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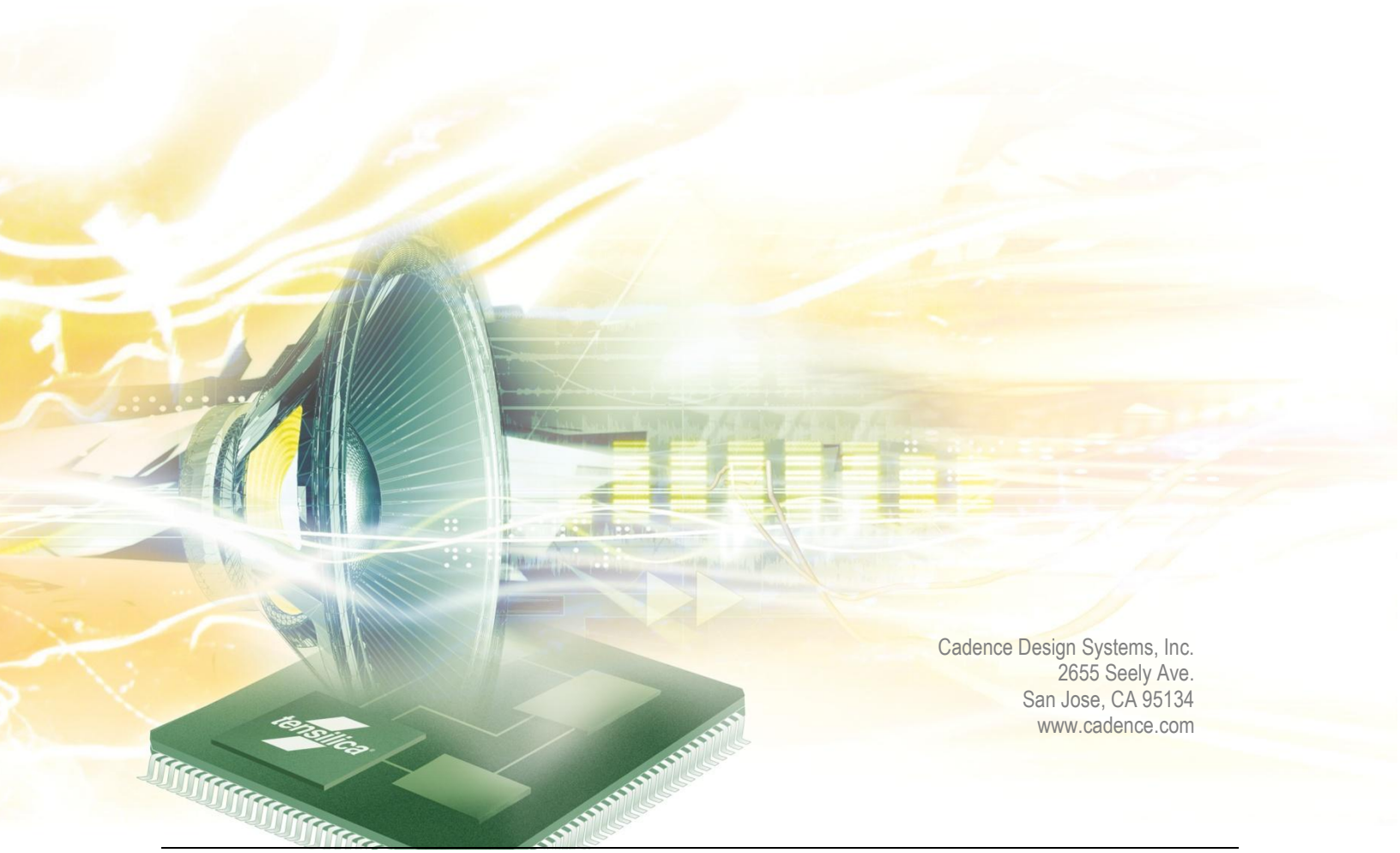
HiFi 5 Neural Network Library

Programmer's Guide - API

For HiFi 5/5s DSPs



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Abbreviations

CNN	Convolutional Neural Networks
LSTM	Long Short-Term Memory
GRU	Gated Recurrent Unit
TFLM	TensorFlow Lite for Micro-controllers
VFPU	Vector Floating Point Unit
LSH	Locality Sensitive Hashing
RNN	Recurrent Neural Network
SVDF	Singular Value Decomposition Filters

Document Change History

Version	Changes
1.0	■ Initial version
1.1	■ Added quantized 8 bit variants for depthwise convolution, fully connected and softmax
1.2	■ Added quantized 8 bit kernels for SVDF support and for standard convolution, average pooling, and quantization.
1.3	■ Added quantized 8 bit kernels (asymmetric int8) for pointwise convolution, max pooling, elementwise addtion and multiplication.
1.4	■ Added description of 8 bit kernels (asymmetric int8) for elementwise compare operations, elementwise subtraction, maximum, minimum, tanh, prelu and hardswish.
1.5	■ Added description of logical operation kernels (Boolean 1-byte) for elementwise logical_and, logical_or, logical_not operations. ■ Added per channel quantized sym8s kernel, asym8s input, asym8s output – dilated 2D convolution (without stride support). ■ Added desciption of L2 Normalization, reduce mean, reduce max kernels (asymmetric int8). ■ Added description of boradcast variants of elementwise maximum, minumum kernels.
1.6	■ Updated Tensorflow Lite For Microcontrollers (TFLM) operator support table with newly supported operators. Added a separate table for TFLM operators which are optimized without any NNLib kernels. ■ Standard 2D convolution with Dilation description is updated to support stride. ■ Added description for matXvec batch kernels with accumulation. ■ Added descriptions for 16-bit input/output sigmoid and tanh. ■ Added description for following quantized int8 kernel: leaky_relu. ■ Elementwise Quantize kernels are renamed to Elementwise Requantize, two new variants are also added. ■ Added description for Elementwise Dequantize kernels (quantized int8 to float32). ■ Added descriptions for following float32 kernels: add, abs, sin, cos, log, sqrt, rsqrt, square, fill, ceil, round, neg. ■ Added description for 8-bit broadcast kernel. ■ Added descriptions for following memory operation kernels: memset (float32), memmove.

	■ L2 Normalization kernel description moved to “Normalization Kernels” section from "Basic Operations and Miscellaneous Kernels". ■ Added description for following 8-bit reorg kernels: depth_to_space, space_to_depth, pad, batch_to_space, space_to_batch. ■ Added sample testbench descriptions for reorg sample testbench. Updated matXvec, conv, activation, basic testbench descriptions.
1.7	■ Updated the API for dilated conv2d std getsize function. ■ Created separate performance document, and removed the performance data from this document.
1.8	■ Updated Tensorflow Lite For Microcontrollers (TFLM) operator support table with newly supported operators and precisions. ■ Single Rounding support for Tensorflow Lite Micro operators’ quantized datatype kernels. ■ Improved optimization for TensorFlow Lite Micro variants of Sigmoid and Tanh kernels. ■ Matrix X Vector Multiplication and Fully Connected kernels added with asym8sxasym8s_asym8s datatype support. ■ Matrix Multiplication kernels added with per_chan_sym8sxsym16s_sym16s and asym8sxasym8s_asym8s datatype support. ■ Added Transpose Convolution and Strided Slice kernels for Int16 datatype. ■ Added Int16 support for following kernels : Standard 2D Convolution, Pointwise 2D Convolution, Leaky ReLU, Pad. ■ Added Quantize single precision float to quantized Int8 and Requantize quantized Int8 to quantized Int8 kernels. ■ Added following quantized datatype elementwise kernels with 4D broadcasting: Add (Int8 and Int16), Sub (Int8 and Int16), Mul (Int8), Squared Diff (Int8). ■ Updated matXvec, conv, activation, basic and reorg testbench descriptions.
1.9	■ Added matXvec, fully connected, conv2d_depth for sym8sxsym16s_sym16s ■ Added elm_requantize_asym16s_asym16s, strided_slice_int8 ■ Updated Tensorflow Lite For Microcontrollers (TFLM) operator support table with newly supported operators and precisions.
2.0	■ Added get_softmax_scratch_size helper API in softmax section. Reviewed and corrected some minor errors/typos. ■ Updated the TFLM operator support table. Also sorted the table alphabetically. ■ Added matmul 8x16_16, 16x16_16 and f32xf32_f32 variants.
2.1	■ Added sigmoid and tanh kernels for sym16sxsym16s precisions. ■ Added matmul kernel for sym8sxsym16s_sym16s precision. ■ Added elm_mul_broadcast_4D_sym16sxsym16s_sym16s, elm_dequantize_asym16s_f32, elm_quantize_f32_asym16s, elm_sub_broadcast_4D_f32xf32_f32 kernels.

	■ Added transpose_8_8, pad_32_32, strided_slice_int32 kernels. ■ Added dilated_conv2d_depthwise kernel for f32 and sym8sxasym8s precisions. Also added dilated_conv2d_depthwise_getsize helper API for this kernel. Also added transpose_conv_f32 kernel. ■ Added LSTM helper API kernels elm_add_16x16_16, elm_mul_sym16sxsym16s_asym8s, lstm_cell_state_update_16. ■ Updated Error codes for GRU API. Added pytorch equations for GRU.
2.2	■ Added the transpose convoluion kernel for the sym8sxasym8s_asym8s precision. ■ Added the squared difference broadcast 4D kernel for the sym16sxsym16s_sym16s precision. ■ Added reduce mean 4D & reduce max 4D kernels for the asym16s precision. ■ Added the memmove kernel for the int16 precision.
2.3	■ Added fully_connected, conv2d_std, conv2d_depthwise, matmul and conv2d_pointwise kernels for the half-precision floating point (f16) precision. ■ Added the fully_connected kernel for the asym4sxasym8s_asym8s precision, and the conv2d_std kernel for the sym4sxasym8s_asym8s precision. ■ Added the conv2d_group kernel (for group convolution) for the sym8sxasym8s_asym8s precision.
3.0	■ Added batch_norm_3D and resize_bilinear kernels for the 8-bit precision. ■ Added the batched fully connected kernel for the asym4sxasym8s precision. ■ Removed sigmoid, tanh, relu_std, relu, relu1, relu6, and softmax kernels for 32-bit precisions. ■ Added tanh and sigmoid kernels for the half-precision float (f16) precision. ■ Added xa_nn_conv2d_per_chan support for the sym8sxsym16s_sym16s precision. ■ Replaced the group convolution kernel xa_nn_conv2d_group_sym8sxasym8s with xa_nn_conv2d_per_chan_sym8sxasym8s. Also added xa_nn_conv2d_getsize API for these kernels. ■ Arguments for xa_nn_conv2d_std_getsize API are altered.
3.1	■ Added kernels xa_nn_concat_8_8, xa_nn_split_v_8_8, xa_nn_transpose_16_16. ■ Added requantize kernel for asym8u_asym8s precision(xa_nn_elm_requantize_asym8u_asym8s). ■ Added softmax kernel for sym16s_16 precision (xa_nn_softmax_sym16s_16).
3.2	■ Added kernel xa_nn_dilated_conv2d_std for 16-bit quantized datatype. ■ Added _v2 kernels with fused min-max activation, stricter alignment requirements and provision for DMA config (currently unused) for xa_nn_matXvec, xa_nn_matmul, xa_nn_transpose_conv, xa_nn_conv2d_std, xa_nn_conv2d, xa_nn_dilated_conv2d_std, xa_nn_conv2d_depthwise, xa_nn_conv2d_pointwise, xa_nn_fully_connected functions for 8-bit and 16- bit quantized datatypes. ■ Added _v2 kernels with fused min-max activation, stricter alignment requirements and provision for DMA config (currently unused) for xa_nn_dilated_conv2d_depthwise function for 8-bit quantized datatype.

	■ Added batch matrix multiplication kernels for asym8s and sym16s precisions. ■ Added elementwise requantize kernels for asym8s input and asym8u, asym16s, asym16u output. ■ Added xa_nn_renorm_asym8s_asym8s, xa_nn_shuffle_3D_8_8 kernels.
4.0	■ Added elementwise select_32, compare_f32, min_f32, max_f32, clamp_f32 kernels. ■ Added 4D broadcasting variant for basic kernels like add_f32, mul_f32, div_f32, min_f32 , max_f32, select_32 and compare_f32 ■ Added new kernels xa_nn_transpose_32_32, xa_nn_broadcast_32_32, xa_nn_concat_32_32. ■ Added xa_nn_elm_quantize_f32_asym8u, xa_nn_elm_dequantize_asym8u_f32 variants for quantize and dequamtize kernels. ■ Added xa_nn_dilated_conv2d_depthwise_v2_per_chan_sym8sxsym16s kernel. ■ Added lstm kernel for precision sym8sxasym8s_16. ■ Added layer normalization calc and apply APIs for 8-bit and 16-bit input precision.
4.1	■ Added xa_nn_elm_requantize_asym32s_asym16s, xa_nn_elm_requantize_asym32s_asym8s ■ Added xa_nn_gru_hidden_state_update_8, xa_nn_gru_sym8sxasym8s ■ Added bit-exact implementation of xa_nn_matmul_f32xf32_f32, xa_nn_transpose_conv_f32 and xa_nn_matXvec_f32_circ kernels. ■ Added odd weight depth support for fully_connected_asym4sxsym8s_asym8s ■ Added odd rowstride support for matXvec_asym4sxasym8s_asym8s ■ Added hidden FC biases support in LSTM kernel and backward LSTM support ■ Added CSTUB build support

1.Introduction to the HiFi 5 NN Library

The HiFi 5 Neural Network (NN) Library is a HiFi-optimized implementation of various NN layers and low-level NN kernels. The library is designed with speech and audio neural network domain focus. The low-level NN kernels are HiFi-optimized building blocks for NN layer implementation with a generic and simple interface. The NN layers are built using low-level kernels and accept input in the form of 'shapes'[1] (up to four dimensions) and produce the output, in the form of shapes. The layers use the weights or coefficients and biases stored 'externally'[2] for their operation. The shape of the input, output, weights, and biases are as per the layer's design.

This guide refers to the HiFi 5 NN Library as HiFi NN Library, NN layers simply as layers, and low-level NN kernels as low-level kernels. The current version of the library implements GRU, LSTM (forward path), and CNN layers. It also implements matrix vector multiply, activation, pooling, convolution, fully connected, basic operation, normalization, and reorg functions as low-level kernels.

Note This version of the library supports HiFi 5/5s DSPs with the NN Extension enabled. The SP-VFPU (Single Precision Vector Floating Point Unit) and HP-VFPU (Half Precision Vector Floating Point Unit) are optional. The library can be compiled for HiFi 5 DSPs with or without enabling the SP-VFPU or HP-VFPU. If the core does not have SP-VFPU or HP-VFPU (or both), the APIs for related precisions will not be available.

Note This version of the HiFi5 NN Library is tested with the xt-clang/xt-clang++ compilers using Xtensa Software Tools from the RJ-2024.3 release.

1.1 Organization of the HiFi 5 NN Library Package

The HiFi NN Library package includes the HiFi NN library containing all layers and low-level kernels implementations and a set of sample test applications (for layers and low-level kernels).

The HiFi NN library implements a set of NN layers. The application can instantiate these layers and connect inputs and outputs across the layers to form a Neural Network system.

The HiFi NN library also provides a set of low-level NN kernels. The application can use these kernels to implement or optimize the performance of other NN layers.

[1] Refer to Section 2.1 Shape

[2] Refer to Section 2.2.3 Weights and Biases Memory

The sample test applications implement a file-based application to test an instance of a layer or low-level NN kernels for the given specification using pre-generated input, weight or coefficients, and bias shapes stored in the files in raw binary format.

1.1.1 Document Overview

This document covers all the information required to integrate the HiFi NN Library into a Neural Network system. All the layers implement “HiFi NN layer APIs”, which are generic and explained in Section 2. The low-level NN kernels are explained in Section 3. Section 3.8.10 describes the APIs for each layer. Section 5 provides details about available sample testbenches. Section 6 lists the references.

1.2 HiFi 5 NN Library Specification

The current version of the HiFi NN Library provides the following HiFi optimized low-level kernels and layer implementations.

1.2.1 Low-Level Kernels

Matrix-vector multiplication kernels

Convolution kernels

Activation kernels

Pooling kernels

Basic operations kernels

Fully connected kernels

Normalization kernels

Reorg kernels

These kernels support fixed point 8-bit, 16-bit, single precision floating point (float32/f32), and half precision floating point (float16/f16) data types for weights or coefficients, biases, input, and output. For more information, see Section 3. Both float32 and float16 are IEEE-754 compliant data types.

Additionally, 8-bit and 16-bit quantized datatypes as defined in TensorFlow (TF), TensorFlow Lite for Microcontrollers (TFLM) are also supported for select kernels [3]. These datatypes use 8-bit/16-bit quantized values (asym8u – asymmetric 8-bit unsigned, asym8s – asymmetric 8-bit signed, sym8s – symmetric 8-bit signed) for weights or coefficients, input, and output. Biases are 32-bit quantized values.

8-bit quantized types are either unsigned (0, 255) or signed (-128, 127) 8-bit integers with three additional parameters.

Three numbers are associated with a quantized 8-bit value that can be used to convert the 8-bit integer to the real value and vice versa. These numbers are:

Shift: an integer value indicating the amount of shift. If the value is positive, it is left shift, and if negative, it is right shift

Multiplier: a 32-bit (Q31) fixed point value greater than zero.

Zero point: a 32 bit integer, in the range [0, 255] for unsigned type, in the range [-128, 127] for signed type.

The formula is:

$$real\_value = (quantized\_value - zero\_point) * 2^{shift} * multiplier$$

The 'sym8s' type is symmetrical around 0, which means that quantized values are between -127 to 127 and the zero point is 0. Thus, all the calculations required due to the zero point are avoided.

To match the asym8u/asym8s/sym8s APIs with TensorFlow, we define zero point as zero_bias in the NN library APIs. The zero_bias is an integer value having range asym8u - [0, 255], asym8s – [-128, 127] (or asym8u - [-255, 0], asym8s – [-127, 128] in case of the reverse operation depending on the corresponding TensorFlow kernel).

In addition to the quantized 8-bit datatypes, a similar 16-bit quantized datatype (asym16s) is used for a few kernels. The zero_bias for asym16s datatype is an integer value having range – [-32768, 32767].

With HiFi 5 NN Library v3.2, _v2 API variants are added for some low-level kernels. _v2 APIs have min-max activation functions fused with kernel wherever applicable or required. These kernels also have stricter requirements on input and output buffer alignment for cycle performance, and stricter requirements on data formats for code size optimization, see respective API description in Chapter 3 for details. These APIs also add a placeholder for the DMA config structure for DMA support in upcoming versions, it is unused currently. Note that these _v2 APIs are in the beta stage and may change in the next version.

1.2.2 Layers

GRU layer (8x16, 16x16 precision)

LSTM (forward path) layer (8x16, 16x16 precision)

CNN layer (8x8, 8x16, 16x16, and float32xfloat32 precision)

Note MxN precision above denotes (weights or coefficients) x (input, output, bias) precision. For more information, see Section 3.8.10.

1.2.3 Support for TensorFlow Lite Micro Operators

The HiFi 5 NN Library low-level kernels can be used to implement the following operators of TensorFlow Lite Micro. HiFi5 NN Library supports both rounding modes available in TensorFlow Lite Micro for applicable operators[5.1] :

No.	Operator	Float32 Datatype Support	Uint8 (asymmetric quantized uint8) Datatype Support	Int8 (quantized int8) Datatype Support	Int16 (quantized int16) Datatype Support	Boolean (1 Byte) Datatype Support
1	ABS	Yes				
2	ADD	Yes		Yes	Yes	
3	AVERAGE_POOL_2D	Yes	Yes	Yes		
4	BATCH_TO_SPACE_ND			Yes		
5	CEIL	Yes				
6	CIRCULAR_BUFFER			Yes		
7	CONCAT			Yes		
8	CONV_2D	Yes	Yes	Yes	Yes	
9	COS	Yes				
10	DEPTH_TO_SPACE			Yes		
11	DEPTHWISE_CONV_2D	Yes	Yes	Yes		
12	DEQUANTIZE			Yes[3]	Yes	
13	EQUAL			Yes		
14	FILL	Yes				
15	FLOOR	Yes				
16	FULLY_CONNECTED	Yes	Yes	Yes	Yes	
17	GREATER			Yes		
18	GREATEREQUAL			Yes		
19	HARDSWISH			Yes		
20	L2 NORM	Yes		Yes		
21	LEAKY_RELU			Yes	Yes	
22	LESS			Yes		
23	LESSEQUAL			Yes		
24	LOG	Yes				
25	LOGICALAND					Yes
26	LOGICALNOT					Yes
27	LOGICALOR					Yes
28	LOGISTIC	Yes		Yes	Yes	
29	MAX_POOL_2D	Yes		Yes		
30	MAXIMUM			Yes		
31	MEAN			Yes		
32	MINIMUM			Yes		
33	MUL	Yes		Yes	Yes	
34	NEG	Yes				

[3] For TFLM DEQUANTIZE operator, output is always single precision float whereas multiple input data types are supported. The HiFi 5 NN Library has kernel for quantized Int8 and quantized Int16 input data type.

No.	Operator	Float32 Datatype Support	Uint8 (asymmetric quantized uint8) Datatype Support	Int8 (quantized int8) Datatype Support	Int16 (quantized int16) Datatype Support	Boolean (1 Byte) Datatype Support
35	NOTEQUAL			Yes		
36	PAD	Yes		Yes	Yes	
37	PADV2			Yes	Yes	
38	PRELU			Yes		
39	QUANTIZE[4]		Yes	Yes	Yes	
40	REDUCEMAX			Yes	Yes	
41	RELU	Yes	Yes	Yes		
42	RELU6	Yes	Yes	Yes		
43	ROUND	Yes				
44	RSQRT	Yes				
45	SIN	Yes				
46	SOFTMAX		Yes	Yes	Yes	
47	SPACE_TO_BATCH_ND			Yes		
48	SPLIT_V			Yes		
49	SQRT	Yes				
50	SQUARE	Yes				
51	SQUARED_DIFF			Yes	Yes	
52	STRIDED_SLICE	Yes		Yes	Yes	
53	SUB	Yes		Yes	Yes	
54	SVDF			Yes		
55	TANH	Yes		Yes	Yes	
56	TRANSPOSE			Yes	Yes	
57	TRANSPOSE_CONV	Yes		Yes	Yes[5]	
58	UnidirectionSequenceLSTM			Yes		

The following TFLM operators get optimized out of box on HiFi 5 and do not require any HiFi 5 NNLib kernels:

No.	Operator	Float32 Datatype Support	Uint8 (asymmetric quantized uint8) Datatype Support	Int8 (quantized int8) Datatype Support	Int32	Int64	Boolean (1 Byte) Datatype Support
1	PACK	Yes	Yes	Yes	Yes	Yes	
2	EXPAND_DIMS	Yes		Yes			

[4] QUANTIZE operator has different input and output quantized data types, HiFi5 NN Library has kernels for Unsigned Int8 to Int8, Int16 to Int8, Int8 to Int32, Int16 to Int32, int8 to int8, Float32 to Int8, Float32 to Int16, and Int16 to Int16.

[5] Two variants are available – sym8s kernel with sym16s input, and float 32-bit kernel with float 32-bit output.

3	RESHAPE[6]						
4	ELU			Yes			
5	SQUEEZE[7]						

[6] For RESHAPE, the datatype is not specified in TensorFlow Lite Micro.

[7] For SQUEEZE, the datatype is not specified in TensorFlow Lite Micro.

2. Generic HiFi NN Layer API

Note This section explains an evolving API standard. The APIs may undergo some changes in future versions.

This section describes the API that is common to all the HiFi NN layers. The API facilitates any layer instance that works in the overall method shown in Figure 2-1.

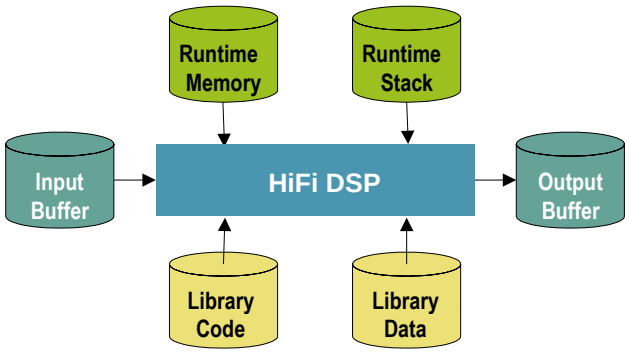

Figure 2-1 HiFi NN Layer Interfaces

All the buffers, input, output, weights, and biases are described as shapes. Section 2.1 explains the shape structure.

Section 2.2 discusses all the types of runtime memory required by the layer instances. There is no state information held in static memory, therefore, a single thread can perform time division processing of multiple layer instances. Additionally, multiple threads can perform concurrent layer instance processing.

If the precision and dimension match, the output from one instance can be fed as input to the next.

The data types, structures, and error codes explained in this section are declared/defined in `xa_nnlib_standards.h`. By default, each layer's API header file includes this header file; the application need not include it.

2.1 Shape

The shapes are used to describe any buffer used in the NN library. The structure xa_nnlib_shape_t is defined in `xa_nnlib_standards.h`. The shape can be vector, matrix, or cube.

Vector is a one-dimensional shape specified by length.

Matrix is a two-dimensional shape specified by rows, columns, and row_offset. This assumes that the elements in a row are stored at consecutive addresses in memory.

Cube is a three-dimensional shape specified by height, width, depth, height_offset, width_offset, and depth offset. Cube supports the following shape types:

- SHAPE_CUBE_DWH_T

  This assumes that elements are stored in depth (D), width (W), and height (H) order; that is, elements with the same height and width indices are stored consecutively. In other words, in memory, depth is the innermost dimension, width is the middle dimension, and height is the outer dimension. This type is also referred to as the NHWC or DWHN format or the depth-first format (N = Number of batches, H = Height, W = Width, C = Channels / depth).

- SHAPE_CUBE_WHD_T

  This assumes that elements are stored in width (W), height (H), and depth (D) order; that is, elements with the same height and depth are stored consecutively. In other words, in memory, width is the innermost dimension, height is the middle dimension, and depth is the outer dimension. This type is also referred to as the NCHW format or the width-first format (N = Number of batches, C = Channels / depth, and H = Height, W = Width).

Figure 2-2 explains the dimension variables of matrix and cube shapes.

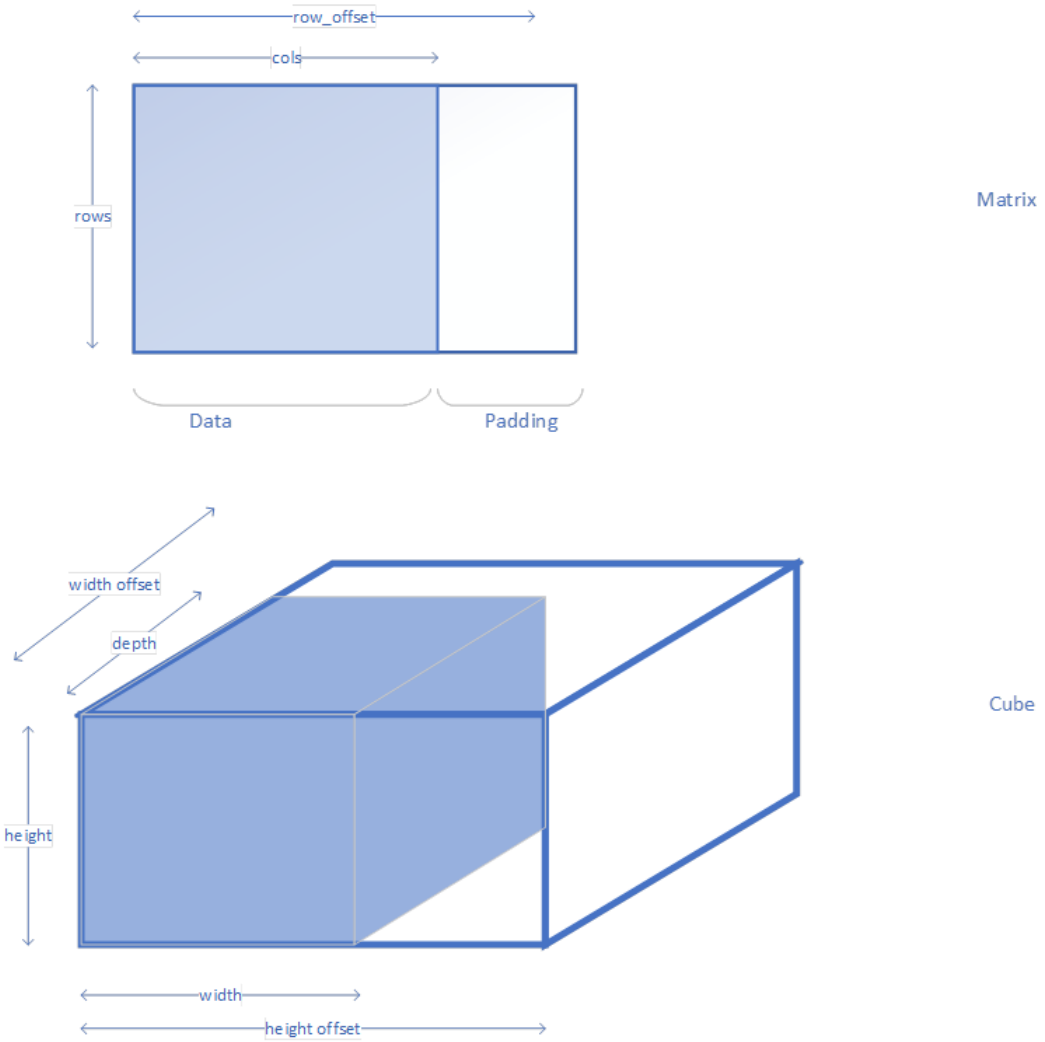

Figure 2-2 Matrix and Cube (SHAPE_CUBE_DWH_T) Shape Representation

2.2 Memory Management

The HiFi NN layer API supports a flexible memory scheme and a simple interface that eases integration into the final application. The API allows the layers to request the required memory for their operations during runtime.

The runtime memory requirement consists primarily of scratch and persistent memory. The components also require an input buffer and output buffer for the passing of data into and out of the layer.

2.2.1 API Handle / Persistent Memory

The layer API stores persistent state information in a structure that is referenced through an opaque handle. The handle is passed by the application for each API call. This object contains all state and history information that is maintained from one-layer frame invocation to the next within the same thread or instance. The layers expect that the contents of the persistent memory be unchanged by the system apart from the layer itself for the complete lifetime of the layer.

2.2.2 Scratch Memory

This is the temporary buffer the layer uses during a single frame processing call. The contents of this memory region must not be changed if the actual layer execution process is active; that is, if the thread running the layer is inside any API call. The system can use this region freely between successive calls to the layer.

2.2.3 Weights and Biases Memory

The application must manage theweights or coefficients and biasesand the API must not request the memory. If the design requires DMA access from or to the internal memory for better performance, a ping-pong or circular buffer is allocated as part of the scratch into which the weights, biases, input, and output are copied using DMA. If require d, these memories can also be persistent.

2.2.4 Input Buffer

This is the buffer from which the layer reads the input. This buffer must be made available for the layer before its execution call. The input buffer must have an associated shape information to describe the input data format. The application between calls to the layer can change the input buffer pointer, but shape information cannot be changed. This allows the layer to read directly from the output of another layer.

2.2.5 Output Buffer

This is the buffer to which the layer writes the output. This buffer must be made available for the layer before its execution call. The output buffer must have an associated shape information to which the layer can describe the output data format. The application between calls to the layer can change the output buffer pointer. This allows the layer to write directly to the input of another layer.

2.3 Generic API Errors

The Layer API functions return an error code of type `Int32`, which is of type `signed int`. The format of the error codes is defined in the following table.

31	30 – 27	26-12	11 – 7	6 - 0
Fatal	Class	Reserved	Component	Sub code

The errors that can be returned from the API are subdivided into those that are fatal, which require resetting the layer and those that are nonfatal and are provided for information to the application.

The class of an error can be API, Config, or Execution. API category errors are concerned with the incorrect use of the API. Config errors are produced when the layer parameters are incorrect or outside the supported usage. Execution errors are returned after a call to the main process and indicate situations that have arisen due to the input data.

Reserved, Component, and Sub code error bits are unused for HiFi 5 NNLib.

2.3.1 Common API Errors

The following errors are fatal and must not be encountered during regular application operation. They signal that a serious error has occurred in the application calling the layer.

XA_NNLIB_FATAL_MEM_ALLOC

At least one of the pointers passed into the API function is NULL.

XA_NNLIB_FATAL_MEM_ALIGN

At least one of the pointers passed into the API function is not properly aligned.

XA_NNLIB_FATAL_INVALID_SHAPE

At least one of the shapes passed to the API function is invalid.

2.4 C Language API

An overview of the NN layer flow is shown in Figure 2-3. The NN layer API consists of query, initialization, and execution functions.

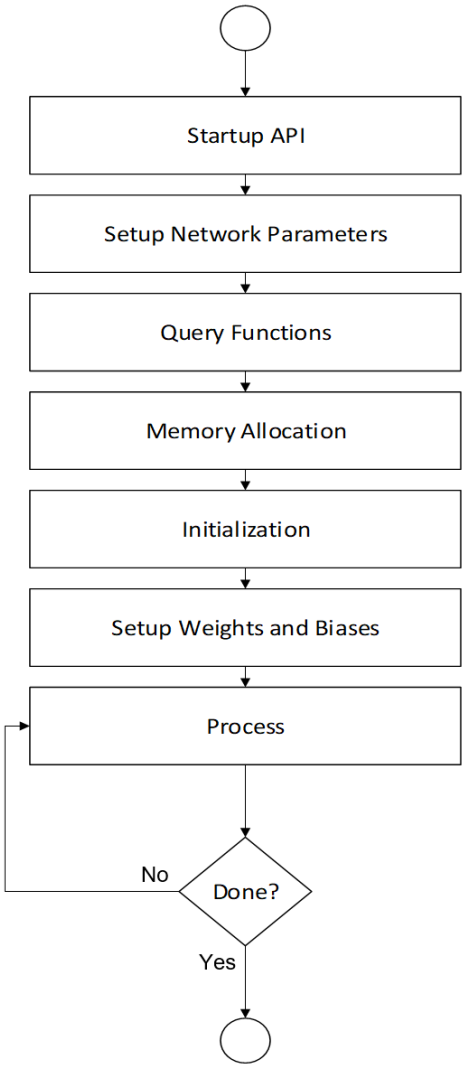

Figure 2-3 NN Layer Flow Overview

2.4.1 Startup Functions

The API startup functions shown in Table 2-1 get the various identification strings from the component library. They are for information only, and their usage is optional. These functions do not take any input arguments and return `const char *`.

Table 2-1 Library Identification Functions

Function	Description
`xa_nnlib_get_lib_name_string`	Get the name of the library.
`xa_nnlib_get_lib_version_string`	Get the version of the library.
`xa_nnlib_get_lib_api_version_string`	Get the version of the API.

Example

```
const char *name = xa_nnlib_get_lib_name_string();
const char *ver = xa_nnlib_get_lib_version_string();
const char *aver = xa_nnlib_get_lib_api_version_string();
```

Errors

None

2.4.2 Query Functions

The query functions are used in the startup and memory allocation stages to obtain information about the memory requirements of the library.

The following is the naming convention for the query functions:

```
xa_nnlib_<layer>_get_{persistent | scratch}_fast
```

Where:

<layer> indicates the module name (gru | lstm | cnn).

2.4.3 Initialization Functions

The initialization functions reset the layer to its initial state. Because the layers are fully re-entrant, the application can initialize the layer multiple times.

The following is the naming convention for the initialization functions:

```
xa_nnlib_<layer>_init
```

2.4.4 Execution Functions

The execution functions generate the output shape by processing one input shape.

The following is the naming convention for the execution functions:

```
xa_nnlib_<layer>_process
```

3. HiFi 5 NN Library – Low-Level Kernels

This section explains the low-level kernels provided in the NN library. All the low-level kernels have a generic and simple interface.

The NN library is a single archive containing all low-level kernels and layer implementations. The following sections explain each low-level kernel in detail.

3.1 Matrix X Vector Multiplication Kernels

3.1.1 Matrix X Vector Kernels

Description

The Matrix X Vector kernels perform the dual matXvec operation with bias addition; `z = mat1*vec1 + mat2*vec2 + bias`. The column dimension of `mat1` must match the row dimension of `vec1` and similarly for `mat2`, `vec2`. Bias and resulting output vector `z` have as many rows as `mat1` and `mat2`.

The kernel API provides the `bias_shift` and `acc_shift` arguments to adjust the Q format of bias and output, respectively. Both `bias_shift` and `acc_shift` can be either positive or negative, where a positive value denotes a left shift and a negative value denotes a right shift.

`bias_shift` is the shift in the number of bits applied to the bias to make it in the same Q format as matXvec multiplication – accumulation result. `acc_shift` is the shift in the number of bits applied to the accumulator to obtain the output in the required Q format.

Note The `acc_shift` and `bias_shift` arguments are not relevant in the case of floating-point kernels and quantized 8-bit kernels.

The `row_stride1` and `row_stride2` arguments are provided in kernel API for row offsets of `mat1` and `mat2`, respectively.

Note The input matrices are expected to be appropriately padded in case of `row_stride > cols`.

For conversion from a higher precision accumulator to a lower precision output, symmetric rounding is used.

The arguments, `mat1_zero_bias, mat2_zero_bias, vec1_zero_bias, vec2_zero_bias,` are provided to convert the quantized 8-bit inputs into their real values and perform matXvec operation. The `out_zero_bias`, `out_multiplier`, and `out_shift` values are used to quantize real values of output back to 8-bit.

The _v2 variants do not support mat2, vec2 multiplication and have fused minmax activation operation.

The function variants are available as `xa_nn_matXvec_[p]x[q]_[r]` and `xa_nn_matXvec_v2_[p]x[q]_[r]` where:

`[p]`: Matrix precision in bits

`[q]`: Vector precision in bits

`[r]`: Output precision in bits

Precision

The following fourteen variants are available for `xa_nn_matXvec_[p]x[q]_[r]`:

Type	Description
16x16_16	16-bit matrix inputs, 16-bit vector inputs, 16-bit output
16x16_32	16-bit matrix inputs, 16-bit vector inputs, 32-bit output
16x16_64	16-bit matrix inputs, 16-bit vector inputs, 64-bit output
8x16_16	8-bit matrix inputs, 16-bit vector inputs, 16-bit output
8x16_32	8-bit matrix inputs, 16-bit vector inputs, 32-bit output
8x16_64	8-bit matrix inputs, 16-bit vector inputs, 64-bit output
8x8_8	8-bit matrix inputs, 8-bit vector inputs, 8-bit output
8x8_16	8-bit matrix inputs, 8-bit vector inputs, 16-bit output
8x8_32	8-bit matrix inputs, 8-bit vector inputs, 32-bit output
f32xf32_f32	float32 matrix inputs, float32 vector inputs, float32 output
asym8uxasym8u_asym8u	asym8u matrix inputs, asym8u vector inputs, asym8u output
sym8sxasym8s_asym8s	sym8s matrix inputs, asym8s vector inputs, asym8s output
asym8sxasym8s_asym8s	asym8s matrix inputs, asym8s vector inputs, asym8s output
sym8sxsym16s_sym16s	sym8s matrix inputs, sym16s vector inputs, sym16s output
asym4sxasym8s_asym8s	asym4s matrix inputs, asym8s vector inputs, asym8s output

The following two variants are available for `xa_nn_matXvec_v2_[p]x[q]_[r]`:

Type	Description
asym8sxasym8s_asym8s	asym8s matrix inputs, asym8s vector inputs, asym8s output
sym8sxsym16s_sym16s	sym8s matrix inputs, sym16s vector inputs, sym16s output

Algorithm

$$z_n = 2^{acc\text{-}shift}\left(\sum_{m=0}^{cols1-1} mat1_{n,m}\cdot vec1_m + \sum_{m=0}^{cols2-1} mat2_{n,m}\cdot vec2_m + 2^{bias\text{-}shift}bias_n\right)$$

For floating-point and quantized 8-bit routines, `acc_shift=0` and `bias_shift=0`.

Thus, $2^{acc\text{-}shift} = 2^{bias\text{-}shift} = 1$

Prototype

```
WORD32 xa_nn_matXvec_16x16_16
(WORD16 * p_out,         WORD16 * p_mat1,        WORD16 * p_mat2,
```

```
 WORD16 * p_vec1,        WORD16 * p_vec2,        WORD16 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_matXvec_16x16_32
(WORD32 * p_out,         WORD16 * p_mat1,        WORD16 * p_mat2,
 WORD16 * p_vec1,        WORD16 * p_vec2,        WORD16 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_matXvec_16x16_64
(WORD64 * p_out,         WORD16 * p_mat1,        WORD16 * p_mat2,
 WORD16 * p_vec1,        WORD16 * p_vec2,        WORD16 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_matXvec_8x16_16
(WORD16 * p_out,         WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD16 * p_vec1,        WORD16 * p_vec2,        WORD16 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_matXvec_8x16_32
(WORD32 * p_out,         WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD16 * p_vec1,        WORD16 * p_vec2,        WORD16 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_matXvec_8x16_64
(WORD64 * p_out,         WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD16 * p_vec1,        WORD16 * p_vec2,        WORD16 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_matXvec_8x8_8
(WORD8 * p_out,          WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD8 * p_vec1,         WORD8 * p_vec2,         WORD8 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_matXvec_8x8_16
(WORD16 * p_out,         WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD8 * p_vec1,         WORD8 * p_vec2,         WORD8 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_matXvec_8x8_32
(WORD32 * p_out,         WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD8 * p_vec1,         WORD8 * p_vec2,         WORD8 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_matXvec_f32xf32_f32
(FLOAT32 * p_out,        const FLOAT32 * p_mat1, const FLOAT32 * p_mat2,
 const FLOAT32 * p_vec1, const FLOAT32 * p_vec2, const FLOAT32 * p_bias,
 WORD32 rows,            WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,     WORD32 row_stride2);
WORD32 xa_nn_matXvec_asym8uxasym8u_asym8u
(UWORD8 * p_out,         const UWORD8 * p_mat1,  const UWORD8 * p_mat2,
 const UWORD8 * p_vec1,  const UWORD8 * p_vec2,  const WORD32 * p_bias,
```

```
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 mat1_zero_bias,
 WORD32 mat2_zero_bias,   WORD32 vec1_zero_bias,  WORD32 vec2_zero_bias,
 WORD32 out_multiplier,   WORD32 out_shift,       WORD32 out_zero_bias);
WORD32 xa_nn_matXvec_sym8sxasym8s_asym8s
(WORD8 * p_out,           const WORD8 * p_mat1,   const WORD8 * p_mat2,
 const WORD8 * p_vec1,    const WORD8 * p_vec2,   const WORD32 * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 vec1_zero_bias,
 WORD32 vec2_zero_bias,   WORD32 out_multiplier,  WORD32 out_shift,
 WORD32 out_zero_bias);
WORD32 xa_nn_matXvec_asym8sxasym8s_asym8s
(WORD8 * p_out,           const WORD8 * p_mat1,   const WORD8 * p_mat2,
 const WORD8 * p_vec1,    const WORD8 * p_vec2,   const WORD32 * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 mat1_zero_bias,
 WORD32 vec1_zero_bias,   WORD32 vec2_zero_bias,  WORD32 out_multiplier,
 WORD32 out_shift,        WORD32 out_zero_bias);
WORD32 xa_nn_matXvec_asym4sxasym8s_asym8s
(WORD8 * p_out,           const WORD4 * p_mat1,   const WORD4 * p_mat2,
 const WORD8 * p_vec1,    const WORD8 * p_vec2,   const WORD32 * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 mat1_zero_bias,
 WORD32 vec1_zero_bias,   WORD32 vec2_zero_bias,  WORD32 out_multiplier,
 WORD32 out_shift,        WORD32 out_zero_bias);

WORD32 xa_nn_matXvec_sym8sxsym16s_sym16s
(WORD16 * p_out,          const WORD8 * p_mat1,    const WORD8 * p_mat2,
 const WORD16 * p_vec1,   const WORD16 * p_vec2,   const WORD64 * p_bias,
 WORD32 rows,             WORD32 cols1,            WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,      WORD32 out_multiplier,
 WORD32 out_shift);
WORD32 xa_nn_matXvec_v2_sym8sxsym16s_sym16s
(WORD16 * __restrict__ p_out,        const WORD8 * __restrict__ p_mat1,
 const WORD16 * __restrict__ p_vec1, const WORD64 * __restrict__ p_bias,
 WORD32 rows,                        WORD32 cols,
 WORD32 row_stride,                  WORD32 out_multiplier,
 WORD32 out_shift,                   WORD32 out_activation_min,
 WORD32 out_activation_max,          xa_dma_cfg_t *p_dma_cfg);

WORD32 xa_nn_matXvec_v2_asym8sxasym8s_asym8s
(WORD8 * __restrict__ p_out,       const WORD8 * __restrict__ p_mat1,
 const WORD8 * __restrict__ p_vec1, const WORD32 * __restrict__ p_bias,
 WORD32 rows,                      WORD32 cols,
 WORD32 row_stride,                WORD32 mat_zero_bias,
 WORD32 vec_zero_bias,             WORD32 out_multiplier,
 WORD32 out_shift,                 WORD32 out_zero_bias,
 WORD32 out_activation_min,        WORD32 out_activation_max,
 xa_dma_cfg_t * p_dma_cfg);
```

Arguments

For `xa_nn_matXvec_[p]x[q]_[r]`:

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *,	p_mat1	rows*cols1	Input matrix 1, fixed, floating point, asym8u or sym8s

Type	Name	Size	Description
const FLOAT32 * const UWORD8 *, const WORD8 *			
WORD16 *, WORD8 *, const FLOAT32 * const UWORD8 *, const WORD8 *	p_mat2	rows*cols2	Input matrix 2, fixed, floating point, asym8u or sym8s
WORD16 *, WORD8 *, const FLOAT32 * const UWORD8 *, const WORD8 *	p_vec1	cols1*1	Input vector 1, fixed, floating point, asym8u, sym16s or asym8s
WORD16 *, WORD8 *, const FLOAT32 * const UWORD8 *, const WORD8 *	p_vec2	cols2*1	Input vector 2, fixed, floating point, asym8u, sym16s or asym8s
WORD16 *, WORD8 *, const WORD32 *, const FLOAT32 *, const WORD64 *	p_bias	rows*1	Bias vector, fixed or floating point
WORD32	rows		Number of rows in matrix 1, 2 and bias
WORD32	cols1		Number of columns in matrix 1 and rows in vector 1
WORD32	cols2		Number of columns in matrix 2 and rows in vector 2
WORD32	row_stride1		Row offset of matrix 1
WORD32	row_stride2		Row offset of matrix 2
WORD32	acc_shift		Shift applied to accumulator
WORD32	bias_shift		Shift applied to bias
WORD32	mat1_zero_bias		Zero offset of matrix 1
WORD32	mat2_zero_bias		Zero offset of matrix 2
WORD32	vec1_zero_bias		Zero offset of vector 1
WORD32	vec2_zero_bias		Zero offset of vector 2
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32	out_zero_bias		Zero offset of output
Output			
WORD8 *, UWORD8 *, WORD16 *, WORD32 *, WORD64 *,	p_out	rows*1	Output, fixed, floating point, asym8u, sym16s or asym8s.

