibration correctly.
Engine Compatibility Errors	`The engine plan file is not compatible with this version of TensorRT, expecting (format|library) version <X> got <Y>, please rebuild.`	This error message can occur if you are running TensorRT using an engine PLAN file that is incompatible with the current version of TensorRT. Ensure you use the same version of TensorRT when generating the engine and running it.
	`The engine plan file is generated on an incompatible device, expecting compute <X> got compute <Y>, please rebuild.`	This error message can occur if you build an engine on a device of a different compute capability than the device that is used to run the engine.
	`Using an engine plan file across different models of devices is not recommended and is likely to affect performance or even cause errors.`	This warning message can occur if you build an engine on a device with the same compute capability but is not identical to the device that is used to run the engine. As indicated by the warning, it is highly recommended to use a device of the same model when generating the engine and deploying it to avoid compatibility issues.
Out Of Memory Errors	`GPU memory allocation failed during initialization of (tensor|layer): <name>` `GPU memory`	These error messages can occur if there is insufficient GPU memory available to instantiate

	Error Message	Description
	`Allocation failed during deserialization of weights.` `GPU does not meet the minimum memory requirements to run this engine …`	a given TensorRT engine. Verify that the GPU has sufficient available memory to contain the required layer weights and activation tensors.
FP16 Errors	`Network needs native FP16 and platform does not have native FP16`	This error message can occur if you attempt to deserialize an engine that uses FP16 arithmetic on a GPU that does not support FP16 arithmetic. You either need to rebuild the engine without FP16 precision inference or upgrade your GPU to a model that supports FP16 precision inference.
Plugin Errors	`Custom layer <name> returned non-zero initialization`	This error message can occur if the `initialize()` method of a given plugin layer returns a non-zero value. Refer to the implementation of that layer to debug this error further. For more information, refer to TensorRT Layers.

Appendix A. Appendix

A.1. TensorRT Layers

In TensorRT, layers represent distinct flavors of mathematical and/or programmatic operations. The following sections describe every layer that TensorRT supports. The minimum workspace required by TensorRT depends on the operators used by the network. A suggested minimum build-time setting is 16 MB. Regardless of the maximum workspace value provided to the builder, TensorRT will allocate at runtime no more than the workspace it requires. To view a list of the specific attributes supported by each layer, refer to the TensorRT API Reference documentation.

TensorRT can optimize performance by fusing layers. For information about how to enable layer fusion optimizations, refer to Types Of Fusions. For information about optimizing individual layer performance, refer to How Do I Optimize My Layer Performance?.

For details about the types of precision and features supported per layer, refer to the TensorRT Support Matrix.

A.1.1. `IActivationLayer`

The `IActivationLayer` implements element-wise activation functions.

Layer Description

Apply an activation function on an input tensor **A**, and produce an output tensor **B** with the same dimensions.

The Activation layer supports the following operations:

```
rectified Linear Unit (ReLU): B = ReLU(A)
Hyperbolic tangent: B = tanh(A)
"s" shaped curve (sigmoid): B = σ(A)
```

Conditions And Limitations

None

Refer to the C++ class `IActivationLayer` or the Python class `IActivationLayer` for further details.

A.1.2. IConcatenationLayer

The `IConcatenationLayer` links together multiple tensors of the same non-channel sizes along the channel dimension.

Layer Description

The concatenation layer is passed in an array of m input tensors $\mathbf{A}^i$ and a channel axis c.

All dimensions of all input tensors must match in every axis except axis c. Let each input tensor have dimensions $\mathbf{a}^i$. The concatenated output tensor will have dimensions **b** such that

$$\mathbf{b}_j = \left\{ a_j \text{ if } j \neq c \text{ and } \sum_{i=0}^{m-1} a_c^i \text{ otherwise} \right\}.$$

Conditions And Limitations

The default channel axis is assumed to be the third from the last axis or the first non-batch axis if there are fewer than three non-batch axes. Concatenation cannot be done along the batch axis. All input tensors must be non-INT32 type, or all must be INT32 type.

Refer to the C++ class `IConcatenationLayer` or the Python class `IConcatenationLayer` for further details.

A.1.3. IConstantLayer

The `IConstantLayer` outputs a tensor with values provided as parameters to this layer, enabling the convenient use of constants in computations.

Layer Description

Given dimensions **d** and weight vector **w**, the constant layer will output a tensor **B** of dimensions **d** with the constant values in **w**. This layer takes no input tensor. The number of elements in the weight vector **w** is equal to the volume of **d**.

Conditions And Limitations

The output can be a tensor of zero to seven dimensions. Boolean weights are not supported.

Refer to the C++ class `IConstantLayer` or the Python class `IConstantLayer` for further details.

A.1.4. IConvolutionLayer

The `IConvolutionLayer` computes a 2D (channel, height, and width) convolution or 3D (channel, depth, height, and width) convolution, with or without bias.

Note: The operation that the `IConvolutionLayer` performs is actually a correlation. Therefore, it is a consideration if you are formatting weights to import via an API rather than via the NvCaffeParser library.

Layer Description: 2D convolution

Compute a cross-correlation with 2D filters on a 4D tensor **A**, of dimensions **a**, to produce a 4D tensor **B**, of dimensions **b**. The dimensions of **B** depend on the dimensions of **A**, the number of output maps m, kernel size **k**, symmetric padding **p**, stride **s**, dilation **d**, and dilated kernel size $\mathbf{t} = \mathbf{1} + \mathbf{d}(\mathbf{k} - \mathbf{1})$, such that height and width are adjusted accordingly as follows:

- $\mathbf{b} = [\mathbf{a}_0\ m\ \mathbf{b}_2\ \mathbf{b}_3]$
- $\mathbf{b}_2 = \left\lfloor (\mathbf{a}_2 + 2\mathbf{p}_0 - \mathbf{t}_0) / \mathbf{s}_0 \right\rfloor + 1$
- $\mathbf{b}_3 = \left\lfloor (\mathbf{a}_3 + 2\mathbf{p}_1 - \mathbf{t}_1) / \mathbf{s}_1 \right\rfloor + 1$

The kernel weights **w** and bias weights **x** (optional) for the number of groups g are such that:

- **w** is ordered according to shape $[m\ \mathbf{a}_1 / g\ \mathbf{r}_0\ \mathbf{r}_1]$
- **x** has length m

Let tensor **K** with dimensions $\mathbf{k} = [m\ \mathbf{a}_1 / g\ \mathbf{t}_0\ \mathbf{t}_1]$ be defined as the zero-filled tensor, such that:

- $\mathbf{k}_{i,\ j,\ \mathrm{hh},\ \mathrm{ll}} = \mathbf{w}_{i,\ j,\ h,\ l}$
- $\mathrm{hh} = \{0 \text{ if } h = 0,\ h + \mathbf{d_0}(h - 1) \text{ otherwise}\}$
- $\mathrm{ll} = \{0 \text{ if } l = 0,\ l + \mathbf{d_1}(l - 1) \text{ otherwise}\}$

and tensor **C** the zero-padded copy of **A** with dimensions $[\mathbf{a}_0\ \mathbf{a}_1\ \mathbf{a}_2 + \mathbf{p}_0\ \mathbf{a}_3 + \mathbf{p}_1]$, then tensor **B** is defined as $\mathbf{B}_{i,\ j,\ k,\ l} = \Sigma(\mathbf{C}_{i,\ :,\ \mathrm{k:kk},\ \mathrm{l:ll}} \times \mathbf{K}_{j,\ :,\ :,\ :}) + \mathbf{x}_j$ where $\mathrm{kk} = k + \mathbf{t}_0 - 1$ and $\mathrm{ll} = l + \mathbf{t}_1 - 1$.

Layer Description: 3D convolution

Compute a cross-correlation with 3D filters on a 5D tensor **A**, of dimensions **a**, to produce a 5D tensor **B**, of dimensions **b**. The dimensions of **B** depend on the dimensions of **A**, the number of output maps m, kernel size **k**, symmetric padding **p**, stride **s**, dilation **d**, and dilated kernel size $\mathbf{t} = \mathbf{1} + \mathbf{d}(\mathbf{k} - \mathbf{1})$, such that height and width are adjusted accordingly as follows:

- $\mathbf{b} = [\mathbf{a}_0\ m\ \mathbf{b}_2\ \mathbf{b}_3\ \mathbf{b}_4]$
- $\mathbf{b}_2 = (\mathbf{a}_2 + 2\mathbf{p}_0 - \mathbf{t}_0) / \mathbf{s}_0 + 1$

- $\mathbf{b}_3 = \left(\mathbf{a}_3 + 2\mathbf{p}_1 - \mathbf{t}_1\right) / \mathbf{s}_1 + 1$
- $\mathbf{b}_4 = \left(\mathbf{a}_4 + 2\mathbf{p}_2 - \mathbf{t}_2\right) / \mathbf{s}_1 + 1$

The kernel weights **w** and bias weights **x** (optional) for the number of groups g, are such that:

- **w** is ordered according to shape $\left[m\,\mathbf{a}_1 / g\,\mathbf{r}_0\,\mathbf{r}_1\,\mathbf{r}_2\right]$
- **x** has length m

Let tensor **K** with dimensions $\mathbf{k} = \left[m\,\mathbf{a}_1 / g\,\mathbf{t}_0\,\mathbf{t}_1\,\mathbf{t}_2\right]$ be defined as the zero-filled tensor, such that:

- $\mathbf{k}_{i,\,j,\,\mathrm{dd},\,\mathrm{hh},\,\mathrm{ll}} = \mathbf{w}_{i,\,j,\,d,\,h,\,l}$
- $\mathrm{dd} = \left\{0 \text{ if } d = 0,\ d + \mathbf{d_0}\left(d - 1\right) \text{otherwise}\right\}$
- $\mathrm{hh} = \left\{0 \text{ if } h = 0,\ h + \mathbf{d_1}\left(h - 1\right) \text{otherwise}\right\}$
- $\mathrm{ll} = \left\{0 \text{ if } l = 0,\ l + \mathbf{d_2}\left(l - 1\right) \text{otherwise}\right\}$

and tensor **C** the zero-padded copy of **A** with dimensions $\left[\mathbf{a}_0\,\mathbf{a}_1\,\mathbf{a}_2 + \mathbf{p}_0\,\mathbf{a}_3 + \mathbf{p}_1\,\mathbf{a}_4 + \mathbf{p}_2\right]$, then tensor **B** is defined as $\mathbf{B}_{i,\,j,\,d,\,k,\,l} = \Sigma\left(\mathbf{C}_{i,\,:,\,\mathrm{d:dd},\,\mathrm{k:kk},\,\mathrm{l:ll}} \times \mathbf{K}_{j,\,:,\,:,\,:}\right) + \mathbf{x}_j$ where $\mathrm{dd} = d + \mathbf{t}_0 - 1$, $\mathrm{kk} = k + \mathbf{t}_1 - 1$, and $\mathrm{ll} = l + \mathbf{t}_2 - 1$.

Conditions And Limitations

The number of input kernel dimensions determine 2D or 3D. For 2D convolution, input and output may have more than four dimensions; beyond four, all dimensions are treated as multipliers on the batch size, and input and output are treated as 4D tensors. For 3D convolution, similar to 2D convolution, if input or output has more than 5 dimensions, all dimensions beyond five are treated as multipliers on the batch size. If groups are specified and INT8 data type is used, then the size of the groups must be a multiple of four for both input and output.

Refer to the C++ class `IConvolutionLayer` or the Python class `IConvolutionLayer` for further details.

A.1.5. `IDeconvolutionLayer`

The `IDeconvolutionLayer` computes a 2D (channel, height, and width) or 3D (channel, depth, height and width) deconvolution, with or without bias.

Note: This layer actually applies a 2D/3D transposed convolution operator over a 2D/3D input. It is also known as fractionally-strided convolution or transposed convolution.

Layer Description: 2D deconvolution

Compute a cross-correlation with 2D filters on a 4D tensor **A**, of dimensions **a**, to produce a 4D tensor **B**, of dimensions **b**. The dimensions of **B** depend on the dimensions of **A**, the number of output maps m, kernel size **k**, symmetric padding **p**, stride **s**, dilation **d**, and dilated kernel size $\mathbf{t} = \mathbf{1} + \mathbf{d}(\mathbf{k} - \mathbf{1})$, such that height and width are adjusted accordingly as follows:

- $\mathbf{b} = [\mathbf{a}_0\ m\ \mathbf{b}_2\ \mathbf{b}_3]$
- $\mathbf{b}_2 = (\mathbf{a}_2 - 1) * \mathbf{s}_0 + t_0 - 2\mathbf{p}_0$
- $\mathbf{b}_3 = (\mathbf{a}_3 - 1) * \mathbf{s}_1 + t_1 - 2\mathbf{p}_1$

The kernel weights **w** and bias weights **x** (optional) for the number of groups g, are such that:

- **w** is ordered according to shape $[\mathbf{a}_1 / g\ m\ \mathbf{r}_0\ \mathbf{r}_1]$
- **x** has length m

Let tensor **K** with dimensions $\mathbf{k} = [m\ \mathbf{b}_1 / g\ \mathbf{t}_0\ \mathbf{t}_1]$ be defined as the zero-filled tensor, such that:

- $\mathbf{k}_{i,\ j,\ \mathrm{hh},\ \mathrm{ll}} = \mathbf{w}_{i,\ j,\ h,\ l}$
- $\mathrm{hh} = \{0 \text{ if } h = 0,\ h + \mathbf{d}_0(h - 1) \text{ otherwise}\}$
- $\mathrm{ll} = \{0 \text{ if } l = 0,\ l + \mathbf{d}_1(l - 1) \text{ otherwise}\}$

and tensor **C** the zero-padded copy of **A** with dimensions $[\mathbf{a}_0\ \mathbf{a}_1\ \mathbf{a}_2 + \mathbf{p}_0\ \mathbf{a}_3 + \mathbf{p}_1]$, then tensor **B** is defined as $\mathbf{B}_{i,\ j,\ k,\ l} = \Sigma_{u,\ v}(\mathbf{C}_{i,\ \mathrm{j},\ \mathrm{k\text{-}u},\ \mathrm{l\text{-}v}}\ \mathbf{K}) + \mathbf{x}_j$ where u ranges from 0 to $\min(\mathbf{t}_0 - 1,\ k)$, and v ranges from 0 to $\min(\mathbf{t}_1 - 1,\ l)$.

Layer Description: 3D deconvolution

Compute a cross-correlation with 3D filters on a 5D tensor **A**, of dimensions **a**, to produce a 5D tensor **B**, of dimensions **b**. The dimensions of **B** depend on the dimensions of **A**, the number of output maps m, kernel size **k**, symmetric padding **p**, stride **s**, dilation **d**, and dilated kernel size $\mathbf{t} = \mathbf{1} + \mathbf{d}(\mathbf{k} - \mathbf{1})$, such that height and width are adjusted accordingly as follows:

- $\mathbf{b} = [\mathbf{a}_0\ m\ \mathbf{b}_2\ \mathbf{b}_3]$
- $\mathbf{b}_2 = (\mathbf{a}_2 - 1) * \mathbf{s}_0 + t_0 - 2\mathbf{p}_0$
- $\mathbf{b}_3 = (\mathbf{a}_3 - 1) * \mathbf{s}_1 + t_1 - 2\mathbf{p}_1$
- $\mathbf{b}_4 = (\mathbf{a}_4 - 1) * \mathbf{s}_2 + t_2 - 2\mathbf{p}_2$

The kernel weights **w** and bias weights **x** (optional) for the number of groups g, are such that:

- **w** is ordered according to shape $[\mathbf{a}_1 / g\ m\ \mathbf{r}_0\ \mathbf{r}_1\ \mathbf{r}_2]$

- **x** has length m

Let tensor **K** with dimensions $\mathbf{k} = [m\,\mathbf{b}_1 / g\,\mathbf{t}_0\,\mathbf{t}_1\,\mathbf{t}_2]$ be defined as the zero-filled tensor, such that:

- $\mathbf{k}_{i,\,j,\,\mathrm{dd},\,\mathrm{hh},\,\mathrm{ll}} = \mathbf{w}_{i,\,j,\,d,\,h,\,l}$
- $\mathrm{dd} = \{0 \text{ if } d = 0,\ d + \mathbf{d_0}(d - 1) \text{ otherwise}\}$
- $\mathrm{hh} = \{0 \text{ if } h = 0,\ h + \mathbf{d_1}(h - 1) \text{ otherwise}\}$
- $\mathrm{ll} = \{0 \text{ if } l = 0,\ l + \mathbf{d_2}(l - 1) \text{ otherwise}\}$

and tensor **C** the zero-padded copy of **A** with dimensions $[\mathbf{a}_0\,\mathbf{a}_1\,\mathbf{a}_2 + \mathbf{p}_0\,\mathbf{a}_3 + \mathbf{p}_1\,\mathbf{a}_4 + \mathbf{p}_2]$, then tensor **B** is defined as $\mathbf{B}_{i,\,j,\,k,\,l,\,m} = \Sigma_{u,\,v,\,w}(\mathbf{C}_{i,\,\mathrm{j},\,\mathrm{k\text{-}u},\,\mathrm{l\text{-}v},\,\mathrm{m\text{-}w}}\,\mathbf{K}) + \mathbf{x}_j$ where u ranges from 0 to $\min(\mathbf{t}_0 - 1,\ k)$, and v ranges from 0 to $\min(\mathbf{t}_1 - 1,\ l)$, and w ranges from 0 to $\min(\mathbf{t}_2 - 1,\ m)$.

Conditions And Limitations

2D or 3D is determined by the number of input kernel dimensions. For 2D deconvolution, input and output may have more than 4 dimensions; beyond 4, all dimensions are treated as multipliers on the batch size, and input and output are treated as 4D tensors. For 3D deconvolution, similar to 2D deconvolution, dimensions beyond 5 are treated as multipliers on the batch size. If groups are specified and INT8 data type is used, then the size of the groups must be a multiple of 4 for both input and output.

Refer to the C++ class `IDeconvolutionLayer` or the Python class `IDeconvolutionLayer` for further details.

A.1.6. `IDequantizeLayer`

The `IDequantizeLayer` implements dequantization operators.

Layer Description

The `IDequantizeLayer` layer accepts a signed 8-bit integer input tensor, and uses the configured scale and zero-point inputs to dequantize the input according to:

```
output = (input - zeroPt) * scale
```

The first input (`index 0`) is the tensor to be quantized. The second input (`index 1`), and third input (`index 2`), are the scale and zero-point respectively.

Refer to the C++ class `IDequantizeLayer` or the Python class `IDequantizeLayer` for further details.

A.1.7. `IElementWiseLayer`

The `IElementWiseLayer`, also known as the Eltwise layer, implements per-element operations.

Layer Description

This layer computes a per-element binary operation between input tensor **A** and input tensor **B** to produce an output tensor **C**. For each dimension, their lengths must match, or one of them must be one. In the latter case, the tensor is broadcast along that axis. The output tensor has the same number of dimensions as the inputs. The output tensor has the same number of dimensions as the inputs. For each output dimension, its length is equal to the lengths of the corresponding input dimensions if they match; otherwise, it is equal to the corresponding input dimension that is not one.

The `IElementWiseLayer` supports the following operations:

```
Sum: C = A+B
Product: C = A*B
Minimum: C = min(A, B)
Maximum: C = max(A, B)
Subtraction: C = A-B
Division: C = A/B
Power: C = A^B
Floor division : C = floor(A/B)
And : C = A & B
Or : C = A | B
Xor : C = A xor B
Equal : C = (A == B)
Greater : C = A > B
Less: C = A < B
```

Conditions And Limitations

The length of each dimension of the two input tensors **A** and **B** must be equal or equal to one.

Refer to the C++ class `IElementWiseLayer` or the Python class `IElementWiseLayer` for further details.

A.1.7.1. ElementWise Layer Setup

The ElementWise layer is used to execute the second step of the functionality provided by a FullyConnected layer. The output of the `fcbias` Constant layer and Matrix Multiplication layer are used as inputs to the ElementWise layer. The output from this layer is then supplied to the TopK layer. The code below demonstrates how to setup the layer:

```
auto fcbias = network->addConstant(Dims2(VOCAB_SIZE, 1), weightMap[FCB_NAME]);
auto addBiasLayer = network->addElementWise(
*matrixMultLayer->getOutput(0),
*fcbias->getOutput(0), ElementWiseOperation::kSUM);
assert(addBiasLayer != nullptr);
addBiasLayer->getOutput(0)->setName("Add Bias output");
```

For more information, refer to the TensorRT API documentation.

A.1.8. `IFillLayer`

The `IFillLayer` is used to generate an output tensor with the specified mode.

Layer Description

Given an output tensor size, the layer will generate data with the specified mode and fill the tensor. The alpha and beta perform as different parameters for different modes.

The `IFillLayer` supports the following operations:

- `LINSPACE`: Output = `alpha(scalar) + beta(different on each axis) * element_index`
- `RANDOM_UNIFORM`: Output = `Random(min = alpha, max = beta)`

Conditions And Limitations

The layer can only generate a 1D tensor if using static tensor size. When using the dynamic tensor size, the dimensions for alpha and beta should match each mode's requirement.

Refer to the C++ class `IFillLayer` or the Python class `IFillLayer` for further details.

A.1.9. `IFullyConnectedLayer`

The `IFullyConnectedLayer` implements a matrix-vector product, with or without bias.

Layer Description

The `IFullyConnectedLayer` expects an input tensor **A** of three or more dimensions. Given an input tensor **A** of dimensions $\mathbf{a} = [\mathbf{a}_0 \ldots \mathbf{a}_{n\text{-}1}]$, it is first reshaped into a tensor **A'** of dimensions $\mathbf{a}' = [\mathbf{a}_0 \ldots \mathbf{a}_{n\text{-}4} (\mathbf{a}_{n\text{-}3} * \mathbf{a}_{n\text{-}2} * \mathbf{a}_{n\text{-}1})]$ by squeezing the last three dimensions into one dimension.

Then, the layer performs the operation $\mathbf{B}' = \mathbf{W}\mathbf{A}' + \mathbf{X}$ where **W** is the weight tensor of dimensions $\mathbf{w} = [(\mathbf{a}_{n\text{-}3} * \mathbf{a}_{n\text{-}2} * \mathbf{a}_{n\text{-}1})\, k]$, **X** is the bias tensor of dimensions $\mathbf{x} = (k)$ broadcasted along the other dimensions, and k is the number of output channels, configured via `setNbOutputChannels()`. If **X** is not specified, the value of the bias is implicitly `0`. The resulting **B'** is a tensor of dimensions $\mathbf{b}' = [\mathbf{a}_0 \ldots \mathbf{a}_{n\text{-}4}\, k]$.

Finally, **B'** is reshaped again into the output tensor **B** of dimensions $\mathbf{b} = [\mathbf{a}_0 \ldots \mathbf{a}_{n\text{-}4}\, k\, 1\, 1]$ by inserting two lower dimensions each of size `1`.

In summary, for input tensor **A** of dimensions $\mathbf{a} = [\mathbf{a}_0 \ldots \mathbf{a}_{n\text{-}1}]$, the output tensor **B** will have dimensions $\mathbf{b} = [\mathbf{a}_0 \ldots \mathbf{a}_{n\text{-}4}\, k\, 1\, 1]$.

Conditions And Limitations

A must have three dimensions or more.

Refer to the C++ class `IFullyConnectedLayer` or the Python class `IFullyConnectedLayer` for further details.

A.1.10. IGatherLayer

The `IGatherLayer` implements the `gather` operation on a given axis.

Layer Description

The `IGatherLayer` gathers elements of each data tensor **A** along the specified axis *x* using indices tensor **B** of zero dimensions or more dimensions to produce output tensor **C** of dimensions **c**.

If **B** has zero dimensions and it is a scalar *b*, then $\mathbf{c_k} = \{\mathbf{a}_k \text{ if } k < x, \text{ and } \mathbf{a}_{k+1} \text{ if } k < x\}$ and **c** has a length equal to one less than the length of **a**. In this case, $\mathbf{C}_i = \mathbf{A}_j$ where $\mathbf{j}_k = \{b \text{ if } k = x, \ \mathbf{i}_k \text{ if } k < x, \text{ and } \mathbf{i}_{k\text{-}1} \text{ if } k > x\}$.

If **B** is a tensor of dimensions **b** (with length *b*), then $\mathbf{c}_k = \{\mathbf{a}_k \text{ if } k < x, \ \mathbf{b}_{k\text{-}x} \text{ if } k \geq x \text{ and } k < x + b, \text{ and } \mathbf{a}_{k\text{-}b+1} \text{ otherwise}\}$. In this case, $\mathbf{C}_i = \mathbf{A}_j$ where $\mathbf{j}_k = \{\mathbf{B}_{X(i)} \text{ if } k = x, \ \mathbf{i}_k \text{ if } k < x, \text{ and } \mathbf{i}_{k\text{-}b} \text{ if } k > x\}$ and $X(\mathbf{i}) = \mathbf{i}_{x, .., x+b\text{-}1}$.

Conditions And Limitations

- The indices tensor **B** must contain only INT32 values.
- If there are any invalid indices elements in the indices tensor, then zeros will be stored at the appropriate locations in the output tensor.

Applicable to implicit batch mode:

- Elements cannot be gathered along the batch size dimension.
- The data tensor **A** must contain at least one non-batch dimension.
- The data tensor **A** must contain at least `axis` + 1 non-batch dimensions.
- The parameter `axis` is zero-indexed and starts at the first non-batch dimension of data tensor **A**.

Applicable to explicit batch mode:

- The data tensor **A** must contain at least one dimension.
- The data tensor **A** must contain at least `axis` + 1 dimensions.
- The parameter axis is zero-indexed and starts at the first dimension of data tensor **A**.
- `axis` must be larger than or equal to the number of element-wise dimensions set by `IGatherLayer::setNbElementWiseDimensions()`.
- The number of ElementWise dimensions can only be set to 0 or 1.
- If the number of ElementWise dimensions is set to 1, the behavior will be similar to implicit batch mode. The leading dimension will be treated like batch dimension in implicit batch mode, which is not part of the gather operation. For example, data tensor **A** has dimensions of `[N, C, H, W]`, and indices tensor **B** has the dimensions of `[N, K]`. If

`nbElementWiseDimensions` is 1 and the *axis* is set to 1, the dimensions of the result will be `[N, K, H, W]`. If `nbElementWiseDimensions` is 0 and the `axis` is set to 1, the dimensions of the result will be `[N, N, K, H, W]`.

- ElementWise dimensions support broadcasts like `IElementWiseLayer`.

Refer to the C++ class `IGatherLayer` or the Python class `IGatherLayer` for further details.

A.1.11. `IIdentityLayer`

The `IIdentityLayer` implements the identity operation.

Layer Description

The output of the layer is mathematically identical to the input. This layer allows you to precisely control the precision of tensors and transform from one precision to another. If the input is at a different precision than the output, the layer will convert the input tensor into the output precision.

Conditions And Limitations

None

Refer to the C++ class `IIdentityLayer` or the Python class `IIdentityLayer` for further details.

A.1.12. `IIteratorLayer`

The `IIteratorLayer` enables a loop to iterate over a tensor. A loop is defined by *loop boundary layers*.

For more information about the `IIteratorLayer`, including how loops work and their limitations, refer to Working With Loops.

Refer to the C++ class `IIteratorLayer` or the Python class `IIteratorLayer` for further details.

A.1.13. `ILoopBoundaryLayer`

Class `ILoopBoundaryLayer`, derived from class `ILayer`, is the base class for the loop-related layers, specifically `ITripLimitLayer`, `ILoopIteratorLayer`, `IRecurrenceLayer`, and `ILoopOutputLayer`. Class `ILoopBoundaryLayer` defines a virtual method `getLoop()` that returns a pointer to the associated `ILoop`.