Type	Name	Size	Description
FLOAT32 *			

For xa_nn_matXvec_v2_[p]x[q]_[r]:

Type	Name	Size	Description
Input			
const WORD8 *	p_mat1	rows*cols1	Input matrix 1, fixed point, asym8u or sym8s
const WORD16 *, const WORD8 *	p_vec1	cols1*1	Input vector 1, fixed point, asym8u, sym16s or sym8s
const WORD32 *, const WORD64 *	p_bias	rows*1	Bias vector, fixed point
WORD32	Rows		Number of rows in matrix 1 and bias
WORD32	cols		Number of columns in matrix 1 and rows in vector 1
WORD32	row_stride		Row offset of matrix 1
WORD32	bias_shift		Shift applied to bias
WORD32	mat1_zero_bias		Zero offset of matrix 1
WORD32	vec1_zero_bias		Zero offset of vector 1
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32	out_zero_bias		Zero offset of output
WORD32	out_activation_min		Min value for output minmax activation function
WORD32	out_activation_max		Max value for output minmax activation function
xa_dma_cfg_t *	p_dma_cfg		This is a placeholder
Output			
WORD8 *, WORD16 *,	p_out	rows*1	Output, fixed point, asym8u, sym16s or sym8s

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
row_stride1, row_stride2, cols1, cols2	row_stride1 >= cols1 row_stride2 >= cols2 row_stride=cols1 if row_stride1 value is odd, in asym4sxasym8s_asym8s
p_mat1, p_mat2, p_vec1, p_vec2, p_bias, p_out	Aligned on <size of one element> boundary Aligned on 16-byte boundary for _v2 kernels. Should not overlap
p_mat1, p_vec1, p_out	Cannot be NULL
p_bias	Cannot be NULL (except for asym8uxasym8u, sym8sxasym8s and sym8sxsym16s precisions)

acc_shift, bias_shift, out_shift	{-31, ..., 31}
mat1_zero_bias, mat2_zero_bias, vec1_zero_bias, vec2_zero_bias	{-255,....., 0} for asym8u, {-127,....., 128} for asym8s
out_multiplier	Greater than 0
out_zero_bias	{0,....., 255} if out type is asym8u, {-128,....,127} if out type is asym8s

3.1.2 Fused (Activation) Matrix X Vector Kernels

Description

The Fused (Activation) Matrix X Vector kernels perform the fused dual matXvec operation with an activation function: Z = activation (mat1*vec1 + mat2*vec2 + bias). The column dimension of mat1 must match the row dimension of vec1, and similarly for mat2, vec2. Bias and resulting output vector z have as many rows as mat1 and mat2.

The intermediate output of (mat1*vec1 + mat2*vec2 + bias) is stored in temporary memory provided by the p_scratch argument to kernel API. The Activation function is applied to this intermediate output to get the final output.

Note For fixed point kernels, the activation function always takes input in Q6.25 format.

The bias_shift and acc_shift arguments are provided in the kernel API to adjust the Q format of bias and intermediate output respectively. Both bias_shift and acc_shift can be either positive or negative, where positive value denotes a left shift and a negative value denotes a right shift.

bias_shift is the shift in the number of bits applied to the bias to make it in the same Q format as matXvec multiplication – accumulation result. acc_shift is the shift in the number of bits applied to the accumulator to obtain the intermediate output in Q6.25 format.

Note The acc_shift and bias_shift arguments are not relevant in the case of floating point kernels.

The row_stride1 and row_stride2 arguments are provided in kernel API for row offsets of mat1 and mat2, respectively.

Note The input matrices are expected to be appropriately padded in case of row_stride > cols.

Symmetric rounding is used for conversion from a higher precision accumulator to a lower precision output.

The function variants are available as xa_nn_matXvec_[p]x[q]_[r]_<activation>, where:

[p]: Matrix precision in bits

[q]: Vector precision in bits

`[r]`: Output precision in bits

`<activation>`: activation tag `'tanh'` or `'sigmoid'`

Precision

The following eight variants are available:

Type	Description
`16x16_16_tanh`	16-bit matrix inputs, 16-bit vector inputs, 16-bit output with tanh activation function
`16x16_16_sigmoid`	16-bit matrix inputs, 16-bit vector inputs, 16-bit output with sigmoid activation function
`8x16_16_tanh`	8-bit matrix inputs, 16-bit vector inputs, 16-bit output with tanh activation function
`8x16_16_sigmoid`	8-bit matrix inputs, 16-bit vector inputs, 16-bit output with sigmoid activation function
`8x8_8_tanh`	8-bit matrix inputs, 8-bit vector inputs, 8-bit output with tanh activation
`8x8_8_sigmoid`	8-bit matrix inputs, 8-bit vector inputs, 8-bit output with sigmoid activation
`f32xf32_f32_tanh`	float32 matrix inputs, float32 vector inputs, float32 output with tanh activation
`f32xf32_f32_sigmoid`	float32 matrix inputs, float32 vector inputs, float32 output with sigmoid activation

Algorithm

$$z_n = activation\left(2^{acc\text{-}shift}\left(\sum_{m=0}^{cols1-1} mat1_{n,m}\cdot vec1_m + \sum_{m=0}^{cols2-1} mat2_{n,m}\cdot vec2_m + 2^{bias\text{-}shift} bias_n\right)\right), \quad n = 0,\ldots,\overline{rows-1}$$

In case of the floating point routine, `acc_shift=0` and `bias_shift=0`.

Thus, $2^{acc\text{-}shift} = 2^{bias\text{-}shift} = 1$

$activation$ is `tanh` or `sigmoid`

Prototype

```
WORD32 xa_nn_matXvec_16x16_16_tanh
(WORD16 * p_out,          WORD16 * p_mat1,        WORD16 * p_mat2,
 WORD16 * p_vec1,         WORD16 * p_vec2,        VOID * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 acc_shift,
 WORD32 bias_shift,       WORD32 bias_precision,  VOID * p_scratch);
WORD32 xa_nn_matXvec_16x16_16_sigmoid
(WORD16 * p_out,          WORD16 * p_mat1,        WORD16 * p_mat2,
 WORD16 * p_vec1,         WORD16 * p_vec2,        VOID * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
```

```
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 acc_shift,
 WORD32 bias_shift,       WORD32 bias_precision,  VOID * p_scratch);
WORD32 xa_nn_matXvec_8x16_16_tanh
(WORD16 * p_out,          WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD16 * p_vec1,         WORD16 * p_vec2,        VOID * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 acc_shift,
 WORD32 bias_shift,       WORD32 bias_precision,  VOID * p_scratch);
WORD32 xa_nn_matXvec_8x16_16_sigmoid
(WORD16 * p_out,          WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD16 * p_vec1,         WORD16 * p_vec2,        VOID * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 acc_shift,
 WORD32 bias_shift,       WORD32 bias_precision,  VOID * p_scratch);
WORD32 xa_nn_matXvec_8x8_8_tanh
(WORD8 * p_out,           WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD8 * p_vec1,          WORD8 * p_vec2,         VOID * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 acc_shift,
 WORD32 bias_shift,       WORD32 bias_precision,  VOID * p_scratch);
WORD32 xa_nn_matXvec_8x8_8_sigmoid
(WORD8 * p_out,           WORD8 * p_mat1,         WORD8 * p_mat2,
 WORD8 * p_vec1,          WORD8 * p_vec2,         VOID * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2,     WORD32 acc_shift,
 WORD32 bias_shift,       WORD32 bias_precision,  VOID * p_scratch);
WORD32 xa_nn_matXvec_f32xf32_f32_tanh
(FLOAT32 * p_out,         FLOAT32 * p_mat1,       FLOAT32 * p_mat2,
 FLOAT32 * p_vec1,        FLOAT32 * p_vec2,       FLOAT32 * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2      FLOAT32 * p_scratch);
WORD32 xa_nn_matXvec_f32xf32_f32_sigmoid
(FLOAT32 * p_out,         FLOAT32 * p_mat1,       FLOAT32 * p_mat2,
 FLOAT32 * p_vec1,        FLOAT32 * p_vec2,       FLOAT32 * p_bias,
 WORD32 rows,             WORD32 cols1,           WORD32 cols2,
 WORD32 row_stride1,      WORD32 row_stride2      FLOAT32 * p_scratch);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *	p_mat1	rows*cols1	Input matrix 1, fixed or floating point
WORD16 *, WORD8 *, FLOAT32 *	p_mat2	rows*cols2	Input matrix 2, fixed or floating point
WORD16 *, WORD8 *, FLOAT32 *	p_vec1	cols1*1	Input vector 1, fixed or floating point
WORD16 *, WORD8 *, FLOAT32 *	p_vec2	cols2*1	Input vector 2, fixed or floating point
VOID *, FLOAT32 *	p_bias	rows*1	Bias vector, fixed or floating point
WORD32	rows		Number of rows in matrix 1,2, bias and output
WORD32	cols1		Number of columns in matrix 1 and rows in vector 1

WORD32	cols2		Number of columns in matrix 2 and rows in vector 2
WORD32	row_stride1		Row offset of matrix 1
WORD32	row_stride2		Row offset of matrix 2
WORD32	acc_shift		Shift applied to accumulator
WORD32	bias_shift		Shift applied to bias
WORD32	bias_precision		Precision of bias in bytes
Output			
WORD8 *, WORD16 *, FLOAT32 *	p_out	rows*1	Output, fixed (Q7, Q15) or floating point
Temporary			
VOID *, FLOAT32 *	p_scratch	rows*4	Scratch (temporary) memory pointer

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
row_stride1, row_stride2, cols1, cols2	Multiples of 4 (2 in case of floating point)
p_mat1, p_mat2, p_vec1, p_vec2, p_bias, p_out	Aligned on 16-byte boundary Should not overlap
p_mat1, p_vec1, p_bias, p_out	Cannot be NULL
p_scratch	Cannot be NULL Should not overlap For 16x16 and 8x16 -> Aligned on 4-bytes boundary For 8x8 and f32xf32 -> Aligned on 16-bytes boundary
acc_shift, bias_shift	{-31, ..., 31}
bias_precision	{-1, 8, 16, 32, 64} (-1 in case of floating point)

3.1.3 Matrix X Vector Batch Kernels

Description

The Matrix X Vector Batch kernels perform the operation of multiplication of a single matrix with a series of vectors along with bias addition; that is, `zi = mat1*vec1i + bias`. These kernels can also be viewed as matrix X matrix-transpose multiplication kernels. The column dimension of `mat1` must match the row dimension of vectors in `vec1`. Bias and the resulting output vector sequence `z` have as many rows as `mat1`. `vec1` is a sequence of `vec_count` number of input vectors and bias is added to each resulting vector after multiplication with `mat1`. Thus, output `z` has dimensions `rows*vec_count`. `vec_count` number of input and output vectors are provided as an array of pointers arguments to kernel API.

The `bias_shift` and `acc_shift` arguments are provided in the kernel API to adjust the bias and output O format respectively. Both `bias_shift` and `acc_shift` can be either positive or negative where a positive value denotes a left shift and negative value denotes a right shift.

`bias_shift` is the shift in the number of bits applied to the bias to make it in the same Q format as matXvec multiplication – accumulation result. `acc_shift` is the shift in the number of bits applied to the accumulator to obtain the output in the required Q format.

Note The `acc_shift` and `bias_shift` arguments are not relevant in the case of floating point kernels.

The `row_stride1` argument is provided in kernel API for the row offset of `mat1`.

Note The input matrix is expected to be appropriately padded in case of `row_stride1 > cols1`.

Symmetric rounding to convert from from a higher precision accumulator to a lower precision output.

The function variants are available as `xa_nn_matXvec_batch_[p]x[q]_[r]`, where:

`[p]`: Matrix precision in bits

`[q]`: Vector precision in bits

`[r]`: Output precision in bits

Precision

The following are five variants are available:

Type	Description
`16x16_64`	16-bit matrix inputs, 16-bit vector inputs, 64-bit output vectors
`8x16_64`	8-bit matrix inputs, 16-bit vector inputs, 64-bit output vectors
`8x8_32`	8-bit matrix inputs, 8-bit vector inputs, 32-bit output vectors
`f32xf32_f32`	float32 matrix inputs, float32 vector inputs, float32 output
`asym8uxasym8u_asym8u`	asym8u matrix inputs, asym8u vector inputs, asym8u output vectors

Algorithm

$$z_{n,i} = 2^{acc\text{-}shift}\left(\sum_{m=0}^{cols1-1} mat1_{n,m} \cdot vec1_{m,i} + 2^{bias\text{-}shift} bias_n\right),$$

$$n = 0, \ldots, \overline{rows - 1} \quad ; \quad i = 0, \ldots, \overline{vec\text{-}count - 1}$$

In case of floating point routine, `acc_shift=0` and `bias_shift=0`.

Thus, $2^{acc\text{-}shift} = 2^{bias\text{-}shift} = 1$

Prototype

```
WORD32 xa_nn_matXvec_batch_16x16_64
(WORD64 ** p_out,          WORD16 * p_mat1,        WORD16 ** p_vec1,
 WORD16 * p_bias,          WORD32 rows,            WORD32 cols1,
 WORD32 row_stride1,       WORD32 acc_shift,       WORD32 bias_shift,
 WORD32 vec_count);
WORD32 xa_nn_matXvec_batch_8x16_64
(WORD64 ** p_out,          WORD8 * p_mat1,         WORD16 ** p_vec1,
 WORD16 * p_bias,          WORD32 rows,            WORD32 cols1,
 WORD32 row_stride1,       WORD32 acc_shift,       WORD32 bias_shift,
 WORD32 vec_count);
WORD32 xa_nn_matXvec_batch_8x8_32
(WORD32 ** p_out,          WORD8 * p_mat1,         WORD8 ** p_vec1,
 WORD8 * p_bias,           WORD32 rows,            WORD32 cols1,
 WORD32 row_stride1,       WORD32 acc_shift,       WORD32 bias_shift,
 WORD32 vec_count);
WORD32 xa_nn_matXvec_batch_f32xf32_f32
(FLOAT32 ** p_out,         FLOAT32 * p_mat1,       FLOAT32 ** p_vec1,
 FLOAT32 * p_bias,         WORD32 rows,            WORD32 cols1,
 WORD32 row_stride1,       WORD32 vec_count);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *	p_mat1	rows*cols1	Input matrix, fixed or floating point
WORD16 **, WORD8 **, FLOAT32 **	p_vec1	cols1*vec_count	Input vector pointers, fixed or floating point
WORD16 *, WORD8 *, FLOAT32 *	p_bias	rows*1	Bias vector, fixed or floating point
WORD32	rows		Number of rows in input matrix, bias and output
WORD32	cols1		Number of columns in input matrix and rows in input vector
WORD32	row_stride1		Row offset of input matrix
WORD32	acc_shift		Shift applied to accumulator
WORD32	bias_shift		Shift applied to bias
WORD32	vec_count		Number of input vectors
Output			
WORD32 **, WORD64 **, FLOAT32 **	p_out	rows*vec_count	Output vector pointers, fixed or floating point

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions

row_stride1, cols1	Multiples of 4 (2 in case of floating point)
p_mat1, p_vec1, p_bias, p_out	Aligned on 16-byte boundary Should not overlap Cannot be NULL
acc_shift, bias_shift ,out_shift	{-31, …., 31}
vec_count, out_multiplier	Greater than Zero
out_zero_bias	{0, …, 255}
mat1_zero_bias, vec1_zero_bias	{-255, …, 0}

3.1.4 Matrix Multiplication Kernels

Description

The Matrix Multiplication kernels perform the operation of multiplication of a matrix `mat1` with another matrix `mat2` along with bias addition; that is, `z = mat1 * mat2 + bias`. The first matrix must be stored in row-major order, and the second matrix must be stored in column-major order. The first matrix is of dimensions `rows x cols`. The second matrix `mat2` is of dimensions `cols x vec_count`. These kernels can also be viewed as a modification of the Matrix X Vector Batch kernels. The column dimension of `mat1` matches the row dimension of `mat2`, that is, the length of each vector in `p_mat2`. Bias and the resulting output vector sequence `z` have as many rows as `mat1`. `mat2` is a sequence of `vec_count` number of input vectors and bias is added to each resulting vector after multiplication with `mat1`. Thus, output `z` has dimensions `rows * vec_count`. The arguments `vec_offset`, and `out_offset` are offsets to the next vector and output addresses. The argument `out_stride` defines the row offset for the output matrix. For standard matrix multiplication, `vec_offset` must be equal to `cols`, `out_offset` equal to 1 and `out_stride` must be equal to `vec_count`, that is, columns of mat2.

The `bias_shift` and `acc_shift` arguments are provided in the kernel API to adjust the bias and output Q format, respectively. Both `bias_shift` and `acc_shift` can be either positive or negative where a positive value denotes a left shift and negative value denotes a right shift.

`bias_shift` is the shift in the number of bits applied to the bias to make it in the same Q format as multiplication – accumulation result. `acc_shift` is the shift in number of bits applied to the accumulator to obtain the output in the required Q format.

Note The `acc_shift` and `bias_shift` arguments are not relevant in the case of quantized 8-bit kernels.

The `row_stride` argument indicates the offset to the next row of `mat1`.

The `vec_offset` argument refers to the column offset of `mat2`.

Similarly, the `out_offset` and `out_stride` arguments refer to the column offset and row offset of the output matrix `rows * vec_count`, respectively.

For conversion from a higher precision accumulator to a lower precision output, symmetric rounding is used.

The arguments, `mat1_zero_bias`, and `mat2_zero_bias`, convert the quantized 8-bit inputs into their real values and perform matXvec batch operation. The `out_zero_bias`, `out_multiplier`, and `out_shift` values quantize real values of output back to quantized 8-bit values.

For the quantized int8 variant, we have per-row quantized input `mat1`.

The _v2 kernels have fused minmax activation operation.

Floating point bit-exact support is added for the xa_nn_matmul_f32xf32_f32 kernel.

The function variants are available as `xa_nn_matmul_[p]x[q]_[r]`, where:

`[p]`: Matrix 1 precision in bits

`[q]`: Matrix 2 precision in bits

`[r]`: Output precision in bits

Precision

There are fifteen variants available:

Type	Description
`16x16_16`	16-bit matrix inputs, 16-bit matrix inputs, 16-bit output matrix
`8x16_16`	8-bit matrix inputs, 16-bit matrix inputs, 16-bit output matrix
`8x8_8`	8-bit matrix inputs, 8-bit matrix inputs, 8-bit output matrix
`f32xf32_f32`	float32 matrix inputs, float32 matrix inputs, float32 output matrix
`asym8uxasym8u_asym8u`	asym8u matrix inputs, asym8u matrix inputs, asym8u output matrix
`per_chan_sym8sxasym8s_asym8s`	per channel quantized sym8s vector inputs, asym8s vector inputs, asym8s output vectors
`per_chan_sym8sxsym16s_sym16s`	per channel quantized sym8s vector inputs, sym16s vector inputs, sym16s output vectors
`asym8sxasym8s_asym8s`	asym8s matrix inputs, asym8s matrix inputs, asym8s output matrix
`sym8sxsym16s_sym16s`	sym8s matrix inputs, sym16s matrix inputs, sym16s output matrix
`f16xf16_f16`	float16 matrix inputs, float16 matrix inputs, float16 output matrix
`asym4sxasym8s_asym8s`	asym4s matrix inputs, asym8s matrix inputs, asym8s output matrix
`v2_asym8sxasym8s_asym8s`	asym8s matrix inputs, asym8s matrix inputs, asym8s output matrix. _v2 API
`v2_per_chan_sym8sxasym8s_asym8s`	per channel quantized sym8s matrix inputs, asym8s vector inputs, asym8s output vectors. _v2 API
`v2_per_chan_sym8sxsym16s_sym16s`	per channel quantized sym8s matrix inputs, sym16s vector inputs, sym16s output vectors. _v2 API
`v2_sym8sxsym16s_sym16s`	sym8s matrix inputs, sym16s matrix inputs, sym16s output matrix. _v2 API

Algorithm

$$z_{n,i} = 2^{acc\text{-}shift}\left(\sum_{m=0}^{cols1-1} mat1_{n,m} \cdot mat2_{m,i} + 2^{bias\text{-}shift} bias_n\right),$$

$$n = 0, \ldots, \overline{rows - 1} \;\; ; \;\; i = 0, \ldots, \overline{vec\text{-}count - 1}$$

In case of quantized 8-bit routines, `acc_shift=0` and `bias_shift=0`.

Thus, $2^{acc\text{-}shift} = 2^{bias\text{-}shift} = 1$

Prototype

```
WORD32 xa_nn_matmul_16x16_16
(WORD16 * p_out,          WORD16 * p_mat1,        WORD16 * p_mat2,
 WORD16 * p_bias,         WORD32 rows,            WORD32 cols,
 WORD32 row_stride,       WORD32 acc_shift,       WORD32 bias_shift,
 WORD32 vec_count,        WORD32 vec_offset,      WORD32 out_offset,
 WORD32 out_stride);
WORD32 xa_nn_matmul_8x16_16
(WORD16 * p_out,          WORD8 * p_mat1,         WORD16 * p_mat2,
 WORD16 * p_bias,         WORD32 rows,            WORD32 cols,
 WORD32 row_stride,       WORD32 acc_shift,       WORD32 bias_shift,
 WORD32 vec_count,        WORD32 vec_offset,      WORD32 out_offset,
 WORD32 out_stride);
WORD32 xa_nn_matmul_8x8_8
(WORD8 * p_out,           WORD8 * p_mat1,          WORD8 * p_mat2,
 WORD8 * p_bias,          WORD32 rows,             WORD32 cols,
 WORD32 row_stride,       WORD32 acc_shift,        WORD32 bias_shift,
 WORD32 vec_count,        WORD32 vec_offset,       WORD32 out_offset,
 WORD32 out_stride);
WORD32 xa_nn_matmul_f32xf32_f32
(FLOAT32  * __restrict__ p_out,        const FLOAT32  * __restrict__ p_mat1,
 const FLOAT32  * __restrict__ p_mat2, const FLOAT32  * __restrict__ p_bias,
 WORD32 rows,                          WORD32 cols,
 WORD32 row_stride,                    WORD32 vec_count,
 WORD32 vec_offset,                    WORD32 out_offset,
 WORD32 out_stride);
WORD32 xa_nn_matmul_asym8uxasym8u_asym8u
(UWORD8 * p_out,          const UWORD8 * p_mat1,   const UWORD8 * p_mat2,
 const WORD32 * p_bias,   WORD32 rows,             WORD32 cols,
 WORD32 row_stride,       WORD32 vec_count,        WORD32 vec_offset,
 WORD32 out_offset,       WORD32 out_stride,       WORD32 mat1_zero_bias,
 WORD32 vec1_zero_bias,   WORD32 out_multiplier,   WORD32 out_shift,
 WORD32 out_zero_bias);
WORD32 xa_nn_matmul_per_chan_sym8sxasym8s_asym8s
(WORD8  * p_out,          const WORD8 * p_mat1,    const WORD8 * p_mat2,
 const WORD32 * p_bias,   WORD32 rows,             WORD32 cols,
 WORD32 row_stride,       WORD32 vec_count,        WORD32 vec_offset,
 WORD32 out_offset,       WORD32 out_stride,       WORD32 vec1_zero_bias
 const WORD32 *p_out_multiplier, const WORD32 *p_out_shift,
 WORD32 out_zero_bias);
WORD32 xa_nn_matmul_per_chan_sym8sxsym816s_sym16s
(WORD16  * p_out,         const WORD8 * p_mat1,    const WORD16 * p_mat2,
```

```
 const WORD64 * p_bias,   WORD32 rows,             WORD32 cols,
 WORD32 row_stride,       WORD32 vec_count,        WORD32 vec_offset,
 WORD32 out_offset,       WORD32 out_stride,       WORD32 vec1_zero_bias
 const WORD32 *p_out_multiplier, const WORD32 *p_out_shift,
 WORD32 out_zero_bias);
WORD32 xa_nn_matmul_asym8sxasym8s_asym8s
(WORD8  * p_out,          const WORD8 * p_mat1,    const WORD8 * p_mat2,
 const WORD32 * p_bias,   WORD32 rows,             WORD32 cols,
 WORD32 row_stride,       WORD32 vec_count,        WORD32 vec_offset,
 WORD32 out_offset,       WORD32 out_stride,       WORD32 mat1_zero_bias,
 WORD32 vec1_zero_bias    WORD32 out_multiplier,   WORD32 out_shift,
 WORD32 out_zero_bias);
WORD32 xa_nn_matmul_sym8sxsym16s_sym16s
(WORD16 * p_out,          const WORD8 * p_mat1,    const WORD16 * p_vec1,
 const WORD64 * p_bias,   WORD32 rows,             WORD32 cols1,
 WORD32 row_stride1,      WORD32 vec_count,        WORD32 vec_offset,
 WORD32 out_offset,       WORD32 out_stride,       WORD32 vec1_zero_bias,
 WORD32 out_multiplier,   WORD32 out_shift,        WORD32 out_zero_bias);
WORD32 xa_nn_matmul_f16xf16_f16
 (WORD16 * p_out,         const WORD16 * p_mat1,  const WORD16 * p_vec1,
  const WORD16 * p_bias,  WORD32 rows,            WORD32 cols1,
  WORD32 row_stride1,     WORD32 vec_count,       WORD32 vec_offset,
  WORD32 out_offset,      WORD32 out_stride);
WORD32 xa_nn_matmul_asym4sxasym8s_asym8s
(WORD8 * p_out,           const WORD8 * p_mat1,    const WORD8 * p_mat2,
 const WORD32 * p_bias,   WORD32 rows,             WORD32 cols,
 WORD32 row_stride,       WORD32 vec_count,        WORD32 vec_offset,
 WORD32 out_offset,       WORD32 out_stride,       WORD32 mat1_zero_bias,
 WORD32 vec1_zero_bias,   WORD32 out_multiplier,   WORD32 out_shift,
 WORD32 out_zero_bias,    void * pscratch);
WORD32 xa_nn_matmul_v2_asym8sxasym8s_asym8s
(WORD8 * __restrict__ p_out,        const WORD8 * __restrict__ p_mat1,
 const WORD8 * __restrict__ p_mat2, const WORD32 * __restrict__ p_bias,
 WORD32 rows,                       WORD32 cols,
 WORD32 row_stride,                 WORD32 vec_count,
 WORD32 vec_offset,                 WORD32 out_offset,
 WORD32 out_stride,                 WORD32 mat1_zero_bias,
 WORD32 vec1_zero_bias,             WORD32 out_multiplier,
 WORD32 out_shift,                  WORD32 out_zero_bias,
 WORD32 out_activation_min,         WORD32 out_activation_max,
 xa_dma_cfg_t *p_dma_cfg);
WORD32 xa_nn_matmul_v2_per_chan_sym8sxasym8s_asym8s
(WORD8 * __restrict__ p_out,                 const WORD8 * __restrict__ p_mat1,
 const WORD8 * __restrict__ p_mat2,          const WORD32 * __restrict__ p_bias,
 WORD32 rows,                                WORD32 cols1,
 WORD32 row_stride1,                         WORD32 vec_count,
 WORD32 vec_offset,                          WORD32 out_offset,
 WORD32 out_stride,                          WORD32 vec1_zero_bias,
 const WORD32* __restrict__ p_out_multiplier, const WORD32* __restrict__ p_out_shift,
 WORD32 out_zero_bias,                       WORD32 out_activation_min,
 WORD32 out_activation_max,                  xa_dma_cfg_t * p_dma_cfg);
WORD32 xa_nn_matmul_v2_per_chan_sym8sxsym16s_sym16s
(WORD16 * __restrict__ p_out,                const WORD8 * __restrict__ p_mat1,
 const WORD16 * __restrict__ p_mat2,         const WORD64 * __restrict__ p_bias,
 WORD32 rows,                                WORD32 cols,
```

```
 WORD32 row_stride1,                          WORD32 vec_count,
 WORD32 vec_offset,                           WORD32 out_offset,
 WORD32 out_stride,                           WORD32 vec1_zero_bias,
 const WORD32* __restrict__ p_out_multiplier, const WORD32* __restrict__ p_out_shift,
 WORD32 out_zero_bias,                        WORD32 out_activation_min,
 WORD32 out_activation_max,                   xa_dma_cfg_t   *p_dma_cfg);
WORD32 xa_nn_matmul_v2_sym8sxsym16s_sym16s
(WORD16 * __restrict__ p_out,                 const WORD8 * __restrict__ p_mat1,
 const WORD16 * __restrict__ p_mat2,          const WORD64 * __restrict__ p_bias,
 WORD32 rows,                                 WORD32 cols,
 WORD32 row_stride1,                          WORD32 vec_count,
 WORD32 vec_offset,                           WORD32 out_offset,
 WORD32 out_stride,                           WORD32 vec1_zero_bias,
 WORD32 out_multiplier,                       WORD32 out_shift,
 WORD32 out_zero_bias,                        WORD32 out_activation_min,
 WORD32 out_activation_max,                   xa_dma_cfg_t   *p_dma_cfg);
```

Arguments

Type	Name	Size	Description
Input			
WORD8 *, WORD16 *, UWORD8 *, const WORD8 *, FLOAT32 *	p_mat1	rows*cols	Input matrix 1, f32, f16, fixed point, asym8u, or sym8s
WORD8 *, WORD16 *, UWORD8 *, const WORD8 *, FLOAT32 *	p_mat2	cols * vec_count	Input matrix 2, f32, f16, fixed , asym8u, or sym8s
WORD8 *, WORD16 *, const WORD32 *, FLOAT32 *	p_bias	rows*1	Bias vector, fixed point, f32, or f16
VOID *	pscratch	4*(cols+ 32)+32	Scratch pointer, asym4sxasym8s
WORD32	rows		Number of rows in input matrix, bias and output
WORD32	cols		Number of columns in input matrix and rows in input vector
WORD32	row_stride		Row offset of input matrix
WORD32	acc_shift		Shift applied to accumulator
WORD32	bias_shift		Shift applied to bias
WORD32	vec_count		Number of vectors (columns) in matrix 2
WORD32	vec_offset		Offset to the next vector address
WORD32	out_offset		Offset to the next output address
WORD32	out_stride		Row offset of output matrix
WORD32	mat1_zero_bias		Zero offset of matrix 1
WORD32	vec1_zero_bias		Zero offset of matrix 2
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output

Type	Name	Size	Description
WORD32	out_zero_bias		Zero offset of output
WORD32	out_activation_min		Min value for output minmax activation function This argument is only for _v2 variants
WORD32	out_activation_max		Max value for output minmax activation function This argument is only for _v2 variants
xa_dma_cfg_t *	p_dma_cfg		This is a placeholder
Output			
WORD8 *, WORD16 *, UWORD8 *, FLOAT32 *	p_out	rows*vec_count	Output matrix, fixed-point, f32, f16, or asym8u

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_mat1, p_mat2, p_out	Aligned on (size of one element)-byte boundary p_mat1, p_mat2 aligned on 16-byte boundary for v2_asym8sxasym8s_asym8s Cannot be NULL Should not overlap
p_scratch	Aligned on 8-byte boundary
p_bias	Aligned on (size of one element)-byte boundary Aligned on 16-byte boundary for v2_asym8sxasym8s_asym8s
acc_shift, bias_shift, out_shift	{-31, …., 31}
vec_count	Greater than 0
row_stride	Multiple of 2 for asym4sxasym8s_asym8s kernel. No restriction for other kernels.
vec_offset, out_offset, out_stride	Should not be 0
mat1_zero_bias,	{-255, …, 0} for asym8u, {-127,……, 128} for asym8s,
vec1_zero_bias	{-255,……, 0} for asym8u, {-127,……, 128} for asym8s,

	0 for sym16s
out_multiplier	Greater than 0
p_out_multiplier, p_out_shift	Aligned on (size of one element)-byte boundary Cannot be NULL (range of values are specified for out_multiplier and out_shift)
out_zero_bias	{0,.....,255} if out type is asym8u, {-128....,127} if out type is asym8s, 0 for sym16s

3.1.5 Matrix X Vector Kernels with Output Stride

Description

The Matrix X Vector kernels with output stride perform a single matXvec operation with bias addition; that is, `z = mat1*vec1 + bias`. The column dimension of `mat1` must match the row dimension of `vec1`. Bias and resulting output vector `z` have as many rows as `mat1`.

The `row_stride1` is provided in kernel API for row offsets of `mat1`.

Note The input matrices are expected to be appropriately padded in case of `row_stride1 > cols1`.

Symmetric rounding is used to convert from a higher precision accumulator to a lower precision output.

The argument `out_stride` helps store the output at a given offset.

The argument `vec1_zero_bias` is provided to convert the quantized 8-bit inputs into their real values and perform the matXvec operation. The `out_multiplier` and `out_shift` values are used to convert the real values of output to 16-bit.

The function variants are available as `xa_nn_matXvec_[p]x[q]_[r]`, where:

`[p]`: Matrix precision in bits

`[q]`: Vector precision in bits

`[r]`: Output precision in bits

Precision

The following variant is available:

Type	Description
sym8sxasym8s_16	sym8s matrix inputs, asym8s vector inputs, asym8s output

Algorithm

$$z_n = \left(\sum_{m=0}^{cols1-1} mat1_{n,m} \cdot vec1_m + bias_n \right)$$

Prototype

```
WORD32 xa_nn_matXvec_out_stride_sym8sxasym8s_16
(WORD16 * p_out,          const WORD8  * p_mat1,  const WORD8  * p_vec1,
 const WORD32 * p_bias,   WORD32 rows,            WORD32 cols1,
 WORD32 row_stride1,      WORD32 out_stride,      WORD32 vec1_zero_bias,
 WORD32 out_multiplier,   WORD32 out_shift);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_mat1	rows*cols1	Input matrix, sym8s
const WORD8 *	p_vec1	cols1*1	Input vector, asym8s
const WORD32 *	p_bias	rows*1	Bias vector
WORD32	rows		Number of rows in matrix and number of elements in bias
WORD32	cols1		Number of columns in matrix and elements in vector
WORD32	row_stride1		Row offset of matrix
WORD32	out_stride		Row offset of output
WORD32	vec1_zero_bias		Zero offset of vector
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
Output			
WORD16 *	p_out	rows*1	Output, 16-bit

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
row_stride1, cols1	row_stride1 >= cols1
p_mat1, p_vec1, p_bias, p_out	Aligned on <size of one element> boundary Should not overlap
p_mat1, p_vec1, p_out	Cannot be NULL
out_shift	{-31, ..., 31}
vec1_zero_bias	{-127,....., 128} for asym8s
out_multiplier	Greater than 0

3.1.6 Matrix X Vector Batch Kernels with Accumulation

The Matrix X Vector Batch kernels with accumulation perform the operation of multiplication of a single matrix with a series of vectors along with bias addition; that is, `zi = zi + mat1*vec1i + bias`. These kernels can also be viewed as matrix X matrix-transpose multiplication kernels. The column dimension of `mat1` must match the row dimension of vectors in `vec1`. Bias and the resulting output vector sequence `z` have as many rows as `mat1`. `vec1` is a sequence of `vec_count` number of input vectors and bias is added to each resulting vector after multiplication with `mat1`. Thus, output `z` has dimensions `rows*vec_count`. `vec_count` number of input and output vectors are provided as pointers to the start of first vector, and subsequent vectors are supposed to be stored contiguously in memory. The result of matrix X vector batch operation is accumulated to the values present at the output.

The `row_stride1` argument is provided in kernel API for the row offset of `mat1`.

Note The input matrix is expected to be appropriately padded in case of `row_stride1 > cols1`.

The `out_zero_bias`, `out_multiplier`, and `out_shift` values are used to quantize the output to 16-bits.

The function variants are available as `xa_nn_matXvec_acc_batch_[p]x[q]_[r]`, where:

`[p]`: Matrix precision in bits

`[q]`: Vector precision in bits

`[r]`: Output precision in bits

Precision

The following variant is available:

Type	Description
`sym8sx8_asym16s`	sym8s matrix inputs, 8-bit vector inputs, asym16s output vectors

Algorithm

$$z_{n,i} = z_{n,i} + \left(\sum_{m=0}^{cols1-1} mat1_{n,m} \cdot vec1_{m,i} + bias_n \right),$$

$$n = 0, \ldots, \overline{rows - 1} \quad ; \quad i = 0, \ldots, \overline{vec\text{-}count - 1}$$

Prototype

```
WORD32 xa_nn_matXvec_acc_batch_sym8sx8_asym16s
(WORD16 * p_out,        const WORD8 * p_mat1,    const WORD8 * p_vec1,
 const WORD32 * p_bias, WORD32 rows,             WORD32 cols1,
```

```
WORD32 row_stride1,    WORD32 out_multiplier,   WORD32 out_shift,
WORD32 out_zero_bias,  WORD32 vec_count);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_mat1	rows*cols1	Input matrix, sym8s
const WORD8 *	p_vec1	cols1*vec_count	Input vectors, 8-bit
const WORD32 *	p_bias	rows*1	Bias vector, 32-bit
WORD32	rows		Number of rows in input matrix, bias and output
WORD32	cols1		Number of columns in input matrix and rows in input vector
WORD32	row_stride1		Row offset of input matrix
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32	out_zero_bias		Zero offset of output
WORD32	vec_count		Number of input vectors
Output			
WORD16	p_out	rows*vec_count	Output vectors, asym16s

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_mat1, p_vec1, p_bias, p_out	Aligned on <size of one element> boundary
	Cannot be NULL
	Should not overlap
rows, cols1, vec_count	Should be greater than 0.
row_stride1	Cannot be less than cols1
out_shift	{-31, …., 31}
out_zero_bias	{-32768, …., 32767}

3.1.7 Batch Matrix Multiplication Kernels

Description

Batch_matmul kernels multiply 2 5-D matrices (where the last or innermost 2 dimensions are rows, columns and the first or outermost 3 dimensions are batches) to produce one 5-D matrix at the output, optionally one or both matrices are transposed (transpose involves interchanging last or innermost 2 dimensions, 3

outer dimensions remain as it is) before multiplying depending on the parameters passed. The first 3 dimensions can be broadcasted for input matrices as required, so they should either match or be 1.

Input matrix 1 : M1D0 x M1D1 x M1D2 x M1D3 x M1D4

Input matrix 2 : M2D0 x M2D1 x M2D2 x M2D3 x M2D4

Produces output matrix : OD0 x OD1 x OD2 x OD3 x OD4

The function variants are available as `xa_nn_batch_matmul_[p]x[q]_[r]`, where:

`[p]`: Matrix 1 precision in bits

`[q]`: Matrix 2 precision in bits

`[r]`: Output precision in bits

Precision

The following variants are available:

Type	Description
`asym8sxasym8s_asym8s`	asym8s matrix inputs, asym8s matrix inputs, asym8s output matrix
`sym16sxsym16s_sym16s`	sym16 matrix inputs, sym16 matrix inputs, sym16 output matrix

Algorithm

If mat1_transpose = 1
acc = M1D3;
else
acc = M1D4;
For no transpose case, the equation is:

$$out(d0,d1,d2,d3,d4) = \sum_{x=0}^{x=acc-1} m1(min(d0,M1D0),min(d1,M1D1),min(d2,M1D2),d4,x) * m2(min(d0,M2D0),min(d1,M2D1),min(d2,M2D2),d3,x)$$

If matrix 1 requires transpose, d4 and x are interchanged for m1. If matrix 2 requires transpose d3 and x are interchanged for m2.
Dimensions should satisfy the following restrictions:
M1D0 == M2D0 or M1D0 == 1 or M2D0 == 1, OD0 = max(M1D0, M2D0)
M1D1 == M2D1 or M1D1 == 1 or M2D1 == 1, OD1 = max(M1D1, M2D1)
M1D2 == M2D2 or M1D2 == 1 or M2D2 == 1, OD2 = max(M1D2, M2D2)
If mat1_transpose == 0 and mat2_transpose == 0
M1D4 == M2D4, OD3 == M2D3, OD4 = M1D3
If mat1_transpose == 1 and mat2_transpose == 0

M1D3 == M2D4, OD3 == M2D3, OD4 = M1D4
If mat1_transpose == 0 and mat2_transpose == 1
M1D4 == M2D3, OD3 == M2D4, OD4 = M1D3
If mat1_transpose == 1 and mat2_transpose == 1
M1D3 == M2D3, OD3 == M2D4, OD4 = M1D4

Prototype

```
WORD32 xa_nn_batch_matmul_getsize
(const WORD32 *const p_mat1_shape, const WORD32 *const p_mat2_shape,
 WORD32 mat1_transpose,             WORD32 mat2_transpose,
 WORD32 mat1_precision,             WORD32 mat2_precision);
WORD32 xa_nn_batch_matmul_asym8sxasym8s_asym8s
(WORD8 * __restrict__ p_out,        const WORD32 *const p_out_shape,
 const WORD8 * __restrict__ p_mat1, const WORD32 *const p_mat1_shape,
 const WORD8 * __restrict__ p_mat2, const WORD32 *const p_mat2_shape,
 WORD32 mat1_transpose,             WORD32 mat2_transpose,
 WORD32 mat1_zero_bias,             WORD32 mat2_zero_bias,
 WORD32 out_multiplier,             WORD32 out_shift,
 WORD32 out_zero_bias,              VOID   *p_scratch);

WORD32 xa_nn_batch_matmul_sym16sxsym16s_sym16s
(WORD16 * __restrict__ p_out,        const WORD32 *const p_out_shape,
 const WORD16 * __restrict__ p_mat1, const WORD32 *const p_mat1_shape,
 const WORD16 * __restrict__ p_mat2, const WORD32 *const p_mat2_shape,
 WORD32 mat1_transpose,              WORD32 mat2_transpose,
 WORD32 mat1_zero_bias,              WORD32 mat2_zero_bias,
 WORD32 out_multiplier,              WORD32 out_shift,
 WORD32 out_zero_bias,               VOID   *p_scratch);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 * const WORD16 *	p_mat1		Input matrix 1
const WORD8 * const WORD16 *	p_mat2		Input matrix 2
const WORD32 *	p_mat1_shape		Shape of input tensor containing matrix 1
const WORD32 *	p_mat2_shape		Shape of input tensor containing matrix 2
WORD32	mat1_transpose		Indicates if mat1 is to be transposed before multiplication
WORD32	mat2_transpose		Indicates if mat2 is to be transposed before multiplication
WORD32	mat1_precision		Precision of matrix1
WORD32	mat2_precision		Precision of matrix2
WORD32	mat1_zero_bias		Zero offset of matrix 1
WORD32	mat2_zero_bias		Zero offset of matrix 2
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32	out_zero_bias		Zero offset of output
VOID *	p_scratch		

Type	Name	Size	Description
Output			
WORD8 * WORD16 *	p_out		Output matrix

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_mat1, p_mat2, p_out	Aligned on <size of one element> boundary
	Cannot be NULL
	Must not overlap
p_mat1_shape, p_mat2_shape, p_out_shape	Aligned on <size of one element> boundary
	Cannot be NULL
mat1_transpose, mat2_transpose	Must be 0 or 1
mat1_precision, mat2_precision	-4 for asym8s, -8 for sym16s
mat1_zero_bias, mat2_zero_bias, out_zero_bias	{-127,....., 128} for asym8s 0 for sym16s
out_multiplier	Greater than 0
out_shift	{-31, ..., 31}

3.2 Convolution Kernels

3.2.1 Standard 2D Convolution Kernels

Description

The Standard 2D Convolution kernels perform the 2D convolution operation as `z = inp(*)kernel + bias`. A 3D input cube (`input_height x input_width x input_channels`) is convolved with a 3D kernel cube (`kernel_height x kernel_width x input_channels`) to produce a 2D convolution output plane (`out_height x out_width`). With `out_channels` number of such 3D kernels, an output cube (`out_height x out_width x out_channels`) is produced. The bias having dimension (`out_channels`) is added after the convolution (one bias value is added to each output channel) to produce the final output.

Note The depth or channel dimension (`input_channels`) of the input and kernel must be identical for 2D convolution.

The bias_shift and acc_shift arguments are provided in the kernel API to adjust the bias and output Q format, respectively. Both bias_shift and acc_shift can be either positive or negative where a positive value denotes a left shift and a negative value denotes a right shift.

bias_shift is the shift in number of bits applied to the bias to make it in the same Q format as the convolution - accumulation result. acc_shift is the shift in the number of bits applied to the accumulator to obtain the output in the required Q format.

Note The acc_shift and bias_shift arguments not relevant in the case of floating point kernels and quantized datatype kernels.

The x_stride and y_stride arguments in the kernel API define the step size of the kernel when traversing the input in width and height dimensions respectively.

The x_padding argument defines padding to the left of the input in the width dimension, and the y_padding argument defines padding to the top of the input in the height dimension.

The right padding is calculated based on out_width as right_paddding = kernel_width + (out_width – 1) * x_stride – (x_padding + input_width).

The bottom padding is calculated based on out_height as bottom_paddding = kernel_height + (out_height – 1) * y_stride – (y_padding + input_height).

Symmetric rounding is used to convert from a higher precision accumulator to a lower precision output.

The kernel is expected to be padded in the depth or channels dimension if the number of input_channels is not a multiple of 4 in case of fixed point variants other than the 8x8, asym8uxasym8u, per_chan_sym8sxasym8s and per_chan_sym8sxsym16s_sym16s variant, and 2 in case of floating point variant. No padding is needed for the 8x8 and quantized 8-bit variants.

These kernels require a temporary buffer for convolution computation. This temporary buffer is provided by p_scratch argument of kernel API. The temporary buffer size must be queried using the xa_nn_conv2d_std_getsize() helper API for kernels, except for the sym4sxasym8s variant. For the sym4sxasym8s variant, the xa_nn_conv2d_std_getsize_sym4s() helper API must be used to query the temporary buffer size.

The arguments input_zero_bias, kernel_zero_bias, out_zero_bias, out_multiplier, and out_shift are provided to handle scaling and quantization in the quantized Standard 2D Convolution variants.

These kernels expect input and kernel cubes in the SHAPE_CUBE_DWH_T shape type and can produce an output cube in either SHAPE_CUBE_DWH_T or SHAPE_CUBE_WHD_T shape type. The out_data_format argument to kernel API controls the output cube shape type.

The _v2 kernels have fused minmax activation operation.

The function variants are available as xa_nn_conv2d_std_[p]x[q], where:

[p]: Kernel precision in bits

`[q]`: Input precision in bits

Precision

There are eleven variants available.

Type	Description
`16x16`	16-bit kernel, 16-bit input, 16-bit output
`8x16`	8-bit kernel, 16-bit input, 16-bit output
`8x8`	8-bit kernel, 8-bit input, 8-bit output
`f32`	float32 kernel, float32 input, float32 output
`asym8uxasym8u`	asym8u kernel, asym8u input, asym8u output
`per_chan_sym8sxasym8s`	per channel quantized sym8s kernel, asym8s input, asym8s output
`per_chan_sym8sxsym16s`	per channel quantized sym8s kernel, sym16s input, sym16s output
`f16`	float16 kernel, float16 input, float16 output
`per_chan_sym4sxasym8s`	per channel quantized sym4s kernel, asym8s input, asym8s output
`v2_per_chan_sym8sxasym8s`	per channel quantized sym8s kernel, asym8s input, asym8s output. _v2 API
`v2_per_chan_sym8sxsym16s`	v2, per channel quantized sym8s kernel, sym16s input, sym16s output

Algorithm

$$z_{h,w,d} = 2^{acc\text{-}shift}\left(\sum_{i=0}^{K_H-1}\sum_{j=0}^{K_W-1}\sum_{k=0}^{I_C-1} in_{pad}{}_{(h*y\text{-}stride+i),(w*x\text{-}stride+j),k} \cdot ker_{pad}{}_{d,i,j,k} + 2^{bias\text{-}shift}\, b_d\right)$$

$h = 0, \ldots, \overline{out\text{-}height - 1}, w = 0, \ldots, \overline{out\text{-}width - 1},$
$d = 0, \ldots, \overline{out\text{-}channels - 1}$

In case of floating-point kernels and quantized 8-bit kernels, `acc_shift=0` and `bias_shift=0`.

Thus, $2^{acc\text{-}shift} = 2^{bias\text{-}shift} = 1$

in_{pad}, ker_{pad} denote the padded `p_inp` and padded `p_ker` shapes, respectively.

K_H, K_W, I_C denote kernel_height, kernel_width, and input_channels, respectively.

b denotes the `bias` shape.

Prototype

```
WORD32 xa_nn_conv2d_std_getsize
(WORD32 input_height, WORD32 input_width, WORD32 input_channels,
 WORD32 kernel_height,WORD32 kernel_width,WORD32 kernel_channels,
 WORD32 y_stride,     WORD32 y_padding,   WORD32 x_stride,
 WORD32 x_padding,    WORD32 out_height,  WORD32 out_width,
```

```
 WORD32 output_channels, WORD32 input_precision, WORD32 kernel_precision,
 WORD32 dilation_height, WORD32 dilation_width,  WORD32 out_data_format);
WORD32 xa_nn_conv2d_std_getsize_sym4s
(WORD32 input_height,    WORD32 input_channels,   WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 y_stride,         WORD32 y_padding,
 WORD32 out_height,      WORD32 out_channels,     WORD32 input_precision);
WORD32 xa_nn_conv2d_std_16x16
(WORD16 * p_out,           WORD16 * p_inp,       WORD16 * p_ker,
 WORD16 * p_bias,          WORD32 input_height,  WORD32 input_width,
 WORD32 input_channels,    WORD32 kernel_height, WORD32 kernel_width ,
 WORD32 out_channels,      WORD32 x_stride,      WORD32 y_stride,
 WORD32 x_padding,         WORD32 y_padding,     WORD32 out_height,
 WORD32 out_width,         WORD32 bias_shift,    WORD32 acc_shift,
 WORD32 out_data_format,   VOID   * p_scratch);
WORD32 xa_nn_conv2d_std_8x16
(WORD16 * p_out,           WORD16  * p_inp,      WORD8 * p_ker,
 WORD16 * p_bias,          WORD32 input_height,  WORD32 input_width,
 WORD32 input_channels,    WORD32 kernel_height, WORD32 kernel_width,
 WORD32 out_channels,      WORD32 x_stride,      WORD32 y_stride,
 WORD32 x_padding,         WORD32 y_padding,     WORD32 out_height,
 WORD32 out_width,         WORD32 bias_shift,    WORD32 acc_shift,
 WORD32 out_data_format,   VOID   * p_scratch);
WORD32 xa_nn_conv2d_std_8x8
(WORD8  * p_out,           WORD8  * p_inp,       WORD8  * p_ker,
 WORD8  * p_bias,          WORD32 input_height,  WORD32 input_width,
 WORD32 input_channels,    WORD32 kernel_height, WORD32 kernel_width,
 WORD32 out_channels,      WORD32 x_stride,      WORD32 y_stride,
 WORD32 x_padding,         WORD32 y_padding,     WORD32 out_height,
 WORD32 out_width,         WORD32 bias_shift,    WORD32 acc_shift,
 WORD32 out_data_format,   VOID   * p_scratch);
WORD32 xa_nn_conv2d_std_f32
(FLOAT32 * p_out,          const FLOAT32 * p_inp, const FLOAT32 * p_ker,
 const FLOAT32 * p_bias,   WORD32 input_height,   WORD32 input_width,
 WORD32 input_channels,    WORD32 kernel_height,  WORD32 kernel_width,
 WORD32 out_channels,      WORD32 x_stride,       WORD32 y_stride,
 WORD32 x_padding,         WORD32 y_padding,      WORD32 out_height,
 WORD32 out_width,         WORD32 out_data_format,VOID   * p_scratch);
WORD32 xa_nn_conv2d_std_asym8uxasym8u
(UWORD8 * p_out,           const UWORD8 * p_inp,  const UWORD8 * p_ker,
 const WORD32 * p_bias,    WORD32 input_height,   WORD32 input_width,
 WORD32 input_channels,    WORD32 kernel_height,  WORD32 kernel_width,
 WORD32 out_channels,      WORD32 x_stride,       WORD32 y_stride,
 WORD32 x_padding,         WORD32 y_padding,      WORD32 out_height,
 WORD32 out_width,         WORD32 input_zero_bias,WORD32 kernel_zero_bias,
 WORD32 out_multiplier,    WORD32 out_shift,      WORD32 out_zero_bias,
 WORD32 out_data_format,   VOID   * p_scratch);
WORD32 xa_nn_conv2d_std_per_chan_sym8sxasym8s
(WORD8  * p_out,           const WORD8 * p_inp,   const WORD8 * p_ker,
 const WORD32 * p_bias,    WORD32 input_height,   WORD32 input_width,
 WORD32 input_channels,    WORD32 kernel_height,  WORD32 kernel_width,
 WORD32 out_channels,      WORD32 x_stride,       WORD32 y_stride,
 WORD32 x_padding,         WORD32 y_padding,      WORD32 out_height,
 WORD32 out_width,         WORD32 input_zero_bias,WORD32 * p_out_multiplier,
 WORD32 * p_out_shift,     WORD32 out_zero_bias,  WORD32 out_data_format,
 VOID   * p_scratch);
WORD32 xa_nn_conv2d_std_per_chan_sym8sxsym16s
(WORD16* p_out,            const WORD16* p_inp,    const WORD8* p_kernel,
 const WORD64* p_bias,     WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,    WORD32 kernel_height,   WORD32 kernel_width,
 WORD32 out_channels,      WORD32 x_stride,        WORD32 y_stride,
```

```
 WORD32 x_padding,          WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,          WORD32 input_zero_bias, WORD32 * p_out_multiplier,
 WORD32 * p_out_shift,      WORD32 out_zero_bias,   WORD32 out_data_format,
 VOID   * p_scratch);
WORD32 xa_nn_conv2d_std_f16
 (WORD16* p_out,          const WORD16* p_inp,      const WORD16* p_kernel,
  const WORD16* p_bias,  WORD32 input_height,      WORD32 input_width,
  WORD32 input_channels, WORD32 kernel_height,     WORD32 kernel_width,
  WORD32 out_channels,   WORD32 x_stride,          WORD32 y_stride,
  WORD32 x_padding,      WORD32 y_padding,         WORD32 out_height,
  WORD32 out_width,      WORD32 out_data_format,   VOID *p_scratch);
WORD32 xa_nn_conv2d_std_per_chan_sym4sxasym8s
 (WORD8* p_out,           const WORD8* p_inp,       const WORD8* p_kernel,
 const WORD32* p_bias,   WORD32 input_height,      WORD32 input_width,
 WORD32 input_channels,  WORD32 kernel_height,     WORD32 kernel_width,
 WORD32 out_channels,    WORD32 x_stride,          WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,         WORD32 out_height,
 WORD32 out_width,       WORD32 input_zero_bias,   WORD32 * p_out_multiplier,
 WORD32 * p_out_shift,   WORD32 out_zero_bias,     WORD32 out_data_format,
 VOID *p_scratch);
WORD32 xa_nn_conv2d_std_v2_per_chan_sym8sxasym8s
(WORD8* __restrict__ p_out,          const WORD8* __restrict__ p_inp,
 const WORD8* __restrict__ p_kernel, const WORD32* __restrict__ p_bias,
 WORD32 input_height,                WORD32 input_width,
 WORD32 input_channels,              WORD32 kernel_height,
 WORD32 kernel_width,                WORD32 out_channels,
 WORD32 x_stride,                    WORD32 y_stride,
 WORD32 x_padding,                   WORD32 y_padding,
 WORD32 out_height,                  WORD32 out_width,
 WORD32 input_zero_bias,             WORD32 * p_out_multiplier,
 WORD32 * p_out_shift,               WORD32 out_zero_bias,
 WORD32 out_data_format,             VOID *p_scratch,
 WORD32 out_activation_min,          WORD32 out_activation_max,
 xa_dma_cfg_t *p_dma_cfg);
WORD32 xa_nn_conv2d_std_v2_per_chan_sym8sxsym16s
(WORD16* __restrict__ p_out,         const WORD16* __restrict__ p_inp,
 const WORD8* __restrict__ p_kernel, const WORD64* __restrict__ p_bias,
 WORD32 input_height,                WORD32 input_width,
 WORD32 input_channels,              WORD32 kernel_height,
 WORD32 kernel_width,                WORD32 out_channels,
 WORD32 x_stride,                    WORD32 y_stride,
 WORD32 x_padding,                   WORD32 y_padding,
 WORD32 out_height,                  WORD32 out_width,
 WORD32 input_zero_bias,             WORD32 * p_out_multiplier,
 WORD32 * p_out_shift,               WORD32 out_zero_bias,
 WORD32 out_data_format,             VOID *p_scratch,
 WORD32 out_activation_min,          WORD32 out_activation_max,
 xa_dma_cfg_t *p_dma_cfg);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, const FLOAT32 *, const UWORD8 *, const WORD8 *, const WORD16 *	p_inp	input_height* input width* input_channels	Input cube, fixed, floating point, asym8u, asym8s or sym16s, in SHAPE_CUBE_DWH_T

Type	Name	Size	Description
WORD16 *, WORD8 *, const FLOAT32 *, const UWORD8 * const WORD8 *	p_ker	out_channels* (kernel_height * kernel width* input_channels)	Kernel cube, fixed, floating point, sym4s, asym8u, or sym8s, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *, const WORD32 *, const WORD64 *	p_bias	out_channels	Bias vector, fixed or floating point
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of input channels
WORD32	kernel_height		Kernel height
WORD32	kernel_width		Kernel width
WORD32	out_channels		Number of output channels
WORD32	x_stride		Horizontal stride over input
WORD32	y_stride		Vertical stride over input
WORD32	x_padding		Left padding width on input
WORD32	y_padding		Top padding height on input
WORD32	out_height		Output height
WORD32	out_width		Output width
WORD32	bias_shift		Shift applied to bias
WORD32	acc_shift		Shift applied to accumulator
WORD32	input_zero_bias		Zero offset of input
WORD32	kernel_zero_bias		Zero offset of kernel
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
const WORD32 *	p_out_multiplier		Vector having multiplier values of output for per channel quantization
const WORD32 *	p_out_shift		Vector having shift values of output for per channel quantization
WORD32	out_zero_bias		Zero offset of output
WORD32	out_data_format		Output data format 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
VOID *	p_scratch	xa_nn_conv2d_std_getsize()	Scratch memory pointer
WORD32	out_activation_min		Min value for output minmax activation function

Type	Name	Size	Description
			This argument is only for _v2 variants
WORD32	out_activation_max		Max value for output minmax activation function This argument is only for _v2 variants
xa_dma_cfg_t *	p_dma_cfg		This is a placeholder
Output			
WORD16 *, WORD8 *, FLOAT32 *, UWORD8 *	p_out	(out_height* out_width)* out_channels	Output cube, fixed, floating point, asym8u, asym8s, or sym16s, as per the out_data_format argument.

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_out, p_inp, p_ker, p_bias, p_scratch	Cannot be NULL (p_bias can be NULL for asym8s and sym16s variants)
	Should not overlap
	Aligned on 16-byte boundary except for quantized 8-bit kernels where only p_scratch is required to be 16-byte aligned.and other (size of one element) byte aligned
	For p_scratch – memory size >= size returned by xa_nn_conv2d_std_getsize()
p_out_multiplier, p_out_shift	Cannot be NULL
	Should not overlap
	Aligned on 4-byte boundary
input_height, input_width, input_channels	Greater than or equal to 1
kernel_height	{1, 2, …, input_height}
kernel_width	{1, 2, …, input_width}
out_channels	Greater than or equal to 1
x_stride	{1, 2, …, kernel_width}
y_stride	Greater than or equal to 1
x_padding, y_padding	Greater than or equal to 0
out_height, out_width	Greater than or equal to 1
acc_shift, bias_shift, out_shift	{-31,…., 31} for fixed point and quantized datatype APIs
input_zero_bias	{-255,….., 0} for asym8u input, {-127,….., 128} for asym8s input, 0 for sym16s input

kernel_zero_bias	{-255,……, 0} for asym8u kernel
out_zero_bias	{0,……., 255} for asym8u output, {-128,….., 127} for asym8s output, 0 for sym16s output
out_multiplier	Greater than 0
out_data_format	Can be 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T
kernel_height*kernel_width* input_channels	The value of this multiplication must be even for sym4s data-type. No restriction for other data-types

3.2.2 Standard 2D Convolution Kernels with Dilation

Description

The Standard 2D Convolution kernels with dilation perform the dilated 2D convolution operation as `z = inp(*)kernel + bias`. A 3D input cube (`input_height x input_width x input_channels`), is convolved with a 3D dilated kernel cube to produce a 2D convolution output plane (`out_height x out_width`). With the `out_channels` number of such 3D kernels, an output cube (`out_height x out_width x out_channels`) is produced. Before convolution, the 3D kernel cube (`kernel_height x kernel_width x input_channels`) is dilated by skipping `dilation_height-1` elements in height dimension and `dilation_width-1` elements in width dimension with `dilation_height>=1` and/or `dilation_width>=1`. Post dilation, the kernel cube is of size `kernel_height_dilation = kernel_height + (kernel_height-1)*( dilation_height-1)` in height dimension and `kernel_width_dilation = kernel_width + (kernel_width-1)*( dilation_width-1)` in width dimension. The bias having dimension (`out_channels`) is added after the convolution (one bias value is added to each output channel) to produce the final output.

Note The depth or channels dimension (`input_channels`) of input and kernel must be identical for 2D convolution.

The `bias_shift` and `acc_shift` arguments are provided in the kernel API to adjust the Q format of bias and output, respectively. Both `bias_shift` and `acc_shift` can be either positive or negative, where a positive value denotes a left shift and a negative value denotes a right shift.

`bias_shift` is the shift in the number of bits applied to the bias to make it in the same Q format as convolution - accumulation result. `acc_shift` is the shift in the number of bits applied to the accumulator to obtain the output in required Q format.

The `x_stride` and `y_stride` arguments in kernel API define the step size of the kernel when traversing the input in width and height dimensions, respectively.

The `x_padding` argument defines padding to the left of the input in the width dimension, and the `y_padding` argument defines padding to the top of the input in the height dimension.

The right padding is calculated based on `out_width` as `right_paddding = kernel_width_dilation + (out_width – 1) * x_stride – (x_padding + input_width).`

The bottom padding is calculated based on `out_height` as `bottom_paddding = kernel_height_dilation + (out_height - 1) * y_stride - (y_padding + input_height)`.

For conversion from a higher precision accumulator to a lower precision output, symmetric rounding is used.

These kernels require temporary buffer for convolution computation. This temporary buffer is provided by `p_scratch` argument of kernel API. The size of temporary buffer must be queried using `xa_nn_dilated_conv2d_std_getsize()` helper API.

These kernels expect input and kernel cubes in SHAPE_CUBE_DWH_T shape type and can produce output cubes in either SHAPE_CUBE_DWH_T or SHAPE_CUBE_WHD_T shape type. The `out_data_format` argument to kernel API controls the output cube shape type.

The _v2 kernels have fused minmax activation operation.

Precision

Type	Description
`per_chan_sym8sxasym8s`	per channel quantized sym8s kernel, asym8s input, asym8s output
`v2_per_chan_sym8sxasym8s`	per channel quantized sym8s kernel, asym8s input, asym8s output. _v2 API
`per_chan_sym8sxsym16s`	per channel quantized sym8s kernel, sym16s input, sym16s output
`v2_per_chan_sym8sxsym16s`	per channel quantized sym8s kernel, sym16s input, sym16s output. _v2 API

Algorithm

$$z_{h,w,d} = 2^{acc\text{-}shift}\left(\sum_{i=0}^{K_H-1}\sum_{j=0}^{K_W-1}\sum_{k=0}^{I_C-1} in_{pad_{(h*y\text{-}stride+i*dilation\text{-}height),(w*x\text{-}stride+j*dilation\text{-}width),k}} \cdot ker_{d,i,j,k} + 2^{bias\text{-}shift} b_d\right)$$

$$h = 0,\ldots,\overline{out\text{-}height - 1}, w = 0,\ldots,\overline{out\text{-}width - 1},$$
$$d = 0,\ldots,\overline{out\text{-}channels - 1}$$

in_{pad}, ker denote the padded `p_inp` and kernel `p_ker` shapes, respectively.

K_H, K_W, I_C denote kernel_height, kernel_width, and input_channels, respectively.

b denotes the `bias` shape.

Prototype

```
WORD32 xa_nn_dilated_conv2d_std_getsize
(WORD32 input_height,      WORD32 input_channels,   WORD32 kernel_height,
 WORD32 kernel_width,      WORD32 y_stride,         WORD32 y_padding,
```

```
 WORD32 out_height,        WORDD32 out_channels,    WORD32 input_precision,
 WORD32 dilation_height);


WORD32 xa_nn_dilated_conv2d_std_per_chan_sym8sxasym8s
(WORD8  * p_out,           const WORD8 * p_inp,     const WORD8 * p_ker,
 const WORD32 * p_bias,    WORD32 input_height,     WORD32 input_width,
 WORD32 input_channels,    WORD32 kernel_height,    WORD32 kernel_width,
 WORD32 out_channels,      WORD32 x_stride,         WORD32 y_stride,
 WORD32 x_padding,         WORD32 y_padding,        WORD32 out_height,
 WORD32 out_width,         WORD32 input_zero_bias,  WORD32 * p_out_multiplier,
 WORD32 * p_out_shift,     WORD32 out_zero_bias,    WORD32 out_data_format,
 VOID   * p_scratch,       WORD32 dilation_height,  WORD32 dilation_width);
WORD32 xa_nn_dilated_conv2d_std_v2_per_chan_sym8sxasym8s
(WORD8* __restrict__ p_out,          const WORD8* __restrict__ p_inp,
 const WORD8* __restrict__ p_ker, const WORD32* __restrict__ p_bias,
 WORD32 input_height,                WORD32 input_width,
 WORD32 input_channels,              WORD32 kernel_height,
 WORD32 kernel_width,                WORD32 out_channels,
 WORD32 x_stride,                    WORD32 y_stride,
 WORD32 x_padding,                   WORD32 y_padding,
 WORD32 out_height,                  WORD32 out_width,
 WORD32 input_zero_bias,             WORD32 * p_out_multiplier,
 WORD32 * p_out_shift,               WORD32 out_zero_bias,
 WORD32 out_data_format,             VOID *p_scratch,
 WORD32 dilation_height,             WORD32 dilation_width,
 WORD32 out_activation_min,          WORD32 out_activation_max,
 xa_dma_cfg_t *p_dma_cfg);

WORD32 xa_nn_dilated_conv2d_std_per_chan_sym8sxsym16s
(WORD16* __restrict__ p_out,         const WORD16* __restrict__ p_inp,
 const WORD8* __restrict__ p_ker, const WORD64* __restrict__ p_bias,
 WORD32 input_height,                WORD32 input_width,
 WORD32 input_channels,              WORD32 kernel_height,
 WORD32 kernel_width,                WORD32 out_channels,
 WORD32 x_stride,                    WORD32 y_stride,
 WORD32 x_padding,                   WORD32 y_padding,
 WORD32 out_height,                  WORD32 out_width,
 WORD32 input_zero_bias,             WORD32 * p_out_multiplier,
 WORD32 * p_out_shift,               WORD32 out_zero_bias,
 WORD32 out_data_format,             VOID *p_scratch,
 WORD32 dilation_height,             WORD32 dilation_width);
 WORD32 xa_nn_dilated_conv2d_std_v2_per_chan_sym8sxsym16s
(WORD16* __restrict__ p_out,         const WORD16* __restrict__ p_inp,
 const WORD8* __restrict__ p_kernel, const WORD64* __restrict__ p_bias,
 WORD32 input_height,                WORD32 input_width,
 WORD32 input_channels,              WORD32 kernel_height,
 WORD32 kernel_width,                WORD32 out_channels,
 WORD32 x_stride,                    WORD32 y_stride,
 WORD32 x_padding,                   WORD32 y_padding,
 WORD32 out_height,                  WORD32 out_width,
 WORD32 input_zero_bias,             WORD32 * p_out_multiplier,
 WORD32 * p_out_shift,               WORD32 out_zero_bias,
 WORD32 out_data_format,             VOID *p_scratch,
 WORD32 dilation_height,             WORD32 dilation_width,
 WORD32 out_activation_min,          WORD32 out_activation_max,
 xa_dma_cfg_t *p_dma_cfg);
```

Arguments

Type	Name	Size	Description
Input			

Type	Name	Size	Description
WORD16 *, WORD8 *, const FLOAT32 *, const UWORD8 *, const WORD8 *	p_inp	input_height* input width* input_channels	Input cube, fixed, floating point, asym8u or asym8s, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, const FLOAT32 *, const UWORD8 * const WORD8 *	p_ker	out_channels* (kernel_height * kernel width* input_channels)	Kernel cube, fixed, floating point, asym8u or sym8s, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *, const WORD32 *	p_bias	out_channels	Bias vector, fixed or floating point
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of input channels
WORD32	kernel_height		Kernel height
WORD32	kernel_width		Kernel width
WORD32	out_channels		Number of output channels
WORD32	x_stride		Horizontal stride over input
WORD32	y_stride		Vertical stride over input
WORD32	x_padding		Left padding width on input
WORD32	y_padding		Top padding height on input
WORD32	out_height		Output height
WORD32	out_width		Output width
WORD32	bias_shift		Shift applied to bias
WORD32	acc_shift		Shift applied to accumulator
WORD32	input_zero_bias		Zero offset of input
WORD32	kernel_zero_bias		Zero offset of kernel
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32	out_zero_bias		Zero offset of output
WORD32	out_data_format		Output data format 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
VOID *	p_scratch	xa_nn_dilated_conv2d_std_getsize()	Scratch memory pointer
WORD32	dilation_height		Kernel height dilation factor
WORD32	dilation_width		Kernel width dilation factor

Type	Name	Size	Description
WORD32	out_activation_min		Min value for output minmax activation function This argument is only for _v2 variants
WORD32	out_activation_max		Max value for output minmax activation function This argument is only for _v2 variants
xa_dma_cfg_t *	p_dma_cfg		This is a placeholder
Output			
WORD16 *, WORD8 *, FLOAT32 *, UWORD8 *	p_out	(out_height* out_width)* out_channels	Output cube, fixed, floating point, asym8u or asym8s, as per the out_data_format argument.

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_out, p_inp, p_ker, p_bias, p_scratch	Cannot be NULL (p_bias can be NULL for asym8s and sym16s variants)
	Should not overlap
	Aligned on 16-byte boundary except for quantized 8-bit kernels where only p_scratch is required to be 16-byte aligned.
	For p_scratch - memory size >= size returned by xa_nn_conv2d_std_getsize()
input_height, input_width, input_channels	Greater than or equal to 1
kernel_height	{1, 2, …, input_height}
kernel_width	{1, 2, …, input_width}
out_channels	Greater than or equal to 1
x_stride	Greater than or equal to 1
y_stride	Greater than or equal to 1
x_padding, y_padding	Greater than or equal to 0
dilation_height, dilation_width	Greater than or equal to 1
out_height, out_width	Greater than or equal to 1
acc_shift, bias_shift, out_shift	{-31,…., 31} for fixed point and quantized 8-bit APIs
input_zero_bias	{-255,….., 0} for asym8u input, {-127,….., 128} for asym8s input
kernel_zero_bias	{-255……, 0} for asym8u kernel

out_zero_bias	{0,....., 255} for asym8u output, {-128,....., 127} for asym8s output
out_multiplier	Greater than 0
out_data_format	Can be 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T

3.2.3 Standard 1D Convolution Kernels

Description

The Standard 1D Convolution kernels perform the 1D convolution operation as `z = inp(*)kernel + bias`. A 3D input cube (`input_height x input_width x input_channels`) is convolved with a 3D kernel cube (`kernel_height x input_width x input_channels`) to produce a 1D convolution output vector (`out_height`). With the `out_channels` number of such 3D kernels, the output matrix (`out_height x out_channels`) is produced. The bias having dimension (`out_channels`) is added after the convolution (one bias value is added to each output column) to produce the final output.

Note The depth or channels dimension (`input_channels`) of the input and kernel must be identical, and the width dimension (`input_width`) of the input and kernel also must be identical for 1D convolution.

The `bias_shift` and `acc_shift` arguments are provided in the kernel API to adjust the Q format of bias and output, respectively. Both `bias_shift` and `acc_shift` can be positive or negative, where a positive value denotes a left shift and a negative value denotes a right shift.

`bias_shift` is the shift in the number of bits applied to the bias to make it in the same Q format as convolution - accumulation result. `acc_shift` is the shift in the number of bits applied to the accumulator to obtain the output in the required Q format.

Note The `acc_shift` and `bias_shift arguments` are not relevant in the case of floating-point kernels.

The `y_stride` argument to kernel API defines the step size of the kernel when traversing the input in the height dimension.

The `y_padding` argument defines padding to the top of the input in the height dimension.

The bottom padding is calculated based on `out_height` as `bottom_paddding = kernel_height + (out_height – 1) * y_stride – (y_padding + input_height)`.

For conversion from higher precision accumulator to a lower precision output, symmetric rounding is used.

The kernel is expected to be padded if the product `input_channels*input_width` is not a multiple of 4 in case of fixed-point variants, and 2 in the case of floating-point variant.

These kernels require a temporary buffer for convolution computation. This temporary buffer is provided by `p_scratch` argument of the kernel API. The size of temporary buffer must be queried using `xa_nn_conv1d_std_getsize()` helper API.

These kernels expect input and kernel cubes in the SHAPE_CUBE_DWH_T shape type and can produce an output matrix with either (`out_height x out_channels`) or (`out_channels x out_height`) dimensions. The `out_data_format` argument to the kernel API controls the output matrix height and width order.

The function variants are available as `xa_nn_conv1d_std_[p]`, where:

`[p]`: precision in bits

Precision

The following five variants are available:

Type	Description
`16x16`	16-bit kernel, 16-bit input, 16-bit output
`8x16`	8-bit kernel, 16-bit input, 16-bit output
`8x8`	8-bit kernel, 8-bit input, 8-bit output
`f32`	float32 kernel, float32 input, float32 output
`asym8uxasym8u_asym8u`	asym8u matrix inputs, asym8u vector inputs, asym8u output vectors

Algorithm

$$z_{h,d} = 2^{acc\text{-}shift}\left(\sum_{i=0}^{K_H-1}\sum_{j=0}^{I_W-1}\sum_{k=0}^{I_C-1} in_{pad_{(h*y\text{-}stride+i),j,k}} \cdot ker_{pad_{d,i,j,k}} + 2^{bias\text{-}shift} b_d\right)$$

$$h = 0, \ldots, \overline{out\text{-}height - 1}, d = 0, \ldots, \overline{out\text{-}channels - 1}$$

In case of floating point kernel, `acc_shift=0` and `bias_shift=0`.

Thus, $2^{acc\text{-}shift} = 2^{bias\text{-}shift} = 1$

n_{pad}, ker_{pad} denote the padded `p_inp` and padded `p_ker` shapes, respectively.

K_H, I_W, I_C denote kernel_height, input_width, and input_channels, respectively.

b denotes the `bias` shape.

Prototype

```
WORD32 xa_nn_conv1d_std_getsize
(WORD32 kernel_height,  WORD32 input_width,   WORD32 input_channels,
 WORD32 input_precision);

WORD32 xa_nn_conv1d_std_16x16
(WORD16 * p_out,        WORD16 * p_inp,       WORD16 * p_ker,
 WORD16 * p_bias,       WORD32 input_height,  WORD32 input_width,
 WORD32 input_channels, WORD32 kernel_height, WORD32 out_channels,
 WORD32 y_stride,       WORD32 y_padding,     WORD32 out_height,
```

```
 WORD32 bias_shift,     WORD32 acc_shift,     WORD32 out_data_format,
 VOID   * p_scratch);
WORD32 xa_nn_conv1d_std_8x16
(WORD16 * p_out,        WORD16 * p_inp,       WORD8  * p_ker,
 WORD16 * p_bias,       WORD32 input_height,  WORD32 input_width,
 WORD32 input_channels, WORD32 kernel_height, WORD32 out_channels,
 WORD32 y_stride,       WORD32 y_padding,     WORD32 out_height,
 WORD32 bias_shift,     WORD32 acc_shift,     WORD32 out_data_format,
 VOID   * p_scratch);
WORD32 xa_nn_conv1d_std_8x8
(WORD8  * p_out,        WORD8  * p_inp,       WORD8  * p_ker,
 WORD8  * p_bias,       WORD32 input_height,  WORD32 input_width,
 WORD32 input_channels, WORD32 kernel_height, WORD32 out_channels,
 WORD32 y_stride,       WORD32 y_padding,     WORD32 out_height,
 WORD32 bias_shift,     WORD32 acc_shift,     WORD32 out_data_format,
 VOID   * p_scratch);
WORD32 xa_nn_conv1d_std_f32
(FLOAT32 * p_out,         FLOAT32 * p_inp,        FLOAT32 * p_ker,
 FLOAT32 * p_bias,        WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,   WORD32 kernel_height,   WORD32 out_channels,
 WORD32 y_stride,         WORD32 y_padding,       WORD32 out_height,
 WORD32 out_data_format,  VOID   * p_scratch);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *,	p_inp	input_height* input width* input_channels	Input cube, fixed or floating point, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *,	p_ker	out_channels* (kernel_height* input width* input_channels)	Kernel cube, fixed or floating point, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *,	p_bias	out_channels	Bias vector, fixed or floating point
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of input channels
WORD32	kernel_height		Kernel height
WORD32	out_channels		Number of output channels
WORD32	y_stride		Vertical stride over input
WORD32	y_padding		Top padding height on input
WORD32	out_height		Output height
WORD32	bias_shift		Shift applied to bias
WORD32	acc_shift		Shift applied to accumulator
WORD32	out_data_format		Output matrix order 0: out_height x out_channels 1: out_channels x out_height

VOID *	p_scratch	xa_nn_conv1d_std_getsize()	Scratch memory pointer
Output			
WORD16 *, WORD8 *, FLOAT32 *,	p_out	out_height* out_channels	Output matrix, fixed or floating point, as per the out_data_format argument.

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_out, p_inp, p_ker, p_bias, p_scratch	Cannot be NULL
	Should not overlap
	Aligned on 16-byte boundary
	For p_scratch – memory size >= size returned by xa_nn_conv1d_std_getsize()
input_height, input_width, input_channels	Greater than or equal to 1
kernel_height	{1, 2, ..., input_height}
out_channels	Greater than or equal to 1
y_stride	{1, 2, ..., kernel_height}
y_padding	Greater than or equal to 0
out_height	Greater than or equal to 1
acc_shift, bias_shift	{-31,...., 31} for fixed point APIs
out_data_format	Can be 0: out_height x out_channels or 1: out_channels x out_height

3.2.4 Depthwise Separable 2D Convolution Kernels

The Depthwise Separable 2D Convolution is computed in two steps using the following two low-level kernels:

First step: xa_nn_conv2d_depthwise_xx() low-level kernel

These kernels convolve each input 2D plane (input_height x input_width) from the input cube (input_height x input_width x input_channels) with channels_multiplier number of 2D kernels (kernel_height x kernel_width) to produce channels_multiplier number of 2D output planes (out_height x out_width). Thus, with kernel cube of dimension (kernel_height x kernel_width x (channels_multiplier * input_channels)), output cube of dimension (out_height x out_width x (channels_multiplier * input_channels)) is produced. Bias is added to the convolution output. There is one bias value

for each output 2D plane; that is, bias is a vector of dimension (`channels_multiplier * input_channels`).

Second step: xa_nn_conv2d_pointwise_xx() low-level kernel

These kernels take the output cube (`out_height x out_width x (channels_multiplier * input_channels)`) of the first step as input and perform pointwise multiplication with kernel vector (`channels_multiplier * input_channels`) in-depth dimension to produce output 2D plane (`out_height x out_width`). Thus, with `out_channels` kernel vectors, an output cube of dimension (`out_height x out_width x out_channels`) is produced. Bias is added to the pointwise multiplication output. There is one bias value for each output 2D plane; that is, bias is a vector of dimension `out_channels`.

The following are the descriptions of these two low-level kernels.

Depthwise 2D Convolution Kernels

Description

These kernels perform the 2D depthwise convolution operation as `z = inp (*) kernel + bias`. These kernels convolve each input 2D plane (`input_height x input_width`) from the input cube (`input_height x input_width x input_channels`) with channels_multiplier number of 2D kernels (`kernel_height x kernel_width`) to produce channels_multiplier number of 2D output planes (out_height x out_width). Thus, with kernel cube of dimension (`kernel_height x kernel_width x (channels_multiplier * input_channels)`), output cube of dimension (`out_height x out_width x (channels_multiplier * input_channels)`) is produced. Bias is added to the convolution output. There is one bias value for each output 2D plane; that is, bias is a vector of dimension (`channels_multiplier * input_channels`).

The `bias_shift` and `acc_shift` arguments are provided in kernel API to adjust the Q format of bias and the output, respectively. Both `bias_shift` and `acc_shift` can be either positive or negative where a positive value denotes a left shift and a negative value denotes a right shift.

`bias_shift` is the shift in number of bits applied to the bias to make it in the same Q format as a convolution - accumulation result. `acc_shift` is the shift in the number of bits applied to the accumulator to obtain the output in required Q format.

Note The `acc_shift` and `bias_shift` arguments are not relevant in the case of floating-point kernels and quantized 8-bit kernels.

The `x_stride` and `y_stride` arguments in kernel API define the step size of the kernel when traversing the input in width and height dimensions, respectively.

The `x_padding` argument defines padding to the left of the input in the width dimension, and `y_padding` argument defines padding to the top of the input in the height dimension.

The right padding is calculated based on `out_width` as `right_paddding = kernel_width + (out_width – 1) * x_stride – (x_padding + input_width)`.

The bottom padding is calculated based on `out_height` as `bottom_paddding = kernel_height + (out_height – 1) * y_stride – (y_padding + input_height).`

For conversion from higher precision accumulator to a lower precision output, symmetric rounding is used.

These kernels require a temporary buffer for convolution computation. The kernel API provides this buffer with the p_scratch argument. The size of the temporary buffer must be queried using the `xa_nn_conv2d_depthwise_getsize()` helper API.

The arguments `input_zero_bias`, `kernel_zero_bias` are provided to convert the quantized 8-bit inputs into their real values and perform Depthwise 2D Convolution operation. The `out_zero_bias`, `out_multiplier`, and `out_shift` values quantize real values of output back to 8-bit.

The depthwise kernels expect input cube in SHAPE_CUBE_DWH_T and SHAPE_CUBE_WHD_T shape type and produce output cube in SHAPE_CUBE_DWH_T shape types respectively. The `inp_data_format` argument to the kernel API can be 0 or 1 to indicate input cube shape respectively.

The `out_data_format` argument to the kernel API must be 0 for all the kernels to indicate the output cube shape.

The _v2 kernels have fused minmax activation operation and support only inp_data_format 0.

The function variants are available as `xa_nn_conv2d_depthwise_[p]`, where:

`[p]`: precision in bits

Precision

There are ten variants available:

Type	Description
`16x16`	16-bit kernel, 16-bit input, 16-bit output
`8x16`	8-bit kernel, 16-bit input, 16-bit output
`8x8`	8-bit kernel, 8-bit input, 8-bit output
`f32`	float32 kernel, float32 input, float32 output
`asym8uxasym8u`	asym8u kernel, asym8u input, asym8u output
`per_chan_sym8sxasym8s`	per channel quantized sym8s kernel, asym8s input, asym8s output
`per_chan_sym8sxsym16s`	per channel quantized sym8s kernel, sym16s input, sym16s output
`f16`	float16 kernel, float16 input, float16 output
`v2_per_chan_sym8sxasym8s`	per channel quantized sym8s kernel, asym8s input, asym8s output. _v2 API
`v2_per_chan_sym8sxsym16s`	per channel quantized sym8s kernel, asym16s input, asym16s output. _v2 API

Algorithm

$$z_{h,w,d*C_M+m} = 2^{acc\text{-}shift}\left(\sum_{i=0}^{K_H-1}\sum_{j=0}^{K_W-1} in_{pad_{(h*y\text{-}stride+i),(w*x\text{-}stride+j),d}} \cdot ker_{pad_{i,j,(d*C_M+m)}} + 2^{bias\text{-}shift}\, b_{0,0,d*C_M+m}\right)$$

$h = 0, \ldots, \overline{out\text{-}height - 1}, w = 0, \ldots, \overline{out\text{-}width - 1}$,
$d = 0, \ldots, \overline{input\text{-}channels - 1}$,
$m = 0, \ldots, \overline{channels\text{-}multiplier - 1}$

In case of floating-point kernel and quantized 8-bit kernels, `acc_shift=0` and `bias_shift=0`.

Thus, $2^{acc\text{-}shift} = 2^{bias\text{-}shift} = 1$

in_{pad}, ker_{pad} denote the padded `p_inp` and padded `p_ker` shapes, respectively.

K_H, K_W, C_M denote `kernel_height`, `kernel_width`, and `channels_multiplier`, respectively.

b denotes the `bias shape`.

Prototype

```
WORD32 xa_nn_conv2d_depthwise_getsize
(WORD32 input_height,       WORD32 input_width      WORD32 input_channels,
 WORD32 kernel_height,      WORD32 kernel_width,    WORD32 channels_multiplier,
 WORD32 x_stride,           WORD32 y_stride,        WORD32 x_padding,
 WORD32 y_padding,          WORD32 output_height,   WORD32 output_width,
 WORD32 circ_buf_precision, WORD32 inp_data_format);

WORD32 xa_nn_conv2d_depthwise_16x16
(WORD16 * p_out,            WORD16 *  p_ker,        WORD16 *   p_inp,
 WORD16 * p_bias,           WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,     WORD32 kernel_height,   WORD32 kernel_width,
 WORD32 channels_multiplier,WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,          WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,          WORD32 acc_shift,       WORD32 bias_shift,
 WORD32 inp_data_format,    WORD32 out_data_format, VOID   * p_scratch);
WORD32 xa_nn_conv2d_depthwise_8x16
(WORD16 * p_out,            WORD8 * p_ker,          WORD16 * p_inp,
 WORD16 * p_bias,           WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,     WORD32 kernel_height,   WORD32 kernel_width,
 WORD32 channels_multiplier,WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,          WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,          WORD32 acc_shift,       WORD32 bias_shift,
 WORD32 inp_data_format,    WORD32 out_data_format, VOID   * p_scratch);
WORD32 xa_nn_conv2d_depthwise_8x8
(WORD8  * p_out,            WORD8  * p_ker,         WORD8  * p_inp,
 WORD8  * p_bias,           WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,     WORD32 kernel_height,   WORD32 kernel_width,
 WORD32 channels_multiplier,WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,          WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,          WORD32 acc_shift,       WORD32 bias_shift,
 WORD32 inp_data_format,    WORD32 out_data_format, VOID   * p_scratch);
WORD32 xa_nn_conv2d_depthwise_f32
(FLOAT32 * p_out,           const FLOAT32 * p_ker,  const FLOAT32 * p_inp,
```

```
 const FLOAT32 * p_bias,    WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,     WORD32 kernel_height,   WORD32 kernel_width,
 WORD32 channels_multiplier,WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,          WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,          WORD32 inp_data_format, WORD32 out_data_format,
 VOID   * p_scratch);
WORD32 xa_nn_conv2d_depthwise_asym8uxasym8u
(pUWORD8 p_out,             const UWORD8 * p_kernel, const UWORD8 * p_inp,
 const WORD32 * p_bias,     WORD32 input_height,     WORD32 input_width,
 WORD32 input_channels,     WORD32 kernel_height,    WORD32 kernel_width,
 WORD32 channels_multiplier,WORD32 x_stride,         WORD32 y_stride,
 WORD32 x_padding,          WORD32 y_padding,        WORD32 out_height,
 WORD32 out_width,          WORD32 input_zero_bias,  WORD32 kernel_zero_bias,
 WORD32 out_multiplier,     WORD32 out_shift,        WORD32 out_zero_bias,
 WORD32 inp_data_format,    WORD32 out_data_format,  pVOID p_scratch);
WORD32 xa_nn_conv2d_depthwise_per_chan_sym8sxasym8s
(pWORD8 p_out,              const WORD8 * p_kernel,  const WORD8 * p_inp,
 const WORD32 * p_bias,     WORD32 input_height,     WORD32 input_width,
 WORD32 input_channels,     WORD32 kernel_height,    WORD32 kernel_width,
 WORD32 channels_multiplier,WORD32 x_stride,         WORD32 y_stride,
 WORD32 x_padding,          WORD32 y_padding,        WORD32 out_height,
 WORD32 out_width,          WORD32 input_zero_bias,  const WORD32 * p_out_multiplier,
 const WORD32 * p_out_shift,WORD32 out_zero_bias,    WORD32 inp_data_format,
 WORD32 out_data_format,    pVOID p_scratch);
WORD32 xa_nn_conv2d_depthwise_per_chan_sym8sxsym16s
 (pWORD16  p_out,               const WORD8 * p_kernel,    const WORD16 * p_inp,
  const WORD64 * p_bias,        WORD32  input_height,      WORD32  input_width,
  WORD32  input_channels,       WORD32  kernel_height,     WORD32  kernel_width,
  WORD32  channels_multiplier,  WORD32  x_stride,          WORD32  y_stride,
  WORD32  x_padding,            WORD32  y_padding,         WORD32  out_height,
  WORD32  out_width,            WORD32  input_zero_bias,   const WORD32 *p_out_multiplier,
  const WORD32 *p_out_shift,    WORD32  out_zero_bias,     WORD32  inp_data_format,
  WORD32  out_data_format,      pVOID p_scratch);
WORD32 xa_nn_conv2d_depthwise_f16
 (WORD16* p_out,                const WORD16* p_kernel,   const WORD16* p_inp,
  const WORD16* p_bias,         WORD32  input_height,     WORD32  input_width,
  WORD32  input_channels,       WORD32  kernel_height,    WORD32  kernel_width,
  WORD32  channels_multiplier,  WORD32  x_stride,         WORD32  y_stride,
  WORD32  x_padding,            WORD32  y_padding,        WORD32  out_height,
  WORD32  out_width,            WORD32  inp_data_format,  WORD32  out_data_format,
  pVOID p_scratch);
WORD32 xa_nn_conv2d_depthwise_v2_per_chan_sym8sxasym8s
(pWORD8 __restrict__ p_out,       const WORD8 *__restrict__ p_kernel,
 const WORD8 *__restrict__ p_inp, const WORD32 *__restrict__ p_bias,
 WORD32  input_height,            WORD32  input_width,
 WORD32  input_channels,          WORD32  kernel_height,
 WORD32  kernel_width,            WORD32  channels_multiplier,
 WORD32  x_stride,                WORD32  y_stride,
 WORD32  x_padding,               WORD32  y_padding,
 WORD32  out_height,              WORD32  out_width,
 WORD32  input_zero_bias,         const WORD32  *p_out_multiplier,
 const WORD32  *p_out_shift,      WORD32  out_zero_bias,
 WORD32  inp_data_format,         WORD32  out_data_format,
 pVOID p_scratch,                 WORD32 out_activation_min,
 WORD32 out_activation_max,       xa_dma_cfg_t *p_dma_cfg);
WORD32 xa_nn_conv2d_depthwise_v2_per_chan_sym8sxsym16s
(pWORD16 __restrict__ p_out,       const WORD8 *__restrict__ p_kernel,
 const WORD16 *__restrict__ p_inp, const WORD64 *__restrict__ p_bias,
 WORD32  input_height,             WORD32  input_width,
 WORD32  input_channels,           WORD32  kernel_height,
 WORD32  kernel_width,             WORD32  channels_multiplier,
 WORD32  x_stride,                  WORD32  y_stride,
 WORD32  x_padding,                 WORD32  y_padding,
 WORD32  out_height,                WORD32  out_width,
 WORD32  input_zero_bias,           const WORD32  *p_out_multiplier,
```

```
const WORD32  *p_out_shift,
WORD32  inp_data_format,
pVOID p_scratch,
WORD32  out_activation_max,
WORD32  output_zero_bias,
WORD32  out_data_format,
WORD32  out_activation_min,
xa_dma_cfg_t *p_dma_cfg);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *, const UWORD8 *, const WORD8 *	p_ker	kernel_height* kernel width* input_channels* channels_multiplier	Kernel cube, fixed, floating point, asym8u or sym8s, in SHAPE_CUBE_DWH or SHAPE_CUBE_WHD_T
WORD16 *, WORD8 *, FLOAT32 *, const UWORD8 *, const WORD8 *	p_inp	input_height* input width* input_channels	Input cube, fixed, floating point, asym8u or asym8s in SHAPE_CUBE_DWH or SHAPE_CUBE_WHD_T
WORD16 *, WORD8 *, FLOAT32 *, const WORD32 * const WORD64 *	p_bias	input_channels*channels_multiplier	Bias vector, fixed or floating point
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of input channels
WORD32	kernel_height		Kernel height
WORD32	kernel_width		Kernel width
WORD32	channels_multiplier		Multiplier value for each input channel
WORD32	x_stride		Horizontal stride over input
WORD32	y_stride		Vertical stride over input
WORD32	x_padding		Left padding width on input
WORD32	y_padding		Right padding height on input
WORD32	out_height		Output height
WORD32	out_width		Output width
WORD32	acc_shift		Shift applied to accumulator

Type	Name	Size	Description
WORD32	bias_shift		Shift applied to bias
WORD32	input_zero_bias		Zero offset of input
WORD32	kernel_zero_bias		Zero offset of kernel
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32 *	p_out_multiplier	input_channels*channels_multiplier	Array of multiplier values of output
WORD32 *	p_out_shift	input_channels*channels_multiplier	Array of shift values of output
WORD32	out_zero_bias		Zero offset of output
WORD32	inp_data_format		Input and Kernel data format 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
WORD32	out_data_format		Output data format 0:SHAPE_CUBE_DWH_T
VOID *	p_scratch	xa_nn_conv2d_depthwise_getsize()	Scratch memory pointer
WORD32	out_activation_min		Min value for output minmax activation function This argument is only for _v2 variants
WORD32	out_activation_max		Max value for output minmax activation function This argument is only for _v2 variants
xa_dma_cfg_t *	p_dma_cfg		This is a placeholder
Output			
WORD16 *, WORD8 *, UWORD8 * FLOAT32 *,	p_out	out_height* out width* input_channels* channels_multiplier	Output cube, fixed, floating point, asym8u or asym8s, in SHAPE_CUBE_DWH_T

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_out, p_ker, p_inp, p_bias,	Cannot be NULL
	Should not overlap
	Aligned on <size of one element> boundary
p_scratch	Cannot be NULL
	Should not overlap with other buffers
	Aligned on 16-byte boundary
	For p_scratch – memory size >= size returned by xa_nn_conv2d_depthwise_getsize( )
p_out_multiplier	Cannot be NULL
	Should not overlap
	Aligned on 4-byte boundry
p_out_shift	Cannot be NULL
	Should not overlap
	Aligned on 4-byte boundry
	Each 32-bit value must be in range [-31 … 31]
input_height, input_width, input_channels	Greater than or equal to 1
kernel_height	{1,2, ..., input_height}
kernel_width	{1,2, ..., input_width}
channels_multiplier	Greater than or equal to 1
x_stride	{1,2, ..., kernel_width}
y_stride	{1,2, ..., kernel_height}
x_padding, y_padding	Greater than or equal to 0
out_height, out_width	Greater than or equal to 1
acc_shift,bias_shift, out_shift	{-31,...., 31} for fixed point and quantized 8-bit APIs
input_zero_bias	{-255,....., 0} for asym8u input, {-127,....., 128} for asym8s input Must be 0 for sym16s input
kernel_zero_bias	{-255……, 0} for asym8u kernel
out_zero_bias	{0,.....,255} for asym8u output, {-128….., 127} for asym8s output Must be 0 for sym16s output
out_multiplier	Greater than 0
inp_data_format	can be 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T , must be 0 for _v2 variants.
out_data_format	must be 0: SHAPE_CUBE_DWH_T

Pointwise 2D Convolution Kernel

Description

These kernels perform pointwise multiplication of input cube (`input_height x input_width x input_channels`) with kernel vector (`input_channels`) in depth dimension to produce output 2D plane (`input_height x input_width`). Thus, with `out_channels` kernel vectors, an output cube of dimension (`input_height x input_width x out_channels`) is produced. Bias is added to the pointwise multiplication output. There is one bias value for each output 2D plane; that is, bias is a vector of dimension `out_channels`.

The `bias_shift` and `acc_shift` arguments are provided in kernel API to adjust the Q format of bias and output, respectively. Both `bias_shift` and `acc_shift` can be either positive or negative, where a positive value denotes a left shift and a negative value denotes a right shift.

`bias_shift` is the shift in the number of bits applied to the bias to make it in the same Q format as convolution - accumulation result. `acc_shift` is the shift in the number of bits applied to the accumulator to obtain the output in required Q format.

Note The `acc_shift` and `bias_shift` arguments are not relevant in case of floating point kernels and quantized 8-bit kernels.

Symmetric rounding is used for conversion from a higher precision accumulator to a lower precision output.