For more information about the `ILoopBoundaryLayer`, including how loops work and their limitations, refer to Working With Loops.

Refer to the C++ class `ILoopBoundaryLayer` or the Python class `ILoopBoundaryLayer` for further details.

A.1.14. ILoopOutputLayer

The `ILoopOutputLayer` specifies an output from the loop. A loop is defined by *loop boundary layers*.

For more information about the `ILoopOutputLayer`, including how loops work and their limitations, refer to Working With Loops.

Refer to the C++ class `ILoopOutputLayer` or the Python class `ILoopOutputLayer` for further details.

A.1.15. ILRNLayer

The `ILRNLayer` implements cross-channel Local Response Normalization (LRN).

Layer Description

Given an input **A**, the LRN layer performs a cross-channel LRN to produce output **B**of the same dimensions. The operation of this layer depends on four constant values: w is the size of the cross-channel window over which the normalization will occur, α, β, and k are normalization parameters. This formula shows the operation performed by the layer:

$$\mathbf{B}_I = \frac{A_I}{\left(k + \mathrm{aA}_{j(I)}{}^2\right)\beta}$$

Where I represents the indexes of tensor elements, and $j(I)$ the indices where the channel dimension is replaced by j. For channel index c of C channels, index j ranges from $\max(0,\ c-w)$ and $\min(C-1,\ c+w)$.

Conditions And Limitations

A must have three or more dimensions. The following list shows the possible values for the parameters:

$$W \in \{1,\ 3,\ 5,\ 7,\ 9,\ 11,\ 13,\ 15\}$$
$$\alpha \in [-1 \times 10^{20},\ 1 \times 10^{20}]$$
$$\beta \in [0.01,\ 1 \times 10^{5}]$$
$$k \in [1 \times 10^{-5},\ 1 \times 10^{10}]$$

Refer to the C++ class `ILRNLayer` or the Python class `ILRNLayer` for further details.

A.1.16. IMatrixMultiplyLayer

The `IMatrixMultiplyLayer` implements matrix multiplication for a collection of matrices.

Layer Description

The `IMatrixMultiplyLayer` computes the matrix multiplication of input tensors **A**, of dimensions **a**, and **B**, of dimensions **b**, and produces output tensor C, of dimensions **c**. **A**, **B**, and **C** all have the same rank $n \geq 2$. If $n > 2$, then **A**, **B**, and **C** are treated as collections

of matrices; **A** and **B** may be optionally transposed (the transpose is applied to the last two dimensions). Let $\mathbf{A}^I$ and $\mathbf{B}^I$ be the input tensors after the optional transpose, then $\mathbf{C}_{i0,..,\text{in-3},:,:} = \mathbf{A}^I_{i0,..,\text{in-3},:,:} * \mathbf{B}^I_{i0,..,\text{in-3},:,:}$

Given the corresponding dimensions $\mathbf{a}^I$ and $\mathbf{b}^I$ of $\mathbf{A}^I$ and $\mathbf{B}^I$, then $\mathbf{C}_i = \left\{\max\left(\mathbf{a}_i, \mathbf{b}_i\right) \text{ if } i < n-2,\ \mathbf{a}^I_i \text{ if } i = n-2, \text{ and } \mathbf{b}^I_i \text{ if } i = n-1\right\}$; that is, the resulting collection has the same number of matrices as the input collections, and the rows and columns correspond to the rows in $\mathbf{A}^I$ and the columns in $\mathbf{B}^I$. Notice also the use of max in lengths, for the case of broadcast on a dimension.

Conditions And Limitations

Tensors `A` and `B` must have at least two dimensions and agree on the number of dimensions. The length of each dimension must be the same, assuming that dimensions of length one are broadcast to match the corresponding length.

Refer to the C++ class `IMatrixMultiplyLayer` or the Python class `IMatrixMultiplyLayer` for further details.

A.1.16.1. MatrixMultiply Layer Setup

The Matrix Multiplication layer is used to execute the first step of the functionality provided by a FullyConnected layer. As shown in the code below, a Constant layer will need to be used so that the FullyConnected weights can be stored in the engine. The output of the Constant and RNN layers are then used as inputs to the Matrix Multiplication layer. The RNN output is transposed so that the dimensions for the MatrixMultiply are valid.

```
weightMap["trt_fcw"] = transposeFCWeights(weightMap[FCW_NAME]);
auto fcwts = network->addConstant(Dims2(VOCAB_SIZE, HIDDEN_SIZE), weightMap["trt_fcw"]);
auto matrixMultLayer = network->addMatrixMultiply(
*fcwts->getOutput(0), false, *rnn->getOutput(0), true);
assert(matrixMultLayer != nullptr);
matrixMultLayer->getOutput(0)->setName("Matrix Multiplication output");
```

For more information, refer to the TensorRT API documentation.

A.1.17. `IParametricReluLayer`

The `IParametricReluLayer` represents a parametric ReLU operation, meaning a leaky ReLU where the slopes for `x < 0` can be different for each element.

Layer Description

Users provide a data tensor **X** and a slopes tensor **S**. At each element, the layer computes `y = x` if `x ≥ 0` and `y = x*s` if `x < 0`. The slopes tensor may be broadcast to the size of the data tensor and vice versa.

Conditions And Limitations

Parametric ReLU is not supported in many fusions; therefore, the performance may be worse than with standard ReLU.

Refer to the C++ class `IParametricReluLayer` or the Python class `IParametricReluLayer` for further details.

A.1.18. `IPaddingLayer`

The `IPaddingLayer` implements spatial zero-padding of tensors along the two innermost dimensions.

Layer Description

The `IPaddingLayer` pads zeros to (or trims edges from) an input tensor **A** along each of the two innermost dimensions and gives the output tensor **B**. Padding can be different on each dimension, asymmetric, and can be either positive (resulting in expansion of the tensor) or negative (resulting in trimming). Padding at the beginning and end of the two dimensions is specified by 2D vectors **x** and **y** for pre and post padding respectively.

For input tensor **A** of n dimensions **a,** the output **B** will have n dimensions **b** such that $\mathbf{b}_i = \left\{\mathbf{x}_0 + \mathbf{a}_{n\text{-}2} + \mathbf{y}_0 \text{ if } i = n\text{-}2;\ \mathbf{x}_1 + \mathbf{a}_{n\text{-}1} + \mathbf{y}_1 \text{ if } i = n\text{-}1;\ \textbf{and } \mathbf{a}_i \text{ otherwise}\right\}$. Accordingly, the values of $\mathbf{B_w}$ are zeros if $\mathbf{w}_{n\text{-}2} < \mathbf{x}_0 \text{ or } \mathbf{x}_0 + a_{n\text{-}2} \le \mathbf{w}_{n\text{-}2} \text{ or } \mathbf{w}_{n\text{-}1} < \mathbf{x}_1 \text{ or } \mathbf{x}_1 + \mathbf{a}_{n\text{-}2} \le \mathbf{w}_{n\text{-}1}$. Otherwise, $\mathbf{B}_w = \mathbf{A}_z$ where $\mathbf{z}_{n\text{-}2} = \mathbf{w}_{n\text{-}2} + \mathbf{x}_0$, $\mathbf{z}_{n\text{-}1} = \mathbf{w}_{n\text{-}1} + \mathbf{x}_1$ and $\mathbf{z}_i = \mathbf{w}_i$ for all other dimensions i.

Conditions And Limitations

- **A** must have three dimensions or more.
- The padding can only be applied along the two innermost dimensions.
- Only zero-padding is supported.

Refer to the C++ class `IPaddingLayer` or the Python class `IPaddingLayer` for further details.

A.1.19. `IPluginV2Layer`

The `IPluginV2Layer` provides the ability to extend the functionalities of TensorRT by using custom implementations for unsupported layers.

Layer Description

The `IPluginV2Layer` is used to set up and configure the plugin. Refer to the IPluginV2 API Description for more details on the API. TensorRT also has support for a Plugin Registry, which is a single registration point for all plugins in the network. In order to register plugins with the registry, implement the `IPluginV2` class and the `IPluginCreator` class for your plugin.

Conditions And Limitations

None

Refer to the C++ class `IPluginV2Layer` or the Python class `IPluginV2Layer` for further details.

A.1.20. `IPoolingLayer`

The `IPoolingLayer` implements pooling within a channel. Supported pooling types are `maximum`, `average`, and `maximum-average blend`.

Layer Description: 2D pooling

Compute a pooling with 2D filters on a tensor **A**, of dimensions **a**, to produce a tensor **B**, of dimensions **b**. The dimensions of **B** depend on the dimensions of **A**, window size **r**, symmetric padding **p** and stride **s** such that:

- $\mathbf{b} = [\mathbf{a_0}\, \mathbf{a}_1 \ldots \mathbf{a}_{n-3}\, \mathbf{b}_{n-2}\, \mathbf{b}_{n-1}]$
- $\mathbf{b}_{n-2} = \left(\mathbf{a}_{n-2} + 2\mathbf{p}_0 + \mathbf{r}_0\right) / \mathbf{s}_0 + 1$
- $\mathbf{b}_{n-1} = \left(\mathbf{a}_{n-1} + 2\mathbf{p}_1 + \mathbf{r}_1\right) / \mathbf{s}_1 + 1$

Let tensor **C** be the zero-padded copy of **A** with dimensions $\left[\mathbf{a}_0\, \mathbf{a}_1 \ldots \mathbf{a}_{n-2} + 2\mathbf{p}_0\, \mathbf{a}_{n-1} + 2\mathbf{p}_1\right]$ then, $\mathbf{B}_{j,\ldots,kl} = \mathbf{func}\left(\mathbf{C}_{j,\ldots,kkk\,lll}\right)$ where $kk = k + \mathbf{r}_0 - 1$ and $ll = l + \mathbf{r}_1 - 1$.

Where **func** is defined by one of the pooling types **t**:

`PoolingType::kMAX`
Maximum over elements in window.

`PoolingType::kAVERAGE`
Average over elements in the window.

`PoolingType::kMAX_AVERAGE_BLEND`
Hybrid of maximum and average pooling. The results of the maximum pooling and the average pooling are combined with the blending factor as `(1-blendFactor)*maximumPoolingResult + blendFactor*averagePoolingResult` to yield the result. The **blendFactor** can be set to a value between 0 and 1.

By default, average pooling is performed on the overlap between the pooling window and the padded input. If the **exclusive** parameter is set to **true**, the average pooling is performed on the overlap area between the pooling window and unpadded input.

Layer Description: 3D pooling

Compute a pooling with 3D filters on a tensor **A**, of dimensions **a**, to produce a tensor **B**, of dimensions **b**. The dimensions of **B** depend on the dimensions of **A**, window size **r**, symmetric padding **p** and stride **s** such that:

- $\mathbf{b} = [\mathbf{a_0}\, \mathbf{a}_1 \ldots \mathbf{a}_{n-4}\, \mathbf{b}_{n-3}\, \mathbf{b}_{n-2}\, \mathbf{b}_{n-1}]$
- $\mathbf{b}_{n-3} = \left(\mathbf{a}_{n-3} + 2\mathbf{p}_0 + \mathbf{r}_0\right) / \mathbf{s}_0 + 1$
- $\mathbf{b}_{n-2} = \left(\mathbf{a}_{n-2} + 2\mathbf{p}_1 + \mathbf{r}_1\right) / \mathbf{s}_1 + 1$
- $\mathbf{b}_{n-1} = \left(\mathbf{a}_{n-1} + 2\mathbf{p}_2 + \mathbf{r}_2\right) / \mathbf{s}_2 + 1$

Let tensor **C** be the zero-padded copy of **A** with dimensions $\left[\mathbf{a}_0\,\mathbf{a}_1 \ldots \mathbf{a}_{n-3} + 2\mathbf{p}_0\,\mathbf{a}_{n-2} + 2\mathbf{p}_1\,\mathbf{a}_{n-1} + 2\mathbf{p}_2\right]$ then, $\mathbf{B}_{j\ldots\ldots klm} = \mathbf{func}\left(\mathbf{C}_{j\ldots.\,kkk\,lll\,mmm}\right)$ where $kk = k + \mathbf{r}_0 - 1$, $ll = l + \mathbf{r}_1 - 1$, and $mm = m + \mathbf{r}_2 - 1$.

Where **func** is defined by one of the pooling types **t**:

`PoolingType::kMAX`
Maximum over elements in window.

`PoolingType::kAVERAGE`
Average over elements in the window.

`PoolingType::kMAX_AVERAGE_BLEND`
Hybrid of maximum and average pooling. The results of the maximum pooling and the average pooling are combined with the blending factor as `(1-blendFactor)*maximumPoolingResult + blendFactor*averagePoolingResult` to yield the result. The **blendFactor** can be set to a value between 0 and 1.

By default, average pooling is performed on the overlap between the pooling window and the padded input. If the **exclusive** parameter is set to **true**, the average pooling is performed on the overlap area between the pooling window and unpadded input.

Conditions And Limitations

The number of input kernel dimensions determine 2D or 3D. For 2D pooling, input and output tensors should have three or more dimensions. For 3D pooling, input and output tensors should have four or more dimensions.

Refer to the C++ class `IPoolingLayer` or the Python class `IPoolingLayer` for further details.

A.1.21. `IQuantizeLayer`

This `IQuantizeLayer` layer implements quantization operators.

Layer Description

The `IQuantizeLayer` layer accepts a floating-point data input tensor and uses the scale and zero-point inputs to quantize the data to an 8-bit signed integer according to:

```
output = clamp(round(input / scale) +  zeroPt)
```

Rounding type is rounding-to-nearest ties-to-even. Clamping is in the range `[-128, 127]`. The first input (`index 0`) is the tensor to be quantized. The second (`index 1`) and third (`index 2`) are the scale and zero-point respectively.

Refer to the C++ class `IQuantizeLayer` or the Python class `IQuantizeLayer` for further details.