These kernels expect the input cube in SHAPE_CUBE_DWH_T shape type, kernel as matrix, bias as a vector, and produce an output cube in SHAPE_CUBE_WHD_T or SHAPE_CUBE_DWH_T (only for 8x8, asym8uxasym8u and per_chan_sym8sxasym8s kernels) shape type. The `out_data_format` argument to kernel API must be always 1 except for 8x8 and quantized 8-bit kernels for which it can be 0 or 1 indicating SHAPE_CUBE_DWH_T and SHAPE_CUBE_WHD_T respectively.

The _v2 kernels have fused minmax activation operation.

The function variants are available as `xa_nn_conv2d_pointwise_[p]`, where:

`[p]`: precision in bits

Precision

There are ten variants available:

Type	Description
`16x16`	16-bit kernel, 16-bit input, 16-bit output
`8x16`	8-bit kernel, 16-bit input, 16-bit output
`8x8`	8-bit kernel, 8-bit input, 8-bit output
`f32`	float32 kernel, float32 input, float32 output
`asym8uxasym8u`	asym8u kernel, asym8u input, asym8u output
`per_chan_sym8sxasym8s`	per channel quantized sym8s kernel, asym8s input, asym8s output
`per_chan_sym8sxsym16s`	per channel quantized sym8s kernel, sym16s input, sym16s output
`f16`	float16 kernel, float16 input, float16 output
`v2_per_chan_sym8sxasym8s`	v2, sym8s kernel, asym8s input, asym8s output

`v2_per_chan_sym8sxsym16s`	v2, sym8s kernel, sym16s input, sym16s output

Algorithm

$$z_{h,w,d} = 2^{acc\text{-}shift}\left(\sum_{k=0}^{I_C-1} in_{h,w,k} \cdot ker_{d,0,0,k} + 2^{bias\text{-}shift}\, b_{0,0,d}\right)$$

$$h = 0,..\overline{input\text{-}height - 1}, w = 0,..\overline{input\text{-}width - 1},$$
$$d = 0,..\overline{out_{channels} - 1}$$

In case of floating-point kernel and quantized 8-bit kernels, `acc_shift=0` and `bias_shift=0`. Thus, $2^{acc\text{-}shift} = 2^{bias\text{-}shift} = 1$

in, ker denote the `p_inp`, and `p_ker` shapes respectively.

I_C denotes `input_channels`

b denotes the `bias` shape

Prototype

```
WORD32 xa_nn_conv2d_pointwise_16x16
(WORD16 * p_out,            WORD16 * p_ker,         WORD16 * _inp,
 WORD16 * p_bias,           WORD32  input_height,   WORD32 input_width,
 WORD32 input_channels,     WORD32 out_channels,    WORD32 acc_shift,
 WORD32 bias_shift,         WORD32 out_data_format);
WORD32 xa_nn_conv2d_pointwise_8x16
(WORD16 * p_out,            WORD8  * p_ker,         WORD16 * p_inp,
 WORD16 * p_bias,           WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,     WORD32 out_channels,    WORD32 acc_shift,
 WORD32 bias_shift,         WORD32 out_data_format);
WORD32 xa_nn_conv2d_pointwise_8x8
(WORD8  * p_out,            WORD8  * p_ker,         WORD8  * p_inp,
 WORD8  * p_bias,           WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,     WORD32 out_channels,    WORD32 acc_shift,
 WORD32 bias_shift,         WORD32 out_data_format);
WORD32 xa_nn_conv2d_pointwise_f32
(FLOAT32 * p_out,           const FLOAT32 * p_ker,  const FLOAT32 *  p_inp,
 const FLOAT32 *  p_bias,         WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,     WORD32 out_channels,
 WORD32 out_data_format);
WORD32 xa_nn_conv2d_pointwise_asym8uxasym8u
(UWORD8 * p_out,            const UWORD8 * p_ker,    const UWORD8 * p_inp,
 WORD32 * p_bias,           WORD32 input_height,     WORD32 input_width,
 WORD32 input_channels,     WORD32 out_channels,     WORD32 input_zero_bias,
 WORD32 kernel_zero_bias,   WORD32 out_multiplier,   WORD32 out_shift,
 WORD32 out_zero_bias,      WORD32 out_data_format);
WORD32 xa_nn_conv2d_pointwise_asym8uxasym8u
(UWORD8 * p_out,            const UWORD8 * p_ker,    const UWORD8 * p_inp,
 const WORD32 * p_bias,     WORD32 input_height,     WORD32 input_width,
 WORD32 input_channels,     WORD32 out_channels,     WORD32 input_zero_bias,
 WORD32 kernel_zero_bias,   WORD32 out_multiplier,   WORD32 out_shift,
 WORD32 out_zero_bias,      WORD32 out_data_format);
WORD32 xa_nn_conv2d_pointwise_per_chan_sym8sxasym8s
(WORD8  * p_out,            const WORD8 * p_ker,     const WORD8 * p_inp,
 const WORD32 * p_bias,     WORD32 input_height,     WORD32 input_width,
```

```
 WORD32 input_channels,    WORD32 out_channels,     WORD32 input_zero_bias,
 WORD32 * p_out_multiplier,WORD32 * p_out_shift,    WORD32 out_zero_bias,
 WORD32 out_data_format);
WORD32 xa_nn_conv2d_pointwise_per_chan_sym8sxsym16s
(WORD16  * p_out,          const WORD8 * p_ker,     const WORD8 * p_inp,
 const WORD64 * p_bias,    WORD32 input_height,     WORD32 input_width,
 WORD32 input_channels,    WORD32 out_channels,     WORD32 input_zero_bias,
 WORD32 * p_out_multiplier,WORD32 * p_out_shift,    WORD32 out_zero_bias,
 WORD32 out_data_format);
WORD32 xa_nn_conv2d_pointwise_f16
 (WORD16* p_out,           WORD16* p_kernel,      WORD16* p_inp,
  WORD16* p_bias,          WORD32  input_height,  WORD32  input_width,
  WORD32  input_channels,  WORD32  out_channels,  WORD32  out_data_format);
WORD32 xa_nn_conv2d_pointwise_v2_per_chan_sym8sxasym8s
(WORD8* __restrict__ p_out, WORD8* __restrict__ p_kernel, WORD8* __restrict__ p_inp,
 WORD32* __restrict__ p_bias,           WORD32  input_height, WORD32  input_width,
 WORD32  input_channels,                WORD32  out_channels, WORD32  input_zero_bias,
 WORD32* __restrict__ p_out_multiplier, WORD32* __restrict__ p_out_shift,
 WORD32  out_zero_bias,                 WORD32  out_data_format,
 WORD32  out_activation_min,            WORD32  out_activation_max,
 xa_dma_cfg_t *   p_dma_cfg);
WORD32 xa_nn_conv2d_pointwise_v2_per_chan_sym8sxsym16s
(WORD16* __restrict__ p_out,           WORD8* __restrict__ p_kernel,
 WORD16* __restrict__ p_inp,           WORD64* __restrict__ p_bias,
 WORD32  input_height,                 WORD32  input_width,
 WORD32  input_channels,               WORD32  out_channels,
 WORD32  input_zero_bias,              WORD32* __restrict__ p_out_multiplier,
 WORD32* __restrict__ p_out_shift,     WORD32  out_zero_bias,
 WORD32  out_data_format,              WORD32  out_activation_min,
 WORD32  out_activation_max,           xa_dma_cfg_t    *p_dma_cfg);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, const FLOAT32 *, const UWORD8 *, const WORD8 *	p_ker	out_channels * input_channels	Kernel matrix, fixed, floating point, asym8u or asym8s, (out_channels x input_channels)
WORD16 *, WORD8 *, const FLOAT32 *, const UWORD8 *, const WORD8 *, const WORD16 *	p_inp	input_height* input width* input_channels	Input cube, fixed or floating point, asym8u or sym8s, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *, const WORD32 *, const WORD64 *	p_bias	out_channels	Bias vector, fixed or floating point
WORD32	input_height		Input height
WORD32	input_width		Input width

Type	Name	Size	Description
WORD32	input_channels		Number of input channels
WORD32	out_channels		Number of output channels
WORD32	acc_shift		Shift applied to accumulator
WORD32	bias_shift		Shift applied to bias
WORD32	input_zero_bias		Zero offset of input
WORD32	kernel_zero_bias		Zero offset of kernel
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32	out_zero_bias		Zero offset of output
WORD32	out_data_format		Output data format 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
WORD32	out_activation_min		Min value for output minmax activation function This argument is only for _v2 variants
WORD32	out_activation_max		Max value for output minmax activation function This argument is only for _v2 variants
xa_dma_cfg_t *	p_dma_cfg		This is a placeholder
Output			
WORD16 *, WORD8 *, FLOAT32 *, UWORD8 *	p_out	(out_height* out_width)* out_channels	Output cube, fixed, floating point, asym8u or asym8s, as per the out_data_format argument.

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_out, p_ker, p_inp, p_bias	Cannot be NULL
	Should not overlap
	Aligned on 16-byte boundary except for 8x8 and quantized 8-bit/16-bit kernels
input_height, input_width	Greater than or equal to 1
input_channels	Greater than or equal to 4, multiple of 4 except for 8x8 and and quantized datatype kernels
out_channels	Greater than or equal to 1
acc_shift, bias_shift, out_shift	{-31,…., 31} for fixed point and quantized datatype APIs
input_zero_bias	{-255,….., 0} for asym8u input, {-127,….., 128} for asym8s input, 0 for sym16s input

kernel_zero_bias	{-255,……, 0} for asym8u kernel
out_zero_bias	{0,....., 255} for asym8u output, {-128,....., 127} for asym8s output, 0 for sym16s output
out_multiplier	Greater than 0
out_data_format	Can be 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T for 8x8 and quantized 8-bit kernels. Must be 1 for other kernels.

3.2.5 Depthwise Separable 2D Convolution Kernels with Dilation

Description

These kernels perform the dilated 2D depthwise convolution operation as `z = inp (*) kernel + bias`. These kernels convolve each input 2D plane (`input_height x input_width`) from input cube (`input_height x input_width x input_channels`) with channels_multiplier number of 2D dilated kernels (`dilated_kernel_height x dilated_kernel_width`) to produce channels_multiplier number of 2D output planes (out_height x out_width). Thus, with kernel cube of dimension (`dilated_kernel_height x dilated_kernel_width x (channels_multiplier * input_channels)`), output cube of dimension (`out_height x out_width x (channels_multiplier * input_channels)`) is produced. Bias is added to the convolution output. There is one bias value for each output 2D plane; that is, bias is a vector of dimension (`channels_multiplier * input_channels`).

The kernel is dilated by inserting (dilation_height – 1) zeros between consecutive height elements and (dilation_width -1) zeros between consecutive width elements. Post dilation, the kernel cube is of size `dilated_kernel_height = kernel_height+(kernel_height-1)*(dilation_height-1)` in height dimension, and `dilated_kernel_width = kernel_width + (kernel_width-1)*( dilation_width-1)` in width dimension.

The `x_stride` and `y_stride` arguments in kernel API define the step size of the kernel when traversing the input in width and height dimensions, respectively.

The `x_padding` argument defines padding to the left of the input in the width dimension, and the `y_padding` argument defines padding to the top of the input in the height dimension.

The right padding is calculated based on `out_width` as `right_padding = dilated_kernel_width + (out_width – 1) * x_stride – (x_padding + input_width)`.

The bottom padding is calculated based on `out_height` as `bottom_padding = dilated_kernel_height + (out_height – 1) * y_stride – (y_padding + input_height)`.

Symmetric rounding is used to convert from a higher precision accumulator to a lower precision output.

These kernels require a temporary buffer for convolution computation. The `p_scratch` argument of kernel API provides this temporary buffer. The size of the temporary buffer must be queried using the `xa_nn_dilated_conv2d_depthwise_getsize()` helper API.

The argument `input_zero_bias` is provided to convert the asym8s inputs into their real values and perform Dilated Depthwise 2D Convolution operation. The `out_zero_bias`, `p_out_multiplier`, and `p_out_shift` arguments are used to quantize real output values back to asym8s.

The depthwise kernels expect the input cube in SHAPE_CUBE_DWH_T and SHAPE_CUBE_WHD_T shape types and produce the output cube in SHAPE_CUBE_DWH_T shape types, respectively.

The `inp_data_format` argument to the kernel API can be 0 or 1 to indicate the input cube shape, respectively.

The `out_data_format` argument to the kernel API must be 0 for all the kernels to indicate the output cube shape.

The _v2 kernels have fused minmax activation operation and support only inp_data_format 0.

Precision

The following four variants are available:

Type	Description
`per_chan_sym8sxasym8s_asym8s`	per channel quantized sym8s kernel, asym8s input, asym8s output
`f32xf32_f32`	Float 32-bit kernel, Float 32-bit input, Float 32-bit output
`v2_per_chan_sym8sxasym8s_asym8s`	sym8s kernel, asym8s input, asym8s output. _v2 API
`v2_per_chan_sym8sxsym16s_asym16s`	sym8s kernel, sym16s input, sym16s output. _v2 API

Algorithm

$$z_{h,w,d*C_M+m} = \left(\sum_{i=0}^{K_H-1} \sum_{j=0}^{K_W-1} in_{pad_{(h*y_{stride}+i*dilation\_height),(w*x-stride+j*dilation\_width),d}} \cdot ker_{pad_{i,j,(d*C_M+m)}} + b_{0,0,d*C_M+m} \right)$$

$h = 0, \ldots, \overline{out\text{-}height - 1}, w = 0, \ldots, \overline{out\text{-}width - 1}$,
$d = 0, \ldots, \overline{input\text{-}channels - 1}$,
$m = 0, \ldots, \overline{channels\text{-}multiplier - 1}$

in_{pad}, ker_{pad} denote the padded `p_inp` and padded `p_ker` shapes, respectively.

K_H, K_W, C_M denote `kernel_height`, `kernel_width`, and `channels_multiplier`, respectively.

b denotes the `bias shape`.

Prototype

```
WORD32 xa_nn_dilated_conv2d_depthwise_getsize
```

```
(WORD32 input_height,       WORD32 input_width,      WORD32 input_channels,
 WORD32 kernel_height,      WORD32 kernel_width,     WORD32 channels_multiplier,
 WORD32 dilation_height,    WORD32 dilation_width,   WORD32 x_stride,
 WORD32 y_stride,           WORD32 x_padding,        WORD32 y_padding,
 WORD32 output_height       WORD32 output_width      WORD32 circ_buf_precision
 WORD32 inp_data_format);

WORD32 xa_nn_dilated_conv2d_depthwise_f32
(FLOAT32* p_out,             const FLOAT32* p_kernel,        const FLOAT32* p_inp,
 const FLOAT32* p_bias,      WORD32  input_height,           WORD32  input_width,
 WORD32  input_channels,     WORD32  kernel_height,          WORD32  kernel_width,
 WORD32  channels_multiplier,WORD32  dilation_height,        WORD32  dilation_width,
 WORD32  x_stride,           WORD32  y_stride,               WORD32  x_padding,
 WORD32  y_padding,          WORD32  out_height,             WORD32  out_width,
 WORD32  inp_data_format,    WORD32  out_data_format,        pVOID p_scratch);

WORD32 xa_nn_dilated_conv2d_depthwise_per_chan_sym8sxasym8s
(pWORD8* p_out,              const WORD8* p_kernel,          const WORD8 * p_inp,
 const WORD32 *p_bias,       WORD32  input_height,           WORD32  input_width,
 WORD32  input_channels,     WORD32  kernel_height,          WORD32  kernel_width,
 WORD32  channels_multiplier,WORD32  dilation_height,        WORD32  dilation_width,
 WORD32  x_stride ,          WORD32  y_stride,               WORD32  x_padding,
 WORD32  y_padding,          WORD32  out_height,             WORD32  out_width,
 WORD32  input_zero_bias,    const WORD32 *p_out_multiplier, const WORD32 *p_out_shift,
 WORD32  out_zero_bias,      WORD32  inp_data_format,        WORD32  out_data_format,
 pVOID p_scratch);

WORD32 xa_nn_dilated_conv2d_depthwise_v2_per_chan_sym8sxasym8s
(pWORD8 __restrict__ p_out,       const WORD8 *__restrict__ p_kernel,
 Const WORD8 *__restrict__ p_inp, const WORD32 *__restrict__ p_bias,
 WORD32  input_height,            WORD32  input_width,
 WORD32  input_channels,           WORD32  kernel_height,
 WORD32  kernel_width,             WORD32  channels_multiplier,
 WORD32  dilation_height,          WORD32  dilation_width,
 WORD32  x_stride,                 WORD32  y_stride,
 WORD32  x_padding,                WORD32  y_padding,
 WORD32  out_height,               WORD32  out_width,
 WORD32  input_zero_bias,          const WORD32 *p_out_multiplier,
 const WORD32 *p_out_shift,        WORD32  out_zero_bias,
 WORD32  inp_data_format,          WORD32  out_data_format,
 pVOID p_scratch,                  WORD32  out_activation_min,
 WORD32  out_activation_max,       xa_dma_cfg_t *p_dma_cfg);

WORD32 xa_nn_dilated_conv2d_depthwise_v2_per_chan_sym8sxsym16s
(pWORD16 __restrict__ p_out,         const WORD8 *__restrict__ p_kernel
 ,const WORD16 *__restrict__ p_inp,  const WORD64 *__restrict__ p_bias
 ,WORD32  input_height,              WORD32  input_width
 ,WORD32  input_channels,            WORD32  kernel_height
 ,WORD32  kernel_width,              WORD32  channels_multiplier
 ,WORD32  dilation_height,           WORD32  dilation_width
 ,WORD32  x_stride,                  WORD32  y_stride
 ,WORD32  x_padding,                 WORD32  y_padding
 ,WORD32  out_height,                WORD32  out_width
,WORD32  input_zero_bias,            const WORD32 *p_out_multiplier
,const WORD32 *p_out_shift,          WORD32  out_zero_bias
,WORD32  inp_data_format,            WORD32  out_data_format
,pVOID p_scratch,                    WORD32  out_activation_min
,WORD32  out_activation_max,         xa_dma_cfg_t *p_dma_cfg
 );
```

Arguments

Type	Name	Size	Description
Input			

const WORD8 *, const FLOAT32 *,	p_kernel	kernel_height* kernel width* input_channels* channels_multiplier	Kernel matrix, sym8s or floating point in SHAPE_CUBE_DWH or SHAPE_CUBE_WHD_T
const WORD8 *, const WORD16 * const FLOAT32 *	p_inp	input_height* input width* input_channels	Input cube, asym8s or floating point, in SHAPE_CUBE_DWH or SHAPE_CUBE_WHD_T
const WORD32 *, const FLOAT32 *, const WORD64 *	p_bias	input_channels* channels_multiplier	Bias vector, fixed or floating point
VOID *	p_scratch	xa_nn_dilated_conv2d _depthwise_getsize()	Scratch memory pointer
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of input channels
WORD32	kernel_height		Kernel height
WORD32	kernel_width		Kernel width
WORD32	channels_multipl ier		Multiplier value for each input channel
WORD32	dilation_height		Kernel height dilation factor
WORD32	dilation_width		Kernel width dilation factor
WORD32	x_stride		Horizontal stride over input
WORD32	y_stride		Vertical stride over input
WORD32	x_padding		Left padding width on input
WORD32	y_padding		Top padding height on input
WORD32	out_height		Output height
WORD32	out_width		Output width
WORD32	input_zero_bias		Input offset
WORD32	output_zero_bias		Output offset
WORD32 *	p_out_multiplier		Vector having multiplier values of output for per channel quantization.
WORD32 *	p_out_shift		Vector having shift values of output for per channel quantization.
WORD32	inp_data_format		input data format 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
WORD32	out_data_format		Output data format 0:SHAPE_CUBE_DWH_T
WORD32	out_activation_m in		Min value for output minmax activation function This argument is only for _v2 variants
WORD32	out_activation_m ax		Max value for output minmax activation function This argument is only for _v2 variants
xa_dma_cfg _t *	p_dma_cfg		This is a placeholder
Output			
WORD8 *, FLOAT32 *	p_out	(out_height* out_width)* input_channels* channels_multiplier	Output cube, floating point or asym8s, in SHAPE_CUBE_DWH_T

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_out, p_ker, p_inp	Cannot be NULL
	Must not overlap
p_bias, p_out_multiplier, p_out_shift	Cannot be NULL, Aligned on a 4-byte boundary. p_out_shift[i] {-31, …, 31}
p_scratch	Cannot be NULL, Aligned on a 16-byte boundary.
input_height, input_width, kernel_height, kernel_width, channel_multiplier,	Greater than 0
input_channels	Greater than 0
dilation_height, dilation_width,	Greater than 0
y_stride,x_stirde	Greater than 0
x_padding, y_padding	Greater than or equal to 0
out_height, out_width	Greater than 0
input_zero_bias	{-127, …, 128} for sym8sxasym8s variant
output_zero_bias	{-128, …, 127} for sym8sxasym8s variant
input_data_format	can be 0 or 1, must be 0 for _v2 variants.
output_data_format	Should be 0

3.2.6 Transpose Convolution

Description

This kernel performs Transpose reverse convolution operation only in the sense that the transpose convolution output has the same spatial dimension as that of the input in standard convolution. A transpose convolution layer is generally used for upsampling, that is, to generate an output that has more samples than the input.

As illustrated below, the input is multiplied with every value in the kernel and accumulated at appropriate indices in the output.

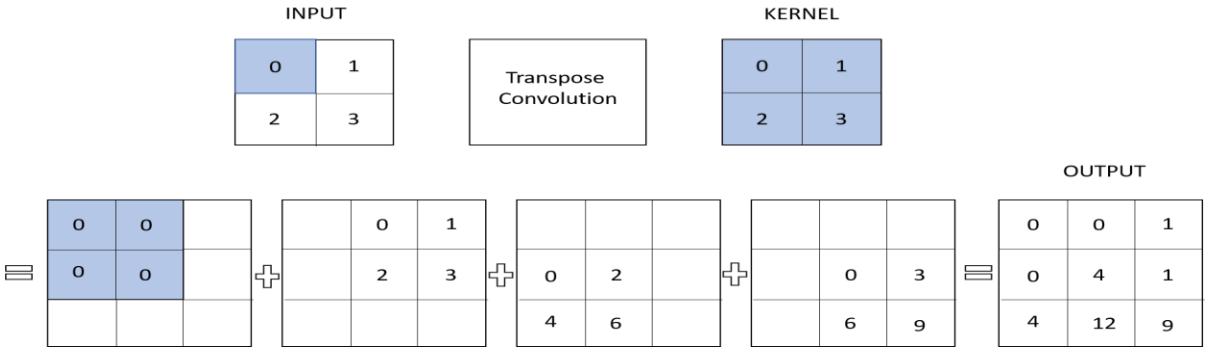

Figure 3-1 Example of Transpose Convolution (with padding 0 and stride 1)

These kernels require temporary buffer for convolution computation. This temporary buffer is provided by the scratch_buffer argument of kernel API. The size of the temporary buffer must be queried using `xa_nn_transpose_conv_getsize()` helper API.

The `stride_width` and `stride_height` arguments in kernel API define the step size to store intermediate multiplications in the output's width and height dimensions, respectively.

The `pad_width` and `pad_height` arguments define padding at the transpose convolution output, that is, the original input to standard convolution.

The _v2 kernels have fused minmax activation operation.

Floating point bit-exact support is added for the xa_nn_transpose_conv_f32 kernel.

Function variants available are `xa_nn_transpose_conv_[p]`, where:

- `[p]`: precision

Precision

There are five variants available.

Type	Description
`sym8sxsym16s`	sym8s kernel, sym16s input, sym16s output
`sym8sxasym8s`	sym8s kernel, asym8s input, asym8s output
`f32`	f32 kernel, f32 input, f32 output
`v2_sym8sxasym8s`	sym8s kernel, asym8s input, asym8s output. _v2 API
`v2_sym8sxsym16s`	sym8s kernel, sym16s input, sym16s output. _v2 API

Algorithm

$for\ iny = 0, \ldots, \overline{input\_height - 1}$
$for\ inx = 0, \ldots, \overline{input\_width - 1}$
$for\ inz = 0, \ldots, \overline{input\_depth - 1}$
$for\ ky = 0, \ldots, \overline{filter\_height - 1}$
$for\ kx = 0, \ldots, \overline{filter\_width - 1}$
$for\ outz = 0, \ldots, \overline{output\_depth - 1}$

$$if\ (outx\ \hat{I}\ [0, out\_width - 1]\ \&\&\ outy\ \hat{I}\ [0, out\_height - 1]$$
$$Z_{outy,outx,outz} += \left(input_{iny,inx,inz} \cdot kernel_{outz,ky,kx,inz}\right)$$

Where,

$outx = (inx * stride\_width) - pad\_width + kx$

$outy = (iny * stride\_height) - pad\_height + ky$

Prototype

```
WORD32 xa_nn_transpose_conv_getsize
(WORD32 input_height,       WORD32 input_width,       WORD32 input_channels,
 WORD32 kernel_height,      WORD32 kernel_width,      WORD32 x_stride,
 WORD32 y_stride,           WORD32 output_height,     WORD32 output_width,
 WORD32 output_channels,    WORD32 num_groups,         WORD32 kernel_precision,
 WORD32 output_precision);

WORD32 xa_nn_transpose_conv_sym8sxsym16s
(WORD16 * output_data,      const WORD16 * input_data,const WORD8* filter_data,
 const WORD64 * bias_data,  WORD32 stride_width,      WORD32 stride_height,
 WORD32 pad_width,          WORD32 pad_height,        WORD32 input_depth,
 WORD32 output_depth,       WORD32 input_height,      WORD32 input_width,
 WORD32 filter_height,      WORD32 filter_width,      WORD32 output_height,
 WORD32 output_width,       WORD32 num_elements,      WORD32 num_groups,
 WORD32 * output_shift, WORD32 * output_multiplier,VOID * scratch_buffer);
int xa_nn_transpose_conv_sym8sxasym8s
(WORD8* output_data,        const WORD8* input_data, const WORD8* filter_data,
 const WORD32* bias_data,   int stride_width,        int stride_height,
 int pad_width,             int pad_height,          int input_depth,
 int output_depth,          int input_height,        int input_width,
 int filter_height,         int filter_width,        int output_height,
 int output_width,          int num_elements,        WORD32 num_groups,
 int input_offset,          int output_offset,       int *output_shift,
 int *output_multiplier,    VOID* scratch_buffer);
WORd32 xa_nn_transpose_conv_f32
(FLOAT32* output_data,      const FLOAT32* input_data,const FLOAT32* filter_data,
 const FLOAT32* bias_data,  int stride_width,         int stride_height,
 int pad_width,             int pad_height,          int input_depth,
 int output_depth,          int input_height,        int input_width,
 int filter_height,         int filter_width,        int output_height,
 int output_width,          int num_elements,        int num_groups,
 VOID* scratch_buffer);
WORD32 xa_nn_transpose_conv_v2_sym8sxasym8s
(WORD8* output_data,       const WORD8* input_data,
 const WORD8* filter_data, const WORD32* bias_data,
 int stride_width,         int stride_height,
 int pad_width,            int pad_height,
 int input_depth,          int output_depth,
 int input_height,         int input_width,
 int filter_height,        int filter_width,
 int output_height,        int output_width,
 int num_elements,         int num_groups,   int input_offset,
 int output_offset,        int *output_shift,
 int *output_multiplier,   void* scratch_buffer,
 int out_activation_min,   int out_activation_max,
 xa_dma_cfg_t * p_dma_cfg);
WORD32 xa_nn_transpose_conv_v2_sym8sxsym16s
(WORD16* output_data,      const WORD16* input_data,
 const WORD8* filter_data, const WORD64* bias_data,
 int stride_width,         int stride_height,
 int pad_width,            int pad_height,
 int input_depth,          int output_depth,
 int input_height,         int input_width,
 int filter_height,        int filter_width,
```

```
int output_height,          int output_width,
int num_elements,           int num_groups,   int *output_shift,
int *output_multiplier,     void* scratch_buffer,
int out_activation_min,     int out_activation_max,
xa_dma_cfg_t *p_dma_cfg);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *, const WORD16 *, const FLOAT32 *	input_data	input_height* input width* input_depth	Input cube, asym8s, sym16s, or f32 SHAPE_CUBE_DWH_T
const WORD8 *, const FLOAT32 *	filter_data	out_depth* (kernel_height * kernel width* input_depth)	Kernel cube, f32, or fixed sym8s in SHAPE_CUBE_DWH_T
const WORD64 *, const FLOAT32 *	bias_data	out_channels	Bias vector, fixed point
WORD32	input_offset		Zero offset of the input
WORD32	output_offset		Zero offset of the output
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_depth		Number of input channels
WORD32	filter_height		Kernel height
WORD32	filter_width		Kernel width
WORD32	output_depth		Number of output channels
WORD32	pad_width		Left padding width on output
WORD32	pad_height		Top padding height on output
WORD32	stride_width		Horizontal stride over output
WORD32	stride_height		Vertical stride over output
WORD32	out_height		Output height
WORD32	out_width		Output width
WORD32 *	output_multiplier		Multiplier value of output
WORD32 *	output_shift		Shift value of output
WORD32	num_groups		Number of groups. Supported only for sym8sxasym8s and sym8sxsym16s variants
WORD32	num_elements	(out_height* out_width)* output_depth	Number of output points
WORD64 * FLOAT32 *	scratch_buffer	xa_nn_transpose_conv_getsize()	Scratch memory pointer
int	out_activation_min		Min value for output minmax activation function

Type	Name	Size	Description
			This argument is only for _v2 variants
int	out_activation_max		Max value for output minmax activation function This argument is only for _v2 variants
xa_dma_cfg_t *	p_dma_cfg		This is a placeholder
Output			
WORD8 * WORD16 * FLOAT32 *	output_data	(out_height* out_width)* output_depth	Output cube, asym8s, sym16s, or f32.

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions

Arguments	Restrictions
input_data, output_data	Cannot be NULL Aligned on <size of one element> boundary. Should not overlap
filter_data	Cannot be NULL Aligned on <size of one element> boundary.
scratch_buffer	Cannot be NULL Aligned on 16-byte boundary
bias_data	Aligned on 8-byte boundary for sym8sxsym16s, and 4-byte for f32 and sym8sxasym8s.
input_offset	{-127, ..., 128}
output_offset	{-128, ..., 127}
num_groups	Greater than zero.
input_height,input_width, input_depth,filter_height, filter_width,output_depth, stride_height,stride_width, output_height,output_width, num_elements, num_groups	Greater than zero input_depth and output_depth must be multiple of num_groups
pad_height, pad_width	Greater than or equal to zero

3.2.7 2D Convolution Kernel

Description

The 2D Convolution kernels perform the convolution operation as `z = inp(*)kernel + bias`. A 3D input cube (`input_height x input_width x input_channels`) is convolved with a 3D kernel cube (`kernel_height x kernel_width x kernel_channels`) to produce a 2D convolution output plane (`out_height x out_width`). With the `out_channels` number of such 3D kernels, an output cube (`out_height x out_width x out_channels`) is produced. The bias having the same dimensions as

that of the output is added after the convolution to produce the final output. This kernel supports both 2D group and standard convolution operations.

Note The depth or channel's dimension (`input_channels`) must be multiple of kernel depth or channels (`kernel_channels`) for group convolution.

Note The depth or channels dimension (`out_channels`) must be multiple of (`input_channels /kernel_channels`) for group convolution.

The `x_stride` and `y_stride` arguments in the kernel API define the step size of the kernel when traversing the input in width and height dimensions, respectively.

The `x_padding` argument defines padding to the left of the input in the width dimension, and the `y_padding` argument defines padding to the top of the input in the height dimension.

The right padding is calculated based on `out_width` as `right_padding = kernel_width + (out_width – 1) * x_stride – (x_padding + input_width).`

The bottom padding is calculated based on `out_height` as `bottom_padding = kernel_height + (out_height – 1) * y_stride – (y_padding + input_height).`

Symmetric rounding is used to convert from a higher precision accumulator to a lower precision output.

These kernels require a temporary buffer for convolution computation. This temporary buffer is provided by `p_scratch` argument of the kernel API. The size of the temporary buffer must be queried using the `xa_nn_conv2d_getsize()` helper API (the same API used in standard Convolution). For Group convolution, the kernel_channels is passed as the second argument.

The argument `input_zero_bias` is provided to convert the asym8s inputs into their real values and perform the Group Convolution operation. The `out_zero_bias`, `p_out_multiplier`, and `p_out_shift` values quantize real output values back to asym8s.

These kernels expect input, kernel, and bias cubes in the SHAPE_CUBE_DWH_T shape type, and can produce output cubes in either SHAPE_CUBE_DWH_T or SHAPE_CUBE_WHD_T shape type. The `out_data_format` argument to kernel API controls the output cube shape type.

The _v2 kernels have fused minmax activation operation.

The function variants are available as `xa_nn_conv2d_group_[p]`, where:

- [p]: precision in bits

Precision

The following four variants are available:

Type	Description

sym8sxasym8s	per channel quantized sym8s kernel, asym8s input, asym8s output
sym8sxsym16s	per channel quantized sym8s kernel, sym16s input, sym16s output
v2_per_chan_sym8sxasym8s	per channel quantized sym8s kernel, asym8s input, asym8s output. _v2 API
v2_per_chan_sym8sxsym16s	v2, per channel quantized sym8s kernel, sym16s input, sym16s output

Algorithm

$$z_{h,w,d} = 2^{acc\text{-}shift}\left(\sum_{i=0}^{K_H-1}\sum_{j=0}^{K_W-1}\sum_{k=0}^{Kc-1} in_{pad}{}_{(h*y\text{-}stride+i),(w*x\text{-}stride+j),(g*Kc+k)} \cdot ker_{pad}{}_{d,i,j,k} + 2^{bias\text{-}shift}\, b_{h,w,d}\right)$$

$h = 0, \ldots, \overline{out\text{-}height - 1}, w = 0, \ldots, \overline{out\text{-}width - 1},$
$d = 0, \ldots, \overline{out_{channels} - 1}$
$g = floor\left(\frac{d}{G}\right), where\ G = \frac{Ic}{Kc}$

in_{pad}, ker_{pad} denote the padded `p_inp` and padded `p_ker` shapes, respectively.

K_H, K_W, Kc, Ic denote kernel_height, kernel_width, kernel_channels and input channels, respectively.

b denotes the `bias` shape.

Prototype

```
WORD32 xa_nn_conv2d_getsize
(WORD32 input_height,  WORD32 input_width, WORD32 input_channels,
 WORD32 kernel_height, WORD32 kernel_width, WORD32 kernel_channels,
WORD32 dilation_height, WORD32 dilation_width, WORD32 y_stride,
WORD32 y_padding,       WORD32 x_stride,       WORD32 x_padding,
WORD32 out_height,      WORD32 out_width,      WORD32 output_channels,
WORD32 input_precision, WORD32 kernel_precision, WORD32 out_data_format);
WORD32 xa_nn_conv2d_per_chan_sym8sxasym8s
(WORD8* __restrict__ p_out,                                  const WORD8* __restrict__ p_inp,
 const WORD8* __restrict__ p_kernel,                         const WORD32* __restrict__ p_bias,
 WORD32 input_height,         WORD32 input_width,            WORD32 input_channels,
 WORD32 kernel_height,        WORD32 kernel_width,           WORD32 kernel_channels,
 WORD32 dilation_height,      WORD32 dilation_width,         WORD32 out_channels,
 WORD32 x_stride,             WORD32 y_stride,               WORD32 x_padding,
 WORD32 y_padding,            WORD32 out_height,             WORD32 out_width,
 WORD32 input_zero_bias,      WORD32 * p_out_multiplier,     WORD32 * p_out_shift,
 WORD32 out_zero_bias,        WORD32 out_data_format,        VOID *p_scratch);
WORD32 xa_nn_conv2d_per_chan_sym8sxsym16s
(WORD16* __restrict__ p_out,                                 const WORD16* __restrict__ p_inp,
 const WORD8* __restrict__ p_kernel,                         const WORD64* __restrict__ p_bias,
 WORD32 input_height,         WORD32 input_width,            WORD32 input_channels,
 WORD32 kernel_height,        WORD32 kernel_width,           WORD32 kernel_channels,
 WORD32 dilation_height,      WORD32 dilation_width,         WORD32 out_channels,
 WORD32 x_stride,             WORD32 y_stride,               WORD32 x_padding,
 WORD32 y_padding,            WORD32 out_height,             WORD32 out_width,
 WORD32 input_zero_bias,      WORD32 * p_out_multiplier,     WORD32 * p_out_shift,
```

```
 WORD32 out_zero_bias,        WORD32 out_data_format,       VOID *p_scratch);
WORD32 xa_nn_conv2d_v2_per_chan_sym8sxasym8s
(WORD8* __restrict__ p_out,          const WORD8* __restrict__ p_inp,
 const WORD8* __restrict__ p_kernel, const WORD32* __restrict__ p_bias,
 WORD32 input_height,                WORD32 input_width,
 WORD32 input_channels,              WORD32 kernel_height,
 WORD32 kernel_width,                WORD32 kernel_channels,
 WORD32 dilation_height,             WORD32 dilation_width,
 WORD32 out_channels,                WORD32 x_stride,
 WORD32 y_stride,                    WORD32 x_padding,
 WORD32 y_padding,                   WORD32 out_height,
 WORD32 out_width,                   WORD32 input_zero_bias,
 WORD32 * p_out_multiplier,          WORD32 * p_out_shift,
 WORD32 out_zero_bias,               WORD32 out_data_format,
 VOID *p_scratch,                    WORD32 out_activation_min,
 WORD32 out_activation_max,          xa_dma_cfg_t *p_dma_cfg);
WORD32 xa_nn_conv2d_v2_per_chan_sym8sxsym16s
(WORD16* __restrict__ p_out,         const WORD16* __restrict__ p_inp,
 const WORD8* __restrict__ p_kernel, const WORD64* __restrict__ p_bias,
 WORD32 input_height,                WORD32 input_width,
 WORD32 input_channels,              WORD32 kernel_height,
 WORD32 kernel_width,                WORD32 kernel_channels,
 WORD32 dilation_height,             WORD32 dilation_width,
 WORD32 out_channels,                WORD32 x_stride,
 WORD32 y_stride,                    WORD32 x_padding,
 WORD32 y_padding,                   WORD32 out_height,
 WORD32 out_width,                   WORD32 input_zero_bias,
 WORD32 * p_out_multiplier,          WORD32 * p_out_shift,
 WORD32 out_zero_bias,               WORD32 out_data_format,
 VOID *p_scratch,                    WORD32 out_activation_min,
 WORD32 out_activation_max,          xa_dma_cfg_t *p_dma_cfg);
```

Arguments

Type	Name	Size	Description
Input			
WORD8 *, WORD16 *	p_inp	input_height* input width* input_channels	Input cube, fixed, floating point, asym8u or asym8s, in SHAPE_CUBE_DWH_T
WORD8 *	p_ker	out_channels* (kernel_height * kernel width* kernel_channels)	Kernel cube, fixed, floating point, asym8u or sym8s in SHAPE_CUBE_DWH_T
WORD32 *, WORD64 *	p_bias	out_channels	Bias vector, fixed or floating point
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of input channels
WORD32	kernel_height		Kernel height
WORD32	kernel_width		Kernel width
WORD32	kernel_channels		Kernel channels
WORD32	out_channels		Number of output channels
WORD32	x_stride		Horizontal stride over input
WORD32	y_stride		Vertical stride over input
WORD32	x_padding		Left padding width on input
WORD32	y_padding		Top padding height on input
WORD32	out_height		Output height

Type	Name	Size	Description
WORD32	out_width		Output width
WORD32	input_zero_bias		Zero offset of input
const WORD32 *	p_out_multiplier		Vector having multiplier values of output for per channel quantization.
const WORD32 *	p_out_shift		Vector having shift values of output for per channel quantization.
WORD32	out_zero_bias		Zero offset of output
WORD32	out_data_format		Output data format: 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
VOID *	p_scratch	xa_nn_conv2d_std_getsize()	Scratch memory pointer
WORD32	out_activation_min		Min value for output minmax activation function This argument is only for _v2 variants
WORD32	out_activation_max		Max value for output minmax activation function This argument is only for _v2 variants
xa_dma_cfg_t *	p_dma_cfg		This is a placeholder
Output			
WORD8 *, WORD16 *	p_out	(out_height* out_width)* out_channels	Output cube, fixed, floating point, asym8u, or asym8s as per the out_data_format argument.

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_ker, p_scratch	Cannot be NULL
	Must not overlap
	Aligned on an 8-byte boundary (p_bias needs to be only 4-byte aligned for the asym8 variant)
	For p_scratch – memory size >= size returned by xa_nn_conv2d_std_getsize()
p_out, p_inp, p_bias	Cannot be NULL (p_bias can be NULL)
	Must not overlap
	Aligned on (size of one element)-byte boundary
input_height, input_width	Greater than or equal to 1
p_out_multiplier, p_out_shift	Cannot be NULL, must not overlap, and must be aligned to a 4-byte boundary.
Kernel_height	{1, 2, ..., input_height}
kernel_width	{1, 2, ..., input_width}
Kernel_channels	Greater than or equal to 1
input_channels	Greater than or equal to 1
	Input channels must be multiple of kernel_channels
out_channels	Greater than or equal to 1
	out_channels must be multiple of (input_channels/kernel_channels), that is, groups.

Arguments	Restrictions
X_stride	Greater than or equal to 1
y_stride	Greater than or equal to 1
x_padding, y_padding	Greater than or equal to 0
out_height, out_width	Greater than or equal to 1
input_zero_bias	{-127, …, 128} for sym8sxasym8s variant
out_zero_bias	{-128,…, 127} for sym8sxasym8s variant
out_data_format	Can be: 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T

3.3 Activation Kernels

3.3.1 Sigmoid

Description

The Sigmoid kernels perform the sigmoid operation on input vector `x` and give the output vector as `y = sigmoid(x)`. Both the input and output vectors have size `vec_length`.

The 32-bit input fixed-point kernels accept 32-bit input in Q6.25 format and give output in Q16.15 (32-bit), Q15 (16-bit), or Q7 (8-bit) format. The 16-bit input/output fixed-point kernel accepts the input in Q3.12 and gives output in Q15 (16-bit) format.

For the sym16s, asym8u, and asym8s kernels, both the input and output are of sym16s, asym8u and asym8s datatype, respectively.

The 16-bit fixed point variant and the quantized 8-bit variants of sigmoid are based on TensorFlow implementations. 16-bit fixed point and quantized signed 8-bit variants support improved optimization (but 2-bit difference with TensorFlow implementation) for HiFi5 cores, which have activation tie instructions [5.1].

Similarly, the sigmoid sym16s kernel supports improved optimization (but a 2-bit difference with respect to Tensorflow implementation) for the HiFi5 cores with activation tie instructions when the actual input values (dequantized) are in the range: -8 to 8 [5.1].

Note The `input_range_radius` argument for quantized 8-bit variants is derived from other input parameters in TensorFlow. The kernel does not perform a dependency check on the `input_range_radius` and the user will have to ensure that the correct value is passed.

Function variants available are `xa_nn_vec_sigmoid_[p]_[q]`, where:

`[p]`: Input precision in bits

`[q]`: Output precision in bits

Precision

There are eight variants available.

Type	Description
32_16	32-bit input, 16-bit output
32_8	32-bit input, 8-bit output
16_16	16-bit input, 16-bit output
f32_f32	float32 input, float32 output
f16_f16	float16 input, float16 output
asym8u_asym8u	asym8u input, asym8u output
asym8s_asym8s	asym8s input, asym8s output
sym16s_sym16s	sym16s input, sym16s output

Algorithm

$$y_n = \frac{1}{1 + \exp(-x_n)}, \qquad n = 0, \ldots, \overline{vec\text{-}length - 1}$$

Prototype

```
WORD32 xa_nn_vec_sigmoid_32_16
(WORD16 * p_out,            const WORD32 * p_vec,    WORD32 vec_length);
WORD32 xa_nn_vec_sigmoid_32_8
(WORD8 * p_out,             const WORD32 * p_vec,    WORD32 vec_length);
WORD32 xa_nn_vec_sigmoid_f32_f32
(FLOAT32 * p_out,           const FLOAT32 * p_vec,   WORD32 vec_length);
WORD32 xa_nn_vec_sigmoid_asym8u_asym8u
(UWORD8 * p_out,            const UWORD8 * p_vec,    WORD32 zero_point,
 WORD32 input_range_radius, WORD32 input_multiplier, WORD32 input_left_shift,
 WORD32 vec_length);
WORD32 xa_nn_vec_sigmoid_asym8s_asym8s
(WORD8 * p_out,             const WORD8 * p_vec,     WORD32 zero_point,
 WORD32 input_range_radius, WORD32 input_multiplier, WORD32 input_left_shift,
 WORD32 vec_length);
WORD32 xa_nn_vec_sigmoid_16_16
(WORD16 * p_out,            const WORD16 * p_vec,    WORD32 vec_length);
WORD32 xa_nn_vec_sigmoid_sym16s_sym16s
(WORD16 *p_out,             const WORD16 *p_vec,     WORD32 input_multiplier,
 WORD32 input_left_shift,   WORD32 vec_length);
WORD32 xa_nn_vec_sigmoid_f16_f16
(WORD16 *p_out,              const WORD16 *p_vec,     WORD32 vec_length);
```

Arguments

Type	Name	Size	Description
Input			
const WORD32 *, const WORD16 *, const UWORD8 *, const FLOAT32 *, const	p_vec	vec_length	Input vector, Q6.25, Q3.12, floating point, asym8u, asym8s, or sym16s

WORD8 *			
WORD32	zero_point		bias value
WORD32	input_range_radius		Range radius: For asym8u output = ((x_i - zero_point) < radius)? sigmoid() : 255 output = ((x_i - zero_point) > (-radius))? sigmoid() : 0 For asym8s output = ((x_i - zero_point) < radius)? sigmoid() : 127 output = ((x_i - zero_point) > (-radius))? sigmoid() : -128
WORD32	input_multiplier		Multiplier value of input
WORD32	input_left_shift		Left Shift value of input
WORD32	vec_length		Length of input vector
Output			
WORD32 *, WORD16 *, WORD8 *, UWORD8 *, FLOAT32 *	p_out	vec_length	Output vector, fixed (Q16.15, Q15, Q7), floating point, asym8u, asym8s, or sym16s

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_vec, p_out	Should not overlap
	Cannot be NULL
zero_point	[0, 255] for the asym8u kernel [-128, 127] for the asym8s kernel
input_range_radius	Greater than or equal to 0
input_left_shift	[-31, 31] for asym8u and asym8s kernels. Should be greater than or equal to 0 for the sym16s kernel.
input_multiplier	Should not be less than 0.
vec_length	Greater than 0

3.3.2 Tanh

Description

The Tanh kernels perform the hyperbolic tangent operation on input vector `x` and give the output vector as `y = tanh(x)`. Both the input and output vectors have size `vec_length`.

The 32-bit input fixed-point kernels accept 32-bit input in Q6.25 format and give output in Q16.15 (32-bit), Q15 (16-bit), or Q7 (8-bit) format. The 16-bit fixed-point kernel has input argument `integer_bits` to

specify the number of integer bits in input so input Q format is Q(`integer_bits`).(15 – `integer_bits`), and output is given in Q15 (16-bit) format.

For the sym16s and asym8s kernels both the input and output are of sym16s and asym8s datatype, respectively.

The 16-bit fixed point variant and the quantized 8-bit variants of tanh are based on Tensorflow implementations. 16-bit fixed point and quantized signed 8-bit variants support improved optimization (but 2-bit difference with TensorFlow implementation) for HiFi5 cores which have activation tie instructions [5.1].

Similarly, the tanh sym16s kernel supports improved optimization (but a 2-bit difference with respect to Tensorflow implementation) for the HiFi5 cores with activation tie instructions when the actual input values (dequantized) are in the range: -8 to 8 [5.1].

Note The `input_range_radius` argument for quantized 8-bit variant is derived from other input parameters in TensorFlow. The kernel does not perform dependency check on the `input_range_radius` and the user will have to ensure that correct value is passed.

Function variants available are `xa_nn_vec_tanh_[p]_[q]`, where:

`[p]`: Input precision in bits

`[q]`: Output precision in bits

Precision

There are seven variants available:

Type	Description
`32_16`	32-bit input, 16-bit output
`32_8`	32-bit input, 8-bit output
`16_16`	16-bit input, 16-bit output
`f32_f32`	float32 input, float32 output
`f16_f16`	float16 input, float16 output
`asym8s_asym8s`	asym8s input, asym8s output
`sym16s_sym16s`	sym16s input, sym16s output

Algorithm

$y_n = \tanh(x_n), \quad n = 0, \ldots, \overline{vec\text{-}length - 1}$

Prototype

```
WORD32 xa_nn_vec_tanh_32_16
(WORD16 * p_out,            const WORD32 * p_vec,    WORD32 vec_length);
WORD32 xa_nn_vec_tanh_32_8
(WORD8 * p_out,             const WORD32 * p_vec,    WORD32 vec_length);
WORD32 xa_nn_vec_tanh_f32_f32
(FLOAT32 * p_out,           const FLOAT32 * p_vec,   WORD32 vec_length);
WORD32 xa_nn_vec_tanh_asym8s_asym8s
(WORD8 * p_out,             const WORD8 * p_vec,     WORD32 zero_point,
```

```
 WORD32 input_range_radius, WORD32 input_multiplier, WORD32 input_left_shift,
 WORD32 vec_length);
WORD32 xa_nn_vec_tanh_16_16
(WORD16 * p_out,            const WORD16 *p_vec,     WORD32 integer_bits,
 WORD32 vec_length);
WORD32 xa_nn_vec_tanh_sym16s_sym16s
(WORD16 *p_out,             const WORD16 *p_vec,     WORD32 input_multiplier,
 WORD32 input_left_shift,   WORD32 vec_length);
WORD32 xa_nn_vec_tanh_f16_f16
(WORD16 * p_out,            const WORD32 * p_vec,    WORD32 vec_length);
```

Arguments

Type	Name	Size	Description
Input			
const WORD32 *, const WORD16 *, const FLOAT32 *, const WORD8 *	p_vec	vec_length	Input vector, Q6.25, Q(integer_bits).(15-integer_bits), floating point, asym8s or sym16s
WORD32	zero_point		Bias value
WORD32	input_range_radius		Range radius: output = ((x_i - zero_point) < radius)? tanh() : 127 output = ((x_i - zero_point) > (-radius))? tanh() : -128
WORD32	input_multiplier		Multiplier value of input
WORD32	input_left_shift		Left shift value of input
WORD32	vec_length		Length of input vector
WORD32	integer_bits		Number of integer bits in the 16-bit input
Output			
WORD32 *, WORD16 *, WORD8 *, FLOAT32 *	p_out	vec_length	Output vector, fixed (Q16.15, Q15, Q7), floating point, asym8s, or sym16s

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_vec, p_out	Should not overlap
	Cannot be NULL
zero_point	[-128, 127]
input_range_radius	Greater than or equal to 0
input_multiplier	Should not be less than 0
input_left_shift	[-31,31] for the asym8s kernel.

	Should be greater than or equal to 0 for the sym16s kernel.
`vec_length`	Greater than 0
`integer_bits`	[0, 6]

3.3.3 Rectifier Linear Unit (ReLU)

Description

The Rectifier Linear Unit (ReLU) kernels compute the rectifier linear unit function of input vector `x` and give the output vector as `y = relu(x)`. Both the input and output vectors have size `vec_length`.

The fixed-point routines accept 32-bit input in Q6.25 format and give 32-bit output in Q16.15 format.

The `threshold` argument to the kernel API allows setting an upper threshold for proper compression of the output signal and is expected in Q16.15 format. In `relu1` and `relu6` kernels, the thresholds are set to 1 and 6, respectively.

For the asym8u and asym8s kernels, the quantized input is requantized and applied the standard ReLU function to give the output. The `threshold` argument is not applicable for quantized ReLU kernels.

The standard ReLU kernels `relu_std` can be used when the `threshold` is not required.

Function variants available are `xa_nn_vec_relu_[p]_[q]`, `xa_nn_vec_relu1_[p]_[q]`, and `xa_nn_vec_relu6_[p]_[q]`, where:

`[p]`: Input precision in bits

`[q]`: Output precision in bits

Precision

There are six variants available:

Type	Description
`f32_f32`	float32 input, float32 output
`f16_f16`	float32 input, float32 output
`16_16`	16-bit input, 16-bit output
`8_8`	8-bit input, 8-bit output
`asym8u_asym8u`	asym8u input, asym8u output
`asym8s_asym8s`	asym8s input, asym8s output

Algorithm

$y_n = \max(0, \min(x_n, K)), \qquad n = 0, \ldots, \overline{vec\text{-}length - 1}$

K represents `threshold`

Prototype

```
WORD32 xa_nn_vec_relu_f32_f32
(FLOAT32 * p_out,    const FLOAT32 * p_vec,  FLOAT32 threshold,
 WORD32 vec_length);
WORD32 xa_nn_vec_relu_16_16
(WORD16 * p_out,     const WORD16 * p_vec,   WORD16 threshold,
 WORD32 vec_length);
WORD32 xa_nn_vec_relu_8_8
(WORD8 * p_out,      const WORD8  * p_vec,   WORD8 threshold,
 WORD32 vec_length);
WORD32 xa_nn_vec_relu_asym8u_asym8u
(UWORD8 * p_out,        const UWORD8 * p_vec,WORD32 inp_zero_bias,
 WORD32 out_multiplier, WORD32 out_shift,    WORD32 out_zero_bias,
 WORD32 quantized_activation_min, WORD32 quantized_activation_max,
 WORD32 vec_length);
WORD32 xa_nn_vec_relu_asym8s_asym8s
(WORD8 * p_out,         const WORD8 * p_vec, WORD32 inp_zero_bias,
 WORD32 out_multiplier, WORD32 out_shift,    WORD32 out_zero_bias,
 WORD32 quantized_activation_min, WORD32 quantized_activation_max,
 WORD32 vec_length);
WORD32 xa_nn_vec_relu1_f32_f32
(FLOAT32 * p_out,    const FLOAT32 * p_vec,  WORD32 vec_length);
WORD32 xa_nn_vec_relu6_f32_f32
(FLOAT32 * p_out,    const FLOAT32 * p_vec,  WORD32 vec_length);
WORD32 xa_nn_vec_relu_std_32_32
(WORD32 * p_out,     const WORD32 * p_vec,   WORD32 vec_length);
WORD32 xa_nn_vec_relu_std_f32_f32
(FLOAT32 * p_out,    const FLOAT32 * p_vec,  WORD32 vec_length);
WORD32 xa_nn_vec_relu_std_16_16
(WORD16 * p_out,     const WORD16 * p_vec,   WORD32 vec_length);
WORD32 xa_nn_vec_relu_std_8_8
(WORD8 * p_out,      const WORD8  * p_vec,   WORD32 vec_length);
```

Arguments

Type	Name	Size	Description
Input			
const WORD32 *, const FLOAT32 *, const WORD16 *, const WORD8 *, const UWORD8 *	p_vec	vec_length	Input vector, fixed-point, floating point, asym8u or asym8s
WORD32	inp_zero_bias		Zero bias value for input vector
WORD32	out_multipler		Fixed-point multiplier value for output
WORD32	out_shift		Shift value for output
WORD32	vec_length		length of input vector
WORD32	out_zero_bias		Zero bias value for output vector
WORD32	quantized_activation_min		Lower threshold value, quantized.
WORD32, FLOAT32	quantized_activation_max		Upper threshold value, quantized

Type	Name	Size	Description
WORD32 FLOAT32 WORD16 WORD8	threshold		threshold, fixed or floating point
Output			
WORD32 *, FLOAT32 *, WORD16 *, WORD8 *, UWORD8 *	p_out	vec_length	Output vector, fixed-point, floating point, asym8u or asym8s

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_vec, p_out	Should not overlap
	Cannot be NULL
inp_zero_bias, out_zero_bias	{0,....., 255} for asym8u, {-128,....., 127} for asym8s input
out_multiplier	Should not be less than 0.
out_shift	{-31, ..., 31}
quantized_activation_min quantized_activation_max	{0,....., 255} for asym8u output, {-128,....., 127} for asym8s output quantized_activation_min < quantized_activation_max

3.3.4 Softmax

Description

The Softmax kernels compute the Softmax (normalized exponential function) of input vector `x` and give the output vector as `y = softmax(x)`. Both the input and output vectors have size `vec_length`.

The fixed-point kernels accept 32-bit input in Q6.25 format and give 32-bit output in Q16.15 format.

For the asym8u kernels, both the input and output have the same precision and for asym8s kernels, the input is asym8s and the output precision can be asym8s or 16-bit.

These kernels require temporary buffer for softmax computation. This temporary buffer is provided by p_scratch argument of kernel API. The size of the temporary buffer must be queried using the get_softmax_scratch_size() helper API.

Function variants available are `xa_nn_vec_softmax_[p]_[q]`, where:

`[p]`: Input precision in bits

`[q]`: Output precision in bits

Precision

There are five variants available:

Type	Description
`f32_f32`	float32 input, float32 output
`asym8u_asym8u`	asym8u input, asym8u output
`asym8s_asym8s`	asym8s input, asym8s output
`asym8s_16`	asym8s input, 16-bit output
`sym16s_16`	sym16s input, 16-bit fixed point output

Algorithm

$$y_n = \frac{\exp(x_n)}{\sum_k \exp(x_k)}, \qquad n = 0, \ldots, \overline{vec_{length} - 1}\ , \qquad k = 0, \ldots, \overline{vec\text{-}length - 1}$$

Prototype

```
WORD32 xa_nn_vec_softmax_f32_f32
(FLOAT32 * p_out,    const FLOAT32 * p_vec,  WORD32 vec_length);
WORD32 xa_nn_vec_softmax_asym8u_asym8u
(UWORD8 * p_out,     const UWORD8 * p_vec,   WORD32 diffmin,
 WORD32 input_left_shift,     WORD32 input_multiplier,
 WORD32  vec_length,          pVOID  p_scratch);
WORD32 xa_nn_vec_softmax_asym8s_asym8s
(WORD8 * p_out,      const WORD8 * p_vec,    WORD32 diffmin,
 WORD32 input_left_shift,     WORD32 input_multiplier,
 WORD32  vec_length,          pVOID  p_scratch);
WORD32 xa_nn_vec_softmax_asym8s_16
(WORD16 * p_out,     const WORD8 * p_vec,    WORD32 diffmin,
 WORD32 input_left_shift,     WORD32 input_multiplier,
 WORD32  vec_length,          pVOID  p_scratch);
WORD32 xa_nn_vec_softmax_sym16s_16
(WORD16 * p_out,    const   WORD16 * p_vec,   WORD32  diffmin,
 WORD32  input_beta_left_shift, WORD32  input_beta_multiplier,
 WORD32  vec_length,          pVOID   p_scratch);
int get_softmax_scratch_size
(int inp_precision,          int out_precision,      int length);
```

Arguments

Type	Name	Size	Description
Input			
`WORD32 *, FLOAT32 *, const UWORD8 *, const WORD8 *, const WORD16 *`	`p_vec`	`vec_length`	Input vector, Q6.25, floating point, sym16s, asym8u or asym8s
`WORD32`	`diffmin`		Diffmin value:

			output = ((x_i – max) > diffmin) ? softmax() : 0
WORD32	input_ left_shift		left shift value of input
WORD32	input_ multiplier		multiplier value of input
WORD32	vec_length		Length of input vector
Output			
WORD32 *, FLOAT32 *, UWORD8 *, WORD8 *, WORD16 *	p_out	vec_length	Output vector, Q16.15, floating point, asym8u, asym8s or 16-bit.
Temporary			
VOID *,	p_scratch		Scratch (temporary) memory pointer

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_vec, p_out	Should not overlap
	Cannot be NULL
input_left_shift	[-31, 31] for asym8u_asym8u, [0 31] for asym8s_asym8s and asym8s_16
input_multiplier	Should not be less than 0.
vec_length	Greater than 0

3.3.5 Activation Min Max

Description

The Activation Min Max kernels compute the activation minimum and maximum value of input vector `x` and give the output vector as `y = activation_min_max(x)`. Both the input and output vectors have size `num_elm`.

For activation min max kernels, the input precision and the output precision are the same.

The `activation_min` and `activation_max` arguments to the kernel API allow to set the threshold for proper compression of the output. The kernel is a generic implementation of the ReLU function.

Function variant available is `xa_nn_vec_activation_min_max_[p]_[q]`, where:

`[p]`: Input precision in bits

`[q]`: Output precision in bits

Precision

The following four variants are available:

Type	Description
f32_f32	float32 input, float32 output
asym8uxasym8u	asym8u input, asym8u output
16_16	16-bit input, 16-bit output
8_8	8-bit input, 8-bit output

Algorithm

$y_n = \max(activation\text{-}min, \min(x_n, activation\text{-}max)), \qquad n = 0, \ldots, \overline{vec\text{-}length - 1}$

$activation\text{-}min$ represents the lower threshold.

$activation\text{-}max$ represents the upper threshold.

Prototype

```
WORD32 xa_nn_vec_activation_min_max_f32_f32
(FLOAT32 * p_out,       const FLOAT32 * p_vec, FLOAT32 activation_min,
 FLOAT32 activation_max,WORD32  vec_length);
WORD32 xa_nn_vec_activation_min_max_asym8u_asym8u
(UWORD8 * p_out,        const UWORD8 * p_vec,  int activation_min,
 int activation_max,    WORD32 vec_length);
WORD32 xa_nn_vec_activation_min_max_16_16
(WORD16 * p_out,        const WORD16 * p_vec,  int activation_min,
 int activation_max,    WORD32 vec_length);
WORD32 xa_nn_vec_activation_min_max_8_8
(WORD8 * p_out,         const WORD8 * p_vec,   int activation_min,
 int activation_max,    WORD32 vec_length);
```

Arguments

Type	Name	Size	Description
Input			
const UWORD8 *, const FLOAT32 *, const WORD16 *, const WORD8 *	p_vec	vec_length	Input vector, floating-point,asym8u or fixed point.
WORD32	vec_length		Length of input vector
WORD32, FLOAT32	activation_min		Lower threshold value, floating-point, asym8u or fixed point.
WORD32, FLOAT32	activation_max		Upper threshold value, floating-point, asym8u or fixed point
Output			
UWORD8 *, FLOAT32 *, WORD16 *, WORD8 *	p_out	vec_length	Output vector, floating-point, asym8u or fixed point

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_vec, p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL

3.3.6 Hard Swish

Description

The Hard Swish kernels compute the hard-swish function of input vector `x` and give the output vector as `y = hard_swish(x)`. Both the input and output vectors have size `vec_length`.

The hard-swish activation function is a type of activation function based on swish, but replaces the computationally expensive sigmoid function by ReLU6.

Function variants available are `xa_nn_vec_hard_swish_[p]_[q]`, where:

`[p]`: Input precision in bits

`[q]`: Output precision in bits

Precision

The following variant is available:

Type	Description
asym8s_asym8s	asym8s input, asym8s output

Algorithm

$y_n = x_n * [\mathrm{ReLU6}(x_n + 3)/6], \qquad n = 0, \ldots, \overline{vec\text{-}length - 1}$

Prototype

```
WORD32 xa_nn_vec_hard_swish_asym8s_asym8s
(WORD8 * p_out,            const WORD8 * p_vec,    WORD32 inp_zero_bias,
 WORD16 reluish_multiplier,WORD32 reluish_shift,   WORD16 out_multiplier,
 WORD32 out_shift,         WORD32 out_zero_bias,   WORD32 vec_length);
```

Arguments

Type	Name	Size	Description
Input			

const WORD8 *	p_vec	vec_length	Input vector, asym8s
WORD32	inp_zero_bias		Zero bias value for input vector
WORD16	reluish_multiplier		Fixed-point multiplier value for reluish scale
WORD32	reluish_shift		Shift value for reluish scale
WORD16	out_multipler		Fixed-point multiplier value for output
WORD32	out_shift		Shift value for output
WORD32	out_zero_bias		Zero bias value for output vector
WORD32	vec_length		length of input vector
Output			
WORD8 *	p_out	vec_length	Output vector, asym8s

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_vec, p_out	Cannot be NULL Should not overlap (the two pointers could be same, inplace operation is possible)
inp_zero_bias, out_zero_bias	{-128,....., 127} for asym8s datatype
out_multiplier, reluish_multiplier	Should not be less than 0
out_shift,reluish_shift	{-31, ..., 31}

3.3.7 Parametric ReLU (PReLU)

Description

The Parametric ReLU kernels compute the Parametric ReLU function of input vector `x` and give the output vector as `y = prelu(x)`. Both the input and output vectors have size `vec_length`.

The PReLU activation function acts like a standard ReLU function for input values greater than or equal to 0. For input values less than 0, a learnable negative slope parameter alpha(a) is multiplied with input to get the output. This slope value for all the input elements is determined based on the alpha input vector.

Function variants available are `xa_nn_vec_prelu_[p]_[q]`, where:

`[p]`: Input precision in bits

`[q]`: Output precision in bits

Precision

The following variant is available:

Type	Description
asym8s_asym8s	asym8s input, asym8s output

Algorithm

$y_n = x_n, \quad when\ x_n \geq 0 \quad n = 0, \ldots, \overline{vec\text{-}length - 1}$
$y_n = ax_n, \quad when\ x_n < 0$

where a is the learnable negative slope parameter: alpha.

Prototype

```
WORD32 xa_nn_vec_prelu_asym8s_asym8s
(WORD8 * p_out,        const WORD8 * p_vec,    const WORD8 * p_vec_alpha,
 WORD32 inp_zero_bias, WORD32 alpha_zero_bias, WORD32 alpha_multiplier,
 WORD32 alpha_shift,   WORD32 out_multiplier,  WORD32 out_shift,
 WORD32 out_zero_bias, WORD32 vec_length);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_vec	vec_length	Input vector, asym8s
const WORD8 *	p_vec_alpha	vec_length	alpha input vector, asym8s
WORD32	inp_zero_bias		Zero bias value for input vector
WORD32	alpha_zero_bias		Zero bias value for alpha input vector
WORD16	alpha_multipler		Fixed-point multiplier value for alpha input.
WORD32	alpha_shift		Shift value for alpha input.
WORD16	out_multipler		Fixed-point multiplier value for output
WORD32	out_shift		Shift value for output
WORD32	out_zero_bias		Zero bias value for output vector
WORD32	vec_length		length of input vector
Output			
WORD8 *	p_out	vec_length	Output vector, asym8s

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_vec, p_out, p_vec_alpha	Cannot be NULL

	Should not overlap (the two pointers could be same, inplace operation is possible)
inp_zero_bias, alpha_zero_bias	{-127,....., 128} for asym8s datatype
out_zero_bias	{-128,....., 127} for asym8s datatype
out_multiplier, alpha_multiplier	Should not be less than 0
out_shift,alpha_shift	{-31, ..., 31}

3.3.8 Leaky ReLU

Description

The Leaky ReLU kernels compute the Leaky ReLU function of input vector `x` and give the output vector as `y = leaky_relu(x)`. Both the input and output vectors have size `vec_length`.

The Leaky ReLU activation function acts like a standard ReLU function for input values greater than or equal to 0. For input values less than 0, a negative slope parameter alpha(a) is multiplied with input to get the output. The slope value is constant for all the input elements.

Function variants available are `xa_nn_vec_leaky_relu_[p]_[q]`, where:

`[p]`: Input precision in bits

`[q]`: Output precision in bits

Precision

The following two variants are available:

Type	Description
asym8s_asym8s	asym8s input, asym8s output
asym16s_asym16s	asym16s input, asym16s output

Algorithm

$y_n = x_n, \quad when\ x_n \geq 0 \qquad n = 0, \ldots, \overline{vec\text{-}length - 1}$
$y_n = ax_n, \quad when\ x_n < 0$

where a is the negative slope parameter: alpha.

Prototype

```
WORD32 xa_nn_vec_leaky_relu_asym8s_asym8s
(WORD8 * p_out,          const WORD8 * p_vec, WORD32 inp_zero_bias,
 WORD32 alpha_multiplier,WORD32 alpha_shift,  WORD32 out_multiplier,
 WORD32 out_shift,       WORD32 out_zero_bias,WORD32 vec_length);
WORD32 xa_nn_vec_leaky_relu_asym16s_asym16s
(WORD16 * p_out,         const WORD16 * p_vec,WORD32 inp_zero_bias,
 WORD32 alpha_multiplier,WORD32 alpha_shift,  WORD32 out_multiplier,
 WORD32 out_shift,       WORD32 out_zero_bias,WORD32 vec_length);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *, const WORD16 *	p_vec	vec_length	Input vector, asym8s or asym16s
WORD32	inp_zero_bias		Zero bias value for input vector
WORD16	alpha_multipler		Fixed-point multiplier value for alpha input.
WORD32	alpha_shift		Shift value for alpha input.
WORD16	out_multipler		Fixed-point multiplier value for output
WORD32	out_shift		Shift value for output
WORD32	out_zero_bias		Zero bias value for output vector
WORD32	vec_length		length of input vector
Output			
WORD8 *, WORD16 *	p_out	vec_length	Output vector, asym8s or asym16s

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_vec, p_out	Cannot be NULL
	Aligned on size of one element byte boundary
	Should not overlap (the two pointers could be same, inplace operation is possible)
inp_zero_bias	{-128,....., 127} for asym8s datatype {-32768,..., 32767} for asym16s datatype
out_zero_bias	{-128,....., 127} for asym8s datatype {-32768,..., 32767} for asym16s datatype
out_multiplier	Should not be less than 0
out_shift,alpha_shift	{-31, ..., 31}

3.4 Pooling Kernels

3.4.1 Average Pool Kernels

Description

The Average Pool kernels compute a 2D average pool on a set of input planes (matrices) `x` and give a set of planes `y` as output.

The pooling region is defined by `kernel_height` and `kernel_width`. It is shifted over the input plane in steps of `x_stride` horizontally, and in steps of `y_stride` vertically to generate the specified output plane size. The input is extended by zero padding as specified by the padding region. The padding is determined by the parameters `x_padding`, `y_padding` for left and top side padding respectively, and `out_width`, `out_height` for right and bottom padding respectively. Around the edges of input planes, if only a part of the pooling region covers the input plane, then only the average of those elements is calculated, and the denominator is the number of elements from input in the current pooling region.

The average pool kernels accept input as 8-bit, 16-bit integer, asym8u or single precision floating point format and give output in the same precision as input.

These kernels require temporary buffer for average pool computation. The `p_scratch` argument of kernel API provides this temporary buffer. The size of the temporary buffer must be queried using the `xa_nn_avgpool_getsize()` helper API.

These kernels expect input cube in SHAPE_CUBE_WHD_T and SHAPE_CUBE_DWH_T shape type and produce output cube in SHAPE_CUBE_WHD_T and SHAPE_CUBE_DWH_T shape type, respectively. The `inp_data_format` and `out_data_format` arguments to the kernel API can be 0 or 1 to indicate input and output cube shapes respectively.

The value of `inp_data_format` and `out_data_format` must be equal.

Note The fixed-point 8-bit average pool kernel, `xa_nn_avgpool_8` can be used for the quantized int8 datatype.

Function variants available are `xa_nn_avgpool_[p]`, where:

`[p]`: Input and Output precision in bits

Precision

The following four variants are available:

Type	Description
`8`	8-bit input, 8-bit output
`16`	16-bit input, 16-bit output
`f32`	float32 input, float32 output
`asym8u`	asym8u input, asym8u output

Algorithm

$$z_{h,w,d} = \frac{1}{K_H K_W}\left(\sum_{i=0}^{K_H-1}\sum_{j=0}^{K_W-1} in_{(h*y\text{-}stride+i),(w*x\text{-}stride+j),d)}\right)$$
$$h = 0,\ldots,\overline{out\text{-}height\ -\ 1},\ \ w = 0,\ldots,\overline{out\text{-}width\ -\ 1},$$
$$d = 0,\ldots,\overline{out\text{-}channels\ -\ 1}$$

in denotes padded input cube, z denotes output

K_H, K_W denote `kernel_height`, `kernel_width`, respectively.

Prototype

```
WORD32 xa_nn_avgpool_getsize
(WORD32 input_channels,  WORD32 inp_precision,   WORD32 out_precision,
 WORD32 input_height,    WORD32 input_width,     WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 inp_data_format, WORD32 out_data_format);

WORD32 xa_nn_avgpool_8
(WORD8 * p_out,          const WORD8 * p_inp,    WORD32 input_height,
 WORD32 input_width,     WORD32 input_channels,  WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 inp_data_format, WORD32 out_data_format,
 VOID * p_scratch);
WORD32 xa_nn_avgpool_16
(WORD16 * p_out,         const WORD16 * p_inp,   WORD32 input_height,
 WORD32 input_width,     WORD32 input_channels,  WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 inp_data_format, WORD32 out_data_format,
 VOID * p_scratch);
WORD32 xa_nn_avgpool_f32
(FLOAT32 * p_out,        const FLOAT32 * p_inp,  WORD32 input_height,
 WORD32 input_width,     WORD32 input_channels,  WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 inp_data_format, WORD32 out_data_format,
 VOID * p_scratch);
WORD32 xa_nn_avgpool_asym8u
(UWORD8* p_out,          const UWORD8* p_inp,    WORD32 input_height,
 WORD32 input_width,     WORD32 input_channels,  WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 inp_data_format, WORD32 out_data_format,
 VOID *p_scratch);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *, const WORD16 *, const UWORD8 *, const FLOAT32 *	p_inp	input_height * input_width * input_channels	Input cube
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Input number of channels
WORD32	kernel_height		Pooling window height
WORD32	kernel_width		Pooling window width
WORD32	x_stride		Horizontal stride over input
WORD32	y_stride		Vertical stride over input
WORD32	x_padding		Left padding width on input
WORD32	y_padding		Top padding height on input
WORD32	out_height		Output height
WORD32	out_width		Output width
WORD32	inp_data_format		Input data format 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
WORD32	out_data_format		Output data format: 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
Output			
WORD8 *, WORD16 *, UWORD8 *, FLOAT32 *	p_out	out_height * out_width * input_channels	Output cube
Temporary			
VOID *	p_scratch	xa_nn_avgpool_getsize()	Temporary / scratch memory

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_inp, p_out	Cannot be NULL
	Should not overlap
p_scratch	Cannot be NULL
	Should not overlap
	Memory size ≥ size returned by xa_nn_avgpool_getsize()
input_height, input_width	Greater than or equal to 1
input_channels	Greater than or equal to 1
kernel_height	{1, 2, ..., min(input_height, 256)} (for 8-bit and 16-bit) {1, 2, ..., input_height} (for float32)
kernel_width	{1, 2, ..., min(input_width, 256)} (for 8-bit and 16-bit) {1, 2, ..., input_width} (for float32)
x_stride, y_stride	Greater than or equal to 1
x_padding, y_padding	Greater than or equal to 0
out_height, out_width	greater than or equal to 1
inp_data_format	Can be 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T
out_data_format	Must be equal to inp_data_format

3.4.2 Max Pool Kernels

Description

The Max Pool kernels perform a 2D max pooling operation over a set of input planes x and gives as output, a set of planes y.

The pooling region is defined by kernel_height and kernel_width. It is shifted over the input plane horizontally in steps of x_stride and vertically in steps of y_stride to generate the specified output plane size.

The input plane, padded with the maximum negative values is considered while performing the max pooling operation. The padding region is determined by the parameters x_padding, y_padding for left and top side padding, respectively, and out_width, out_height for right and bottom padding, respectively.

The max pool kernels accept input as an 8-bit, 16-bit integer, asym8u or single precision floating point format and give output in the same precision as input.

These kernels require a temporary buffer for max pool computation. This temporary buffer is provided by the p_scratch argument of the kernel API. The size of the temporary buffer must be queried using the xa_nn_maxpool_getsize() helper API.

These kernels expect input cube in SHAPE_CUBE_WHD_T and SHAPE_CUBE_DWH_T shape types and produce output cube in SHAPE_CUBE_WHD_T and SHAPE_CUBE_DWH_T shape types

respectively. The `inp_data_format` and `out_data_format` arguments to the kernel API can be 0 or 1 to indicate input and output cube shapes respectively.

The value of `inp_data_format` and `out_data_format` must be equal.

Note The fixed-point 8-bit max pool kernel, `xa_nn_maxpool_8`, can be used for the quantized int8 datatype.

Function variants available are `xa_nn_maxpool_[p]`, where:

`[p]`: Input and Output precision in bits

Precision

The following four variants are available:

Type	Description
`8`	8-bit input, 8-bit output
`16`	16-bit input, 16-bit output
`f32`	float32 input, float32 output
`asym8u`	asym8u input, asym8u output

Algorithm

$z_{h,w,d} = \max\left(in_{(h*y\text{-}stride+i),(w*x\text{-}stride+j),d)}\right)$
$h = 0, \ldots, \overline{out\text{-}height\ -\ 1}, \quad w = 0, \ldots, \overline{out\text{-}width\ -\ 1},$
$d = 0, \ldots, \overline{out\text{-}channels\ -\ 1}$
$i = 0, \ldots, K_H - 1, \quad j = 0, \ldots, K_W - 1$

in denotes padded input cube, z denotes output.

K_H, K_W denote `kernel_height`, `kernel_width` respectively.

Prototype

```
WORD32 xa_nn_maxpool_getsize
(WORD32 input_channels,  WORD32 inp_precision,   WORD32 out_precision,
 WORD32 input_height,    WORD32 input_width,     WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 inp_data_format, WORD32 out_data_format);

WORD32 xa_nn_maxpool_8
(WORD8 * p_out,          const WORD8 * p_inp,    WORD32 input_height,
 WORD32 input_width,     WORD32 input_channels,  WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 out_data_format,
 VOID * p_scratch);
WORD32 xa_nn_maxpool_16
(WORD16 * p_out,         const WORD16 * p_inp,   WORD32 input_height,
 WORD32 input_width,     WORD32 input_channels,  WORD32 kernel_height,
```

```
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 out_data_format,
 VOID * p_scratch);
WORD32 xa_nn_maxpool_f32
(FLOAT32 * p_out,        const FLOAT32 * p_inp,  WORD32 input_height,
 WORD32 input_width,     WORD32 input_channels,  WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 out_data_format,
 VOID * p_scratch);
WORD32 xa_nn_maxpool_asym8u
(UWORD8* p_out,          const UWORD8* p_inp,    WORD32  input_height,
 WORD32 input_width,     WORD32 input_channels,  WORD32 kernel_height,
 WORD32 kernel_width,    WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,       WORD32 y_padding,       WORD32 out_height,
 WORD32 out_width,       WORD32 inp_data_format, WORD32 out_data_format,
 VOID   *p_scratch);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *, const WORD16 *, const UWORD8 *, const FLOAT32 *	p_inp	input_height * input_width * input_channels	Input cube
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Input number of channels
WORD32	kernel_height		Pooling window height
WORD32	kernel_width		Pooling window width
WORD32	x_stride		Horizontal stride over input
WORD32	y_stride		Vertical stride over input
WORD32	x_padding		Left padding width on input
WORD32	y_padding		Top padding height on input
WORD32	out_height		Output height
WORD32	out_width		Output width
WORD32	inp_data_format		Input data format 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
WORD32	out_data_format		Input data format 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
Output			
WORD8 *, WORD16 *, UWORD8 *, FLOAT32 *	p_out	out_height * out_width * input_channels	Output cube
Temporary			
VOID *	p_scratch	xa_nn_maxpool_getsize()	Temporary / scratch memory

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_inp, p_out	Cannot be NULL
	Should not overlap
	Should not overlap
	Memory size ≥ size returned by xa_nn_maxpool_getsize()
input_height, input_width	Greater than or equal to 1
input_channels	Greater than or equal to 1
kernel_height	{1, 2, ..., input_height}
kernel_width	{1, 2, ..., input_width}
x_stride, y_stride	Greater than or equal to 1
x_padding, y_padding	Greater than or equal to 0
out_height, out_width	Greater than or equal to 1
inp_data_format	Can be 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T
out_data_format	Must be equal to inp_data_format

3.5 Fully Connected Layer

3.5.1 Fully Connected Kernels

Description

The Fully Connected kernels perform the operation of multiplication of weight matrix with input vectors in a fully connected neural network layer, that is, `z = weight*input + bias`. The column dimension of `weight` must match the row dimension of `input`. Bias and resulting output vector `z` have as many number of rows as `weight` matrix.

The `bias_shift` and `acc_shift` arguments are provided in kernel API to adjust the Q format of bias and output, respectively. Both `bias_shift` and `acc_shift` can be either positive or negative, where positive value denotes a left shift and negative value denotes a right shift.

`bias_shift` is the shift in the number of bits applied to the bias to make it in the same Q format as weight X input multiplication – accumulation result. `acc_shift` is the shift in the number of bits applied to the accumulator to obtain the output in the required Q format.

Note The `acc_shift` and `bias_shift` arguments are not relevant in the case of floating point and quantized 8-bit kernels.

For conversion from higher precision accumulator to lower precision output, symmetric rounding is used.

The precision of the output is the same as the precision of the input vector.

The arguments `input_zero_bias`, `weight_zero_bias` are provided to convert the quantized 8-bit inputs into their real values and perform Fully Connected kernel operation. The `out_zero_bias`, `out_multiplier`, and `out_shift` values quantize real values of output back to 8-bit.

The _v2 kernels use matXvec_v2 kernels for their implementation.

Function variants available (for fixed point) are `xa_nn_fully_connected_[p]x[q]_[r]`, where:

`[p]`: Weight matrix precision in bits

`[q]`: Input vector precision in bits

`[r]`: Output vector precision in bits

Precision

There are twelve variants available:

Type	Description
`16x16_16`	16-bit weight matrix, 16-bit input vector, 16-bit output
`8x16_16`	8-bit weight matrix, 16-bit input vector, 16-bit output
`8x8_8`	8-bit weight matrix, 8-bit input vector, 8-bit output
`f32`	float32 weight matrix, float32 input vector, float32 output
`asym8uxasym8u_asym8u`	asym8u weight matrix, asym8u input vector, asym8u output
`sym8sxasym8s_asym8s`	sym8s weight matrix, asym8s input vector, asym8s output
`asym8sxasym8s_asym8s`	asym8s weight matrix, asym8s input vector, asym8s output
`sym8sxsym16s_sym16s`	sym8s weight matrix, sym16s input vector, sym16s output
`f16`	float16 weight matrix, float16 input vector, float16 output
`asym4sxasym8s_asym8s`	asym4s weight matrix, asym8s input vector, asym8s output
`v2_asym8sxasym8s_asym8s`	asym8s weight matrix, asym8s input vector, asym8s output. _v2 API
`v2_sym8sxsym16s_sym16s`	sym8s weight matrix, sym16s input vector, sym16s output. _v2 API

Algorithm

$$z_n = 2^{acc\text{-}shift}\left(\sum_{m=0}^{W_D-1} weight_{n,m}\cdot input_m + 2^{bias\text{-}shift}bias_n\right), \quad n = 0,\ldots,\overline{out\text{-}depth - 1}$$

where W_D represents `weight_depth`

For floating point and quantized 8-bit routines, `acc_shift=0` and `bias_shift=0`

Thus, $2^{acc\text{-}shift} = 2^{bias\text{-}shift} = 1$

Prototype

```
WORD32 xa_nn_fully_connected_16x16_16
(WORD16 * p_out,         WORD16 * p_weight,         WORD16 * p_inp,
 WORD16 * p_bias,        WORD32 weight_depth,       WORD32 out_depth,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_fully_connected_8x16_16
(WORD16 * p_out,         WORD8 * p_weight,          WORD16 * p_inp,
 WORD16 * p_bias,        WORD32 weight_depth,       WORD32 out_depth,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_fully_connected_8x8_8
(WORD8 * p_out,          WORD8 * p_weight,          WORD8 * p_inp,
 WORD8 * p_bias,         WORD32 weight_depth,       WORD32 out_depth,
 WORD32 acc_shift,       WORD32 bias_shift);
WORD32 xa_nn_fully_connected_f32
(FLOAT32 * p_out,        FLOAT32 * p_weight,        FLOAT32 * p_inp,
 FLOAT32 * p_bias,       WORD32 weight_depth,       WORD32 out_depth);
WORD32 xa_nn_fully_connected_asym8uxasym8u_asym8u
(UWORD8 * p_out,         const UWORD8 * p_weight,   const UWORD8 * p_inp,
 const WORD32 * p_bias, WORD32 weight_depth,       WORD32 out_depth,
 WORD32 input_zero_bias,WORD32 weight_zero_bias,   WORD32 out_multiplier,
 WORD32 out_shift,       WORD32 out_zero_bias);
WORD32 xa_nn_fully_connected_sym8sxasym8s_asym8s
(WORD8 * p_out,          const WORD8 * p_weight,    const WORD8 * p_inp,
 const WORD32 * p_bias, WORD32 weight_depth,       WORD32 out_depth,
 WORD32 input_zero_bias,WORD32 out_multiplier,     WORD32 out_shift,
 WORD32 out_zero_bias);

WORD32 xa_nn_fully_connected_asym8sxasym8s_asym8s
(WORD8 * p_out,          const WORD8 * p_weight,    const WORD8 * p_inp,
 const WORD32 * p_bias, WORD32 weight_depth,       WORD32 out_depth,
 WORD32 input_zero_bias,WORD32 weight_zero_bias,   WORD32 out_multiplier,
 WORD32 out_shift,       WORD32 out_zero_bias);
WORD32 xa_nn_fully_connected_sym8sxsym16s_sym16s
(pWORD16  p_out,             const WORD8 * p_weight,       const WORD16 * p_inp,
 const WORD64 * p_bias,      WORD32  weight_depth,         WORD32  out_depth,
 WORD32  out_multiplier,     WORD32  out_shift);
WORD32 xa_nn_fully_connected_f16
 (WORD16 * p_out ,       const WORD16 * p_weight, const WORD16 * p_inp ,
  const WORD16 * p_bias, WORD32  weight_depth,    WORD32  out_depth );
WORD32 xa_nn_fully_connected_asym4sxasym8s_asym8s
 (WORD8 * p_out,             const WORD8 * p_weight,     const WORD8 * p_inp,
  const WORD32 * p_bias,     WORD32  weight_depth,       WORD32  out_depth,
  WORD32  input_zero_bias,   WORD32  weight_zero_bias,   WORD32  out_multiplier,
  WORD32  out_shift,         WORD32  out_zero_bias,      VOID *p_scratch);
WORD32 xa_nn_fully_connected_v2_asym8sxasym8s_asym8s
  (WORD8 *__restrict__ p_out,       const WORD8 *__restrict__ p_weight,
   Const WORD8 *__restrict__ p_inp, const WORD32 *__restrict__ p_bias,
   WORD32  weight_depth,            WORD32  out_depth,
   WORD32  input_zero_bias,         WORD32  weight_zero_bias,
   WORD32  out_multiplier,          WORD32  out_shift,
   WORD32  out_zero_bias,           WORD32  out_activation_min,
   WORD32  out_activation_max,      xa_dma_cfg_t *  p_dma_cfg);
WORD32 xa_nn_fully_connected_v2_sym8sxsym16s_sym16s
  (WORD16 *__restrict__ p_out,       const WORD8 *__restrict__ p_weight,
   const WORD16 *__restrict__ p_inp, const WORD64 *__restrict__ p_bias,
   WORD32  weight_depth,             WORD32  out_depth,
   WORD32  out_multiplier,           WORD32  out_shift,
   WORD32  out_activation_min,       WORD32  out_activation_max,
   xa_dma_cfg_t *  p_dma_cfg);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, pFLOAT32, const UWORD8 *, const WORD8 *	p_weight	out_depth* weight_depth	Weight matrix, fixed, floating point, asym4s, asym8u, or sym8s
WORD16 *, WORD8 *, pFLOAT32, const UWORD8 *, const WORD8 *	p_inp	weight_depth* 1	Input vector, fixed, floating point, asym8u or asym8s
WORD16 *, WORD8 *, pFLOAT32, WORD32 *, const WORD64 *	p_bias	out_depth*1	Bias vector, fixed or floating point, 32-bit for quantized kernels
VOID *	P_scratch	16 + weight_depth	scratch pointer, asym4sxasym8s
WORD32	out_depth		Number of rows in weight matrix, bias and output vector
WORD32	weight_depth		Number of columns in weight matrix and rows in input vector
WORD32	acc_shift		Shift applied to accumulator
WORD32	bias_shift		Shift applied to bias
WORD32	input_zero_bias		Zero offset of input
WORD32	weight_zero_bias		Zero offset of weights
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32	out_zero_bias		Zero offset of output
WORD32	out_activation_min		Min value for output minmax activation function This argument is only for _v2 variants
WORD32	out_activation_max		Max value for output minmax activation function This argument is only for _v2 variants
xa_dma_cfg_t *	p_dma_cfg		This is a placeholder
Output			
WORD8 *, WORD16 *, pFLOAT32, WORD8 *, UWORD8*	p_out	out_depth*1	Output vector, fixed, floating point, asym8u or asym8s

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
`weight_depth`	Multiple of 4 for fixed point and floating point kernels. No restriction for asym4sxasym8s_asym8s. No restriction for other quantized 8-bit kernels.
`p_weight, p_inp, p_bias, p_out`	Aligned on 16-byte boundary, must not overlap.. (size of one element)-byte boundary in case of floating point and quantized 8-bit kernels). Aligned on 16-byte boundary for _v2 kernels.
`p_weight, p_inp, p_out`	Cannot be NULL
`p_scratch`	Cannot be NULL, Aligned on 8-byte boundary
`p_bias`	Cannot be NULL (except for sym8sxasym8s precision)
`out_depth`	Greater than or equal to 1
`out_multiplier`	Greater than 0
`acc_shift, bias_shift, out_shift`	{-31, ….,31}
`input_zero_bias`	{-255, ….,0} for asym8u, {-127, ….,128} for asym8s
`weight_zero_bias`	{-255, ….,0} for asym8u, {-127, ….,128} for asym8s and asym4s
`out_zero_bias`	{0, …,255} for asym8u, {-128, …...,127} for asym8s

3.6 Basic Operations and Miscellaneous Kernels

3.6.1 Interpolation Kernel

Description

The Interpolation kernel performs interpolation between two input vectors, `h` and `y`, using interpolation factor from vector `x` to get output vector `z`.

The interpolation kernel accepts 16-bit inputs and 16-bit interpolation factor in Q15 format and produces 16-bit output in Q15 format.

Precision

Type	Description
`16-bit`	16-bit input, 16-bit interpolation factor, 16-bit output

Algorithm

$z_n = x_n * y_n + (1 - x_n) * h_n \quad , \qquad n = 0 \ldots, \overline{num\text{-}elements - 1}$

x_n represents interpolation factor.

y_n represents first input, h_n represents second input.

z_n represents output.

Prototype

```
WORD32 xa_nn_vec_interpolation_q15
(WORD16 * p_out,       WORD16 * p_ifact,     WORD16 * p_inp1,WORD16 * p_inp2,        WORD32
 num_elements);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *	p_ifact	num_elements	Interpolation factor vector
WORD16 *	p_inp1	num_elements	First input vector
WORD16 *	p_inp2	num_elements	Second input vector
WORD32	num_elements		Number of elements
Output			
WORD16 *	p_out	num_elements	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_ifact, p_inp1, p_inp2, p_out	Aligned on 8-byte boundary
	Should not overlap
	Cannot be NULL
num_elements	Multiple of 4

3.6.2 Dot Product Kernels

Description

The Dot Product kernels perform the dot product operations between two sets of input vectors and to get the output vector. The supported precisions are: f32xf32_f32 and 16x16_asym8s.

Function variants available are `xa_nn_elm_dot_prod_[p]x[q]_[r]`, where:

`[p]`, `[q]`: Input precision

`[r]`: Output precision

Precision

There are two variants available:

Type	Description
f32xf32_f32	float32 input, float32 output
16x16_asym8s	16-bit input, asym8s output

Algorithm

$$z_n = \left(\sum_{m=0}^{vec\text{-}length-1} inp1_m \cdot inp2_m + bias_n \right)$$

$$n = 0, \ldots, \overline{vec\text{-}count - 1}$$

Prototype

```
WORD32 xa_nn_dot_prod_f32xf32_f32
(FLOAT32 * p_out,          const FLOAT32 * p_inp1,      const FLOAT32 * p_inp2,
 WORD32 vec_length,        WORD32 num_vecs);
WORD32 xa_nn_dot_prod_16x16_asym8s
(WORD8 * p_out,            const WORD16 * p_inp1,       const WORD16 * p_inp2,
 const WORD32 * bias_ptr,  WORD32 vec_length,           WORD32 out_multiplier,
 WORD32 out_shift,         WORD32 out_zero_bias,        WORD32 vec_count);
```

Arguments

Type	Name	Size	Description
Input			
const FLOAT32 * const WORD16 *	p_inp1	vec_length	First input vector
const FLOAT32 * const WORD16 *	p_inp2	vec_length	Second input vector
const WORD32 *	bias_ptr	vec_count	Bias vector
WORD32	vec_length		Length of each vector
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32	out_zero_bias		Zero offset of output
WORD32	num_vecs, vec_count		Number of input vectors
Output			
FLOAT32 * WORD8 *	p_out	num_vecs	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp1,p_inp2, p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
vec_length, num_vecs	Greater than 0
out_shift	{-31, …, 31}
out_multiplier	Greater than 0
out_zero_bias	{-128,….,127} for out type asym8s

3.6.3 Elementwise Quantize Kernels

Description

The Elementwise Quantize kernels perform the quantization operation of the input vector elements to get the output vector. The kernels are developed in reference to the Quantize operator implementation in TensorFlow Lite Micro.

Function variants available are `xa_nn_elm_quantize_[p]_[q]`, where:

`[p]`: Input precision

`[q]`: Output precision

Algorithm

for itr = 0:(num_elm-1)

$$p\text{-}out[itr] = (p\text{-}inp[itr] \,/\, out\_scale) \;+\; out\text{-}zero\text{-}bias$$

Precision

Type	Description
f32_asym8s	single precision float input, asym8s output
f32_asym16s	single precision float input, asym16s output
f32_asym8u	single precision float input, asym8u output

Prototype

```
WORD32 xa_nn_elm_quantize_f32_asym8s
(WORD8 *__restrict__ p_out, const FLOAT32 *__restrict__ p_inp,   FLOAT32  out_scale,
 WORD32  out_zero_bias,     WORD32 num_elm);
WORD32 xa_nn_elm_quantize_f32_asym16s
(WORD16 * __restrict_p_out, const FLOAT32 * __restrict__p_inp,   FLOAT32  out_scale,
 WORD32   out_zero_bias,    WORD32 num_elm);
WORD32 xa_nn_elm_quantize_f32_asym8u
(UWORD8 * __restrict__ p_out, const FLOAT32 * __restrict__ p_inp, FLOAT32  out_scale,
 WORD32   out_zero_bias, WORD32   num_elm);
```

Arguments

Type	Name	Size	Description
Input			
const FLOAT32 *	p_inp	num_elm	Input vector
FLOAT32	out_scale		Scale of output
WORD32	out_zero_bias		Zero offset of output
WORD32	num_elm		Number of input elements
Output			
WORD8 * WORD16 * UWORD8 *	p_out	num_elm	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp, p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Should not overlap
num_elm	Greater than 0
out_scale	Not equal to zero and finite single precision float value
out_zero_bias	{-128,…., 127} for out type asym8s {-32768…., 32767} for out type asym16s {0….,255} for out type asym8u

3.6.4 Elementwise Requantize Kernels

Description

The Elementwise Requantize kernels perform the requantization operation of the input vector elements to get the output vector. The kernels are developed in reference to the Quantize operator implementation in TensorFlow Lite Micro.