A.1.22. `IRaggedSoftMaxLayer`

The `IRaggedSoftMaxLayer` applies the SoftMax function on an input tensor of sequences across the sequence lengths specified by the user.

Layer Description

This layer has two inputs: a 2D input tensor **A** of shape `zs` containing `z` sequences of data and a 1D bounds tensor **B** of shape `z` containing the lengths of each of the `z` sequences in **A**. The resulting output tensor **C** has the same dimensions as the input tensor **A**.

The SoftMax function `S` is defined on every `i` of the `z` sequences of data values $A_{i,0:\mathrm{Bi}}$ like in the SoftMax layer.

Conditions And Limitations

None

Refer to the C++ class `IRaggedSoftMaxLayer` or the Python class `IRaggedSoftMaxLayer` for further details.

A.1.23. `IRecurrenceLayer`

The `IRecurrenceLayer` specifies a recurrent definition. A loop is defined by *loop boundary layers*.

For more information about the `IRecurrenceLayer`, including how loops work and their limitations, refer to Working With Loops.

Refer to the C++ class `IRecurrenceLayer` or the Python class `IRecurrenceLayer` for further details.

A.1.24. `IReduceLayer`

The `IReduceLayer` implements dimension reduction of tensors using reduce operators.

Layer Description

The `IReduceLayer` computes a reduction of input tensor **A**, of dimensions **a**, to produce an output tensor **B**, of dimensions **b**, over the set of reduction dimensions **r**. The reduction operator op is one of *`max`*, *`min`*, *`product`*, *`sum`*, and *`average`*. The reduction can preserve the number of dimensions of **A** or not. If the dimensions are kept, then $\mathbf{b}_i = \{1 \text{ if } i \in \mathbf{r}, \text{ and } \mathbf{a}_i \text{ otherwise}\}$; if the dimensions are not kept, then $\mathbf{b}_{j\text{-}m(j)} = \mathbf{a}_j$ where $j \in \mathbf{r}$ and $m(j)$ is the number of reduction indexes in **r** less than or equal to *`j`*.

With the sequence of indexes **i**, $\mathbf{B}_i = \mathrm{op}(\mathbf{A}_j)$, where the sequence of indexes **j** is such that $\mathbf{j}_k = \{: \text{ if } k \in \mathbf{r}, \text{ and } \mathbf{i}_k \text{ otherwise}\}$.

Conditions And Limitations

The input must have at least one non-batch dimension. The batch size dimension cannot be reduced.

Refer to the C++ class `IReduceLayer` or the Python class `IReduceLayer` for further details.

A.1.25. IResizeLayer

The IResizeLayer implements the resize operation on an input tensor.

Layer Description

The IResizeLayer resizes input tensor A, of dimension a, to produce an output tensor B, of dimension b, using a given resize mode m. Output dimension b can either be provided directly or can be computed using resize scales s. If resize scales s are provided, $\text{bi} = \{\text{floor}(\text{ai} * \text{si})\}$.

Interpolation modes such as Nearest and Linear are supported for the resize operation. The nearest mode resizes innermost d dimensions of N-D tensors, where $d \epsilon (0, \min(8, N))$ and N > 0. The linear mode resizes innermost d dimensions of N-D tensors, where $d \epsilon (0, \min(3, N))$ and N > 0.

The coordinate transformation mapping function, while interpolating, can be configured to align corners, asymmetric and half pixel. When resized to a single pixel, we support using either the coordinate transformation or using the upper left pixel. When resize mode is Nearest, we support different rounding modes like half down, half up, round to floor, and round to ceiling.

Conditions And Limitations

Either output dimension b or resize scales s must be known and valid. Number of scales must be equal to the number of input dimensions. Number of output dimensions must be equal to the number of input dimensions.

Refer to the C++ class IResizeLayer or the Python class IResizeLayer for further details.

A.1.26. IRNNv2Layer

The IRNNv2Layer implements recurrent layers such as Recurrent Neural Network (RNN), Gated Recurrent Units (GRU), and Long Short-Term Memory (LSTM). Supported types are RNN, GRU, and LSTM. It performs a recurrent operation, where the operation is defined by one of several well-known recurrent neural network (RNN) "cells."

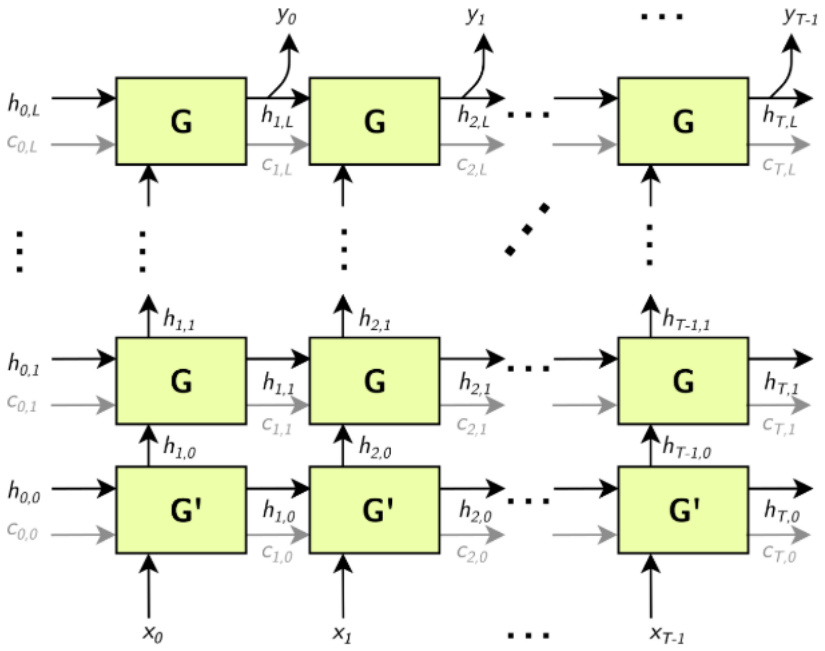
Note: The IRNNv2Layer is deprecated in favor of the loop API; however, it is still available for backward compatibility. For more information about the loop API, refer to the sampleCharRNN sample with the --Iloop option.

Layer Description

This layer accepts an input sequence **X**, initial hidden state $\mathbf{H}_0$, and if the cell is a long short-term memory (LSTM) cell, initial cell state $\mathbf{C}_0$, and produces an output **Y** which represents the output of the final RNN "sub-layer" computed across T timesteps (refer below). Optionally, the layer can also produce an output $\mathbf{h}_T$ representing the final hidden state, and, if the cell is an LSTM cell, an output $\mathbf{c}_T$ representing the final cell state.

Let the operation of the cell be defined as the function $\mathbf{G}(\mathbf{x}, \mathbf{h}, \mathbf{c})$. This function takes vector inputs **x**, **h**, and **c**, and produces up to two vector outputs **h'** and **c'**, representing the hidden and cell state after the cell operation has been performed.

In the default (unidirectional) configuration, the RNNv2 layer applies **G**as shown in the following diagram:



G' is a variant of **G**, .

Arrows leading into boxes are function inputs, and arrows leading away from boxes are function outputs.

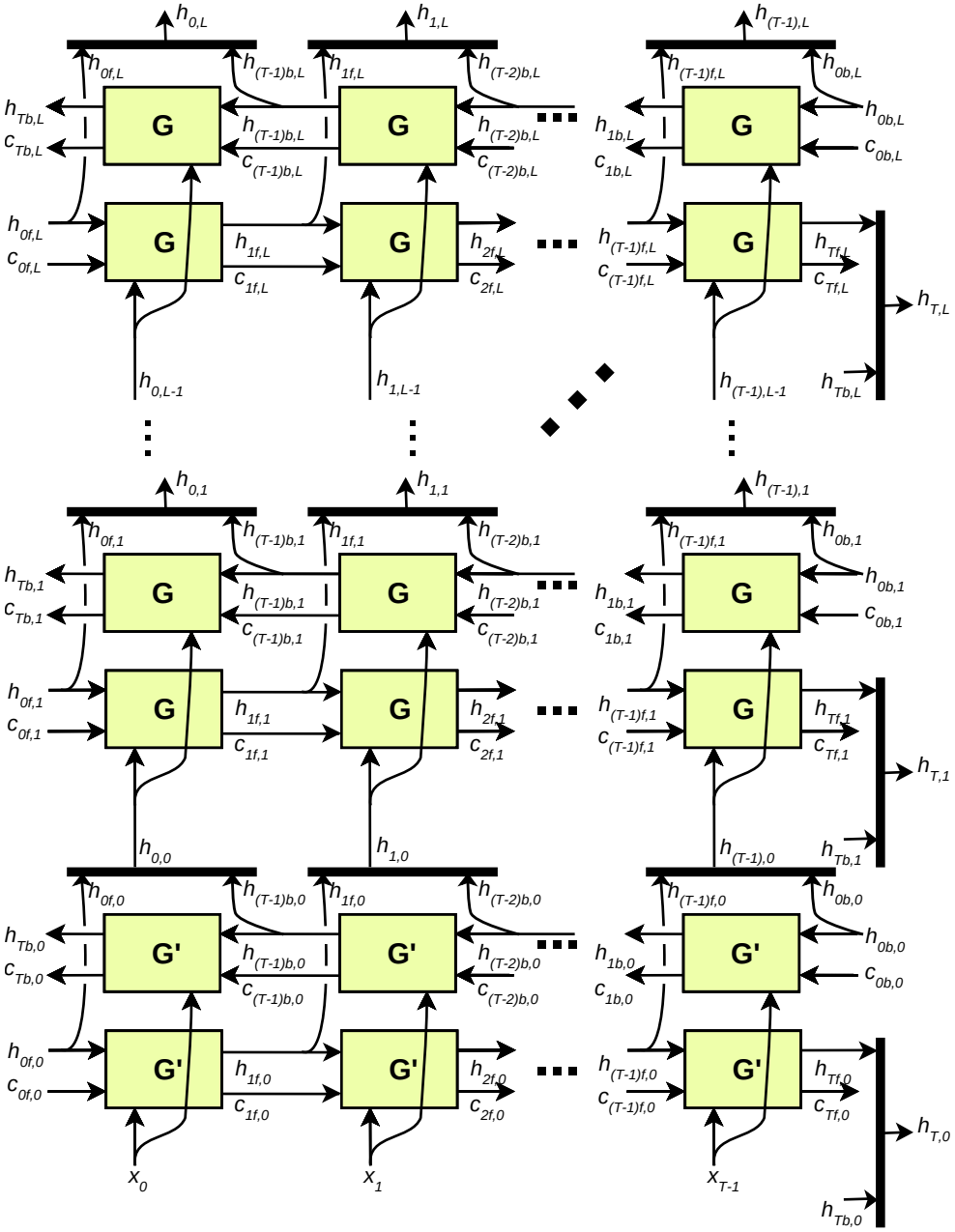
- $\mathbf{X} = [\mathbf{x}_0, \mathbf{x}_1, ..., \mathbf{x}_T]$
- $\mathbf{Y} = [\mathbf{y}_0, \mathbf{y}_1, ..., \mathbf{y}_T]$
- $\mathbf{H_i} = [\mathbf{h}_{i,0}, \mathbf{h}_{i,1}, ..., \mathbf{h}_{i,L}]$
- $\mathbf{C_i} = [\mathbf{c}_{i,0}, \mathbf{c}_{i,1}, ..., \mathbf{c}_{i,L}]$

The gray c edges are only present if the RNN is using LSTM cells for **G** and **G'**.

> **Note:** The above construction has L "sub-layers" (horizontal rows of **G**), and the matrices $\mathbf{H_i}$ and $\mathbf{C_i}$ have dimensionality L.

Optionally, the sequence length Tmay be specified as an input to the RNNv2 layer, allowing the client to specify a batch of input sequences with different lengths.

Bidirectional RNNs (BiRNNs): The RNN can be configured to be bidirectional. In that case, each sub-layer consists of a "forward" layer and a "backward" layer. The forward layer iteratively applies **G** using x_i from 0 to T, and the backward layer iteratively applies **G** using x_i from T to 0, as shown in the diagram below:



Black bars in the diagram above represent concatenation. The full hidden state $\mathbf{h}_t$ is defined by the concatenation of the forward hidden state $\mathbf{h_{tf}}$ and the backward hidden state $\mathbf{h_{tb}}$:

- $\mathbf{h}_{t,i} = \left[h_{\mathrm{tf},i},\ h_{\mathrm{tb},i}\right]$
- $\mathbf{h_t} = \left[\mathbf{h}_{t,0},\ \mathbf{h}_{t,1},\ \ldots,\ \mathbf{h}_{t,L}\right]$

Similarly, for the cell state (not shown), each **ht,i** is used as input to the next sub-layer, as shown above.