Function variants available are `xa_nn_elm_requantize_[p]_[q]`, where:

`[p]`: Input precision

`[p]`: Output precision

Algorithm

for itr = 0:(num_elm-1)

$$p\text{-}out[itr] = ((2\text{^}out\text{-}shift) * (out\text{-}multiplier) * (p\text{-}inp[itr] - inp\text{-}zero\text{-}bias)) + out\text{-}zero\text{-}bias$$

Precision

Type	Description
asym16s_asym8s	asym16s input, asym8s output
asym8s_asym32s	asym8s input, asym32s output
asym16s_asym32s	asym16s input, asym32s output
asym8s_asym8s	asym8s input, asym8s output
asym16s_asym16s	asym16s input, asym16s output
asym8u_asym8s	asym8u input, asym8s output
asym8s_asym8u	asym8s input, asym8u output
asym8s_asym16s	asym8s input, asym16s output
asym8s_asym16u	asym8s input, asym16u output
asym32s_asym16s	asym32s input, asym16s output
asym32s_asym8s	asym32s input, asym8s output

Prototype

```
WORD32 xa_nn_elm_requantize_asym16s_asym8s
(WORD8 *__restrict__ p_out, const WORD16 *__restrict__ p_inp, WORD32  inp_zero_bias,
 WORD32  out_zero_bias,    WORD32  out_shift,          WORD32  out_multiplier,
 WORD32  num_elm);
WORD32 xa_nn_elm_requantize_asym8s_asym32s
(WORD32 * __restrict__ p_out, const WORD8 * __restrict__ p_inp,  WORD32  inp_zero_bias,
 WORD32  out_zero_bias,       WORD32  out_shift,                 WORD32  out_multiplier,
 WORD32  num_elm);
WORD32 xa_nn_elm_requantize_asym16s_asym32s
(WORD32 * __restrict__ p_out, const WORD16 * __restrict__ p_inp, WORD32  inp_zero_bias,
 WORD32  out_zero_bias,       WORD32  out_shift,                 WORD32  out_multiplier,
 WORD32  num_elm);
WORD32 xa_nn_elm_requantize_asym8s_asym8s
(WORD8 * __restrict__ p_out,  const WORD8 * __restrict__ p_inp,  WORD32  inp_zero_bias,
 WORD32  out_zero_bias,       WORD32  out_shift,                 WORD32  out_multiplier,
 WORD32  num_elm);
WORD32 xa_nn_elm_requantize_asym16s_asym16s
(WORD16 * __restrict__ p_out, const WORD16 * __restrict__ p_inp,  WORD32  inp_zero_bias,
 WORD32  out_zero_bias,       WORD32 out_shift,                   WORD32  out_multiplier,
 WORD32  num_elm);

WORD32 xa_nn_elm_requantize_asym8u_asym8s
(WORD8 * __restrict__ p_out,  const UWORD8 * __restrict__ p_inp,  WORD32  inp_zero_bias,
 WORD32  out_zero_bias,       WORD32  out_shift,                 WORD32  out_multiplier,
 WORD32  num_elm);
WORD32 xa_nn_elm_requantize_asym8s_asym8u
(UWORD8 * __restrict__ p_out, const WORD8 * __restrict__ p_inp,   WORD32 inp_zero_bias,
 WORD32 out_zero_bias,        WORD32 out_shift                    WORD32 out_multiplier,
 WORD32 num_elm);
WORD32 xa_nn_elm_requantize_asym8s_asym16s
(WORD16 * __restrict__ p_out, const WORD8 * __restrict__ p_inp,   WORD32 inp_zero_bias,
 WORD32 out_zero_bias,        WORD32 out_shift,                   WORD32 out_multiplier,
 WORD32 num_elm);
WORD32 xa_nn_elm_requantize_asym8s_asym16u
(UWORD16 * __restrict__ p_out, const WORD8 * __restrict__ p_inp,  WORD32 inp_zero_bias,
 WORD32 out_zero_bias,         WORD32 out_shift,                  WORD32 out_multiplier,
 WORD32 num_elm);
```

```
WORD32 xa_nn_elm_requantize_asym32s_asym16s
(WORD16 * __restrict__ p_out, const WORD32 * __restrict__ p_inp,  WORD32 inp_zero_bias,
 WORD32 out_zero_bias,         WORD32 out_shift,                  WORD32 out_multiplier,
 WORD32 num_elm);

WORD32 xa_nn_elm_requantize_asym32s_asym8s
(WORD8 * __restrict__ p_out, const WORD32 * __restrict__ p_inp,  WORD32 inp_zero_bias,
 WORD32 out_zero_bias,         WORD32 out_shift,                  WORD32 out_multiplier,
 WORD32 num_elm);
```

Arguments

Type	Name	Size	Description
Input			
const WORD16 *, const WORD8 *, const UWORD8 *	p_inp	num_elm	Input vector
WORD32	inp_zero_bias		Zero offset of input
WORD32	out_zero_bias		Zero offset of output
WORD32	out_shift		Shift value of output
WORD32	out_multiplier		Multiplier value of output
WORD32	num_elm		Number of input elements
Output			
WORD8 *, WORD16 *, WORD32 *	p_out	num_elm	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp, p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Should not overlap
num_elm	Greater than 0
out_shift	{-31, …, 31}
out_multiplier	Greater than 0
inp_zero_bias	{-2147483648,...,2147483647} for inp type asym32s {-32768,…., 32767} for inp type asym16s {-128,…., 127} for inp type asym8s
out_zero_bias	{-32768,…., 32767} for out type asym16s {-128,…., 127} for out type asym8s Signed 32-bit integer value for out type asym32s

3.6.5 Elementwise Dequantize Kernels

Description

The Elementwise Dequantize kernels perform the dequantization operation of the input vector elements to get the output vector. The kernels are developed in reference to the Dequantize operator implementation in TensorFlow Lite Micro.

Function variants available are `xa_nn_elm_dequantize_[p]_[q]`, where:

`[p]`: Input precision

`[p]`: Output precision

Precision

Type	Description
`asym8s_f32`	asym8s input, float output
`asym16s_f32`	asym16s input, float output
`asym8u_f32`	asym8u input, float output

Algorithm

for itr = 0:(num_elm-1)

$$p\text{-}out[itr] = (p\text{-}inp[itr] - inp\text{-}zero\text{-}bias) * inp\text{-}scale$$

Prototype

```
WORD32 xa_nn_elm_dequantize_asym8s_f32
(FLOAT32 * __restrict__ p_out, const WORD8 * __restrict__ p_inp, WORD32  inp_zero_bias,
 FLOAT32  inp_scale,           WORD32  num_elm);
WORD32 xa_nn_elm_dequantize_asym16s_f32
(FLOAT32 * __restrict__ p_out, const WORD16 *__restrict__ p_inp, WORD32  inp_zero_bias,
 FLOAT32  inp_scale,           WORD32   num_elm);
WORD32 xa_nn_elm_dequantize_asym8u_f32
(FLOAT32 * __restrict__ p_out, const UWORD8 * __restrict__ p_inp, WORD32   inp_zero_bias,
 FLOAT32  inp_scale, WORD32   num_elm);
```

Arguments

Type	Name	Size	Description
Input			
`const WORD8 *, const WORD16 *, const UWORD8 *`	`p_inp`	`num_elm`	Input vector
`WORD32`	`inp_zero_bias`		Zero offset of input
`FLOAT32`	`inp_scale`		Input scale
`WORD32`	`num_elm`		Number of input elements

Output			
FLOAT32 *	p_out	num_elm	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp, p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Should not overlap
num_elm	Greater than 0
inp_zero_bias	{-128,...., 127} for inp type asym8s {-32768,...., 32767} for inp type asym16s {0....,255} for inp type asym8u

3.6.6 Basic Kernels

Description

The Basic kernels perform basic elementwise operations on one or two input vectors x and y to get output vector z. The supported operations are: add, subtract, multiply, floor, minimum, maximum, sine, cosine, log (natural), absolute, ceil, round (banker's), negative, square, square-root, inverse square-root, clamp, and select. The supported precisions are: 8-bit, float32 and asym8s.

The 8-bit elementwise minimum and maximum kernels can be also used for asym8s datatype.

The select operation selects the output value from two input values based on p_condition input parameter.

Function variants available are xa_nn_[o]_[p]_[q], where:

[o]: Operations: elm_add, elm_sub, elm_mul, elm_floor, elm_min, elm_max, elm_sine, elm_cosine, elm_logn, elm_abs, elm_ceil, elm_round, elm_neg, elm_square, elm_sqrt, elm_rsqrt, elm_clamp, elm_select

[p]: Input Precision in bits- input1xinput2 or input1

[q]: Output Precision in bits

Precision

Type	Description
f32xf32_f32	2 float32 inputs, float32 output
f32_f32	float32 input, float32 output
8x8_8	2 8-bit input, 8-bit output
16x16_16	2 16-bit input, 16-bit output

asym8sxasym8s_asym8s	2 asym8s inputs, asym8s output
sym16sxsym16s_asym8s	2 sym16s inputs, asym8s output
32x32_32	2 32-bit input, 32-bit output

Algorithm

elm_add: $z_n = x_n + y_n\,, \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_sub: $z_n = x_n - y_n\,, \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_mul: $z_n = x_n * y_n\,, \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_floor: $z_n = \ddot{e}x_n\hat{u}\,, \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_min: $z_n = \min(x_n, y_n), \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_max: $z_n = \max(x_n, y_n), \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_sine: $z_n = \sin(x_n), \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_cosine: $z_n = \cos(x_n), \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_logn: $z_n = log_e(x_n), \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_abs: $z_n = \text{abs}(x_n), \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_ceil: $z_n = \lceil x_n \rceil\,, \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_round[8]: $z_n = \text{round}(x_n), \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_neg: $z_n = -x_n, \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_square: $z_n = x_n * x_n, \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_sqrt: $z_n = \sqrt{x_n}, \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_rsqrt: $z_n = 1 \div \sqrt{x_n}\,, \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_clamp: $z_n = \max(min, x_n); \quad z_n = min(max, z_n); \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

elm_select: $if(p\_condition) \quad z_n = x_n\,; \quad else \quad z_n = y_n; \quad n = 0 \ldots., \overline{num\text{-}elm - 1}$

x_n represents first input, y_n represents second input.

z_n represents output.

Prototype

```
WORD32 xa_nn_elm_floor_f32_f32
(FLOAT32 * p_out,           const FLOAT32 * p_inp,       WORD32  num_elm);
WORD32 xa_nn_elm_add_asym8sxasym8s_asym8s
(WORD8 * p_out,             WORD32 out_zero_bias,        WORD32 out_shift,
 WORD32 out_multiplier,     WORD32 out_activation_min,   WORD32 out_activation_max,
 const  WORD8 * p_inp1,     WORD32 inp1_zero_bias,       WORD32 inp1_shift,
 WORD32 inp1_multiplier,    const  WORD8 * p_inp2,       WORD32 inp2_zero_bias,
 WORD32 inp2_shift,         WORD32 inp2_multiplier,      WORD32 left_shift,
 WORD32 num_elm);
WORD32 xa_nn_elm_sub_asym8sxasym8s_asym8s
(WORD8 * p_out,             WORD32  out_zero_bias,       WORD32  out_left_shift,
 WORD32  out_multiplier,    WORD32  out_activation_min,  WORD32  out_activation_max,
 const WORD8 * p_inp1,      WORD32  inp1_zero_bias,      WORD32  inp1_left_shift,
 WORD32  inp1_multiplier,   const WORD8 * p_inp2,        WORD32  inp2_zero_bias,
 WORD32  inp2_left_shift,   WORD32  inp2_multiplier,     WORD32  left_shift,
 WORD32  num_elm);
WORD32 xa_nn_elm_mul_asym8sxasym8s_asym8s
(WORD8 * p_out,             WORD32 out_zero_bias,        WORD32 out_shift,
```

[8] The round variant is banker's rounding. It is also called "Round half to even". In this rounding method, if fractional part of input is 0.5, then output is the even integer nearest to input. Thus, for example, +23.5 becomes 24, as does 24.5; while -23.5 becomes -24, as does -24.5.

```
 WORD32 out_multiplier,     WORD32 out_activation_min,   WORD32 out_activation_max,
 const  WORD8 * p_inp1,     WORD32 inp1_zero_bias,       const  WORD8 * p_inp2,
 WORD32 inp2_zero_bias,     WORD32 num_elm);
WORD32 xa_nn_elm_mul_sym16sxsym16s_asym8s
(WORD8 * p_out,             WORD32  out_zero_bias,       WORD32  out_shift,
 WORD32  out_multiplier,    WORD32  out_activation_min,  WORD32  out_activation_max,
 const  WORD16 * p_inp1,    const   WORD16 * p_inp2,     WORD32  num_elm);
WORD32 xa_nn_elm_min_8x8_8
(WORD8* p_out,              const WORD8* p_in1,          const WORD8* p_in2,
 WORD32 num_element);
WORD32 xa_nn_elm_max_8x8_8
(WORD8* p_out,              const WORD8* p_in1,          const WORD8* p_in2,
 WORD32 num_element);
WORD32 xa_nn_elm_sine_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_cosine_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_logn_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_abs_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_ceil_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_round_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_neg_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_square_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_sqrt_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_add_f32xf32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp1,
const FLOAT32 * __restrict__ p_inp2, WORD32  num_elm);
WORD32 xa_nn_elm_add_16x16_16
(WORD16 * __restrict__ p_out,   const WORD16 * __restrict__ p_inp1,
 const WORD16 * __restrict__ p_inp2, WORD32 num_elm);
WORD32 xa_nn_elm_rsqrt_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
WORD32 xa_nn_elm_max_f32xf32_f32
(FLOAT32 * __restrict__ p_out, const FLOAT32 * __restrict__ p_inp1, const FLOAT32 * __restrict__
p_inp2, WORD32 num_elm);
WORD32 xa_nn_elm_min_f32xf32_f32
(FLOAT32 * __restrict__ p_out, const FLOAT32 * __restrict__ p_inp1, const FLOAT32 * __restrict__
p_inp2, WORD32 num_elm);
WORD32 xa_nn_elm_clamp_f32xf32xf32_f32
(FLOAT32 * __restrict__ p_out, const FLOAT32 * __restrict__ p_inp, const FLOAT32 * __restrict__
p_min, const FLOAT32 * __restrict__ p_max, WORD32 num_elm);
WORD32 xa_nn_elm_select_32x32_32
(WORD32 * __restrict__ p_out, const WORD32 * __restrict__ p_inp1, const WORD32 * __restrict__
p_inp2, const unsigned char *__restrict__ p_condition, WORD32 num_elm);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 * WORD16 * FLOAT32 * WORD32 *	p_inp1, p_inp, p_in1	num_elm	First input vector

Type	Name	Size	Description
const WORD8 * WORD16 * FLOAT32 * WORD32 *	p_inp2, P_in2	num_elm	Second input vector
WORD32	num_elm/num_element		Number of elements
WORD32	out_zero_bias		Zero bias of output
WORD32	out_shift		Shift value of output
WORD32	out_multiplier		Multiplier value of output
WORD32	out_activation_min		Activation min of output
WORD32	out_activation_max		Activation max of output
WORD32	inp1_zero_bias		Zero bias of input 1
WORD32	inp1_shift		Shift value of input 1
WORD32	inp1_multiplier		Multiplier value of input 1
WORD32	inp2_zero_bias		Zero bias of input 2
WORD32	inp2_shift		Shift value of input 2
WORD32	inp2_multiplier		Multiplier value of input 2
WORD32	left_shift		Global left shift value for inputs.
const FLOAT32 *	p_min		Min value vector
const FLOAT32 *	p_max		Max value vector
const unsigned char *__	p_condition		Condition vector
Output			
WORD8 * WORD16 * FLOAT32 * WORD32 *	p_out	num_elm	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp1,p_inp2, p_inp,p_in1,p_in2 p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
p_out	Should not overlap with the input pointers (could be same as one of the input pointers, inplace operation is possible)
num_elm, num_element	Greater than 0
inp1_zero_bias, inp2_zero_bias	{-127,….., 128} for asym8s input
inp1_shift, inp2_shift, out_shift	{-31,…., 0} for add,sub quantized datatype kernels, {-31,…., 31} for other fixed point and quantized 8-bit APIs
left_shift	{0 …. 31}

Arguments	Restrictions
inp1_multiplier, inp2_multiplier out_multiplier	Should not be less than 0.
out_zero_bias	{-128,....., 127} for asym8s output
out_activation_min, out_activation_max	{-128,....., 127} for asym8s output out_activation_min < out_activation_max

3.6.7 Basic Kernels with Broadcasting

Description

The Basic kernels with broadcasting perform a broadcast operation and apply an arithmetic operator. The supported operators are: elementwise minimum and maximum.

Details of the broadcast operation can be found at Tensorflow Broadcasting semantics [4].

There are two variants of these kernels, one for 4-dimensional and another for 8-dimensional input/output tensors. Input tensors smaller than these dimensions must have their shapes extended to match either of these two.

Tensors must also be broadcast compatible (as these kernels do not perform any runtime checks and depend on the TensorFlow infrastructure)

The input to these kernels are the IO pointers to tensors stored in row-major format, the shape of the resulting broadcasted output and the input 'strides' [5].

Function variants available are `xa_nn_[op]_[d]_Bcast_[p]`, where:

[op]: Operation: elm_min, elm_max

[d]: Number of IO dimensions: 4D, 8D

[p]: Input/Output precision in bits as [in1_precision]x[in2_precision]_[out_precision]

Precision

Type	Description
8x8_8	Signed 8-bit inputs, signed 8-bit output

Algorithm

$$p\_out[i_0][i_1]\dots[i_N] = [op](p\_in1([i_0\ i_1\ \dots\ i_N] \cdot [s1_0\ s1_1\ \dots\ s1_N]) \ ,\ p\_in2([i_0\ i_1\ \dots\ i_N] \cdot [s2_0\ s2_1\ \dots\ s2_N]))$$

Where,

- $i_n \in (0\ \text{out\_extents}[n]]$, and, $n \in (0\ \ 4]$ for 4D tensors, or, $(0\ \ 8]$ for 8D Tensors
- $s1_n =$ in1_strides$[n]$, with n defined the same as above

- $s2_n$ = in2_strides$[n]$, with n defined the same as above

Prototypes

```
WORD32 xa_nn_elm_min_4D_Bcast_8x8_8(
          WORD8* __restrict__ p_out,  const int* const out_extents,
    const WORD8* __restrict__ p_in1,  const int* const in1_strides,
    const WORD8* __restrict__ p_in2,  const int* const in2_strides )
WORD32 xa_nn_elm_max_4D_Bcast_8x8_8(
          WORD8* __restrict__ p_out,  const int* const out_extents,
    const WORD8* __restrict__ p_in1,  const int* const in1_strides,
    const WORD8* __restrict__ p_in2,  const int* const in2_strides )
WORD32 xa_nn_elm_min_8D_Bcast_8x8_8(
          WORD8* __restrict__ p_out,  const int* const out_extents,
    const WORD8* __restrict__ p_in1,  const int* const in1_strides,
    const WORD8* __restrict__ p_in2,  const int* const in2_strides )
WORD32 xa_nn_elm_max_8D_Bcast_8x8_8(
          WORD8* __restrict__ p_out,  const int* const out_extents,
    const WORD8* __restrict__ p_in1,  const int* const in1_strides,
    const WORD8* __restrict__ p_in2,  const int* const in2_strides )
```

Arguments

Type	Name	Size	Description
Input			
const WORD8*	p_in1	-	First input tensor in row-major
const int* const	in1_strides	4 or 8	Strides for first input tensor
const WORD8*	p_in2	-	Second input tensor in row-major
const int* const	in2_strides	4 or 8	Strides for second input tensor
const int* const	out_extents	4 or 8	Broadcasted output shape
Output			
WORD8*	p_out	prod(out_extents)	Output tensor in row-major

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_in1,p_in2	Aligned on byte boundary
p_out	Cannot be NULL
out_extents, in1_strides, in2_strides	Positive integers

3.6.8 Basic Kernels with 4D Broadcasting

Description

The Basic kernels with 4D broadcasting perform a broadcast operation and apply an arithmetic operator. The supported operators are: elementwise add, sub, mul, squared_diff, div, min, max, select and compare..

The compare kernel supports equal, not equal, greater, greater equal, less, and less equal operations. It selects the comparison operation to perform from the value of the input parameter `kernel_type`. For details refer to the Arguments section.

For select operation, it is assumed that `p_condition_shape` is equal to `p_out_shape`.

Details of the broadcast operation can be found in Tensorflow Broadcasting semantics [4].

These kernels support 4-dimensional input/output tensors. Input/output tensors with less than than 4 dimensions must have their shapes extended to have 4 dimensions.

Tensors must also be broadcast compatible (that is, their dimensions must match or be equal to 1) otherwise kernels return an error.

Function variants available are `xa_nn_[op]_broadcast_4D_[p]`, where:

[op]: Operation: elm_add, elm_sub, elm_mul, elm_squared_diff

[p]: Input/Output precision in bits as [in1_precision]x[in2_precision]_[out_precision]

Precision

Type	Description
`asym8sxasym8s_asym8s`	asym8s inputs, asym8s output
`asym16sxasym16s_asym16s`	asym16s inputs, asym16s output
`sym16sxsym16s_sym16s`	sym16s inputs, sym16s output
`f32xf32_f32`	f32 inputs,_f32 output
`32x32_32`	32 inputs,_32 output

Algorithm

$$p\_out[i_0][i_1]\dots[i_3] = [op](p\_inp1[i1_0][i1_1]\dots[i1_3],\ p\_inp2[i2_0][i2_1]\dots[i2_3])$$

Where,

- $i_n = [0, p\_out\_shape[n] - 1];\ n = [0,3]$
- $i1_n = i_n\ if\ p\_out\_shape[n] = p\_inp1\_shape[n]\ else\ 0;\ n = [0,3]$
- $i2_n = i_n\ if\ p\_out\_shape[n] = p\_inp2\_shape[n]\ else\ 0;\ n = [0,3]$

Ops are:

elm_add: $z_n = x_n + y_n$
elm_sub: $z_n = x_n - y_n$
elm_mul: $z_n = x_n * y_n$
elm_squared_diff: $z_n = (x_n - y_n)^2$
elm_div: $z_n = x_n / y_n$
elm_min: $z_n = \min(x_n, y_n)$
elm_max: $z_n = \max(x_n, y_n)$
elm_select: $if(p\_condition) \quad z_n = x_n ; \quad else \quad z_n = y_n;$

Prototypes

```
WORD32 xa_nn_elm_add_broadcast_4D_asym8sxasym8s_asym8s
(WORD8 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 WORD32  out_zero_bias,
 WORD32  out_left_shift,
 WORD32  out_multiplier,
 WORD32  out_activation_min,
 WORD32  out_activation_max,
 const WORD8 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 WORD32  inp1_zero_bias,
 WORD32  inp1_left_shift,
 WORD32  inp1_multiplier,
 const WORD8 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape,
 WORD32  inp2_zero_bias,
 WORD32  inp2_left_shift,
 WORD32  inp2_multiplier,
 WORD32  left_shift);

WORD32 xa_nn_elm_sub_broadcast_4D_asym8sxasym8s_asym8s
(WORD8 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 WORD32  out_zero_bias,
 WORD32  out_left_shift,
 WORD32  out_multiplier,
 WORD32  out_activation_min,
 WORD32  out_activation_max,
 const WORD8 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 WORD32  inp1_zero_bias,
 WORD32  inp1_left_shift,
 WORD32  inp1_multiplier,
 const WORD8 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape,
 WORD32  inp2_zero_bias,
 WORD32  inp2_left_shift,
 WORD32  inp2_multiplier,
 WORD32  left_shift);

WORD32 xa_nn_elm_mul_broadcast_4D_asym8sxasym8s_asym8s
(WORD8 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 WORD32  out_zero_bias,
```

```
 WORD32  out_shift,
 WORD32  out_multiplier,
 WORD32  out_activation_min,
 WORD32  out_activation_max,
 const    WORD8 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 WORD32  inp1_zero_bias,
 const    WORD8 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape,
 WORD32  inp2_zero_bias);

WORD32 xa_nn_elm_squared_diff_broadcast_4D_asym8sxasym8s_asym8s
(WORD8 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 WORD32  out_zero_bias,
 WORD32  out_left_shift,
 WORD32  out_multiplier,
 WORD32  out_activation_min,
 WORD32  out_activation_max,
 const WORD8 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 WORD32  inp1_zero_bias,
 WORD32  inp1_left_shift,
 WORD32  inp1_multiplier,
 const WORD8 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape,
 WORD32  inp2_zero_bias,
 WORD32  inp2_left_shift,
 WORD32  inp2_multiplier,
 WORD32  left_shift);

WORD32 xa_nn_elm_add_broadcast_4D_asym16sxasym16s_asym16s
(WORD16 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 WORD32  out_zero_bias,
 WORD32  out_left_shift,
 WORD32  out_multiplier,
 WORD32  out_activation_min,
 WORD32  out_activation_max,
 const WORD16 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 WORD32  inp1_zero_bias,
 WORD32  inp1_left_shift,
 WORD32  inp1_multiplier,
 const WORD16 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape,
 WORD32  inp2_zero_bias,
 WORD32  inp2_left_shift,
 WORD32  inp2_multiplier,
 WORD32  left_shift);


WORD32 xa_nn_elm_sub_broadcast_4D_asym16sxasym16s_asym16s
(WORD16 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 WORD32  out_zero_bias,
```

```
 WORD32  out_left_shift,
 WORD32  out_multiplier,
 WORD32  out_activation_min,
 WORD32  out_activation_max,
 const WORD16 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 WORD32  inp1_zero_bias,
 WORD32  inp1_left_shift,
 WORD32  inp1_multiplier,
 const WORD16 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape,
 WORD32  inp2_zero_bias,
 WORD32  inp2_left_shift,
 WORD32  inp2_multiplier,
 WORD32  left_shift);

WORD32 xa_nn_elm_mul_broadcast_4D_sym16sxsym16s_sym16s
(WORD16 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 WORD32  out_zero_bias,
 WORD32  out_shift,
 WORD32  out_activation_min,
 WORD32  out_activation_max,
 const WORD16 * p_inp1,
 const WORD32 *const p_inp1_shape,
 const WORD16 * p_inp2,
 const WORD32 *const p_inp2_shape);

WORD32 xa_nn_elm_sub_broadcast_4D_f32xf32_f32
(FLOAT32 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const FLOAT32 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 const FLOAT32 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape);

WORD32 xa_nn_elm_squared_diff_broadcast_4D_sym16sxsym16s_sym16s
(WORD16 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 WORD32  out_left_shift,
 WORD32  out_multiplier,
 WORD32  out_activation_min,
 WORD32  out_activation_max,
 const WORD16 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 WORD32  inp1_left_shift,
 WORD32  inp1_multiplier,
 const WORD16 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape,
 WORD32  inp2_left_shift,
 WORD32  inp2_multiplier,
 WORD32  left_shift);

WORD32 xa_nn_elm_add_broadcast_4D_f32xf32_f32
(FLOAT32 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
```

```
 const FLOAT32 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 const FLOAT32 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape);

WORD32 xa_nn_elm_mul_broadcast_4D_f32xf32_f32
(FLOAT32 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const FLOAT32 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 const FLOAT32 * __restrict__ p_inp2,
      const WORD32 *const p_inp2_shape);

WORD32 xa_nn_elm_div_broadcast_4D_f32xf32_f32
(FLOAT32 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const FLOAT32 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 const FLOAT32 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape);

WORD32 xa_nn_elm_min_4D_Bcast_f32xf32_f32
(FLOAT32 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const FLOAT32 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 const FLOAT32 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape);

WORD32 xa_nn_elm_max_4D_Bcast_f32xf32_f32
(FLOAT32 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const FLOAT32 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 const FLOAT32 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape);

WORD32 xa_nn_elm_select_broadcast_4D_32x32_32
(WORD32 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const WORD32 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 const WORD32 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape,
 const unsigned char *__restrict__ p_condition,
 const WORD32 *const p_condition_shape
  );
WORD32 xa_nn_elm_compare_broadcast_4D_f32xf32_f32
(WORD8 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const FLOAT32 * __restrict__ p_inp1,
 const WORD32 *const p_inp1_shape,
 const FLOAT32 * __restrict__ p_inp2,
 const WORD32 *const p_inp2_shape,
 compare_ops_t kernel_type);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *, const WORD16 * const FLOAT32 *, WORD32 *	p_inp1	$\prod_{i=0}^{i=3} p\text{-}inp1\text{-}shape[i]$	First input tensor
const WORD8 *, const WORD16 * const FLOAT32 *	p_inp2	$\prod_{i=0}^{i=3} p\text{-}inp2\text{-}shape[i]$	Second input tensor
const WORD32 *const	p_out_shape	4	Shape of output (array of size 4) (first dimension is outer most)
const WORD32 *const	p_inp1_shape	4	Shape of first input (array of size 4) (first dimension is outer most)
const WORD32 *const	p_inp2_shape	4	Shape of second input (array of size 4) (first dimension is outer most)
WORD32	out_zero_bias		Zero bias of output
WORD32	out_shift		Shift value of output
WORD32	out_multiplier		Multiplier value of output
WORD32	out_activation_min		Activation min of output
WORD32	out_activation_max		Activation max of output
WORD32	inp1_zero_bias		Zero bias of input 1
WORD32	inp1_shift		Shift value of input 1
WORD32	inp1_multiplier		Multiplier value of input 1
WORD32	inp2_zero_bias		Zero bias of input 2
WORD32	inp2_shift		Shift value of input 2
WORD32	inp2_multiplier		Multiplier value of input 2
WORD32	left_shift		Global left shift value for inputs.
const unsigned char *	p_condition		Condition tensor
const WORD32 *const	p_condition_shape		Shape of condition
compare_ops_t	kernel_type		0: compare_greaterequal 1: compare_greater 2: compare_lesserequal 3: compare_lesser 4: compare_equal 5: compare_notequal
Output			
WORD8 * FLOAT32 * WORD16 *, WORD32 *	p_out	$\prod_{i=0}^{i=3} p\text{-}out\text{-}shape[i]$	Output tensor

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_inp1,p_inp2, p_out,p_condition	Aligned on (size of one element)-byte boundary
	Cannot be NULL
p_out	Should not overlap with the input pointers (could be same as one of the input pointers, inplace operation is possible)
p_out_shape, p_inp1_shape, p_inp2_shape, p_condition_shape	Cannot be NULL
	Aligned on 4-byte boundary
	Shapes must be broadcast compatible, that is, p_out_shape[i] must be max(p_inp1_shape[i], p_inp2_shape[i]) p_inp1_shape[i] must be either equal to p_inp2_shape[i] or 1 p_inp2_shape[i] must be either equal to p_inp1_shape[i] or 1
inp1_zero_bias, inp2_zero_bias	{-127,….., 128} for asym8s input {-32767,….., 32768} for asym16s input
inp1_shift, inp2_shift, out_shift	{-31,…., 0} for add,sub quantized datatype kernels, {-31,…., 31} for other fixed point and quantized datatype kernels
left_shift	{0,…., 31}
inp1_multiplier, inp2_multiplier out_multiplier	Should not be less than 0.
out_zero_bias	{-128,….., 127} for asym8s output {-32768,….., 32767} for asym16s output
out_activation_min, out_activation_max	{-128,….., 127} for asym8s output {-32768,….., 32767} for asym16s output out_activation_min < out_activation_max
p_condition_shape	p_condition_shape should be equal to p_out_shape
kernel_type	{0……5}

3.6.9 Elementwise Comparison Kernels

Description

The Elementwise Comparison kernels perform elementwise comparison operations on two input vectors `x`, and `y`, to get the output vector `z`. The supported operations are: equal, not equal, greater, greater equal,

less, less equal. The output for all the comparison kernels is a Boolean value that require 1-byte space.The supported precisions are: asym8s.

Function variants available are `xa_nn_[o]_[p]` and xa_nn_elm_compare_f32xf32_f32, where:

`[o]`: Operations: elm_equal, elm_notequal, elm_greater, elm_greaterequal, elm_less, elm_lessequal

`[p]`: Input Precision in bits- input1xinput2

xa_nn_elm_compare_f32xf32_f32 variant selects comparison operation to perform from the value of input parameter `kernel_type`. For details refer to the Arguments section.

Precision

Type	Description
`asym8sxasym8s`	asym8s inputs, Boolean(1-byte) output
`f32xf32`	f32 inputs, Boolean(1-byte) output

Algorithm

elm_equal: $z_n = (x_n == y_n)$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$
elm_notequal: $z_n = (x_n != y_n)$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$
elm_greater: $z_n = (x_n > y_n)$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$
elm_greaterequal: $z_n = (x_n \geq y_n)$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$
elm_less: $z_n = (x_n < y_n)$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$
elm_lessequal: $z_n = (x_n \leq y_n)$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$

x_n represents first input, y_n represents second input.

z_n represents output.

Prototype

```
WORD32 xa_nn_elm_equal_asym8sxasym8s
(WORD8 * p_out,          const WORD8 * p_inp1,    WORD32  inp1_zero_bias,
 WORD32  inp1_shift,     WORD32  inp1_multiplier, const WORD8 * p_inp2,
 WORD32  inp2_zero_bias, WORD32  inp2_shift,      WORD32  inp2_multiplier,
 WORD32  left_shift,     WORD32  num_elm);
WORD32 xa_nn_elm_notequal_asym8sxasym8s
(WORD8 * p_out,          const WORD8 * p_inp1,    WORD32  inp1_zero_bias,
 WORD32  inp1_shift,     WORD32  inp1_multiplier, const WORD8 * p_inp2,
 WORD32  inp2_zero_bias, WORD32  inp2_shift,      WORD32  inp2_multiplier,
 WORD32  left_shift,     WORD32  num_elm);
WORD32 xa_nn_elm_greater_asym8sxasym8s
(WORD8 * p_out,          const WORD8 * p_inp1,    WORD32  inp1_zero_bias,
 WORD32  inp1_shift,     WORD32  inp1_multiplier, const WORD8 * p_inp2,
 WORD32  inp2_zero_bias, WORD32  inp2_shift,      WORD32  inp2_multiplier,
 WORD32  left_shift,     WORD32  num_elm);
WORD32 xa_nn_elm_greaterequal_asym8sxasym8s
(WORD8 * p_out,          const WORD8 * p_inp1,    WORD32  inp1_zero_bias,
 WORD32  inp1_shift,     WORD32  inp1_multiplier, const WORD8 * p_inp2,
```

```
 WORD32  inp2_zero_bias, WORD32  inp2_shift,      WORD32  inp2_multiplier,
 WORD32  left_shift,     WORD32  num_elm);
WORD32 xa_nn_elm_less_asym8sxasym8s
(WORD8 * p_out,          const WORD8 * p_inp1,    WORD32  inp1_zero_bias,
 WORD32  inp1_shift,     WORD32  inp1_multiplier, const WORD8 * p_inp2,
 WORD32  inp2_zero_bias, WORD32  inp2_shift,      WORD32  inp2_multiplier,
 WORD32  left_shift,     WORD32  num_elm);
WORD32 xa_nn_elm_lessequal_asym8sxasym8s
(WORD8 * p_out,          const WORD8 * p_inp1,    WORD32  inp1_zero_bias,
 WORD32  inp1_shift,     WORD32  inp1_multiplier, const WORD8 * p_inp2,
 WORD32  inp2_zero_bias, WORD32  inp2_shift,      WORD32  inp2_multiplier,
 WORD32  left_shift,     WORD32  num_elm);
WORD32 xa_nn_elm_compare_f32xf32_f32
(WORD8 * __restrict__ p_out,          const FLOAT32 * __restrict__ p_inp1,
 const FLOAT32 * __restrict__ p_inp2, WORD32 num_elm,
 compare_ops_t kernel_type);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_inp1	num_elm	First input vector
const WORD8 *	p_inp2	num_elm	Second input vector
WORD32	num_elm		Number of elements
WORD32	inp1_zero_bias		Zero bias of input 1
WORD32	inp1_shift		Shift value of input 1
WORD32	inp1_multiplier		Multiplier value of input 1
WORD32	inp2_zero_bias		Zero bias of input 2
WORD32	inp2_shift		Shift value of input 2
WORD32	inp2_multiplier		Multiplier value of input 2
WORD32	left_shift		Global left shift value for inputs.
Compare_ops_t	kernel_type		0: compare_greaterequal 1: compare_greater 2: compare_lesserequal 3: compare_lesser 4: compare_equal 5: compare_notequal
Output			
WORD8 *	p_out	num_elm	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp1,p_inp2,p_out,	Aligned on (size of one element)-byte boundary

	Cannot be NULL
num_elm	Greater than 0
inp1_zero_bias, inp2_zero_bias	{-127,....., 128} for asym8s input
inp1_shift, inp2_shift	{-31,...., 31} for fixed point and quantized 8-bit APIs
inp1_multiplier, inp2_multiplier	Should not be less than 0.
Left_shift	{0,...., 31}
kernel_type	{0.....5}

3.6.10 Elementwise Logical Kernels

Description

The Elementwise Logical kernels perform elementwise logical operations on two Boolean input vectors `x`, and `y`, to get the Boolean output vector `z`. The supported operations are: logical_and, logical_or, logical_not. The inputs and output for all the logical kernels are Boolean values that require 1-byte space each. The supported precisions is: bool.

Function variants available are `xa_nn_[o]_[p]`, where:

`[o]`: Operations: elm_logicaland, elm_logicalor, elm_logicalnot

`[p]`: Input Precision in bits- input1xinput2

Precision

Type	Description
boolxbool	Boolean(1-byte) inputs, Boolean(1-byte) output

Algorithm

elm_logicaland: $z_n = (x_n \;\&\&\; y_n)\,, \quad n = 0 \ldots, \overline{num\text{-}elm - 1}$

elm_logicalor: $z_n = (x_n \;||\; y_n)\,, \quad n = 0 \ldots, \overline{num\text{-}elm - 1}$

elm_logicalnot: $z_n = (!\, x_n)\,, \quad n = 0 \ldots, \overline{num\text{-}elm - 1}$

x_n represents the first input, y_n represents the second input.

z_n represents output.

Prototype

```
WORD32 xa_nn_elm_logicaland_boolxbool_bool
(WORD8 * __restrict__ p_out, const   WORD8 * __restrict__ p_inp1,
 const   WORD8 * __restrict__ p_inp2, WORD32  num_elm);

WORD32 xa_nn_elm_logicalor_boolxbool_bool
(WORD8 * __restrict__ p_out, const   WORD8 * __restrict__ p_inp1,
 const   WORD8 * __restrict__ p_inp2, WORD32  num_elm);
```

```
WORD32 xa_nn_elm_logicalnot_bool_bool
(WORD8 * __restrict__ p_out, const   WORD8 * __restrict__ p_inp,
 WORD32  num_elm);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_inp1 / p_inp	num_elm	First input vector
const WORD8 *	p_inp2	num_elm	Second input vector
WORD32	num_elm		Number of elements
Output			
WORD8 *	p_out	num_elm	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp1/p_inp,p_inp2,p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
num_elm	Greater than 0

3.6.11 Reduce Kernels

Description

The Reduce kernels perform reduction operations on an input vector x based on the dimensions given in axis vector and get the output vector z. The supported operations are: reduce_max and reduce_mean. The supported precisions are: asym8s and asym16s. The kernels presently support up to 4 dimensions and the input data is assumed to be in “NHWC” or “DWHN” data format (Depth or channels dimension is written first).

Note The axis vector must have non-duplicate values to avoid larger execution time and poor performance.

For the reduce_max kernel, the input and output quantization are expected to be the same. Thus, the API does not include quantization specific multiplier, shift and zero bias arguments. For the dimensions mentioned in the axis vector, a max operation is carried out thereby reducing the dimension size to 1.

For the reduce_mean kernel, the input and output quantization can be different. The arguments `inp_zero_bias`, `out_zero_bias`, `out_multiplier`, and `out_shift` are provided for the Mean operation and requantization into asym8s output. For the dimensions mentioned in the axis vector, the mean operation is carried out thereby reducing the dimension size to 1.

The reduce_mean kernel expects the multiplication factor $\frac{1}{Number\ of\ elements\ in\ axis}$ to be adjusted in `out_multiplier` and `out_shift` parameters.

These kernels require temporary buffer for reduce operation. This temporary buffer is provided by `p_scratch` argument of kernel API. The size of temporary buffer must be queried using `xa_nn_reduce_getsize_nhwc()` helper API. The `reduce_ops` argument accepts an enumerator that states the reduce operation type. It can take the following values: REDUCE_MAX and REDUCE_MEAN.

Function variants available are `xa_nn_reduce_[o]_[n]_[p]`, where:

`[o]`: Operations: reduce_max, reduce_mean

`[n]`: Number of dimensions: `4D`

`[p]`: Input Precision in bits- `input_output`

Precision

Type	Description
`asym8s_asym8s`	asym8s input, asym8s output
`asym16s_asym16s`	asym16s input, asym16s output

Algorithm

Reduce Max:

For every dimension $\boldsymbol{r}$ in axis:

$$Z_{N,H,W,C} = \max(\ in_{n,h,w,c}[\boldsymbol{r}_i],\ \ in_{n,h,w,c}[\boldsymbol{r}_j]\ )$$

Where,

$$\text{The values of output dimensions(N, H, W, C) if reduced will be equal to 1}$$

$$\boldsymbol{r} \in \text{dimensions along which reduce max is to be performed .}$$

$\boldsymbol{r}_i$ and $\boldsymbol{r}_j$ are the elements in the input shape along the $\boldsymbol{r}$ dimension.

Reduce Mean:

For every dimension $\boldsymbol{r}$ in axis:

$$S_{N,H,W,C} = sum(\ in_{n,h,w,c}[\boldsymbol{r}_i],\ \ in_{n,h,w,c}[\boldsymbol{r}_j]\ )$$

Then, we compute the mean

$$Z_{N,H,W,C} = \frac{1}{\mathrm{P}\ nElem_{r}} S_{N,H,W,C}$$

Where,

The values of output dimensions(N, H, W, C) if reduced will be equal to 1

$\boldsymbol{r} \in$ dimensions along which reduce mean is to be performed .

$\boldsymbol{r}_i$ and $\boldsymbol{r}_j$ are the elements in the input shape along the $\boldsymbol{r}$ dimension.

$\mathrm{P}\ nElem_{r}$ is the product of number of elements in every $\boldsymbol{r}$ dimension.

Also refered to as 'Number of elements in axis'.

$S_{N,H,W,C}$ represents the intermediate reduce sum output required for reduce mean.

$Z_{N,H,W,C}$ represents the reduce operation output and $in_{n,h,w,c}$ represents the input vector.

Prototype

```
WORD32 xa_nn_reduce_getsize_nhwc
(WORD32 inp_precision,  const WORD32 *const p_inp_shape,  WORD32 num_inp_dims,
 const WORD32 *p_axis,  WORD32 num_axis_dims,             WORD32 reduce_ops);

WORD32 xa_nn_reduce_max_4D_asym8s_asym8s
(WORD8 * p_out,         const WORD32 *const p_out_shape, const WORD8 * p_inp,
 const WORD32 *const p_inp_shape,     const WORD32 * p_axis,
 WORD32 num_out_dims,   WORD32 num_inp_dims,         WORD32 num_axis_dims,
 pVOID p_scratch_in);

WORD32 xa_nn_reduce_max_4D_asym16s_asym16s
(WORD16 * p_out,        const WORD32 *const p_out_shape,const WORD16 * p_inp,
 const WORD32 *const p_inp_shape,     const WORD32 * p_axis,
 WORD32 num_out_dims,   WORD32 num_inp_dims,          WORD32 num_axis_dims,
 pVOID p_scratch_in);

WORD32 xa_nn_reduce_mean_4D_asym8s_asym8s
(WORD8 * p_out,         const WORD32 *const p_out_shape, const WORD8 * p_inp,
 const WORD32 *const p_inp_shape,     const WORD32 * p_axis,
 WORD32 num_out_dims,   WORD32 num_inp_dims,         WORD32 num_axis_dims,
 WORD32 inp_zero_bias,  WORD32 out_multiplier,       WORD32 out_shift,
 WORD32 out_zero_bias,  pVOID p_scratch_in);

WORD32 xa_nn_reduce_mean_4D_asym16s_asym16s
(WORD16 * _p_out,      const WORD32 *const p_out_shape, const WORD16 * p_inp,
 const WORD32 *const p_inp_shape,     const WORD32 * p_axis,
 WORD32 num_out_dims,  WORD32 num_inp_dims,          WORD32 num_axis_dims,
 WORD32 inp_zero_bias, WORD32 out_multiplier,        WORD32 out_shift
 WORD32 out_zero_bias, pVOID p_scratch_in);
```

Arguments

Type	Name	Size	Description
Input			
const WORD32 *const	p_out_shape	num_out_dims	Output shape vector containing size in each output dimension.

const WORD8 *, const WORD16 *	p_inp	Product of all dims in p_inp_shape	Input vector, asym8s/asym16s
const WORD32 *const	p_inp_shape	num_inp_dims	Input shape vector containing size in each input dimension.
const WORD32 *	p_axis	num_axis_dims	Axis vector, contains dimensions for reduce operation
WORD32	num_out_dims		Number of output dimension
WORD32	num_inp_dims		Number of input dimension
WORD32	num_axis_dims		Number of axis dimension
WORD32	inp_zero_bias		Zero offset of input
WORD32	out_multiplier		Multiplier value of output
WORD32	out_shift		Shift value of output
WORD32	out_zero_bias		Zero offset of output
pVOID	p_scratch	xa_nn_reduce_getsize_nhwc()	Scratch memory pointer
Output			
WORD8 * WORD16 *	p_out	Product of all dims in p_out_shape	Output vector, asym8s/asym16s

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
reduce_ops	Should be REDUCE_MAX or REDUCE_MEAN.
p_inp,p_axis,p_out,p_inp_shape,p_out_shape	Aligned on (size of one element)-byte boundary
	Cannot be NULL and cannot overlap
num_inp_dims, num_out_dims,	Should be more than 0 and less than equal to 4.
num_axis_dims	Should not be less than 0 and more than 4.
p_axis	The axis values must be between 0 and (num_inp_dims – 1).
p_inp_shape,p_out_shape	The shape values must be greater than 0.
inp_zero_bias out_zero_bias	{-128,….,127} for asym8s, {-32768,…., 32767} for asym16s
out_multiplier	Greater than 0
out_shift	{-31, …, 31}

3.6.12 Broadcast Kernel

Description

The Broadcast kernels broadcast an input shape into the specified output shape. The input and output shapes must be compatible for the broadcast operation to succeed.

Details of the broadcast operation can be found in Tensorflow Broadcasting semantics [4].

The dimensions of input and output tensors are passed as `in_shape` and `out_shape`, and the number of dimensions specified by `numDims` must be the same for both. In case the number of input and output dimensions are unequal, the empty leading dimensions of the smaller shape must be filled with ones to equalize them. For example, if the input dimension is 2x1x3 and the output dimension is 4x2x5x3, then `in_shape` must be passed as 1x2x1x3.

Figure 3-2 shows a simple illustration for broadcasting a 1x4x1 tensor into 1x4x3 and 2x4x3.

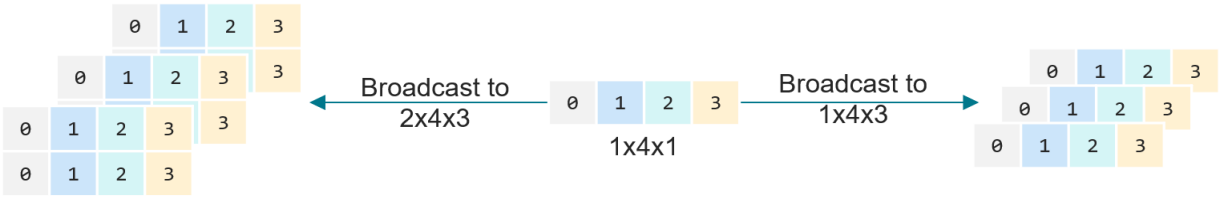

Figure 3-2 Broadcasting a 1x4x1 Tensor to 1x4x3 and 2x4x3

Precision

Type	Description
8_8	8-bit input, 8-bit output
32_32	32-bit input, 32-bit output

Prototype

```
WORD32 xa_nn_broadcast_8_8
(WORD8* __restrict__ p_out,  const int* const out_shape,
 const WORD8* __restrict_p_in,  const int* const  in_shape,
 int numDims);

WORD32 xa_nn_broadcast_32_32
(WORD32* __restrict__ p_out, const int *const out_shape,
 const WORD32* __restrict__ p_in, const int * const in_shape,
 int num_dims);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *, const WORD32 *	p_in	$\prod_{i=0}^{i=num\text{-}dims-1} in\text{-}shape[i]$	Input tensor
const int * const	in_shape out_shape	num_dims	Input/output shapes
int	num_dims	-	Number of dimensions
Output			

WORD8 *, WORD32 *	p_out	$\prod_{i=0}^{i=num\_dims-1} out\_shape[i]$	Output tensor

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_in, p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
inp_shape, out_shape	Aligned on 4-byte boundary
	Cannot be NULL
	All elements must be greater than zero
	inp_shape[i] must be either equal to out_shape[i] or 1 for i = [0, numDims-1]
num_dims	In the range [1, 8]

3.6.13 Memory Operation Kernels

Description

The Memory Operation kernels perform basic memory related operations. The supported operations are: memmove and memset. The supported precisions are: 8-bit, float32.

Memmove kernel does byte-level transfer and takes generic pointers, num_elm must be set to number of 1-byte elements or simply number of bytes to be transferred for data types with sizes bigger than 1-byte.

Function variants available are xa_nn_[o]_[p]_[q], where:

[o]: Operations: memmove, memset

[p]: Input Precision in bits

[q]: Output Precision in bits

Precision

Type	Description
f32_f32	float32 input, float32 output
16	16-bit input, 16-bit output
8_8	8-bit input, 8-bit output

Algorithm

memmove: $z_n = x_n$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$
memset: $z_n = x_0$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$; $x_0 < scalar >$

x_n represents input

z_n represents output.

Prototype

```
WORD32 xa_nn_memset_f32_f32
(FLOAT32 * __restrict__ p_out,  FLOAT32 val,       WORD32  num_elm);
WORD32 xa_nn_memmove_16
(void * pdst,            const void *psrc,         WORD32 n);
WORD32 xa_nn_memmove_8_8
(void * p_out,           const void * p_inp,       WORD32  num_elm);
```

Arguments

Type	Name	Size	Description
Input			
const FLOAT32 * void *	p_inp	num_elm	First input vector
FLOAT32	val		Memset value
WORD32	num_elm		Number of 1-byte elements or Number of bytes
Output			
FLOAT32 * void *	p_out	num_elm	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp, p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
num_elm	Greater than 0

3.6.14 LSTM Cell State Update

Description

This is a helper function for LSTM operator in TFLM. It updates the LSTM cell state based on the values of gate vectors : input_gate, forget_gate, and cell_gate.

The available function variant is, xa_nn_lstm_cell_update_[p], where:

[p]: Input and Output precision

Precision

Type	Description
16	16-bit cell state, forget gate, cell gate, and input_gate

Algorithm

$$c_t = f_t . c_{t-1} + i_t . cg_t$$

Where:

f_t : forget gate vector at time t

i_t : input gate vector at time t

c_t : cell state vector at time t

c_{t-1} : cell state vector at time t-1(Previous cell state)

cg_t : cell gate vector at time t

Prototype

```
WORD32 xa_nn_lstm_cell_state_update_16
(WORD16* p_cell_state,       const WORD16* p_forget_gate,  const WORD16* p_cell_gate,
 const WORD16* p_input_gate, WORD32 cell_to_forget_shift,  WORD32 cell_to_input_shift,
 WORD32 quantized_cell_clip, WORD32 num_elms);
```

Arguments

Type	Name	Size	Description
Input			
const WORD16 *	p_forget_gate	num_elms	Forget gate vector
const WORD16 *	p_cell_state	num_elms	Cell state vector. This argument is both an input and an output.

Type	Name	Size	Description
const WORD16 *	p_cell_gate	num_elms	Cell gate vector
const WORD16 *	p_input_gate	num_elms	Input gate vector
WORD32	cell_to_forget_shift		Shift required for cell_state * forget_gate
WORD32	cell_to_input_shift		Shift required for input_gate * cell_gate
WORD32	quantized_cell_clip		Value to clamping the output
WORD32	num_elms	num_elms	Vector length
Output			
WORD16 *	p_cell_state	num_elms	Cell state vector. This argument is both an input and an output.

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_forget_gate, p_cell_state, p_cell_gate, p_input_gate	Aligned on (size of one element)-byte boundary
	Cannot be NULL
num_elms	Greater than 0
cell_to_forget_shift	{-31, ..., -1}
cell_to_input_shift	{-31, ..., -1}

3.6.15 GRU Hidden State Update:

Description

This is a helper function for GRU operator. It updates the GRU hidden state based on the values of gate vectors : update gate, previous hidden state and candidate hidden state (modulated state).
The available function variant is, xa_nn_gru_hidden_state_update_[p], where:
[p]: Input and Output precision

Precision

Type	Description
8	8-bit hidden state

Algorithm

$h_t = z_t \,.\, h'_t + (1 - z_t).\, h_{t-1}$

Where:

h_t : hidden state vector at time t
z_t : Update gate vector at time t
h'_t : Candidate hidden state (modulated state) vector at time t
h_{t-1} : hidden state vector at time t-1(Previous hidden state)

Prototype

```
WORD32 xa_nn_gru_hidden_state_update_8(WORD8* p_hidden_state,
    const WORD16* p_update_gate,
    const WORD16* p_modulated_state,
    WORD32 update_to_modulated_state_multiplier,
    WORD32 update_to_modulated_state_shift,
    WORD32 update_to_hidden_state_multiplier,
    WORD32 update_to_hidden_state_shift,
    WORD32 out_multiplier,
    WORD32 out_shift,
    WORD32 hidden_zero_bias,
    WORD32 num_elms);
```

Arguments

Type	Name	Size	Description
Input / Output			
WORD8 *	p_hidden_state		Initial hidden state
WORD16 *	p_update_gate		Update gate output
WORD16*	p_modulated_state		Modulated state (candidate hidden state)
WORD32	update_to_modulated_state_multiplier		Multiplier for update gate x modulated state
WORD32	update_to_modulated_state_shift		Shift for update gate x modulated state
WORD32	update_to_hidden_state_multiplier		Multiplier for (1 - update gate) x hidden_state
WORD32	update_to_hidden_state_shift		Shift for (1 - update gate) x hidden_state
WORD32	out_multiplier		Output multiplier
WORD32	out_shift		Output shift
WORD32	hidden_zero_bias		Hidden zero bias
WORD32	num_elms		Number of elements in all input/output buffers

Returns
0: no error
-1: error, invalid parameters

Restrictions

Arguments	Restrictions

p_hidden_state	Cannot be NULL
p_update_gate	Cannot be NULL
p_modulated_state	Cannot be NULL
update_to_modulated_state_shift	Should be within range [-31, 31]
update_to_hidden_state_shift	Should be within range [-31, 31]
out_shift	Should be within range [-31, 31]
hidden_zero_bias	Should be within range [-128, 127]
num_elms	Cannot be negative or zero

3.7 Normalization Kernels

3.7.1 L2 Normalization Kernel

Description

The L2 Normalization kernels perform L2 normalization of an input vector `x` to get output vector `z`. This means every element of input vector x is divided by L2 norm of x, this gives an output vector z whose L2 norm is 1.

The L2 Normalization kernel accepts asym8s input vector and produces asym8s output vector.

Precision

Type	Description
asym8s	asym8s input, asym8s output

Algorithm

$$z_n = \frac{x_n}{\sqrt{\sum_{n=1}^{N}|x_n|^2}}, \qquad n = 1 \ldots., \overline{num\text{-}elements}$$

x_n represents input vector.

z_n represents output vector.

Prototype

```
WORD32 xa_nn_l2_norm_asym8s_asym8s
(WORD8 * p_out,      const WORD8 * p_inp,    WORD32 zero_point,    WORD32 num_elm);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_inp	num_elm	Input vector

WORD32	zero_point		Input zero bias
WORD32	num_elm		Number of elements
Output			
WORD8 *	p_out	num_elm	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_inp, p_out	Aligned on (size of one element)-byte boundary
	Should not overlap
	Cannot be NULL
zero_point	{-128,....., 127} for asym8s input
num_elm	Greater than 0

3.7.2 3D Batch Normalization Kernel

Description

The 3D batch normalization kernel takes a 3D input (io_height x io_width x io_depth) and performs batch normalization along the depth dimension and provides a 3D output (io_height x io_width x io_depth). Two parameters, alpha and beta, are used for batch normalization, which are 1D array of dimension io_depth.

Precision

Type	Description
8_8	8-bit input, 8-bit output

Algorithm

$$z(h,w,d) = x(h,w,d) * alpha(d) + beta(d)$$

$h = 0$ *to* $io\_height - 1$
$w = 0$ *to* $io\_width - 1$
$d = 0$ *to* $io\_depth - 1$

Prototype

```
WORD32 xa_nn_batch_norm_3D_8_8
  (WORD8 * __restrict__ p_out,              const WORD8 * __restrict__ p_inp,
   const WORD16 * __restrict__ p_alpha,     const WORD32 * __restrict__ p_beta,
   WORD32 io_height,                        WORD32 io_width,
   WORD32 io_depth,                         WORD32 out_shift,
```

```
WORD32 out_activation_min,          WORD32 out_activation_max,
WORD32 inp_data_format,             WORD32 out_data_format)
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_inp	io_height*io_width*io_depth	Input cube
const WORD16 *	p_alpha	io_depth	Alpha vector for scaling
const WORD16 *	p_beta	io_depth	Beta vector for bias
WORD32	io_height		Input/Output height
WORD32	io_width		Input/Output width
WORD32	io_depth		Input/Output depth
WORD32	out_shift		Output shift
WORD32	out_activation_min		Min output value
WORD32	out_activation_max		Max output value
WORD32	inp_data_format		Input data format
WORD32	out_data_foramt		Output data format
Output			
WORD8 *	p_out		Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_inp, p_out	Aligned on (size of one element)-byte boundary
	Should not overlap
	Cannot be NULL
io_height,io_width, io_depth	Greater than 0
out_shift	-31 < out_shift < 0
out_activation_min	Greater than -128
out_activation_max	Less than 127
input_data_format, output_data_format	Equal to 0

3.7.3 Renormalization Kernel

Description

The renormalization kernel performs renormalization of an input vector x by a given scale and shift value to get output vector z.

The renormalization kernel accepts asym8s input vector and produces asym8s output vector.

Precision

Type	Description
asym8s_ asym8s	asym8s input, asym8s output

Algorithm

$$zero\_point = (input\_zero\_bias * renorm\_scale) - (output\_zero\_bias << renorm\_shift)$$
$$zn = (zero\_point + xn * renorm\_scale) >>_{asym} renorm\_shift$$

Prototype

```
WORD32 xa_nn_renorm_asym8s_asym8s
(WORD8 * __restrict__ p_out, const WORD8 * __restrict__ p_inp,
 WORD32 num_elm,             WORD32 renorm_scale,
 WORD32 renorm_shift,        WORD32 input_zero_bias,
 WORD32 output_zero_bias);
```

Arguments

Type	Name	Size	Description
Input			
WORD8 *	p_inp	num_elm	Input
WORD32	num_elm		Number of input elements
WORD32	renorm_scale		Scale of renormalization
WORD32	renorm_shift		Shift for renormalization
WORD32	input_zero_bias		Zero bias of input vector
WORD32	output_zero_bias		Zero bias of input vector
Output			
WORD8 *	p_out	num_elm	Output

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_inp, p_out	Aligned on (size of one element)-byte boundary
	Should not overlap
	Cannot be NULL
num_elm	Greater than 0.
renorm_scale	Must be in range [0, 65535]
renorm_shift	Must be in range [0, 23]
input_zero_bias	Must be in range [-128, 127]
output_zero_bias	Must be in range [-128, 127]

3.7.4 Layer Normalization Kernels

The Layer Normalization Calc kernel calculates the parameters for the normalization process. These parameters are used by Layer Normalization Apply kernels. Together, they provide complete functionality for Layer Normalization.

Layer Normalization Calc Kernels

Description

The Layer Normalization Calc kernel calculates the parameters for the normalization process and stores them in the output buffer(s).
The kernels are available as xa_nn_norm_calc_3D_[p]_nhwc, where [p] is input precision.

Precision

Type	Description
8	8-bit input, 16-bit output norm-data
16	16-bit input, 16-bit output norm-data

Algorithm

For across_depth_flag = 1; 8-bit kernel

$$M_{h,w} = \max\left(abs\left(x_{h,w,c}\right)\right), over\ c = 0, \dots, input\_depth$$

$$S_{h,w} = \text{sum}\left(\left(x_{h,w,c}\right)^2\right) \quad , over\ c = 0, \dots, input\_depth$$

$$I_{h,w} = \left(M_{h,w}\right)^{-1}$$

$$N_{h,w} = I_{h,w} * rsqrt(I_{h,w}^2 * S_{h,w})$$

Here $N_{h,w}$ is the norm output data, h and w indicate height and width indices.

For across_depth_flag = 0; 8-bit kernel

$$S = \text{sum}\left(\left(x_{h,w,c}\right)^2\right) \quad , accross\ h, w, c$$

$$N = rsqrt(S)$$

Here N is the norm output data, which is a scalar value.

For across_depth_flag = 1; 16-bit kernel

$$S_{h,w} = \text{sum}\left(\left(x_{h,w,c}\right)^2\right) \quad , over\ c = 0, \dots, input\_depth$$

$$N_{h,w} = rsqrt(S_{h,w})$$

Here, $N_{h,w}$ is used to calculate NSA and Norm output data; h and w indicate height and width indices.

For across_depth_flag = 0; 16-bit kernel

$S = \text{sum}\left(\left(x_{h,w,c}\right)^2\right)$, *accross* h, w, c

$N = rsqrt(S)$

Here N is used to calculate NSA and the norm output data, which are both scalar values

Prototype

```
WORD32 xa_nn_norm_calc_3D_8_nhwc
(WORD16 * p_outnorm,          const WORD8 * p_inp,
 int input_height,            int input_width,       int input_channels,
 int accross_depth_flag,      int out_shift,
 const UWORD16 *prsqrt,       int rsqrt_shift,       int rsqrt_table_len,
 const UWORD16 *precip,       int recip_shift);

WORD32 xa_nn_norm_calc_3D_16_nhwc
(UWORD16 * p_outnorm,         WORD8 * p_outnsa,      const WORD16 * p_inp,
 int input_height,            int input_width,       int input_channels,
 int accros_depth_flag,       int out_shift,         const UWORD16 *prsqrt,
 int rsqrt_table_len);
```

Arguments

Type	Name	Size	Description
Input			
WORD8 *	p_inp	input_height*input_width* input_channels	Input
UWORD16 *	prsqrt	rsqrt_table_len	Inverse square-root (RSQRT) table
UWORD16 *	precip	256	Reciprocal table
WORD32	input_height		Input Height
WORD32	input_width		Input Width
WORD32	input_channels		Input channels (depth)
WORD32	across_depth_flag		Indicates whether operation is depthwise or global
WORD32	out_shift		Output shift
WORD32	rsqrt_shift		RSQRT table index shift
WORD32	recip_shift		Shift for reciprocal table value
WORD32	rsqrt_table_len		Length of RSQRT table
Output			
WORD16 * UWORD16 *	p_outnorm	input_height*input_width (if across_depth_flag = 1) 1 (if across_depth_flag = 0)	Output Norm data
WORD8 *	p_outnsa	input_height*input_width (if across_depth_flag = 1) 1 (if across_depth_flag = 0)	Output NSA data. Used only for 16-bit kernel

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_inp, prsqrt, precip, p_outnorm, p_outnsa	Cannot be NULL
	Aligned on (size of element)-byte boundary
	Non overlapping
out_shift	Cannot be positive
across_depth_flag	Can be: 0 or 1
input_height, input_width, input_channles, rsqrt_table_len	Cannot be negative
recip_shift+out_shift	Cannot be negative (only for 8-bit kernel)
recip_shift-rsqrt_shift	Cannot be negative

Layer Normalization Apply Kernels

Description

The Layer Normalization Apply kernels accept normalization parameters provided by calc kernels and apply the same to the input data to produce output.
The kernels are available as xa_nn_norm_apply_3D_[p]_nhwc, where [p] is input precision.

Precision

Type	Description
8	8-bit input, 8-bit output
16	16-bit input, 16-bit output

Algorithm

For across_depth_flag = 1, 8-bit

$y_{h,w,c} = N_{h,w} * x_{h,w,c}$

Here $y_{h,w,c}$ is quantized using out_multiplier and output shift to produce normalized output, that is written to the output buffer.

For across_depth_flag = 0, 8-bit

$y_{h,w,c} = N * x_{h,w,c}$

Here $y_{h,w,c}$ is quantized using out_multiplier and output shift to produce normalized output, that is written to the output buffer.

For across_depth_flag = 1, 16-bit

$y_{h,w,c} = N_{h,w} * x_{h,w,c}$

Here $y_{h,w,c}$ is quantized using the final multiplier and final shift to produce normalized output, which is written to the output buffer. The final multipliers and shifts are calculated using the output multiplier/shift and NSA data.

For across_depth_flag = 0, 16-bit

$y_{h,w,c} = N * x_{h,w,c}$

Here $y_{h,w,c}$ is quantized using the final multiplier and final shift to produce normalized output, which is written to the output buffer. The final multipliers and shifts are calculated using the output multiplier/shift and NSA data.

Prototype

```
WORD32 xa_nn_norm_apply_3D_8_nhwc
(WORD8 * p_out,               const WORD8 * p_inp,   WORD16 *p_inp_norm,
 int input_height,            int input_width,       int input_channels,
 int across_depth_flag,       int per_chan_flag,     WORD16 * p_out_multiplier,
 WORD32 out_shift,            WORD32 rsqrt_shift);

WORD32 xa_nn_norm_apply_3D_16_nhwc
(WORD16 * p_out,              const WORD16 * p_inp,
 const UWORD16 *p_inp_norm,   const WORD8 *p_inp_nsadata,
 int input_height,            int input_width,       int input_channels,
 int across_depth_flag,       int per_chan_flag,     WORD16 * p_out_multiplier,
 WORD32 out_shift,     WORD32 rsqrt_shift);
```

Arguments

Type	Name	Size	Description
Input			
WORD8 * WORD16 *	p_inp	input_height*input_width*input_channels	Input
WORD16 * UWORD16 *	p_inp_norm	input_height*input_width (if across_depth_flag = 1) 1(if across_depth_flag = 0)	Input norm data provided by Calc kernel
WORD8 *	p_inp_nsadata	input_height*input_width (if across_depth_flag = 1) 1 (if across_depth_flag = 0)	Input NSA data provided by Calc kernel (only applicable to 16-bit kernel)
WORD16 *	p_out_multiplier	input_channels (if per_chan_flag = 1) 1 (if per_chan_flag = 0)	Output multiplier
WORD32	input_height		Input Height
WORD32	input_width		Input Width
WORD32	input_channels		Input channels (depth)
WORD32	across_depth_flag		Indicates whether operation is depthwise or global
WORD32	per_chan_flag		Indicates whether output multiplier is to be applied per channel
WORD32	out_shift		Output shift
WORD32	rsqrt_shift		Shift for RSQRT table value
Output			
WORD8 * WORD16 *	p_out	input_height*input_width*input_channels	Normalized output

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions

Arguments	Restrictions
`p_inp, p_inp_norm, p_inp_nsadata, p_out_multiplier, p_out`	Cannot be NULL
	Aligned on (size of element)-byte boundary
	Non overlapping
`out_shift`	Must be in range: [-15 , 15]
`across_depth_flag`	Can be: 0 or 1
`per_chan_flag`	Can be: 0 or 1
`input_height, input_width, input_channles`	Cannot be negative

3.8 Reorg Kernels

3.8.1 Depth to Space Kernels

Description

The Depth to Space kernels converts the depth dimension of an input cube into the spatial dimensions of an output cube controlled by a block size parameter.

These kernels are based on the DEPTH_TO_SPACE operator in TFLM[3], which collects all elements from the input depth dimension and spreads it across the output spatial dimension using a `block_size` factor. The operation is shown in Figure 3-3.

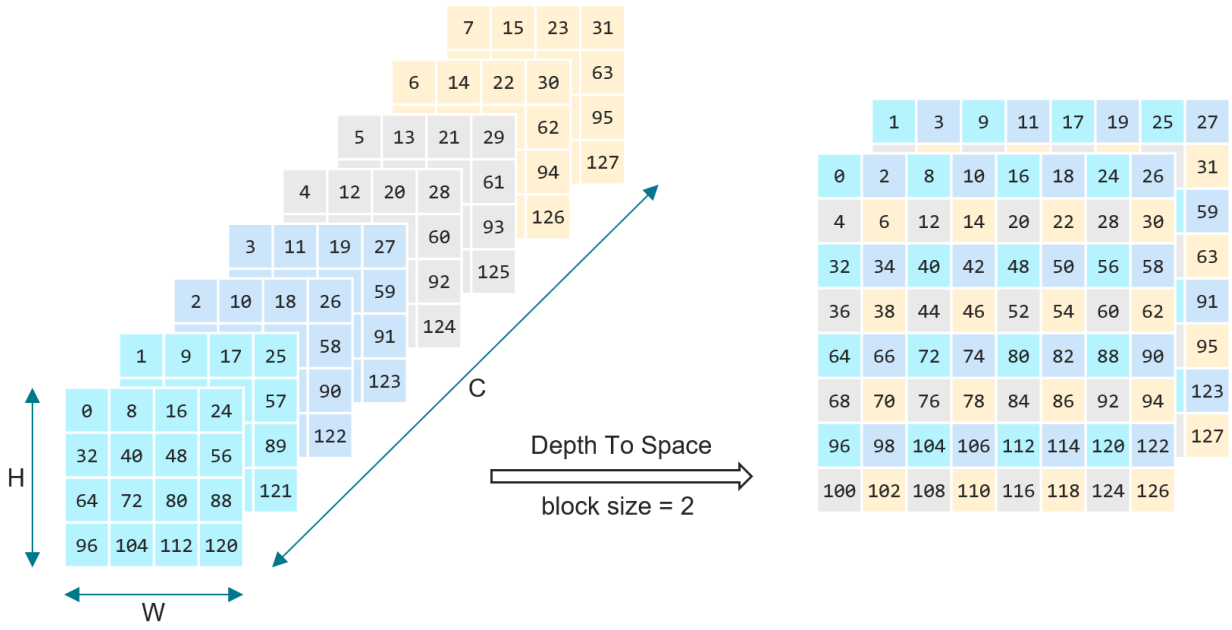

Figure 3-3 Depth to Space Conversion for 4x4x8 Input with Block Size of 2

Given an input cube of shape HxWxC and a `block_size` of K, this kernel gives an output cube of dimensions HKxWKxC/K². The specified output shape, that is, `out_height/width/channels`, must therefore equal HK, WK, and C/K², respectively.

Since the elements collected from one dimension must be spread across two, the input depth dimension C (that is, `input_channels`) must be divisible by K² (that is, `block_size`²).

Precision

Type	Description
8_8	8-bit input, 8-bit output

Prototype

```
WORD32 xa_nn_depth_to_space_8_8
(pWORD8 __restrict__ p_out,  const WORD8 *__restrict__ p_inp,
 WORD32 input_height, WORD32 input_width, WORD32 input_channels,
 WORD32 block_size,
 WORD32 out_height,   WORD32 out_width,   WORD32 out_channels,
 WORD32 inp_data_format, WORD32 out_data_format);
```

Arguments

Type	Name	Size	Description
Input			

const WORD8 *	p_inp	input_height* input_width* input_channels	Input cube data
WORD32	input_height		Input cube height
WORD32	input_width		Input cube width
WORD32	input_channels		Input cube channels
WORD32	block_size		Spatial dimension block size
WORD32	out_height		Output cube height
WORD32	out_width		Output cube width
WORD32	out_channels		Output cube channels
WORD32	inp_data_format		Input data format
WORD32	out_data_format		Output data format
Output			
WORD8 *	p_out	output_height* output_width* output_channels	Output cube data

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_inp, p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Should not overlap
input_height	Must be greater than 0
input_width	Must be greater than 0
input_channels	Must be greater than 0 and divisible by $block\_size^2$
block_size	Must be greater than 0
out_height	Must be input_height*block_size
out_width	Must be input_width*block_size
out_channels	Must be $input\_channels/(block\_size^2)$
inp_data_format	Must be 0 (NHWC)
out_data_format	Must be 0 (NHWC)

3.8.2 Space to Depth Kernels

Description

The Space to Depth kernels convert the spatial dimension of an input cube into the depth dimensions of an output cube controlled by a block size parameter.

These kernels perform the opposite operation of depth_to_space kernels, which is illustrated in Figure 3-4.

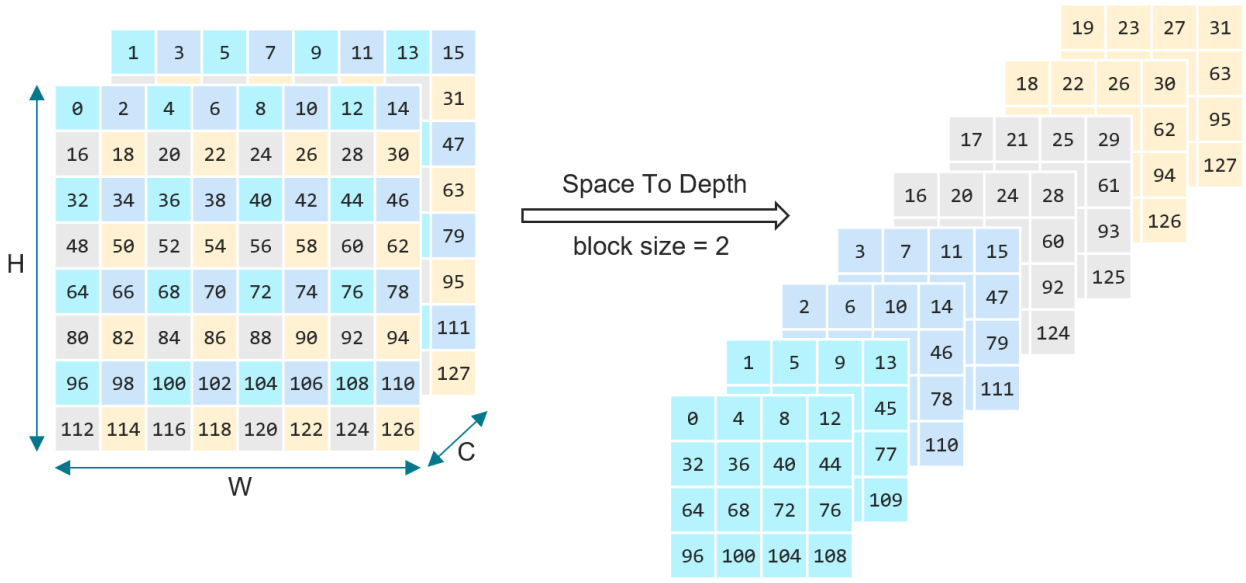

Figure 3-4 Space to Depth Conversion for a 8x8x2 Input with a Block Size of 2

Given an input of shape HxWxC with a `block_size` of K, this kernel collects KxKxC elements from the input cube and serializes it into CK^2 elements across the depth dimension of the output, resulting in an output of shape (H/K)x(W/K)x(CK^2).

The output shape specified i.e `out_height/width/channels` must equal H/K, W/K, and CK^2 respectively.

Because the elements collected from the input 2D spatial dimension must be serialized into one output depth dimension, `output_channels` specified must equal `input_channels*block_size`^{2}.

Precision

Type	Description
8_8	8-bit input, 8-bit output

Prototype

```
WORD32 xa_nn_space_to_depth_8_8
(pWORD8 __restrict__ p_out,  const WORD8 *__restrict__ p_inp,
 WORD32 input_height, WORD32 input_width, WORD32 input_channels,
 WORD32 block_size,
 WORD32 out_height,   WORD32 out_width,   WORD32 out_channels,
 WORD32 inp_data_format, WORD32 out_data_format);
```

Arguments

Type	Name	Size	Description
Input			

const WORD8 *	p_inp	input_height* input_width* input_channels	Input cube data
WORD32	input_height		Input cube height
WORD32	input_width		Input cube width
WORD32	input_channels		Input cube channels
WORD32	block_size		Spatial dimension block size
WORD32	out_height		Output cube height
WORD32	out_width		Output cube width
WORD32	out_channels		Output cube channels
WORD32	inp_data_format		Input data format
WORD32	out_data_format		Output data format
Output			
WORD8 *	p_out	output_height* output_width* output_channels	Output cube data

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_inp, p_out	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Should not overlap
input_height	Must be greater than 0 and divisible by block_size
input_width	Must be greater than 0 and divisible by block_size
input_channels	Must be greater than 0
block_size	Must be greater than 0
out_height	Must be input_height/block_size
out_width	Must be input_width/block_size
out_channels	Must be input_channels*(block_size^2)
inp_data_format	Must be 0 (NHWC)
out_data_format	Must be 0 (NHWC)

3.8.3 Pad Kernels

Description

The Pad kernels pad input with a given pad_value according to the values specified in p_pad_values. p_pad_values is an integer array with size (2 * input_dimensions), giving a pair of values for each input dimension. For each dimension of input, p_pad_values contains a pair of values which indicate how many values to add before the contents of input in that dimension and how many values to add after the contents of input in that dimension. This kernel is based on Pad and PadV2 operators in TFLM.

Input dimensions must be less than or equal to 4. 1/2/3-dimensional input is scaled up to 4D. The output dimension must be equal to the input dimension. Size of `p_pad_values` must be exactly (2 * input_dimensions). The value to be padded can be given through `pad_value`.

The naming convention used for the pad kernel is as follows:

`xa_nn_pad_[p]`

Where [p] = `[input_precision]_[out_precision]`

Precision

Type	Description
`8_8`	Signed 8-bit input, signed 8-bit output
`16_16`	Signed 16-bit input, signed 16-bit output
`32_32`	Signed 32-bit input, signed 32-bit output

Algorithm

If

ob = ib + p_pad_values[0] ; ib = [0, p_inp_shape[0]-1]
oh = ih + p_pad_values[2]; ih = [0, p_inp_shape[1]-1]
ow = iw + p_pad_values[4]; iw = [0, p_inp_shape[2]-1]
od = id + p_pad_values[6]; id = [0, p_inp_shape[3]-1]

$$Output_{ob,oh,ow,od} = Input_{ib,ih,iw,id}$$

else

$$Output_{ob,oh,ow,od} = pad\text{-}value$$

The shape of output after padding is:

for D=0:(`num_inp_dims`-1)

$$p\text{-}out\text{-}shape[D] = p\text{-}pad\text{-}values[2 * D] + p\text{-}inp\text{-}shape[D] + p\text{-}pad\text{-}values[2 * D + 1]$$

Prototype

```
WORD32 xa_nn_pad_8_8
(WORD8 *__restrict__ p_out, const WORD32 *const p_out_shape,
 const WORD8 *__restrict__ p_inp, const WORD32 *const p_inp_shape,
 const WORD32 *__restrict__ p_pad_values, const WORD32 *const p_pad_shape,
 WORD32 num_out_dims, WORD32 num_inp_dims, WORD32 num_pad_dims,
 WORD32 pad_value);
WORD32 xa_nn_pad_16_16
(WORD16 *__restrict__ p_out, const WORD32 *const p_out_shape,
 const WORD16 *__restrict__ p_inp, const WORD32 *const p_inp_shape,
 const WORD32 *__restrict__ p_pad_values, const WORD32 *const p_pad_shape,
```

```
 WORD32 num_out_dims, WORD32 num_inp_dims, WORD32 num_pad_dims,
 WORD32 pad_value);
WORD32 xa_nn_pad_32_32
(WORD32 *__restrict__p_out,  const WORD32 *const p_out_shape,
 const WORD32 *__restrict__ p_inp, const WORD32 *const p_inp_shape,
 const WORD32 * _restrict__ p_pad_values, const WORD32 *const p_pad_shape,
 WORD32 num_out_dims, WORD32 num_inp_dims, WORD32 num_pad_dims,
 WORD32 pad_value);
```

Arguments

Type	Name	Size	Description
Input			
const WORD32 *const	p_out_shape	num_out_dims	Shape of output
const WORD8 *, const WORD16 * const WORD32 *	p_inp	$\prod_{i=0}^{i=num\_inp\_dims-1} p\_inp\_shape[i]$	Input (set of cubes)
const WORD32 *const	p_inp_shape	num_inp_dims	Shape of input
const WORD32 *	p_pad_values	$\prod_{i=0}^{i=num\_pad\_dims-1} p\_pad\_shape[i]$	Pair of values (corresponds to before pad value and after pad value) for each input dimension
const WORD32 *const	p_pad_shape	num_pad_dims	Shape of pad_values
WORD32	num_out_dims		Number of output dimensions
WORD32	num_inp_dims		Number of input dimensions
WORD32	num_pad_dims		Number of pad dimensions
WORD32	pad_value		Value for padding
Output			
WORD8 *, WORD16 *, WORD32 *	p_out	$\prod_{i=0}^{i=num\_out\_dims-1} p\_out\_shape[i]$	Output (set of cubes)

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_out, p_inp	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Should not overlap
p_out_shape, p_inp_shape, p_pad_shape	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap
	All elements must be greater than zero
p_pad_values	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements must be greater than or equal to zero
	Pair of values for each input dimension

num_out_dims	Must be in range [1, 4]
num_inp_dims	Must be in range [1, 4]
num_pad_dims	Must be in range [1, 4]
pad_value	Must be in range [-128, 127]

3.8.4 Batch to Space Kernels

Description

The Batch to Space kernels perform batch to space conversion on a set of input cube `in (input_batch x input_height x input_width x input_depth)` and outputs a set of output cubes `out` of dimension `(out_batch x out_height x out_width x out_depth)`. These kernels are based on BATCH_TO_SPACE_ND operator in TFLM[3].

Input can be 4-dimensional (dimensions are in order – batch, height, width and depth) or 3 dimensional (for 3-dimensional input width is assumed to be 1), output is always 4-dimensional. The conversion is determined by parameters `block_sizes (num_inp_dims – 2)` which determine conversion of a set of vectors in input `(input_batch x input_depth)` to a set of cubes `(out_batch x block_size_height x block_size_width x out_depth)` (`out_depth` must be equal to `input_depth`), this conversion is repeated over all (`input_height x input_width`) sets of vectors in input. Additionally, some parts of output in height and width dimensions can be cropped by using `crop_sizes`.

For 4-dimensional input, the number of `block_sizes` are 2 (in_order - `block_size_height`, `block_size_width`), for 3-dimensional input only `block_size_height` is used and `block_size_width` is ignored.

For 4-dimensional input, the number of `crop_sizes` are 4 (in order – `crop_top`, `crop_bottom`, `crop_left`, `crop_right`), `crop_top` and `crop_left` are used for 4-dimensional input, and only `crop_top` is used for 3-dimensional input.

The naming convention used for the batch_to_space_nd kernels is as follows:

`xa_nn_batch_to_space_nd_[p]`

Where [p] = `[input_precision]_[out_precision]`

Precision

Type	Description
8_8	Signed 8-bit input, signed 8-bit output

Algorithm

$$out_{ob,oh,ow,d} = in_{ib,ih,iw,d}$$

$$ob = ib \,\%\, out\text{-}batch$$

$$oh = ih * block\text{-}size\text{-}height - \left(\frac{ib}{out\text{-}batch}\right) / block\text{-}size\text{-}width - crop\text{-}left$$

$$ow = iw * block\text{-}size\text{-}width - \left(\frac{ib}{out\text{-}batch}\right) \% \ block\text{-}size\text{-}width - crop\text{-}top$$

% represents mod operator in C.

/ represents integer division in C.

For visualization of batch to space conversion, see Figure 3-5.

Prototype

```
WORD32 xa_nn_batch_to_space_nd_8_8
(WORD8 *__restrict__ p_out, const WORD32 *const p_out_shape,
 const WORD8 *__restrict__ p_inp, const WORD32 *const p_inp_shape,
 const WORD32 *const p_block_sizes, const WORD32 *const p_crop_sizes,
 WORD32  num_out_dims, WORD32  num_inp_dims);
```

Arguments

Type	Name	Size	Description
Input			
const WORD32 *const	p_out_shape	num_out_dims	Shape of output
const WORD8 *	p_inp	$\prod_{i=0}^{i=num\_inp\_dims-1} p\text{-}inp\text{-}shape[i]$	Input (set of cubes)
const WORD32 *const	p_inp_shape	num_inp_dims	Shape of input
const WORD32 *const	p_block_sizes	num_inp_dims - 2	Block sizes for spatial dimension.
const WORD32 *const	p_crop_sizes	2*(num_inp_dims - 2)	Crop sizes for cropping output
WORD32	num_out_dims		Number of output dimensions
WORD32	num_inp_dims		Number of input dimensions
Output			
WORD8 *	p_out	$\prod_{i=0}^{i=num\_out\_dims-1} p\text{-}out\text{-}shape[i]$	Output (set of cubes)

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_out, p_inp	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Should not overlap
p_out_shape, p_inp_shape	Aligned on 4-byte boundary
	Cannot be NULL

	Should not overlap
	All elements must be greater than zero
	p_out_shape[num_out_dims – 1] == p_inp_shape[num_inp_dims – 1] (depth for input and output must be equal.
p_block_sizes	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements must be greater than zero
	p_inp_shape[0] == p_out_shape[0]*p_block_sizes[0]*p_block_sizes[1][9]
p_crop_sizes	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements must be greater than or equal to zero
num_out_dims	Must be equal to 4
num_inp_dims	Must be in range {3, 4}

[9] This restriction is for num_inp_dims 4, if num_inp_dims is 3, it becomes p_inp_shape[0] == p_out_shape[0]*p_block_size[0]

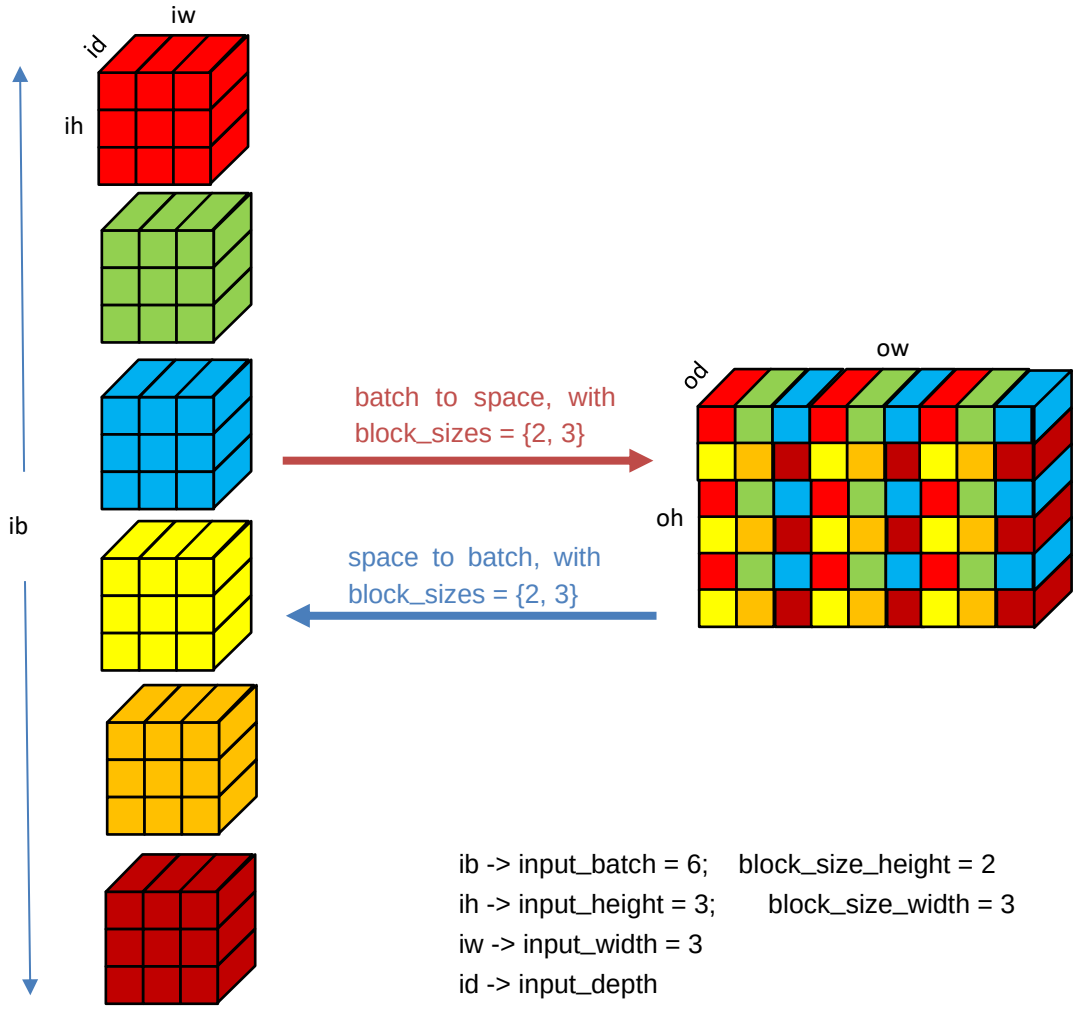

Figure 3-5 batch_to_space and space to batch Conversion

For simplicity, crop_sizes and pad_sizes are assumed to be 0.

3.8.5 Space to Batch Kernels

Description

The Space to Batch kernels perform space to batch conversion on a set of input cubes in `(input_batch x input_height x input_width x input_depth)` and outputs a set of output cubes `out` of dimension `(out_batch x out_height x out_width x out_depth)`. These kernels are based on the SPACE_TO_BATCH_ND operator in TensorFlow Lite Micro[3].

Input can be 4-dimensional (dimensions are in order – batch, height, width and depth) or 3-dimensional (for 3-dimensional input width is assumed to be 1), output must have the same number of dimensions as input. The conversion is determined by parameters `block_sizes (num_inp_dims - 2)` which determine conversion of a set of cubes in input `(input_batch x block_size_height x block_size_width x input_depth)` to a set of vectors `(out_batch x out_depth)` (`out_depth` must be equal to `input_depth`), this conversion is repeated over all of input. Additionally, output can be padded in height and width dimensions according to `pad_sizes`.

For 4-dimensional input, the number of `block_sizes` are 2 (in_order - `block_size_height, block_size_width`), for 3-dimensional input only `block_size_height` is used and `block_size_width` is ignored.

For 4-dimensional input, number of `pad_sizes` are 4 (in order – `pad_top, pad_bottom, pad_left, pad_right`), `pad_top,` and `pad_left` are used for 4-dimensional input, and only `pad_top` is used for 3-dimensional input.

The value to be filled in padding regions can be specified by `pad_value`.

The naming convention used for the space_to_batch_nd kernels is as follows:

`xa_nn_batch_to_space_nd_[p]`

Where [p] = `[input_precision]_[out_precision]`

Precision

Type	Description
`8_8`	Signed 8-bit input, signed 8-bit output

Algorithm

$$out_{ob,oh,ow,d} = in_{ib,ih,iw,d}$$

$$ib = ob \,\%\, out\text{-}batch$$

$$ih = oh * block\text{-}size\text{-}height - \left(\frac{ob}{input\text{-}batch}\right) / block\text{-}size\text{-}width - crop\text{-}left$$

$$iw = ow * block\text{-}size\text{-}width - \left(\frac{ob}{input\text{-}batch}\right) \% \, block\text{-}size\text{-}width - crop\text{-}top$$

% represents mod operator in C.

/ represents integer division in C.

Refer to Figure 3-5 for visualization of space to batch conversion.

Prototype

```
WORD32 xa_nn_space_to_batch_nd_8_8
(WORD8 *__restrict__ p_out, const WORD32 *const p_out_shape,
 const WORD8 *__restrict__ p_inp, const WORD32 *const p_inp_shape,
 const WORD32 *const p_block_sizes, const WORD32 *const p_pad_sizes,
 WORD32 num_out_dims, WORD32 num_inp_dims
 WORD32 pad_value);
```

Arguments

Type	Name	Size	Description
Input			
const WORD32 *const	p_out_shape	num_out_dims	Shape of output
const WORD8 *	p_inp	$\prod_{i=0}^{i=num\_inp\_dims-1} p\text{-}inp\text{-}shape[i]$	Input (set of cubes)
const WORD32 *const	p_inp_shape	num_inp_dims	Shape of input
const WORD32 *const	p_block_sizes	num_inp_dims - 2	Block sizes for spatial dimension.
const WORD32 *const	p_pad_sizes	2*(num_inp_dims - 2)	Crop sizes for cropping output
WORD32	num_out_dims		Number of output dimensions
WORD32	num_inp_dims		Number of input dimensions
WORD32	pad_value		Value for padding
Output			
WORD8 *	p_out	$\prod_{i=0}^{i=num\_out\_dims-1} p\text{-}out\text{-}shape[i]$	Output (set of cubes)

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_out, p_inp	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Should not overlap
p_out_shape, p_inp_shape	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap
	All elements must be greater than zero

Arguments	Restrictions
	p_out_shape[num_out_dims – 1] == p_inp_shape[num_inp_dims – 1] (depth for input and output must be equal.
p_block_sizes	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements must be greater than zero
	p_out_shape[0] == p_inp_shape[0]*p_block_sizes[0]*p_block_sizes[1][10]
p_pad_sizes	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements must be greater than or equal to zero
num_out_dims	Must be in range {3, 4}
num_inp_dims	Must be in range {3, 4}
pad_value	Must be in range [-128, 127]

3.8.6 Strided Slice

Description

The Strided Slice kernels slice the given input based on the start ,stop, and stride parameters. It begins at the location specified by the start parameter and picks elements according to stride value untill it reaches stop point in that dimension. Input dimensions must be less than or equal to 4. 1/2/3/4 -dimensional input can be scaled up to 5D. The stride value can be negative, which represents the slice in backward direction. This kernel is based on Strided Slice operator in TFLM.

Precision

Type	Description
8_8	Signed 8-bit input, signed 8-bit output
16_16	Signed 16-bit input, signed 16-bit output
32_32	Signed 32-bit input, signed 32-bit output

Algorithm

```
for I = start_0 * input_dim_1 : strides_0 * input_dim_1 : ((stop_0 * input_dim_1)-offset_0)
 for J = (I + start_1) * input_dim_2 : strides_1 * input_dim_2 : (((I + stop_1) * input_dim_2)-offset_1)
  for K = (J + start_2) * input_dim_3 : strides_2 * input_dim_3 : (((J + stop_2) * input_dim_3)-offset_2)
   for L = (K + start_3) * input_dim_4 : strides_3 * input_dim_4 : (((K + stop_3) * input_dim_4)-offset_3)
    for M = L + start_4 : strides_4 : ((L + stop_4)-offset_4)
     p_out++ = p_inp[M+1];
    end
   end
```

[10] This restriction is for num_inp_dims 4, if num_inp_dims is 3, it becomes p_out_shape[0] == p_inp_shape[0]*p_block_size[0]

```
  end
 end
end
```

where, offset_x = ((stride_x)<0) ? -1 : 1; x = {0,1,2,3,4}

Prototype