RNN operations: The RNNv2 layer supports the following cell operations:

- **ReLU:** $\mathbf{G}(\mathbf{x},\mathbf{h},\mathbf{c}) := \max(\mathbf{W}_i\mathbf{x} + \mathbf{R}_i\mathbf{h} + \mathbf{W}_b + \mathbf{R}_b,\ 0)$ (**c** not used)
- **tanh:** $\mathbf{G}(\mathbf{x},\mathbf{h},\mathbf{c}) := \tanh(\mathbf{W}_i\mathbf{x} + \mathbf{R}_i\mathbf{h} + \mathbf{W}_b + \mathbf{R}_b)$ (**c** not used)
- **GRU:** $\mathbf{Z} := \text{sigmoid}(\mathbf{W}_z\mathbf{x} + \mathbf{R}_z\mathbf{h} + \mathbf{W}_{bz} + \mathbf{R}_{bz})$
- **GRU:** $\mathbf{M} := \text{sigmoid}(\mathbf{W}_r\mathbf{x} + \mathbf{R}_r\mathbf{h} + \mathbf{W}_{br} + \mathbf{R}_{br})$
- **GRU:** $\mathbf{G}(\mathbf{x},\ \mathbf{h},\ \mathbf{c}) := \tanh(\mathbf{W}_h\mathbf{x} + \mathbf{M}(\mathbf{h} + \mathbf{R}_{bh}) + \mathbf{W}_{bh})$ (**c** not used)
- **LSTM:** $\mathbf{I} := \text{sigmoid}(\mathbf{W}_I\mathbf{x} + \mathbf{R}_I\mathbf{h} + \mathbf{W}_{bi} + \mathbf{R}_{bi})$
- **LSTM:** $\mathbf{F} := \text{sigmoid}(\mathbf{W}_f\mathbf{x} + \mathbf{R}_f\mathbf{h} + \mathbf{W}_{bf} + \mathbf{R}_{bf})$
- **LSTM:** $\mathbf{O} := \text{sigmoid}(\mathbf{W}_o\mathbf{x} + \mathbf{R}_o\mathbf{h} + \mathbf{W}_{bo} + \mathbf{R}_{bo})$
- **LSTM:** $\mathbf{C} := \tanh(\mathbf{W}_c\mathbf{x} + \mathbf{R}_c\mathbf{h} + \mathbf{W}_{bc} + \mathbf{R}_{bc})$
- **LSTM:** $\mathbf{C}' := \mathbf{F} \times \mathbf{C}$
- **LSTM:** $\mathbf{H} := \mathbf{O} \times \tanh(\mathbf{C}')$
- **LSTM:** $\mathbf{G}(\mathbf{x},\ \mathbf{h},\ \mathbf{c}) := \{\mathbf{H},\ \mathbf{C}'\}$

For GRU and LSTM, we refer to the intermediate computations for **Z**, **M**, **I**, **F**, for example, as "gates."

In the unidirectional case, the dimensionality of the **W** matrices is *HxE* for the first layer and *HxH* for subsequent layers (unless skip mode is set, refer below). In the bidirectional case, the dimensionality of the **W** matrices is *HxE* for the first forward/backward layer and *Hx2H* for subsequent layers.

The dimensionality of the **R** matrices is always *HxH*. The biases $\mathbf{W}_{bx}$ and $\mathbf{R}_{bx}$ have dimensionality *H*.

Skip mode: The default mode used by RNNv2 is "linear mode." In this mode, the first sub-layer of the RNNv2 layer uses the cell $\mathbf{G}'(\mathbf{x},\ \mathbf{h},\ \mathbf{c})$, which accepts a vector **x** of size *E* (embedding size), and vectors **h** and **c** of size *H* (hidden state size), and is defined by the cell operation formula. Subsequent layers use the cell $\mathbf{G}(\mathbf{x},\ \mathbf{h},\ \mathbf{c})$, where **x**, **h**, and **c** are all vectors of size *H*, and are also defined by the cell operation formula.

Optionally, the RNN can be configured to run in "skip mode," which means the input weight matrices for the first layer are implicitly identity matrices, and **x** Is expected to be size *H*.

Conditions And Limitations

The data (**X**) input and initial hidden/cell state ($\mathbf{H_0}$ and $\mathbf{C_0}$) tensors have at least two non-batch dimensions. Additional dimensions are considered batch dimensions.

The optional sequence length input T is 0-dimensional (scalar) when excluding batch dimensions.

The data (**Y**) output and final hidden/cell state ($\mathbf{H_T}$ and $\mathbf{C_T}$) tensors have at least two non-batch dimensions. Additional dimensions are considered batch dimensions. If the sequence length input is provided, each output in the batch is padded to the maximum sequence length $T_{\max}$.

The `IRNNv2Layer` supports:

- FP32 and FP16 data type for input and output, hidden, and cell tensors.
- INT32 data type only for the sequence length tensor.

After the network is defined, you can mark the required outputs. RNNv2 output tensors that are not marked as network outputs or used as inputs to another layer are dropped.

```
network->markOutput(*pred->getOutput(1));
pred->getOutput(1)->setType(DataType::kINT32);
rnn->getOutput(1)->setName(HIDDEN_OUT_BLOB_NAME);
network->markOutput(*rnn->getOutput(1));
if (rnn->getOperation() == RNNOperation::kLSTM)
{
rnn->getOutput(2)->setName(CELL_OUT_BLOB_NAME);
network->markOutput(*rnn->getOutput(2));
};
```

Refer to the C++ class `IRNNv2Layer` or the Python class `IRNNv2Layer` for further details.

A.1.26.1. RNNv2 Layer Setup

The first layer in the network is an RNN layer. This is added and configured in the `addRNNv2Layer()` function. This layer consists of the following configuration parameters.

Operation
This defines the operation of the RNN cell. Supported operations are currently `relu`, `LSTM`, `GRU`, and `tanh`.

Direction
This defines whether the RNN is unidirectional or bidirectional (BiRNN).

Input mode
This defines whether the first layer of the RNN carries out a matrix multiply (linear mode), or the matrix multiply is skipped (skip mode).

For example, in the network used in sampleCharRNN, we used a linear, unidirectional LSTM cell containing `LAYER_COUNT` number of stacked layers. The code below shows how to create this RNNv2 layer.

```
auto rnn = network->addRNNv2(*data, LAYER_COUNT, HIDDEN_SIZE, SEQ_SIZE, RNNOperation::kLSTM);
```

Note: For the RNNv2 layer, weights and bias need to be set separately. For more information, refer to RNNv2 Layer - Optional Inputs.

For more information, refer to the TensorRT API documentation.

A.1.26.2. RNNv2 Layer - Optional Inputs

If there are cases where the hidden and cell states need to be pre-initialized to a non-zero value, then you can pre-initialize them via the `setHiddenState` and `setCellState` calls. These are optional inputs to the RNN.

C++ code snippet

```
rnn->setHiddenState(*hiddenIn);
if (rnn->getOperation() == RNNOperation::kLSTM)
    rnn->setCellState(*cellIn);
```

Python code snippet

```
rnn.hidden_state = hidden_in
if rnn.op == trt.RNNOperation.LSTM:
rnn.cell_state = cell_in
```

A.1.27. `IScaleLayer`

The `IScaleLayer` implements a per-tensor, per-channel, or per-element affine transformation and/or exponentiation by constant values.

Layer Description

Given an input tensor **A**, the `IScaleLayer` performs a per-tensor, per-channel, or per-element transformation to produce an output tensor **B** of the same dimensions. The transformations corresponding to each mode are:

`ScaleMode::kUNIFORM` tensor-wise transformation

$$B = (A * scale + \text{shift})^{power}$$

`ScaleMode::kCHANNEL` channel-wise transformation

$$B_I = \left(A_I * scale_{c(I)} + shift_{c(I)}\right)^{power_{c(I)}}$$

`ScaleMode::kELEMENTWISE` element-wise transformation

$$B_I = \left(A_I * scale_I + shift_I\right)^{power_I}$$

Where I represents the indexes of tensor elements and $c_{(I)}$ is the channel dimension in I.

Conditions And Limitations

A must have at least three dimensions in implicit batch mode and at least four dimensions in explicit batch mode.

If an empty weight object is provided for `scale`, `shift`, or `power`, then a default value is used. By default, `scale` has a value of `1.0`, `shift` has a value of `0.0`, and power has a value of `1.0`.

Refer to the C++ class `IScaleLayer` or the Python class `IScaleLayer` for further details.

A.1.28. `ISelectLayer`

The `ISelectLayer` returns either of the two inputs depending on the condition.

Layer Description

This layer returns the elements chosen from input tensor **B**(`thenInput`) or **C**(`elseInput`) depending on the condition tensor **A**.

Conditions And Limitations

All three input tensors must have the same number of dimensions; along each axis, each must have the same length or a length of one. If the length is one, the tensor is broadcast along that axis. The output tensor has the dimensions of the inputs after the broadcast rule is applied. The condition tensor is required to be of boolean type. The other two inputs may be FP32, FP16, or INT32.

Refer to the C++ class `ISelectLayer` or the Python class `ISelectLayer` for further details.

A.1.29. `IShapeLayer`

The `IShapeLayer` gets the shape of a tensor.

Layer Description

The `IShapeLayer` outputs the dimensions of its input tensor. The output is a 1D tensor of type INT32.

Conditions And Limitations

The input tensor must have at least one dimension. The output tensor is a "shape tensor," which can be used as an input only for layers that handle shape tensors. Refer to Execution Tensors vs. Shape Tensors for more information.

Refer to the C++ class `IShapeLayer` or the Python class `IShapeLayer` for further details.

A.1.30. `IShuffleLayer`

The `IShuffleLayer` implements a reshape and transpose operator for tensors.

Layer Description

The `IShuffleLayer` implements reshuffling of tensors to permute the tensor and/or reshape it. An input tensor **A** of dimensions **a** is transformed by applying a transpose, followed by a reshape operation with reshape dimensions **r**, and then followed by another transpose operation to produce an output data tensor **B** of dimensions **b**.

To apply the transpose operation to **A**, the permutation order must be specified. The specified permutation *p1* is used to permute the elements of **A** in the following manner to produce output **C** of dimensions $c_i = a_{\mathrm{p1}(i)}$ and $c_i = A_{\mathrm{p1}(I)}$ for a sequence of indexes `I`. By default, the permutation is assumed to be an identity (no change to the input tensor).

The reshape operation does not alter the order of the elements and reshapes tensor **C** into tensor **R** of shape $\mathbf{r}^I$, such that $\mathbf{r}_i^I = \{\mathbf{r}_i \text{ if } \mathbf{r}_i > 0,\ c_i \text{ if } \mathbf{r}_i = 0,\ \text{inferred if } \mathbf{r}_i = -1\}$. Only one dimension can be inferred, such that $\prod \mathbf{r}_i^I = \prod \mathbf{a}_i$.

The special interpretation of $r_i = 0$ as a placeholder, and not the actual dimensions, can be turned off by calling the method `setZeroIsPlaceholder(false)` on the layer. If using dynamic shapes, it is strongly recommended to turn off the placeholder interpretation of `0` because it can interfere with the correct handling of empty tensors and can decrease optimization by TensorRT. For example, consider a tensor **C** with dimensions `[2,x]` that needs to be reshaped to a tensor **R** with dimensions `[x,2]`. With the placeholder interpretation, when `x=0`, the reshape dimensions expand to `[2,2]`, not `[0,2]` as intended.

The reshape dimensions can be specified as build-time constants in the layer or as runtime values by supplying a second input to the layer, which must be a 1D tensor of type INT32. A placeholder `0` or wildcard `-1` occurring in the second input at runtime are interpreted identically to how they are interpreted if they are build-time constants.

The second transpose operation is applied after the reshape operation. It follows the same rules as the first transpose operation and requires a permutation (say *p2*) to be specified. This permutation produces an output tensor **B** of dimensions **b**, such that $\mathbf{b}_i = r_{p2(I)}$ and $\mathbf{B}_{p2(I)} = \mathbf{R}_I$ for a sequence of indexes `I`.

Conditions And Limitations

Product of dimensions $\mathbf{r}^I$ must be equal to the product of input dimensions **a**.

Refer to the C++ class `IShuffleLayer` or the Python class `IShuffleLayer` for further details.

A.1.31. `ISliceLayer`

The `ISliceLayer` implements a slice operator for tensors.

Layer Description

Giving an input `n`-dimension (excluding batch dimension) tensor `A`, the Slice layer generates an output tensor `B` with elements extracted from `A`. The correspondence between element coordinates in `A` and `B` is given by $a_i = b_i * s_i + o_i (0 \le i < n)$, where `a`, `b`, `s`, `o` are element coordinates in `A`, element coordinates in `B`, stride and starting offset, respectively. The stride can be positive, negative, or zero.

Conditions And Limitations

The corresponding `A` coordinates for every element in `B` must not be out-of-bounds.

Refer to the C++ class `ISliceLayer` or the Python class `ISliceLayer` for further details.

A.1.32. ISoftMaxLayer

The `ISoftMaxLayer` applies the SoftMax function on the input tensor along an input dimension specified by the user.

Layer Description

Given an input tensor **A** of shape **a** and an input dimension `i`, this layer applies the SoftMax function on every slice $A_{a0, \ldots, ai-1, :, ai+1, \ldots, an-1}$ along dimension `i` of **A**. The resulting output tensor **C** has the same dimensions as the input tensor **A**.

The SoftMax function **S** for a slice `x` is defined as $S(x) = \exp(x_j) / \sum \exp(x_j)$

The SoftMax function rescales the input such that every value in the output lies in the range `[0, 1]` and the values of every slice $C_{a0, \ldots, ai-1, :, ai+1, \ldots, an-1}$ along dimension `i` of **C** sum up to `1`.

Conditions And Limitations

For `n` being the length of **a**, the input dimension `i` should be $i \in [0, n-1]$. If the user does not provide an input dimension, then $i = \max(0, n-3)$.

Refer to the C++ class `ISoftMaxLayer` or the Python class `ISoftMaxLayer` for further details.

A.1.33. ITopKLayer

The `ITopKLayer` finds the top K maximum (or minimum) elements along a dimension, returning a reduced tensor and a tensor of index positions.

Layer Description

For an input tensor **A** of dimensions **a**, given an axis i, an operator that is either *max* or *min*, and a value for k, produces a tensor of values **V** and a tensor of indices **I** of dimensions **v** such that $v_j = \{k \text{ if } i \neq j, \text{ and } a_i \text{ otherwise}\}$.

The output values are:

- $V_{a0, \ldots, ai-1, :, ai+1, \ldots, an-1} = \text{sort}(A_{a0, \ldots, ai-1, :, ai+1, \ldots, an-1})_{:K}$
- $I_{a0, \ldots, ai-1, :, ai+1, \ldots, an-1} = \text{argsort}(A_{a0, \ldots, ai-1, :, ai+1, \ldots, an-1})_{:K}$

where `sort` is in descending order for operator *max* and ascending order for operator *min*.

Ties are broken during sorting with lower index considered to be larger for operator *max*, and lower index considered to be smaller for operator *min*.

Conditions And Limitations

The K value must be 3840 or less. Only one axis can be searched to find the top K minimum or maximum values; this axis cannot be the batch dimension.

Refer to the C++ class `ITopKLayer` or the Python class `ITopKLayer` for further details.

A.1.33.1. TopK Layer Setup

The TopK layer is used to identify the character that has the maximum probability of appearing next.

Note: The layer has two outputs. The first output is an array of the top `K` values. The second, which is of more interest to us, is the index at which these maximum values appear.

The code below sets up the TopK layer and assigns the `OUTPUT_BLOB_NAME` to the second output of the layer.

```
auto pred =  network->addTopK(*addBiasLayer->getOutput(0),
     nvinfer1::TopKOperation::kMAX, 1, reduceAxis);
assert(pred != nullptr);
pred->getOutput(1)->setName(OUTPUT_BLOB_NAME);
```

For more information, refer to the TensorRT API documentation.

A.1.34. `ITripLimitLayer`

The `ITripLimitLayer` specifies how many times the loop iterates. A loop is defined by *loop boundary layers*.

For more information about the `ITripLimitLayer`, including how loops work and their limitations, refer to Working With Loops.

Refer to the C++ class `ITripLayer` or the Python class `ITripLayer` for further details.

A.1.35. `IUnaryLayer`

The `IUnaryLayer` supports PointWise unary operations.

Layer Description

The `IUnaryLayer` performs PointWise operations on input tensor **A** resulting in output tensor **B** of the same dimensions. The following functions are supported:

- exp: $B = e\hat{}A$
- abs: $B = |A|$
- log: $B = \ln(A)$
- sqrt: $B = \sqrt{A}$ (rounded to nearest even mode)
- neg: $B = -A$
- recip: $B = 1 / A$ (reciprocal) in rounded to nearest even mode
- sine : $B = \sin(A)$
- Cos : $B = \cos(A)$
- Tan : $B = \tan(A)$

- Tanh : $B = \tanh(A)$
- Sinh : $B = \sinh(A)$
- Cosh : $B = \cosh(A)$
- Asin : $B = \text{asin}(A)$
- Acos : $B = \text{acos}(A)$
- Atan : $B = \tan(A)$
- Asinh : $B = \text{asinh}(A)$
- Acosh : $B = \text{acosh}(A)$
- Atanh : $B = \text{atanh}(A)$
- Ceil : $B = \text{ceil}(A)$
- Floor : $B = \text{floor}(A)$
- ERF : $B = \text{erf}(A)$
- NOT : $B = \sim A$

Conditions And Limitations

Input and output can be zero to 7-dimensional tensors.

Refer to the C++ class `IUnaryLayer` or the Python class `IUnaryLayer` for further details.

A.2. Data Format Descriptions

NVIDIA® TensorRT™ supports different data formats. There are two aspects to consider: data type and layout.

Data type format

The data type is the representation of each individual value. Its size determines the range of values and the precision of the representation, which are FP32 (32-bit floating point, or single precision), FP16 (16-bit floating point or half precision), INT32 (32-bit integer representation), and INT8 (8-bit representation).

Layout format

The layout format determines the ordering in which values are stored. Typically, batch dimensions are the leftmost dimensions, and the other dimensions refer to aspects of each data item, such as `C` is channel, `H` is height, and `W` is width, in images. Ignoring batch sizes, which are always preceding these, `C`, `H`, and `W` are typically sorted as `CHW` (see Figure 13) or `HWC` (see Figure 14).

Figure 13. Layout format for `CHW`: The image is divided into `HxW` matrices, one per channel, and the matrices are stored in sequence; all the values of a channel are stored contiguously.

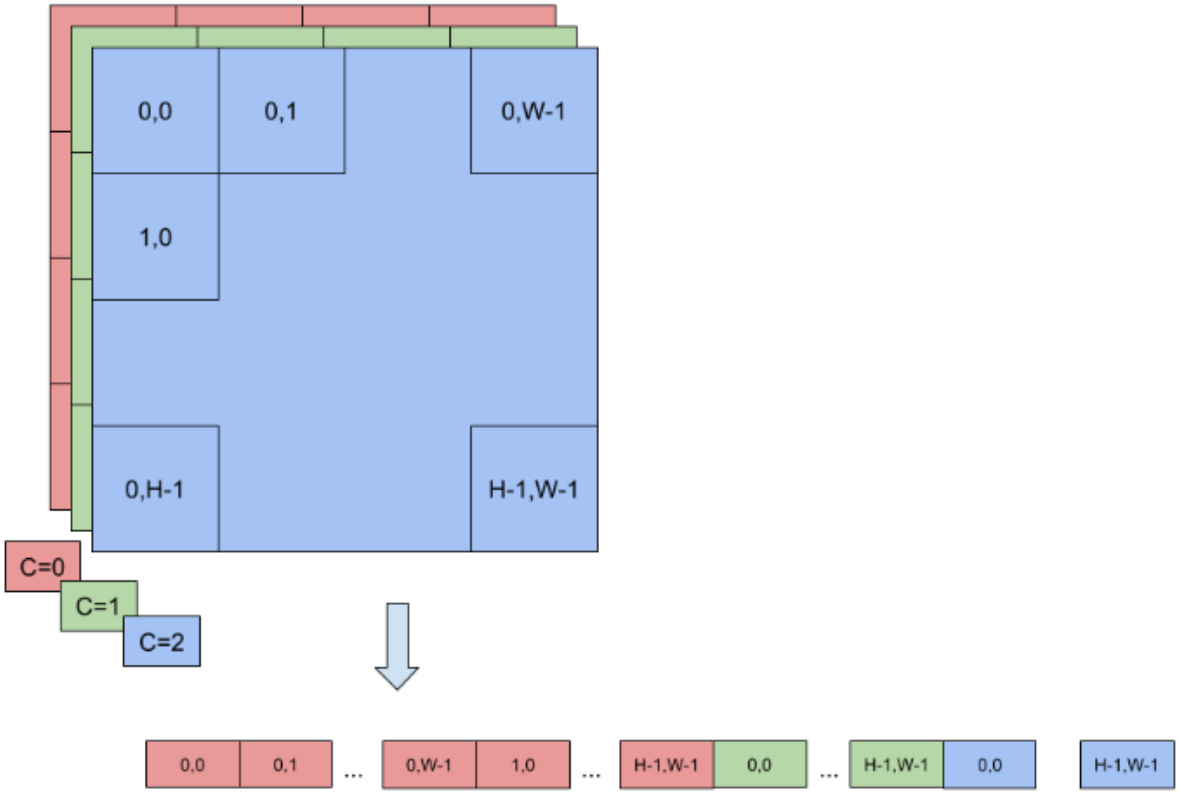
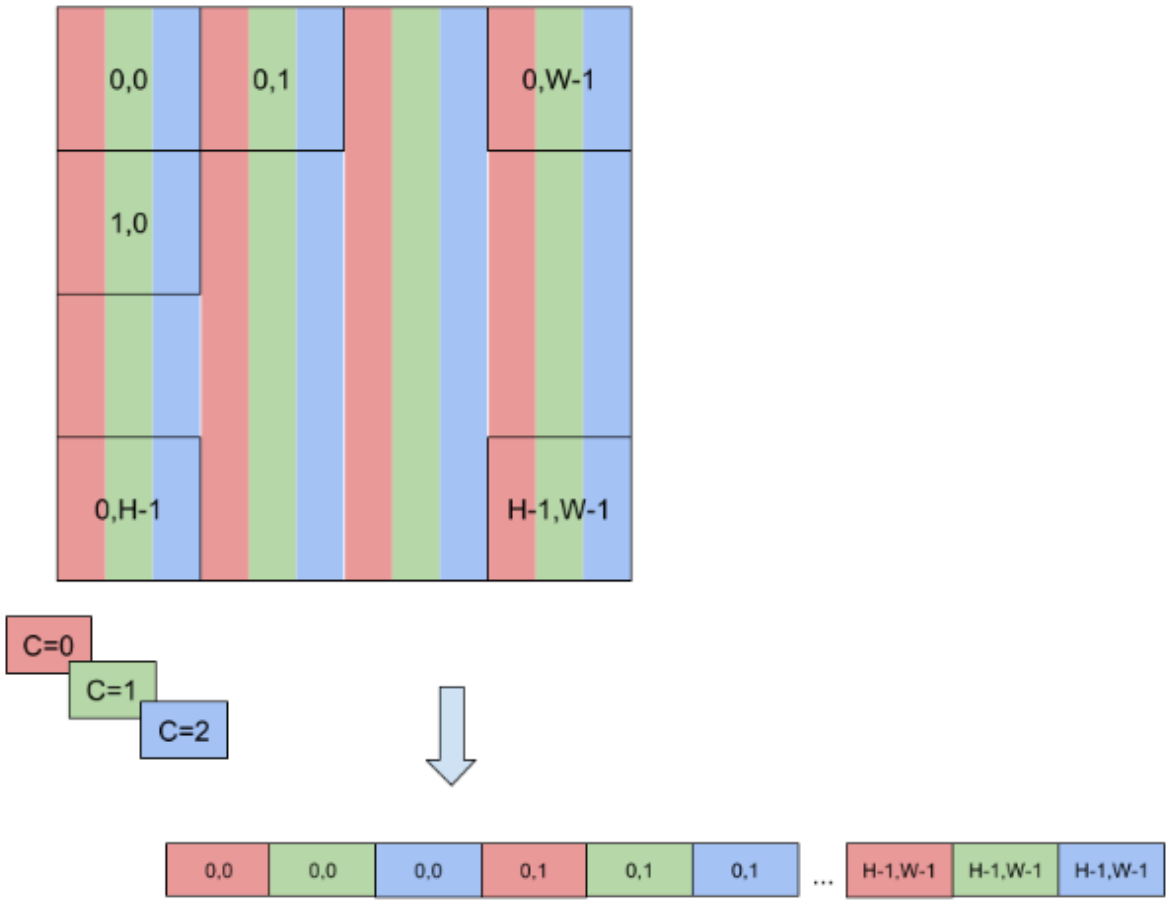


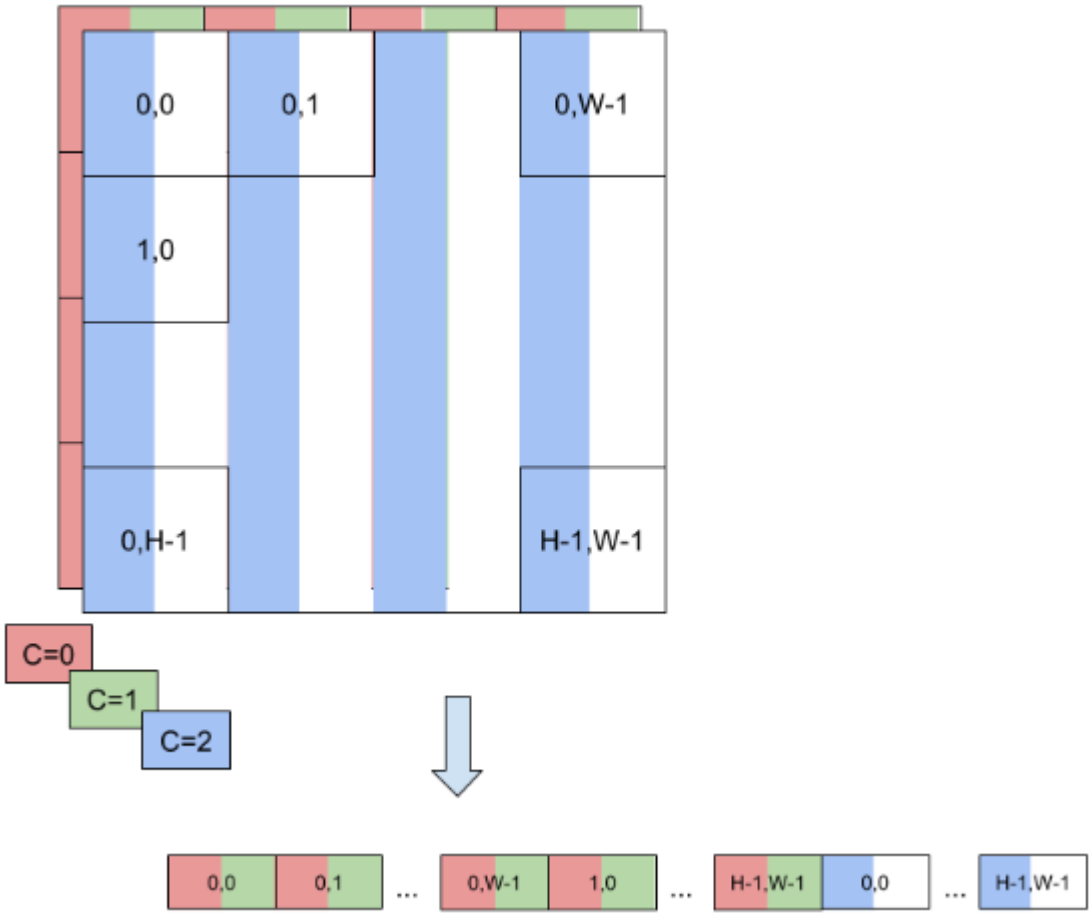
Figure 14. Layout format for `HWC`: The image is stored as a single `HxW` matrix, whose value is actually C-tuple, with a value per channel; all the values of a point (pixel) are stored contiguously.



To enable faster computations, more formats are defined to pack together channel values and use reduced precision. For this reason, TensorRT also supports formats `NC/2HW2` and `NHWC8`.

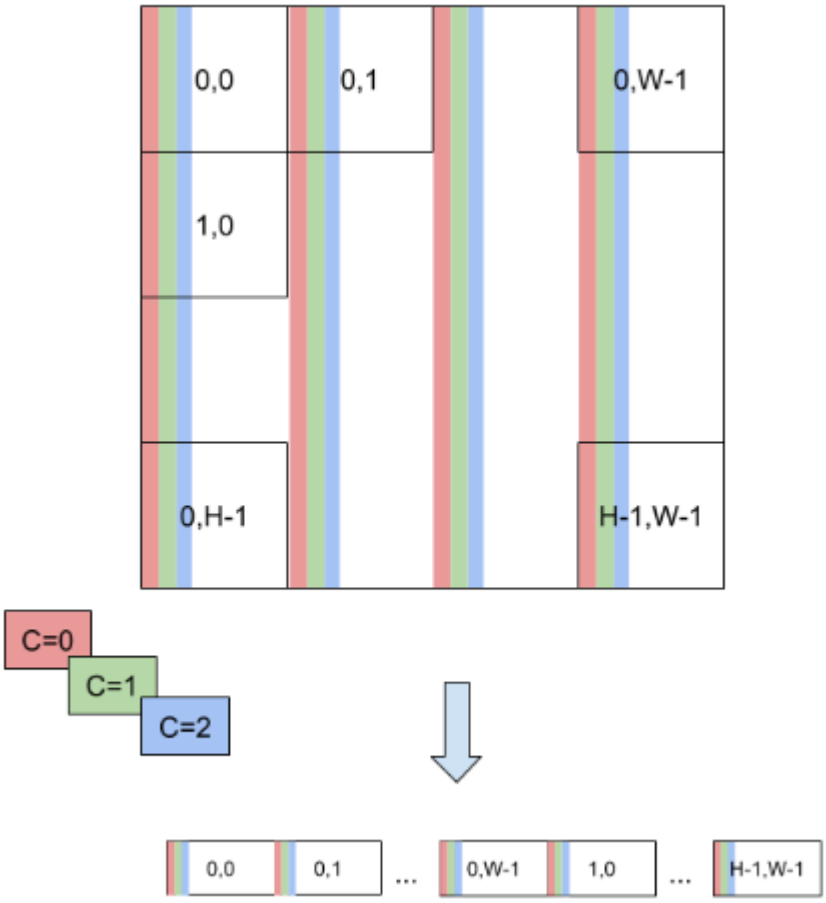
In `NC/2HW2`, pairs of channel values are packed together in each `HxW` matrix (with an empty value in the case of an odd number of channels). The result is a format in which the values of `#C/2#HxW` matrices are pairs of values of two consecutive channels (see Figure 15); notice that this ordering interleaves dimensions as values of channels that have stride `1` if they are in the same pair and stride `2xHxW` otherwise.

Figure 15. A pair of channel values are packed together in each `HxW` matrix. The result is a format in which the values of `[C/2] HxW` matrices are pairs of values of two consecutive channels.



In `NHWC8`, the entries of an `HxW` matrix include the values of all the channels (see Figure 16). In addition, these values are packed together in `#C/8#` 8-tuples, and `C` is rounded up to the nearest multiple of 8.

Figure 16. In this `NHWC8` format, the entries of an `HxW` matrix include the vlaues of all the channels.



A.3. Command-Line Programs

A.3.1. `trtexec`

Included in the `samples` directory is a command-line wrapper tool called `trtexec`. `trtexec` is a tool to quickly utilize TensorRT without having to develop your own application.

The `trtexec` tool has three main purposes:

- It's useful for *benchmarking networks* on random or user-provided input data.
- It's useful for *generating serialized engines* from models.
- It's useful for *generating serialized timing cache* from the builder.

Benchmarking network

If you have a model saved as a UFF file, ONNX file, or if you have a network description in a Caffe prototxt format, you can use the `trtexec` tool to test the performance of running inference on your network using TensorRT. The `trtexec` tool has many options for specifying inputs and outputs, iterations for performance timing, precision allowed, and other options.

To maximize GPU utilization, `trtexec` enqueues the queries one batch ahead of time. In other words, it does the following:

```
enqueue batch 0 -> enqueue batch 1 -> wait until batch 0 is done -> enqueue batch 2 -> wait
 until batch 1 is done -> enqueue batch 3 -> wait until batch 2 is done -> enqueue batch 4 -
> ...
```

If multi-stream (`--streams=N` flag) is used, then `trtexec` follows this pattern on each stream separately.

The `trtexec` tool prints the following performance metrics. The following figure shows an example Nsight System profile of a `trtexec` run with markers showing what each performance metric means.

Throughput
: The observed throughput is computed by dividing the number of queries by the Total Host Walltime. If this is significantly lower than the reciprocal of GPU Compute Time, the GPU may be underutilized because of host-side overheads or data transfers. Using CUDA graphs (with `--useCudaGraph`) or disabling H2D/D2H transfers (with `--noDataTransfer`) may improve GPU utilization. The output log provides guidance on which flag to use when `trtexec` detects that the GPU is underutilized.

Host Latency
: The summation of H2D Latency, GPU Compute Time, and D2H Latency. This is the latency to infer a single query.

End-to-End Host Latency
: The duration from when the H2D of a query is called to when the D2H of the same query is completed, which includes the latency to wait for the completion of the previous query. This is the latency of a query if multiple queries are enqueued consecutively.

Enqueue Time
: The host latency to enqueue a query, including calling H2D/D2H CUDA APIs, running host-side heuristics, and launching CUDA kernels. If this is longer than GPU Compute Time, the GPU may be underutilized and the throughput may be dominated by host-side overhead. Using CUDA graphs (with `--useCudaGraph`) may reduce Enqueue Time.

H2D Latency
: The latency for host-to-device data transfers for input tensors of a single query. Add `--noDataTransfer` to disable H2D/D2H data transfers.

D2H Latency
: The latency for device-to-host data transfers for output tensors of a single query. Add `--noDataTransfer` to disable H2D/D2H data transfers.

GPU Compute Time
: The GPU latency to execute the CUDA kernels for a query.

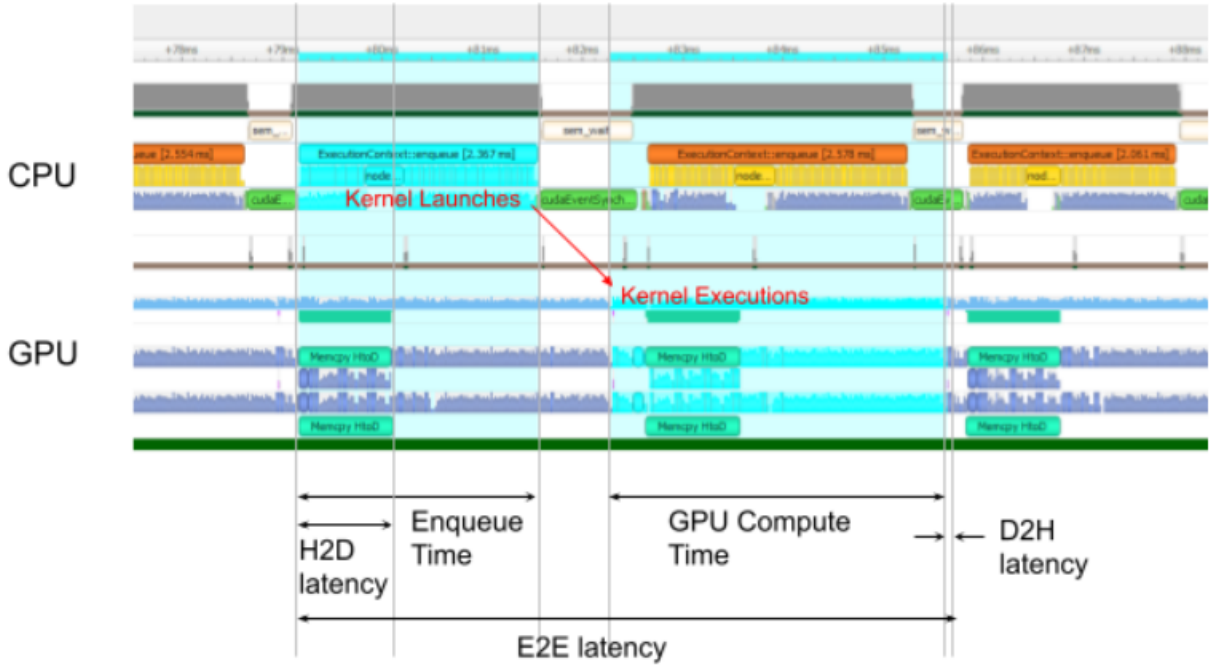
Total Host Walltime

The host walltime from when the first query (after warm-ups) is enqueued to when the last query was completed.

Total GPU Compute Time

The summation of the GPU Compute Time of all the queries. If this is significantly shorter than Total Host Walltime, the GPU may be under-utilized because of host-side overheads or data transfers.

Figure 17. Performance metrics in a normal `trtexec` run under Nsight Systems (ShuffleNet, BS=16, best, TitanRTX@1200MHz)



In addition, add the `--dumpProfile` flag to `trtexec` to show per-layer performance profiles, which allows users to understand which layers in the network take the most time in GPU execution.

Serialized engine generation

If you generate a saved serialized engine file, you can pull it into another application that runs inference. For example, you can use the TensorRT Laboratory to run the engine with multiple execution contexts from multiple threads in a fully pipelined asynchronous way to test parallel inference performance. There are some caveats; for example, if you used a Caffe prototxt

file and a model is not supplied, random weights are generated. Also, in INT8 mode, random weights are used, meaning trtexec does not provide calibration capability.

Serialized timing cache generation

If you provide a timing cache file to the `--timingCacheFile` option, the builder can load existing profiling data from it and add new profiling data entries during layer profiling. The timing cache file can be reused in other builder instances to improve the builder execution time. It is suggested to reuse this cache only in the same hardware/software configurations (for example, CUDA/cuDNN/TensorRT versions, device model, and clock frequency); otherwise, functional or performance issues may occur.

Refer to GitHub: trtexec/README.md file for detailed information about how to build this tool and examples of its usage.

A.4. ACKNOWLEDGEMENTS

TensorRT uses elements from the following software, whose licenses are reproduced below.

Google Protobuf

This license applies to all parts of Protocol Buffers except the following:

- Atomicops support for generic gcc, located in `src/google/protobuf/stubs/atomicops_internals_generic_gcc.h`. This file is copyrighted by Red Hat Inc.
- Atomicops support for AIX/POWER, located in `src/google/protobuf/stubs/atomicops_internals_power.h`. This file is copyrighted by Bloomberg Finance LP.

Copyright 2014, Google Inc. All rights reserved.

Redistribution and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met:

- Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer.
- Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the documentation and/or other materials provided with the distribution.
- Neither the name of Google Inc. nor the names of its contributors may be used to endorse or promote products derived from this software without specific prior written permission.

THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS "AS IS" AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE COPYRIGHT OWNER OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF

SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

Code generated by the Protocol Buffer compiler is owned by the owner of the input file used when generating it. This code is not standalone and requires a support library to be linked with it. This support library is itself covered by the above license.

Google Flatbuffers

Apache License Version 2.0, January 2004 http://www.apache.org/licenses/

TERMS AND CONDITIONS FOR USE, REPRODUCTION, AND DISTRIBUTION

1. Definitions.

   "License" shall mean the terms and conditions for use, reproduction, and distribution as defined by Sections 1 through 9 of this document.

   "Licensor" shall mean the copyright owner or entity authorized by the copyright owner that is granting the License.

   "Legal Entity" shall mean the union of the acting entity and all other entities that control, are controlled by, or are under common control with that entity. For the purposes of this definition, "control" means (i) the power, direct or indirect, to cause the direction or management of such entity, whether by contract or otherwise, or (ii) ownership of fifty percent (50%) or more of the outstanding shares, or (iii) beneficial ownership of such entity.

   "You" (or "Your") shall mean an individual or Legal Entity exercising permissions granted by this License.

   "Source" form shall mean the preferred form for making modifications, including but not limited to software source code, documentation source, and configuration files.

   "Object" form shall mean any form resulting from mechanical transformation or translation of a Source form, including but not limited to compiled object code, generated documentation, and conversions to other media types.

   "Work" shall mean the work of authorship, whether in Source or Object form, made available under the License, as indicated by a copyright notice that is included in or attached to the work (an example is provided in the Appendix below).

   "Derivative Works" shall mean any work, whether in Source or Object form, that is based on (or derived from) the Work and for which the editorial revisions, annotations, elaborations, or other modifications represent, as a whole, an original work of authorship. For the purposes of this License, Derivative Works shall not include works that remain

separable from, or merely link (or bind by name) to the interfaces of, the Work and Derivative Works thereof.

"Contribution" shall mean any work of authorship, including the original version of the Work and any modifications or additions to that Work or Derivative Works thereof, that is intentionally submitted to Licensor for inclusion in the Work by the copyright owner or by an individual or Legal Entity authorized to submit on behalf of the copyright owner. For the purposes of this definition, "submitted" means any form of electronic, verbal, or written communication sent to the Licensor or its representatives, including but not limited to communication on electronic mailing lists, source code control systems, and issue tracking systems that are managed by, or on behalf of, the Licensor for the purpose of discussing and improving the Work, but excluding communication that is conspicuously marked or otherwise designated in writing by the copyright owner as "Not a Contribution."

"Contributor" shall mean Licensor and any individual or Legal Entity on behalf of whom a Contribution has been received by Licensor and subsequently incorporated within the Work.

2. Grant of Copyright License. Subject to the terms and conditions of this License, each Contributor hereby grants to You a perpetual, worldwide, non-exclusive, no-charge, royalty-free, irrevocable copyright license to reproduce, prepare Derivative Works of, publicly display, publicly perform, sublicense, and distribute the Work and such Derivative Works in Source or Object form.
3. Grant of Patent License. Subject to the terms and conditions of this License, each Contributor hereby grants to You a perpetual, worldwide, non-exclusive, no-charge, royalty-free, irrevocable (except as stated in this section) patent license to make, have made, use, offer to sell, sell, import, and otherwise transfer the Work, where such license applies only to those patent claims licensable by such Contributor that are necessarily infringed by their Contribution(s) alone or by combination of their Contribution(s) with the Work to which such Contribution(s) was submitted. If You institute patent litigation against any entity (including a cross-claim or counterclaim in a lawsuit) alleging that the Work or a Contribution incorporated within the Work constitutes direct or contributory patent infringement, then any patent licenses granted to You under this License for that Work shall terminate as of the date such litigation is filed.
4. Redistribution. You may reproduce and distribute copies of the Work or Derivative Works thereof in any medium, with or without modifications, and in Source or Object form, provided that You meet the following conditions:

   a). You must give any other recipients of the Work or Derivative Works a copy of this License; and

   b). You must cause any modified files to carry prominent notices stating that You changed the files; and

   c). You must retain, in the Source form of any Derivative Works that You distribute, all copyright, patent, trademark, and attribution notices from the Source form of the Work, excluding those notices that do not pertain to any part of the Derivative Works; and

d). If the Work includes a "NOTICE" text file as part of its distribution, then any Derivative Works that You distribute must include a readable copy of the attribution notices contained within such NOTICE file, excluding those notices that do not pertain to any part of the Derivative Works, in at least one of the following places: within a NOTICE text file distributed as part of the Derivative Works; within the Source form or documentation, if provided along with the Derivative Works; or, within a display generated by the Derivative Works, if and wherever such third-party notices normally appear. The contents of the NOTICE file are for informational purposes only and do not modify the License. You may add Your own attribution notices within Derivative Works that You distribute, alongside or as an addendum to the NOTICE text from the Work, provided that such additional attribution notices cannot be construed as modifying the License.

You may add Your own copyright statement to Your modifications and may provide additional or different license terms and conditions for use, reproduction, or distribution of Your modifications, or for any such Derivative Works as a whole, provided Your use, reproduction, and distribution of the Work otherwise complies with the conditions stated in this License.

5. Submission of Contributions. Unless You explicitly state otherwise, any Contribution intentionally submitted for inclusion in the Work by You to the Licensor shall be under the terms and conditions of this License, without any additional terms or conditions. Notwithstanding the above, nothing herein shall supersede or modify the terms of any separate license agreement you may have executed with Licensor regarding such Contributions.
6. Trademarks. This License does not grant permission to use the trade names, trademarks, service marks, or product names of the Licensor, except as required for reasonable and customary use in describing the origin of the Work and reproducing the content of the NOTICE file.
7. Disclaimer of Warranty. Unless required by applicable law or agreed to in writing, Licensor provides the Work (and each Contributor provides its Contributions) on an "AS IS" BASIS, WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied, including, without limitation, any warranties or conditions of TITLE, NON-INFRINGEMENT, MERCHANTABILITY, or FITNESS FOR A PARTICULAR PURPOSE. You are solely responsible for determining the appropriateness of using or redistributing the Work and assume any risks associated with Your exercise of permissions under this License.
8. Limitation of Liability. In no event and under no legal theory, whether in tort (including negligence), contract, or otherwise, unless required by applicable law (such as deliberate and grossly negligent acts) or agreed to in writing, shall any Contributor be liable to You for damages, including any direct, indirect, special, incidental, or consequential damages of any character arising as a result of this License or out of the use or inability to use the Work (including but not limited to damages for loss of goodwill, work stoppage, computer failure or malfunction, or any and all other commercial damages or losses), even if such Contributor has been advised of the possibility of such damages.

9. Accepting Warranty or Additional Liability. While redistributing the Work or Derivative Works thereof, You may choose to offer, and charge a fee for, acceptance of support, warranty, indemnity, or other liability obligations and/or rights consistent with this License. However, in accepting such obligations, You may act only on Your own behalf and on Your sole responsibility, not on behalf of any other Contributor, and only if You agree to indemnify, defend, and hold each Contributor harmless for any liability incurred by, or claims asserted against, such Contributor by reason of your accepting any such warranty or additional liability.

END OF TERMS AND CONDITIONS

APPENDIX: How to apply the Apache License to your work.

To apply the Apache License to your work, attach the following boilerplate notice, with the fields enclosed by brackets "[]" replaced with your own identifying information. (Don't include the brackets!) The text should be enclosed in the appropriate comment syntax for the file format. We also recommend that a file or class name and description of purpose be included on the same "printed page" as the copyright notice for easier identification within third-party archives.

Copyright 2014 Google Inc.

Licensed under the Apache License, Version 2.0 (the "License"); you may not use this file except in compliance with the License. You may obtain a copy of the License at: http://www.apache.org/licenses/LICENSE-2.0.

Unless required by applicable law or agreed to in writing, software distributed under the License is distributed on an "AS IS" BASIS, WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied. See the License for the specific language governing permissions and limitations under the License.

BVLC Caffe

COPYRIGHT

All contributions by the University of California:

Copyright (c) 2014, 2015, The Regents of the University of California (Regents) All rights reserved.

All other contributions:

Copyright (c) 2014, 2015, the respective contributors All rights reserved.

Caffe uses a shared copyright model: each contributor holds copyright over their contributions to Caffe. The project versioning records all such contribution and copyright details. If a contributor wants to further mark their specific copyright on a particular contribution, they should indicate their copyright solely in the commit message of the change when it is committed.

LICENSE

Redistribution and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met:

1. Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer.
2. Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the documentation and/or other materials provided with the distribution.

THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS "AS IS" AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE COPYRIGHT OWNER OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

CONTRIBUTION AGREEMENT

By contributing to the BVLC/Caffe repository through pull-request, comment, or otherwise, the contributor releases their content to the license and copyright terms herein.

half.h

Copyright (c) 2012-2017 Christian Rau <rauy@users.sourceforge.net>

Permission is hereby granted, free of charge, to any person obtaining a copy of this software and associated documentation files (the "Software"), to deal in the Software without restriction, including without limitation the rights to use, copy, modify, merge, publish, distribute, sublicense, and/or sell copies of the Software, and to permit persons to whom the Software is furnished to do so, subject to the following conditions:

The above copyright notice and this permission notice shall be included in all copies or substantial portions of the Software.

THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN THE SOFTWARE.

jQuery.js

jQuery.js is generated automatically under doxygen.

In all cases TensorRT uses the functions under the MIT license.

CRC

policies, either expressed or implied, of the Regents of the University of California.

Note: The copyright of UC Berkeley's Berkeley Software Distribution ("BSD") source has been updated. The copyright addendum may be found at ftp://ftp.cs.berkeley.edu/pub/4bsd/README.Impt.License.Change and is

William Hoskins

Director, Office of Technology Licensing

University of California, Berkeley

getopt.c

Copyright (c) 2002 Todd C. Miller <Todd.Miller@courtesan.com>

Permission to use, copy, modify, and distribute this software for any purpose with or without fee is hereby granted, provided that the above copyright notice and this permission notice appear in all copies.

THE SOFTWARE IS PROVIDED "AS IS" AND THE AUTHOR DISCLAIMS ALL WARRANTIES WITH REGARD TO THIS SOFTWARE INCLUDING ALL IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS. IN NO EVENT SHALL THE AUTHOR BE LIABLE FOR ANY SPECIAL, DIRECT, INDIRECT, OR CONSEQUENTIAL DAMAGES OR ANY DAMAGES WHATSOEVER RESULTING FROM LOSS OF USE, DATA OR PROFITS, WHETHER IN AN ACTION OF CONTRACT, NEGLIGENCE OR OTHER TORTIOUS ACTION, ARISING OUT OF OR IN CONNECTION WITH THE USE OR PERFORMANCE OF THIS SOFTWARE.

Sponsored in part by the Defense Advanced Research Projects Agency (DARPA) and Air Force Research Laboratory, Air Force Materiel Command, USAF, under agreement number F39502-99-1-0512.

Copyright (c) 2000 The NetBSD Foundation, Inc.

All rights reserved.

This code is derived from software contributed to The NetBSD Foundation by Dieter Baron and Thomas Klausner.

Redistribution and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met:

1. Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer.
2. Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the documentation and/or other materials provided with the distribution.

THIS SOFTWARE IS PROVIDED BY THE NETBSD FOUNDATION, INC. AND CONTRIBUTORS ``AS IS'' AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE FOUNDATION OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

Notice

This document is provided for information purposes only and shall not be regarded as a warranty of a certain functionality, condition, or quality of a product. NVIDIA Corporation ("NVIDIA") makes no representations or warranties, expressed or implied, as to the accuracy or completeness of the information contained in this document and assumes no responsibility for any errors contained herein. NVIDIA shall have no liability for the consequences or use of such information or for any infringement of patents or other rights of third parties that may result from its use. This document is not a commitment to develop, release, or deliver any Material (defined below), code, or functionality.

NVIDIA reserves the right to make corrections, modifications, enhancements, improvements, and any other changes to this document, at any time without notice.

Customer should obtain the latest relevant information before placing orders and should verify that such information is current and complete.

NVIDIA products are sold subject to the NVIDIA standard terms and conditions of sale supplied at the time of order acknowledgement, unless otherwise agreed in an individual sales agreement signed by authorized representatives of NVIDIA and customer ("Terms of Sale"). NVIDIA hereby expressly objects to applying any customer general terms and conditions with regards to the purchase of the NVIDIA product referenced in this document. No contractual obligations are formed either directly or indirectly by this document.

NVIDIA products are not designed, authorized, or warranted to be suitable for use in medical, military, aircraft, space, or life support equipment, nor in applications where failure or malfunction of the NVIDIA product can reasonably be expected to result in personal injury, death, or property or environmental damage. NVIDIA accepts no liability for inclusion and/or use of NVIDIA products in such equipment or applications and therefore such inclusion and/or use is at customer's own risk.

NVIDIA makes no representation or warranty that products based on this document will be suitable for any specified use. Testing of all parameters of each product is not necessarily performed by NVIDIA. It is customer's sole responsibility to evaluate and determine the applicability of any information contained in this document, ensure the product is suitable and fit for the application planned by customer, and perform the necessary testing for the application in order to avoid a default of the application or the product. Weaknesses in customer's product designs may affect the quality and reliability of the NVIDIA product and may result in additional or different conditions and/or requirements beyond those contained in this document. NVIDIA accepts no liability related to any default, damage, costs, or problem which may be based on or attributable to: (i) the use of the NVIDIA product in any manner that is contrary to this document or (ii) customer product designs.

No license, either expressed or implied, is granted under any NVIDIA patent right, copyright, or other NVIDIA intellectual property right under this document. Information published by NVIDIA regarding third-party products or services does not constitute a license from NVIDIA to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property rights of the third party, or a license from NVIDIA under the patents or other intellectual property rights of NVIDIA.

Reproduction of information in this document is permissible only if approved in advance by NVIDIA in writing, reproduced without alteration and in full compliance with all applicable export laws and regulations, and accompanied by all associated conditions, limitations, and notices.

THIS DOCUMENT AND ALL NVIDIA DESIGN SPECIFICATIONS, REFERENCE BOARDS, FILES, DRAWINGS, DIAGNOSTICS, LISTS, AND OTHER DOCUMENTS (TOGETHER AND SEPARATELY, "MATERIALS") ARE BEING PROVIDED "AS IS." NVIDIA MAKES NO WARRANTIES, EXPRESSED, IMPLIED, STATUTORY, OR OTHERWISE WITH RESPECT TO THE MATERIALS, AND EXPRESSLY DISCLAIMS ALL IMPLIED WARRANTIES OF NONINFRINGEMENT, MERCHANTABILITY, AND FITNESS FOR A PARTICULAR PURPOSE. TO THE EXTENT NOT PROHIBITED BY LAW, IN NO EVENT WILL NVIDIA BE LIABLE FOR ANY DAMAGES, INCLUDING WITHOUT LIMITATION ANY DIRECT, INDIRECT, SPECIAL, INCIDENTAL, PUNITIVE, OR CONSEQUENTIAL DAMAGES, HOWEVER CAUSED AND REGARDLESS OF THE THEORY OF LIABILITY, ARISING OUT OF ANY USE OF THIS DOCUMENT, EVEN IF NVIDIA HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. Notwithstanding any damages that customer might incur for any reason whatsoever, NVIDIA's aggregate and cumulative liability towards customer for the products described herein shall be limited in accordance with the Terms of Sale for the product.

VESA DisplayPort

DisplayPort and DisplayPort Compliance Logo, DisplayPort Compliance Logo for Dual-mode Sources, and DisplayPort Compliance Logo for Active Cables are trademarks owned by the Video Electronics Standards Association in the United States and other countries.

HDMI

HDMI, the HDMI logo, and High-Definition Multimedia Interface are trademarks or registered trademarks of HDMI Licensing LLC.

ARM

ARM, AMBA and ARM Powered are registered trademarks of ARM Limited. Cortex, MPCore and Mali are trademarks of ARM Limited. All other brands or product names are the property of their respective holders. "ARM" is used to represent ARM Holdings plc; its operating company ARM Limited; and the regional subsidiaries ARM Inc.; ARM KK; ARM Korea Limited.; ARM Taiwan Limited; ARM France SAS; ARM Consulting (Shanghai) Co. Ltd.; ARM Germany GmbH; ARM Embedded Technologies Pvt. Ltd.; ARM Norway, AS and ARM Sweden AB.

OpenCL

OpenCL is a trademark of Apple Inc. used under license to the Khronos Group Inc.

NVIDIA Corporation | 2788 San Tomas Expressway, Santa Clara, CA 95051
http://www.nvidia.com

Trademarks

NVIDIA, the NVIDIA logo, and cuBLAS, CUDA, CUDA Toolkit, cuDNN, DALI, DIGITS, DGX, DGX-1, DGX-2, DGX Station, DLProf, GPU, JetPack, Jetson, Kepler, Maxwell, NCCL, Nsight Compute, Nsight Systems, NVCaffe, NVIDIA Ampere GPU architecture, NVIDIA Deep Learning SDK, NVIDIA Developer Program, NVIDIA GPU Cloud, NVLink, NVSHMEM, PerfWorks, Pascal, SDK Manager, T4, Tegra, TensorRT, TensorRT Inference Server, Tesla, TF-TRT, Triton Inference Server, Turing, and Volta are trademarks and/or registered trademarks of NVIDIA Corporation in the United States and other countries. Other company and product names may be trademarks of the respective companies with which they are associated.

Copyright

NVIDIA Corporation | 2788 San Tomas Expressway, Santa Clara, CA 95051
http://www.nvidia.com