```
WORD32 xa_nn_strided_slice_int16(WORD16 * __restrict__ p_out, const   WORD16 * __restrict__
p_inp,
WORD32 start_0, WORD32 stop_0, WORD32 start_1, WORD32 stop_1,
WORD32 start_2, WORD32 stop_2, WORD32 start_3, WORD32 stop_3,
WORD32 start_4, WORD32 stop_4, WORD32 stride_0, WORD32 stride_1,
WORD32 stride_2, WORD32 stride_3, WORD32 stride_4,
WORD32 dims_1, WORD32 dims_2,  WORD32 dims_3, WORD32 dims_4);
WORD32 xa_nn_strided_slice_int8
(WORD8 * __restrict__ p_out, const   WORD8 * __restrict__ p_inp,
WORD32 start_0, WORD32 stop_0, WORD32 start_1, WORD32 stop_1,
WORD32 start_2, WORD32 stop_2, WORD32 start_3, WORD32 stop_3,
WORD32 start_4, WORD32 stop_4, WORD32 stride_0, WORD32 stride_1,
WORD32 stride_2, WORD32 stride_3, WORD32 stride_4,
WORD32 dims_1, WORD32 dims_2,  WORD32 dims_3, WORD32 dims_4);
WORD32 xa_nn_strided_slice_int32
(WORD32 * __restrict__ p_out, const   WORD32 *_restrict__ p_inp,
WORD32 start_0, WORD32 stop_0, WORD32 start_1, WORD32 stop_1,
WORD32 start_2, WORD32 stop_2, WORD32 start_3, WORD32 stop_3,
WORD32 start_4, WORD32 stop_4, WORD32 stride_0, WORD32 stride_1,
WORD32 stride_2, WORD32 stride_3, WORD32 stride_4, WORD32 dims_1,
WORD32 dims_2, WORD32 dims_3, WORD32 dims_4);
```

Arguments

Type	Name	Size	Description
Input			
const WORD16 *, const WORD8 *, const WORD32 *	p_inp		Input vector
WORD32	start_0		begin point for dimension 0
WORD32	start_1		begin point for dimension 1
WORD32	start_2		begin point for dimension 2
WORD32	start_3		begin point for dimension 3
WORD32	start_4		begin point for dimension 4
WORD32	stop_0		end point for dimension 0;
WORD32	stop_1		end point for dimension 1
WORD32	stop_2		end point for dimension 2
WORD32	stop_3		end point for dimension 3

Type	Name	Size	Description
WORD32	stop_4		end point for dimension 4
WORD32	stride_0		stride for dimension 0
WORD32	stride_1		stride for dimension 1
WORD32	stride_2		stride for dimension 2
WORD32	stride_3		stride for dimension 3
WORD32	stride_4		stride for dimension 4
WORD32	dims_1		dimension 1
WORD32	dims_2		dimension 2
WORD32	dims_3		dimension 3
WORD32	dims_4		dimension 4
Output			
WORD16 *, WORD8 *, WORD32 *	p_out	ceil(((stop_0 - start_0)/stride_0))) * ceil(((stop_1 - start_1)/stride_1))) * ceil(((stop_2 - start_2)/stride_2))) * ceil(((stop_3 - start_3)/stride_3))) * ceil(((stop_4 - start_4)/stride_4)))	Output vector

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp, p_out	Should not overlap Cannot be NULL Aligned on size of element boundary
dims_1, dims_2, dims_3, dims_4	Greater than Zero
stride_0,	Equal to one (As we are only supporting 4D input)
stride_1,stride_2, stride_3, stride_4	Not Equal to Zero
start_0	Equal to Zero (As we are only supporting 4D input)
stop_0	Equal to One (As we are only supporting 4D input)
start_1, stop_1	if stride_1 > 0 then {0,..., dims_1} else {-1,..., dims_1 - 1}
start_2, stop_2	if stride_2 > 0 then {0,..., dims_2} else {-1,..., dims_2 - 1}
start_3, stop_3	if stride_3 > 0 then {0,..., dims_3} else {-1,..., dims_3 - 1}
start_4, stop_4	if stride_4 > 0 then {0,..., dims_4} else {-1,..., dims_4 - 1}

3.8.7 Transpose

Description

This kernel performs a transpose operation on an N-dimensional input tensor (up to 5D) as per the combination of dimensions specified in the permute vector. The output tensor's dimension `i` will correspond to the input dimension `permute_vec[i]`. For a 2D tensor, this operation performs a regular matrix transpose.

The number of input dimensions must be less than or equal to 5. 1/2/3/4-dimensional input is scaled up to 5D. The output shape should be conformant with respect to the values in the permute vector.

The naming convention used for the transpose kernel is as follows:

`xa_nn_transpose_[p]`

Where, [p] = `[input_precision]_[out_precision]`

Precision

Type	Description

8_8	Signed 8-bit input, signed 8-bit output.
16_16	Signed 16-bit input, signed 16-bit output.
32_32	Signed 32-bit input, signed 32-bit output

Algorithm

For input P and output Q,
size(Q) = [dim3,dim2,dim4,dim0,dim1] for size(P) = [dim0,dim1,dim2,dim3,dim4] if permute_vec = [3,2,4,0,1]
For point *p* in P, and point *q* in Q,
q(y,x,z,v,w) = *p*(v,w,x,y,z)
where,

v = 0....dim0 - 1
w = 0....dim1 - 1
x = 0....dim2 - 1
y = 0....dim3 - 1
z = 0....dim4 - 1

Prototype

```
WORD32 xa_nn_transpose_8_8
(WORD8 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const WORD8 * __restrict__ p_inp,
 const WORD32 *const p_inp_shape,
 const WORD32 * __restrict__ p_permute_vec,
 WORD32 num_out_dims,
 WORD32 num_inp_dims);

WORD32 xa_nn_transpose_16_16
(WORD16 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const WORD16 * __restrict__ p_inp,
 const WORD32 *const p_inp_shape,
 const WORD32 * __restrict__ p_permute_vec,
 WORD32 num_out_dims,
 WORD32 num_inp_dims);

WORD32 xa_nn_transpose_32_32
(WORD32 * __restrict__ p_out,
 const WORD32 *const p_out_shape,
 const WORD32 * __restrict__ p_inp,
 const WORD32 *const p_inp_shape,
 const WORD32 * __restrict__ p_permute_vec,
 WORD32 num_out_dims,
 WORD32 num_inp_dims);
```

Arguments

Type	Name	Size	Description
Input			
const WORD32 *	p_out_shape	num_out_dims	Shape of output
const WORD8 *, const WOR116 *, const WORD32 *	p_inp	$\prod_{i=0}^{i=num\_inp\_dims-1} p\_inp\_shape[i]$	Input (set of cubes)

Type	Name	Size	Description
const WORD32 *	p_inp_shape	num_inp_dims	Shape of input
const WORD32 *	p_permute_vec	num_inp_dims	Permute Vector
WORD32	num_out_dims		Number of output dimensions
WORD32	num_inp_dims		Number of input dimensions
Output			
WORD8 *, WORD16 *, const WORD32 *	p_out	$\prod_{i=0}^{i=num\text{-}out\text{-}dims-1} p\text{-}out\text{-}shape[i]$	Output (set of cubes)

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_out, p_inp	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Must not overlap
p_out_shape, p_inp_shape	Aligned on a 4-byte boundary
	Cannot be NULL
	Must not overlap
	All elements must be greater than zero
p_out_shape	p_out_shape[i] = p_inp_shape[p_permute_vec[i]]
p_permute_vec	Cannot be NULL
num_out_dims	Must be in the range [1, 5] and should be equal to num_inp_dims.
num_inp_dims	Must be in the range [1, 5] and should be equal to num_out_dims.

3.8.8 Resize Bilinear

Description

The Resize Bilinear kernel resize a 4D input (input_batch x input_height x input_width x input_channels) to a 4D output of size (out_batch x out_height x out_width x out_channels). Batch and depth dimensions remains the same between input and output. The height and width dimensions are resized using the linear interpolation, hence the name bilinear.

Precision

Type	Description

8_8	Signed 8-bit input, signed 8-bit output.

Algorithm

out(b, h, w, c) = (1 – (scaled_h – h0)) * (1 – (scaled_w – w0)) * inp(b, h0, w0, c)
+ (scaled_h – h0) * (1 – (scaled_w – w0)) * inp(b, h1, w0, c)
+ (1 – (scaled_h – h0)) * (scaled_w – w0) * inp(b, h0, w1, c)
+ (scaled_h – h0) * (scaled_w – w0) * inp(b, h1, w1, c)

scaled_h = h * (input_height / out_height) in q10 format in 32-bit datatype
h0 = floor(scaled_h)
h1 = ceil(scaled_h)
scaled_w = w * (input_width / out_width) in q10 format in 32-bit datatype
w0 = floor(scaled_w)
w1 = ceil(scaled_w)

b = 0 to out_batch – 1
h = 0 to out_height – 1
w = 0 to out_width - 1
c = 0 to out_channels - 1

Prototype

```
WORD32 xa_nn_resize_bilinear_8_8
  (pWORD8 __restrict__ p_out,   const WORD8 *__restrict__ p_inp,
   WORD32  input_batch,         WORD32  input_height,
   WORD32  input_width,         WORD32  input_channels,
   WORD32  out_batch,           WORD32  out_height,
   WORD32  out_width,           WORD32  out_channels,
   WORD32  height_scale_10,     WORD32  width_scale_10,
   WORD32  height_shift,        WORD32  width_shift)
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_inp	input_batch x input_height x input_width x input_channels	Input
WORD32	input_batch		Number of input batches
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of Input channels
WORD32	out_batch		Number of output batches
WORD32	out_height		Output height
WORD32	out_width		Output width
WORD32	out_channels		Number of output channels
WORD32	height_scale_10		
WORD32	width_scale_10		
WORD32	height_shift		
WORD32	width_shift		
Output			

Type	Name	Size	Description
WORD8 *	p_out	out_batch x out_height x out_width x out_channels	Output

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_out, p_inp	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Must not overlap
input_height, input_width, input_batch, input_channels, output_height, output_width	Greater than 0
out_channels	Equal to input_channels
out_batch	Equal to Input_batch

3.8.9 Resize Nearest Neighbor

Description

Resize nearest neighbor kernel resizes a 4D input (input_batch x input_height x input_width x input_channels) to a 4D output of size (out_batch x out_height x out_width x out_channels). Batch and depth dimensions remain the same between input and output. Resize is done in height and width dimensions using nearest neighbor interpolation.

Precision

Type	Description
8_8	Signed 8-bit input, signed 8-bit output.

Algorithm

out(b, h, w, c) = inp(b, h0, w0, c)

offset = half_pixel_centers? 0.5f: 0.0f;
scale_h = (align_corners && out_height > 1)? (input_height - 1) / (out_height - 1): (input_height / out_height)
h0 = (align_corners && out_height > 1)? round ((h + offset) * scale_h): floor ((h + offset) * scale_h)
scale_w = (align_corners && out_width > 1)? (input_width - 1) / (out_width - 1): (input_width / out_width)
w0 = (align_corners && out_width > 1)? round ((w + offset) * scale_w): floor ((w + offset) * scale_w)

b = 0 to out_batch – 1
h = 0 to out_height – 1
w = 0 to out_width - 1
c = 0 to out_channels - 1

Prototype

```
WORD32 xa_nn_resize_nearest_neighbour_8_8
  (pWORD8 __restrict__ p_out,   const WORD8 *__restrict__ p_inp
   ,WORD32  input_batch,        WORD32  input_height
   ,WORD32  input_width,        WORD32  input_channels
   ,WORD32  out_batch,          WORD32  out_height
   ,WORD32  out_width,          WORD32  out_channels
   ,FLOAT32 height_scale,       FLOAT32 width_scale
   ,FLOAT32 height_offset,      FLOAT32 width_offset
   ,WORD32  align_corners);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_inp		Input
WORD32	input_batch		Number of input batches
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of Input channels
WORD32	out_batch		Number of output batches
WORD32	out_height		Output height
WORD32	out_width		Output width
WORD32	out_channels		Number of output channels
WORD32	height_scale		
WORD32	width_scale		
WORD32	height_offset		
WORD32	width_offset		
Output			
WORD8 *	p_out		Output

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_out, p_inp	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Must not overlap
input_height, input_width, input_batch, input_channels,	Greater than 0

output_height, output_width	
out_channels	Equal to input_channels
out_batch	Equal to Input_batch

3.8.10 Concat

Description

The concat kernel concatenates the given inputs into a single output along the dimension specified by the axis parameter. It can concatenate upto 6-dimensional inputs and maximum of 10 inputs. For example, 2 inputs of shapes (1, 8, 128, 32) and (1, 16, 128, 32) are concatenated into an output of shape (1, 24, 128, 32) with axis as '1'.

Precision

Type	Description
8_8	8-bit input, 8-bit output
32_32	32-bit input, 32-bit output

Algorithm

i = 0 to num_inp - 1
inp_dims[num_inp][num_dims]
out_dim[num_dims]

For axis = 2
out(d0, d1, sum(inp_dims[0][2] to inp_dims[i-1][2]) + d2, d3, d4, d5) = inp[i](d0, d1, d2, d3, d4, d5)

d0 = 0 to inp_dims[i][0]
d1 = 0 to inp_dims[i][1]
d2 = 0 to inp_dims[i][2]
d3 = 0 to inp_dims[i][3]
d4 = 0 to inp_dims[i][4]
d5 = 0 to inp_dims[i][5]

if j != axis
 inp_dims[i][j] should be equal to out_dim[j]

if j == axis
 out_dim[j] == sum(inp_dims[0][j] ... inp_dims[num_inp - 1][j]

Prototype

```
WORD32 xa_nn_concat_8_8
  (WORD8 * __restrict__ p_out,  const WORD32 *const p_out_shape
   ,const WORD8 **p_inps,       const WORD32 *const *pp_inps_shape
   ,WORD32 num_out_dims,        WORD32 num_inp
   ,WORD32 num_inp_dims,        WORD32 axis);
```

```
WORD32 xa_nn_concat_32_32
(WORD32 * __restrict__ p_out, const WORD32 *const p_out_shape,
 const WORD32 **pp_inps,      const WORD32 *const *pp_inps_shape,
 WORD32 num_out_dims,         WORD32 num_inp,
 WORD32 num_inp_dims,         WORD32 axis);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 ** const WORD32 **	pp_inps		Inputs
const WORD32 *	p_out_shape		Shape of output
const WORD32 **	pp_inps_shape		Shape of Inputs
WORD32	num_out_dims		Number of output dimensions
WORD32	num_inp		Number of Inputs
WORD32	num_inp_dims		Number of Input pointers
WORD32	axis		Dimension to concat
Output			
WORD8 * WORD32 *	p_out		Output

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_out, pp_inps, p_out_shape, pp_inps_shape	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Must not overlap
num_out_dims	Greater than 0 and Less than equal to 6
num_inp	Greater than 0 and Less than equal to 10
num_inp_dims	Equal to num_out_dims
Axis	Less than num_out_dims and Greater than or equal to -num_out_dims

3.8.11 Split_V

Description

The split kernel separates the given input tensor into multiple output tensors along the dimension specified by the axis parameter. It can split up to 6-dimensional inputs, and a maximum of 10 outputs are supported. For example, one input of shape (1, 24, 128, 32) is split into outputs of shapes (1, 8, 128, 32) and (1, 16, 128, 32) with the axis as ‘1’. Input and output shapes should be consistent as per axis.

Precision

Type	Description
8_8	8-bit input, 8-bit output

Algorithm

i = 0 to num_out - 1
inp_dim[num_dims]
out_dims[num_out][num_dims]

For axis = 2
out[i](d0, d1, d2, d3, d4, d5) = inp(d0, d1, sum(out_dims[0][2] to out_dims[i-1][2]) + d2, d3, d4, d5)

d0 = 0 to out_dims[i][0]
d1 = 0 to out_dims[i][1]
d2 = 0 to out_dims[i][2]
d3 = 0 to out_dims[i][3]
d4 = 0 to out_dims[i][4]
d5 = 0 to out_dims[i][5]

if j != axis
 inp_dim[j] should be equal to out_dims[i][j]

if j == axis
 sum(out_dims[0][j] ... out_dims[num_inp - 1][j] = inp_dim[j]

Prototype

```
WORD32 xa_nn_split_v_8_8
(WORD8 ** __restrict__ pp_outs,          const WORD32 *const *pp_outs_shape
 const WORD8 *p_inp                      const WORD32 *const p_inp_shape
 WORD32 num_out                          WORD32 num_out_dims
 WORD32 num_inp_dims                     WORD32 axis)
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	p_inp		Input
const WORD32 **	pp_outs_shape		Shape of outputs
const WORD32 *	p_inp_shape		Shape of Input
WORD32	num_out		Number of outputs
WORD32	num_out_dims		Number of output dimensions
WORD32	num_inp_dims		Number of Input dimensions
WORD32	axis		Dimension to split
Output			
WORD8 **	pp_outs		Outputs

Returns

- 0: no error
- -1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_inp, pp_outs, p_inp_shape, pp_outs_shape	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Must not overlap
num_inp_dims	Greater than 0 and Less than equal to 6
num_out	Greater than 0 and Less than equal to 10
num_out_dims	Equal to num_inp_dims
axis	Less than num_out_dims and Greater than or equal to -num_out_dims

3.8.12 Shuffle

Description

The shuffle kernel performs shuffling of an input vector x over a channel by dividing the channels into a given number of groups and interleaving those group elements to give output vector z.
The shuffle kernel accepts the asym8s input vector and produces the asym8s output vector.

Precision

Type	Description
8_8	8-bit input, 8-bit output

Algorithm

Input: P(input_height, input_width, input_channel)
Output: Q(output_height, output_width, output_channel)
for w→0 to output_height
  for x→0 to output_width
    for y→0 to interleave_group
      for z→0 to (output_channel/interleave_group)
        Q(w,x,z*interleave_group+y)= P(w,x,y*interleave_group+z)

Prototype

```
WORD32 xa_nn_shuffle_3D_8_8
(WORD8 * __restrict__ p_out,  const WORD8 * __restrict__ p_inp,
 WORD32 input_height,         WORD32 input_width,
 WORD32 input_channel,        WORD32 output_height,
```

```
WORD32 output_width,         WORD32 output_channel,
WORD32 interleave_groups);
```

Arguments

Type	Name	Size	Description
Input			
WORD8 *	p_inp		Input
WORD32	input_height		
WORD32	input_width		
WORD32	input_channel		
WORD32	output_height		
WORD32	output_width		
WORD32	output_channel		
WORD32	interleave_groups		Number of groups
Output			
WORD8 *	p_out		Output

Returns

0: no error

-1: error, invalid parameters

Restrictions:

Arguments	Restrictions
p_out, p_inp	Aligned on (size of one element)-byte boundary
	Cannot be NULL
	Must not overlap
input_height, input_width, input_channel, output_height, output_width, output_channel	Greater than 0 input_height & output_height should be same input_width & output_width should be same input_channel & output_channel should be same
interleave_groups	Greater than 0 Less than or equal to output_channel Should be a multiplicative factor of output_channel

3.9 RNN Kernels

3.9.1 LSTM Kernels

Description

These kernels implement unidirection sequence LSTM operator from TFLM. These take 3D input with dimensions n_itr x n_batch x inp_size and produce 3D output with dimensions n_itr x n_batch x out_size. Additionally, the hidden state (or recurrent state) with size n_batch x hidden_size and the cell state with size n_batch x n_cell are taken as input and output, so initial states are read from these and updated in

place. The variant of LSTM implemented has 4 gates (input, forget, cell, and output gate) and doesn't support layer norm, projection, and peephole.

Precision

Type	Description
sym8sxasym8s_16	sym8s weights, asym8s inputs/outputs, 16-bit cell_state

Algorithm

$$i_t = sigmoid(W_i * x_t + U_i * h_{t-1} + b_i)$$
$$f_t = sigmoid(W_f * x_t + U_f * h_{t-1} + b_f)$$
$$cg_t = tanh(W_c * x_t + U_c * h_{t-1} + b_c)$$
$$o_t = sigmoid(W_o * x_t + U_o * h_{t-1} + b_o)$$
$$c_t = f_t . c_{t-1} + i_t . cg_t$$
$$h_t = o_t . \tanh(c_t)$$

* represents matrix multiplication
. represents elementwise multiplication

The above equations are executed n_itr number of times, and the hidden state and cell state are updated in each iteration.

x_t = Input at time instance t (n_batch x inp_size)
h_t = Hidden state at time instance t (n_batch x hidden_size)
c_t = Cell state at time instance t (n_batch x cell_state)
$W_{i/f/c/o}$ = Input FC weight matrices for input/forget/cell/output gate (n_cell x inp_size)
$U_{i/f/c/o}$ = Hidden FC weight matrices for input/forget/cell/output gate (n_cell x n_cell)
$B_{i/f/c/o}$ = Biases for input/forget/cell/output gate (n_cell)
i_t = Input Gate output
f_t = Forget Gate output
cg_t = Cell Gate output
o_t = Output Gate output

Prototype

```
typedef struct _lstm_weights_ptrs
{
  VOID *p_ig_W;
  VOID *p_fg_W;
  VOID *p_cg_W;
  VOID *p_og_W;
  VOID *p_ig_U;
  VOID *p_fg_U;
  VOID *p_cg_U;
  VOID *p_og_U;
} lstm_weights_ptrs;

typedef struct _lstm_bias_ptrs
```

```
{
  VOID *p_ig_W_bias;
  VOID *p_fg_W_bias;
  VOID *p_cg_W_bias;
  VOID *p_og_W_bias;
  VOID *p_ig_U_bias;
  VOID *p_fg_U_bias;
  VOID *p_cg_U_bias;
  VOID *p_og_U_bias;
} lstm_bias_ptrs;

typedef struct _lstm_quant_params
{
  WORD32 ig_W_out_multiplier;
  WORD32 fg_W_out_multiplier;
  WORD32 cg_W_out_multiplier;
  WORD32 og_W_out_multiplier;
  WORD32 ig_U_out_multiplier;
  WORD32 fg_U_out_multiplier;
  WORD32 cg_U_out_multiplier;
  WORD32 og_U_out_multiplier;
  WORD32 ig_W_out_shift;
  WORD32 fg_W_out_shift;
  WORD32 cg_W_out_shift;
  WORD32 og_W_out_shift;
  WORD32 ig_U_out_shift;
  WORD32 fg_U_out_shift;
  WORD32 cg_U_out_shift;
  WORD32 og_U_out_shift;
  WORD16 quantized_cell_clip;
  WORD32 cell_state_scale;
  WORD32 hidden_multiplier;
  WORD32 hidden_shift;
  WORD32 input_zero_bias;
  WORD32 hidden_zero_bias;
} lstm_quant_params;

typedef struct _lstm_flags
{
  WORD32 time_major;
  WORD32 use_cifg;
  WORD32 back;
} lstm_flags;

WORD32 xa_nn_lstm_sym8sxasym8s_16(
  WORD8*  p_out,                      /* out */
  WORD8*  p_hidden_state,             /* inout */
  WORD16* p_cell_state,               /* inout */
  lstm_weights_ptrs *p_lstm_weights,  /* input */
  lstm_bias_ptrs    *p_lstm_biases,   /* input */
  WORD8*  p_inp,                      /* input */
  WORD32 inp_size,
  WORD32 hidden_size,
  WORD32 out_size,
  WORD32 n_batch,
  WORD32 n_itr,
```

```
WORD32 n_cell,
lstm_quant_params *p_lstm_qp,
lstm_flags *p_lstm_flags,
void*  p_scratch);
```

Arguments

Type	Name	Size	Description
Input			
WORD8 *	p_inp	n_itr*n_batch*inp_size	Input
WORD8 *	p_hidden_state	n_batch*out_size	Initial hidden state
WORD16 *	p_cell_state	n_batch*n_cell	Initial cell state
WORD32	inp_size		Length of one input vector
WORD32	hidden_size		Length of one hidden state vector
WORD32	out_size		Length of one output vector
WORD32	n_batch		Number of batches
WORD32	n_itr		Number of time iteration
WORD32	n_cell		Length of one cell state vector
lstm_weighhts_ptrs	p_lstm_weights		Pointer to structure containing pointers to Input and Hidden FC Coefficients
VOID *	p_ig_W, p_fg_W, p_cg_W, p_og_W	n_cell*inp_size	Pointers to Input FC coefficients (ig -> input gate, fg -> forget gate, cg -> cell gate, og -> output gate)
VOID *	p_ig_U, p_fg_U, p_cg_U, p_og_U	n_cell*n_cell	Pointers to Hidden/Recurrent FC coefficients
lstm_bias_ptrs	p_lstm_biases		Pointer to structure containing pointers to Input FC biases
VOID *	p_ig_W_bias, p_fg_W_bias, p_cg_W_bias, p_og_W_bias, p_ig_U_bias, p_fg_U_bias, p_cg_U_bias, p_og_U_bias	n_cell	Pointers to Input and Hidden/Recurrent FC bias vectors
lstm_quant_params	p_lstm_qp		Pointer to structure containing quantization parameters
WORD32	ig_W_out_multiplier, fg_W_out_multiplier, cg_W_out_multiplier, og_W_out_multiplier		Output multipliers for Input FCs
WORD32	ig_U_out_multiplier, fg_U_out_multiplier, cg_U_out_multiplier, og_U_out_multiplier		Output multipliers for Hidden/Recurrent FCs
WORD32	ig_W_out_shift, fg_W_out_shift, cg_W_out_shift, og_W_out_shift		Output shifts for Input FCs
WORD32	ig_U_out_shift, fg_U_out_shift,		Output shifts for Hidden/Recurrent FCs

Type	Name	Size	Description
	cg_U_out_shift, og_U_out_shift		
WORD32	quantized_cell_clip		Quantized Max value for clipping cell_state
WORD32	cell_state_scale		Cell_state scale value
WORD32	hidden_multiplier		Output multiplier for element wise multiplication for calculating hidden_state
WORD32	hidden_shift		Output shift for element wise multiplication for calculating hidden_state
WORD32	hidden_zero_bias		Hidden state zero bias
WORD32	input_zero_bias		Input zero bias
lstm_flags	p_lstm_flags		Pointer to structure containing some flags
WORD32	time_major		Flag for whether Input/Output is in time_major order (i.e.n_itr is the outer most dimension)
WORD32	use_cifg		Flag for whether to use coupled input/forget gate
VOID *	p_scratch	Size returned by xa_nn_lstm_getsize() function	Pointer to scratch
WORD32	back		Flag for direction, 0 -> forward LSTM, 1 -> backward LSTM
Output			
WORD8 *	p_out		
WORD8 *	p_hidden_state	n_batch* out_size	Updated hidden state
WORD16 *	p_cell_state	n_batch* n_cell	Updated cell state

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_out, p_hidden_state, p_cell_state, p_inp	Cannot be NULL
	Aligned on one-element size boundary
p_lstm_weights, p_lstm_biases, p_lstm_qp	Cannot be NULL
p_ig_W, p_fg_W, p_cg_W, p_og_W, p_ig_U, p_fg_U, p_cg_U, p_og_U	Cannot be NULL

p_ig_W_bias, p_fg_W_bias, p_cg_W_bias, p_og_W_bias	Cannot be NULL
	Aligned on one-element size (4-byte for xa_nn_lstm_sym8sxasym8s_16) boundary
p_lstm_qp	All out_shift and hidden_shift values in structure should be within range {-31, …, 31} Input_zero_bias should be within range {-127…128} hidden_zero_bias should be within range {-128…127} cell_state_scale should be within range {-29…1}
quantized_cell_clip	Should be less than or equal to 32767
inp_size, hidden_size, out_size, n_batch, n_cell, n_itr	Greater than 0. hidden_size == out_size == n_cell.
p_lstm_flags	Cannot be NULL
time_major	Can be 0 or 1.
use_cifg	Must be 0
back	Can be 0 or 1.

3.9.2 GRU Kernels

Description

These kernels implement GRU operator. These take 3D input with dimensions n_itr x n_batch x inp_size and produce 3D output with dimensions n_itr x n_batch x out_size. Additionally, the hidden state (or recurrent state) with size n_batch x hidden_size is taken as input and output, so initial state is read from this and updated in place. The variant of GRU implemented is fully gated GRU.

Precision

Type	Description
sym8sxasym8s	sym8s weights, asym8s inputs/outputs

Algorithm

$$z_t = sigmoid(W_z * x_t + U_z * h_{t-1} + b_z)$$
$$r_t = sigmoid(W_r * x_t + U_r * h_{t-1} + b_r)$$
$$h'_t = tanh(W_h * x_t + r_t \,.\, (U_h * h_{t-1}) + b_h)$$
$$h_t = (1 - z_t).\, h_{t-1} + z_t \,.\, h'_t$$

* represents matrix multiplication

. represents elementwise multiplication

The above equations are executed n_itr number of times, and the hidden state is updated in each iteration.

x_t = Input at time instance t (n_batch x inp_size)

h_t = Hidden state at time instance t (n_batch x hidden_size)

$W_{z/r/h}$ = Input FC weight matrices for update gate/reset gate/candidate activation (modulated state) (hidden_size x inp_size)

$U_{z/r/h}$ = Hidden FC weight matrices for update gate/reset gate/candidate activation (modulated state) (hidden_size x hidden_size)

$b_{z/r/h}$ = Biases for update gate/reset gate/candidate activation (modulated state) (hidden_size)

z_t = Update Gate output

r_t = Reset Gate output

h_t' = Candidate hidden state (modulated state)

Prototype

```
typedef struct _gru_weights_ptrs
{
    VOID *p_ug_W;
    VOID *p_rg_W;
    VOID *p_ms_W;
    VOID *p_ug_U;
    VOID *p_rg_U;
    VOID *p_ms_U;
} gru_weights_ptrs;

typedef struct _gru_bias_ptrs
{
    VOID *p_ug_W_bias;
    VOID *p_rg_W_bias;
    VOID *p_ms_W_bias;
    VOID *p_ug_U_bias;
    VOID *p_rg_U_bias;
    VOID *p_ms_U_bias;
} gru_bias_ptrs;

typedef struct _gru_quant_params
{
    WORD32 ug_W_out_multiplier;
    WORD32 rg_W_out_multiplier;
    WORD32 ms_W_out_multiplier;
    WORD32 ug_U_out_multiplier;
    WORD32 rg_U_out_multiplier;
    WORD32 ms_U_out_multiplier;
    WORD32 rg_fcU_out_multiplier;
    WORD32 ug_ms_out_multiplier;
    WORD32 ug_hidden_out_multiplier;
    WORD32 hidden_multiplier;
    WORD32 ug_W_out_shift;
    WORD32 rg_W_out_shift;
    WORD32 ms_W_out_shift;
    WORD32 ug_U_out_shift;
    WORD32 rg_U_out_shift;
    WORD32 ms_U_out_shift;
    WORD32 rg_fcU_out_shift;
    WORD32 ug_ms_out_shift;
    WORD32 ug_hidden_out_shift;
    WORD32 hidden_shift;
    WORD32 hidden_zero_bias;
    WORD32 input_zero_bias;
```

```
} gru_quant_params;

WORD32 xa_nn_gru_getsize(
    WORD32 n_batch,
    WORD32 n_itr,
    WORD32 hidden_size,
    WORD32 hidden_precision);

WORD32 xa_nn_gru_sym8sxasym8s(
    WORD8* p_out,
    const WORD8* p_hidden_state,
    const gru_weights_ptrs *p_gru_weights,
    const gru_bias_ptrs *p_gru_biases,
    const WORD8* p_inp,
    WORD32 inp_size,
    WORD32 hidden_size,
    WORD32 out_size,
    WORD32 n_batch,
    WORD32 n_itr,
    const gru_quant_params *p_gru_qp,
    WORD32 time_major,
    void* p_scratch
);
```

Arguments

Type	Name	Size	Description
Input			
WORD8 *	p_inp	n_itr * n_batch * inp_size	Input
WORD8 *	p_hidden_state	n_batch * hidden_size	Input/Output. Updated hidden state
gru_weights_ptrs	p_gru_weights		Pointer to structure containing pointers to Input and Hidden FC Coefficients
VOID *	p_ug_W, p_rg_W, p_ms_W	hidden_size * inp_size	Pointers to Input FC coefficients (ug -> update gate, rg -> reset gate, ms -> modulated state(candidate hidden state))
VOID *	p_ug_U, p_rg_U, p_ms_U	hidden_size * hidden_size	Pointers to Hidden/Recurrent FC coefficients
gru_bias_ptrs	p_gru_biases		Pointer to structure containing pointers to Input and Hidden FC Biases

Type	Name	Size	Description
VOID *	p_ug_W_bias, p_rg_W_bias, p_ms_W_bias, p_ug_U_bias, p_rg_U_bias, p_ms_U_bias	hidden_size	Pointers to Input and Hidden/Recurrent FC biases
WORD32	inp_size		Length of one input vector
WORD32	hidden_size		Length of one hidden state vector
WORD32	out_size		Length of one output vector
WORD32	n_batch		Number of batches
WORD32	n_itr		Number of time iteration
gru_quant_params	p_gru_qp		Pointer to structure containing pointers to Input and Hidden FC Coefficients
WORD32	ug_W_out_multiplier, rg_W_out_multiplier, ms_W_out_multiplier		Output multipliers for Input FCs
WORD32	ug_U_out_multiplier, rg_U_out_multiplier, ms_U_out_multiplier		Output multipliers for Hidden/Recurrent FCs
WORD32	rg_fcU_out_multiplier, ug_ms_out_multiplier, ug_hidden_out_multiplier, hidden_multiplier		Output multipliers for element wise operations
WORD32	ug_W_out_shift, rg_W_out_shift, ms_W_out_shift		Output shifts for Input FCs
WORD32	ug_U_out_shift, rg_U_out_shift, ms_U_out_shift		Output shifts for Hidden/Recurrent FCs
WORD32	rg_fcU_out_shift, ug_ms_out_shift, ug_hidden_out_shift, hidden_shift		Output shifts for element wise operations
WORD32	hidden_zero_bias, input_zero_bias		Hidden state and Input zero bias
WORD32	time_major		Input and output storage order (whether time/iterations is major dimension or not)
void*	p_scratch	xa_nn_gru_getsize	
Output			
WORD8 *	p_out	n_itr * n_batch* out_size	

Returns

0: no error

-1: error, invalid parameters

Restrictions

Arguments	Restrictions
p_out, p_hidden_state, p_inp	Cannot be NULL
	Aligned on one-element size boundary
p_gru_weights, p_gru_biases, p_gru_qp	Cannot be NULL
p_ug_W, p_rg_W, p_ms_W, p_ug_U, p_rg_U, p_ms_U	Cannot be NULL
p_ug_W_bias, p_rg_W_bias, p_ms_W_bias, p_ug_U_bias, p_rg_U_bias, p_ms_U_bias	Cannot be NULL
	Aligned on one-element size (4-byte for xa_nn_gru_sym8sxasym8s) boundary
p_gru_qp	All out_shift and hidden_shift values in structure should be within range {-31, …, 31} Input_zero_bias should be within range {-127…128} hidden_zero_bias should be within range {-128…127}
inp_size, hidden_size, out_size, n_batch, n_itr	Greater than 0. hidden_size == out_size == n_cell.
ug_W_out_multiplier, rg_W_out_multiplier, ms_W_out_multiplier, ug_U_out_multiplier, rg_U_out_multiplier, ms_U_out_multiplier, rg_fcU_out_multiplier, ug_ms_out_multiplier, ug_hidden_out_multiplier, hidden_multiplier, ug_W_out_shift, rg_W_out_shift, ms_W_out_shift, ug_U_out_shift, rg_U_out_shift, ms_U_out_shift, rg_fcU_out_shift, ug_ms_out_shift, ug_hidden_out_shift, hidden_shift, hidden_zero_bias, input_zero_bias	rg_W_out_shift, ug_W_out_shift, ms_W_out_shift, rg_U_out_shift, ug_U_out_shift, ms_U_out_shift, rg_fcU_out_shift should be within range [-31, 31]
	input_zero_bias should be within range [-127, 128], hidden_zero_bias should be within range [-128, 127]
	hidden_shift should be within range [-31, -1]
time_major	Can be 0 or 1.

4. HiFi 5 NN Library – Layers

This section explains the APIs of each layer implementation in the NN library. All the layers conform to the "generic NN Layer API" and flow explained in Section 2.

The NN library is a single archive containing all layers and low-level kernels implementations. Each layer has its own header file that defines the APIs specific to the layer. The following sections explain each layer in detail.

Note This version of the library supports GRU, LSTM, and CNN layers.

4.1 GRU Layer

The GRU APIs are defined in xa_nnlib_gru_api.h. Refer to the overall signal flow diagram of GRU in [1].

4.1.1 GRU Layer Specification

GRU layer implements the following input-output equations when the split_bias parameter is set as 0.

$$z_t = sigmoid(W_z * x_t + U_z * prev\text{-}h + b_z)$$
$$r_t = sigmoid(W_r * x_t + U_r * prev\text{-}h + b_r)$$
$$g = \tanh(W_h * x_t + U_h * (r_t \cdot prev\text{-}h) + b_h)$$
$$y_t = h_t = z_t \cdot g + (1 - z_t) \cdot prev\text{-}h$$
$$prev\text{-}h = h_t$$

GRU layer implements the following input-output equations when the split_bias parameter is set as 1.

$$z_t = sigmoid(W_z * x_t + b_{sz} + U_z * prev\text{-}h + b_z)$$
$$r_t = sigmoid(W_r * x_t + b_{sr} + U_r * prev\text{-}h + b_r)$$
$$g = \tanh(W_h * x_t + b_{sh} + r_t * (U_h \cdot prev\text{-}h + b_h))$$
$$y_t = h_t = z_t \cdot prev\text{-}h + (1 - z_t) \cdot g$$
$$prev\text{-}h = h_t$$

x_t : input vector	z_t : update gate vector
y_t, h_t : output vector	r_t : reset gate vector
W, U : weight matrices	b : bias vectors
$prev\text{-}h$: previous output vector	

The biases b_{sr}, b_{sz}, b_{sh} are not used when split_bias = 0.

4.1.2 Error Codes Specific to GRU

Other than common error codes explained in Section 2.3, the GRU layer may also report the following error codes, which may be generated during the initialization stage.

XA_NNLIB_GRU_CONFIG_FATAL_INVALID_IN_FEATS[11]

Number of input features is not supported

XA_NNLIB_GRU_CONFIG_FATAL_INVALID_OUT_FEATS

Number of output features is not supported

XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PRECISION

I/O precision is not supported

XA_NNLIB_GRU_CONFIG_FATAL_INVALID_COEFF_QFORMAT

Number of fractional bits for coefficients is not supported.

XA_NNLIB_GRU_CONFIG_FATAL_INVALID_IO_QFORMAT

Number of fractional bits for input-output is not supported.

XA_NNLIB_GRU_CONFIG_FATAL_INVALID_MEMBANK_PADDING

Membank padding must be 0 or 1.

XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PARAM_ID

Parameter identifier (param_id) is not valid

XA_NNLIB_GRU_CONFIG_FATAL_INVALID_SPLIT_BIAS

Parameter split bias must be 0 or 1.

The following error codes may be generated during the execution stage.

XA_NNLIB_GRU_EXECUTE_FATAL_INSUFFICIENT_DATA

Input data passed in is insufficient

XA_NNLIB_GRU_EXECUTE_FATAL_INSUFFICIENT_OUTPUT_BUFFER_SPACE

Output Buffer Size is not sufficient

[11] FEATS := features

4.1.3 API Functions Specific to GRU

Query Functions

Table 4-1 GRU Get Persistent Size Function

Function	`xa_nnlib_gru_get_persistent_fast`
Syntax	`Int32 xa_nnlib_gru_get_persistent_fast( xa_nnlib_gru_init_config_t *config)`
Description	Returns persistent memory size in bytes required by GRU layer.
Parameters	Input: `config` Initial configuration parameters (see Table 4-7).
Errors	If the return value is less than 0, then it is an error. The following are the possible error codes: XA_NNLIB_FATAL_MEM_ALLOC XA_NNLIB_GRU_CONFIG_FATAL_INVALID_IN_FEATS Number of input features is not supported XA_NNLIB_GRU_CONFIG_FATAL_INVALID_OUT_FEATS Number of output features is not supported XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PRECISION I/O precision is not supported XA_NNLIB_GRU_CONFIG_FATAL_INVALID_COEFF_ QFORMAT Number of fractional bits for coefficients is not supported. XA_NNLIB_GRU_CONFIG_FATAL_INVALID_IO_ QFORMAT Number of fractional bits for input-output is not supported.

Table 4-2 GRU Get Scratch Size Function

Function	`xa_nnlib_gru_get_scratch_fast`
Syntax	`Int32 xa_nnlib_gru_get_scratch_fast( xa_nnlib_gru_init_config_t *config)`
Description	Returns scratch memory size in bytes required by GRU layer.
Parameters	Input: `config` Initial configuration parameters (see Table 4-7).
Errors	If return value is less than 0, then it is an error. Following are the possible error codes: XA_NNLIB_FATAL_MEM_ALLOC XA_NNLIB_GRU_CONFIG_FATAL_INVALID_IN_FEATS Number of input features is not supported XA_NNLIB_GRU_CONFIG_FATAL_INVALID_OUT_FEATS Number of output features is not supported XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PRECISION I/O precision is not supported XA_NNLIB_GRU_CONFIG_FATAL_INVALID_COEFF_ QFORMAT Number of fractional bits for coefficients is not supported XA_NNLIB_GRU_CONFIG_FATAL_INVALID_IO_ QFORMAT Number of fractional bits for input-output is not supported

Initialization Stage

Table 4-3 GRU Init Function

Function	`xa_nnlib_gru_init`

Syntax	`Int32`
	`xa_nnlib_gru_init (`
	`xa_nnlib_handle_t handle,`
	`xa_nnlib_gru_init_config_t *config)`

Description	Reset the GRU Layer API handle into its initial state. Set up the GRU Layer to the specified initial configuration parameters. This function sets prev_h vector to 0; the user can enter the required values in prev_h by using set config XA_NNLIB_GRU_RESTORE_CONTEXT (for more information, seeTable 4-11).
Parameters	Input: `handle` Pointer to the component persistent memory. This is the opaque handle. Required size: see `xa_nnlib_gru_get_persistent_fast`. Required alignment: 8 bytes. Input: `config` Initial configuration parameters (see Table 4-7). **Note:** The initial configuration parameters must be identical to those passed to query functions.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers is invalid. XA_NNLIB_FATAL_MEM_ALIGN One of the pointers is not properly aligned. XA_NNLIB_GRU_CONFIG_FATAL_INVALID_IN_FEATS Number of input features is not supported XA_NNLIB_GRU_CONFIG_FATAL_INVALID_OUT_FEATS Number of output features is not supported XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PRECISION I/O precision is not supported. XA_NNLIB_GRU_CONFIG_FATAL_INVALID_COEFF_QFORMAT Number of fractional bits for coefficients is not supported. XA_NNLIB_GRU_CONFIG_FATAL_INVALID_IO_QFORMAT Number of fractional bits for input-output is not supported.

	XA_NNLIB_GRU_CONFIG_FATAL_INVALID_MEMBANK_PADDING Membank padding must be 0 or 1.

Execution Stage

Table 4-4 GRU Execution Function

Function	`xa_nnlib_gru_process`

Syntax	`Int32 xa_nnlib_gru_process(`
	`xa_nnlib_handle_t handle,`
	`void *scratch,`
	`void *input,`
	`void *output,`
	`xa_nnlib_shape_t *p_in_shape,`
	`xa_nnlib_shape_t *p_out_shape)`

Description	Processes one input shape to generate one output shape.
Parameters	Input: `handle` The opaque component handle. Required alignment: 8 bytes. Input: `scratch` A pointer to the scratch buffer. Required alignment: 8 bytes. Input: `input` A pointer to the input buffer. The input buffer contains input data. Required alignment: 8 bytes. Output: `output` A pointer to the output buffer. Output is written to the output buffer. Required alignment: 8 bytes. Input/Output: `p_in_shape` Pointer to the shape containing input buffer dimensions. Contains the length of input data passed to GRU layer. Required alignment: 4 bytes. Input/Output: `p_out_shape` Pointer to the shape for output buffer dimensions. On return, *`p_out_shape` is filled with the length of output generated by HiFi GRU Layer. Required alignment: 4 bytes.

Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers is NULL. XA_NNLIB_FATAL_MEM_ALIGN One of the pointers is not properly aligned. XA_NNLIB_FATAL_INVALID_SHAPE Either input or output shape is invalid. XA_NNLIB_GRU_EXECUTE_FATAL_INSUFFICIENT_DATA Input data passed is insufficient. XA_NNLIB_GRU_EXECUTE_FATAL_INSUFFICIENT_OUTPUT_BUFFER_SPACE Output buffer size is not sufficient.

Table 4-5 GRU Set Parameter Function Details

Function	`xa_nnlib_gru_set_config`

Syntax	`Int32`
	`xa_nnlib_gru_set_config (`
	`xa_nnlib_handle_t handle,`
	`xa_nnlib_gru_param_id_t param_id,`
	`void *params)`

Description	Sets the parameter specified by `param_id` to the value passed in the buffer pointed to by `params`.
Parameters	**Input:** `handle` The opaque component handle. Required alignment: 8 bytes. **Input:** `param_id` Identifies the parameter to be written. For more information on the list of supported parameters, see Table 4-11. **Input:** `params` A pointer to a buffer that contains the parameter value. Required alignment: 4 bytes.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers (`handle` or `params`) is `NULL`.

	XA_NNLIB_FATAL_MEM_ALIGN One of the pointers (`handle` or `params`) is not aligned correctly. XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (`param_id`) is not valid.

Table 4-6 GRU Get Parameter Function Details

Function	`xa_nnlib_gru_get_config`

Syntax	`Int32 xa_nnlib_gru_get_config (`
	`xa_nnlib_handle_t handle,`
	`xa_nnlib_gru_param_id_t param_id,`
	`void *params)`

Description	Gets the value of the parameter specified by `param_id` in the buffer pointed to by `params`.
Parameters	**Input:** `handle` The opaque component handle. Required alignment: 8 bytes. **Input:** `param_id` Identifies the parameter to be read. For more information on the list of supported parameters, see Table 4-11. **Output:** `params` A pointer to a buffer that is filled with the parameter value when the function returns. Required alignment: 4 bytes.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers (`handle` or `params`) is `NULL`. XA_NNLIB_FATAL_MEM_ALIGN One of the pointers (`handle` or `params`) is not aligned correctly. XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (`param_id`) is not valid.

4.1.4 Structures Specific to GRU

Table 4-7 GRU Config Structure xa_nnlib_gru_init_config_t

Element Type	Element Name	Range	Default	Description
Int32	in_feats	4-2048	256	Number of input features (must be multiple of 4)
Int32	out_feats	4-2048	256	Number of output features (must be multiple of 4)
Int32	pad	0, 1	1	Padding 16 bytes for HiFi 5
Int32	mat_prec	8, 16	16	Matrix input precision
Int32	vec_prec	16	16	Vector input precision
xa_nnlib_gru_precision_t	precision	XA_NNLIB_GRU_16bx16b, XA_NNLIB_GRU_8bx16b, XA_NNLIB_GRU_flt32xflt32	XA_NNLIB_GRU_16bx16b	Coef and I/O precision. **Note:** The current library supports only 16bx16b, 8bx16b, and float32xfloat32 precision for GRU
Int16	coeff_Qformat	0-15	15	Number of fractional bits for weights and biases
Int16	io_Qformat	0-15	12	Number of fractional bits for input and output
Int32	split_bias	0,1	0	0 for Tensorflow equations and 1 for PyTorch equations.

Table 4-8 xa_nnlib_gru_weights_t Parameter Type

Element Type	Element Name	Range	Default	Description
coeff_t* coeff8_t* float*	w_z	NA	NA	Pointer to coefficient matrix w_z.
xa_nnlib_shape_t	shape_w_z	NA	NA	Shape information about w_z.
coeff_t* coeff8_t* float*	u_z	NA	NA	Pointer to coefficient matrix u_z.
xa_nnlib_shape_t	shape_u_z	NA	NA	Shape information about u_z.
coeff_t* coeff8_t* float*	w_r	NA	NA	Pointer to coefficient matrix w_r.
xa_nnlib_shape_t	shape_w_r	NA	NA	Shape information about w_r.

Element Type	Element Name	Range	Default	Description
coeff_t* coeff8_t* float*	u_r	NA	NA	Pointer to coefficient matrix u_r.
xa_nnlib_shape_t	shape_u_r	NA	NA	Shape information about u_r.
coeff_t* coeff8_t* float*	w_h	NA	NA	Pointer to coefficient matrix w_h.
xa_nnlib_shape_t	shape_w_h	NA	NA	Shape information about w_h.
coeff_t* coeff8_t* float*	u_h	NA	NA	Pointer to coefficient matrix u_h.
xa_nnlib_shape_t	shape_u_h	NA	NA	Shape information about u_h.

Table 4-9 xa_nnlib_gru_biases_t Parameter Type

Element Type	Element Name	Range	Default	Description
void *	b_z	NA	NA	Pointer to bias vector b_z.
xa_nnlib_shape_t	shape_b_z	NA	NA	Shape information about b_z.
void *	b_r	NA	NA	Pointer to bias vector b_r.
xa_nnlib_shape_t	shape_b_r	NA	NA	Shape information about b_r.
void *	b_h	NA	NA	Pointer to bias vector b_h.
xa_nnlib_shape_t	shape_b_h	NA	NA	Shape information about b_h.
void *	bs_z	NA	NA	Pointer to bias vector bs_z.
xa_nnlib_shape_t	shape_bs_z	NA	NA	Shape information about bs_z.
void *	bs_r	NA	NA	Pointer to bias vector bs_r.
xa_nnlib_shape_t	shape_bs_r	NA	NA	Shape information about bs_r.
void *	bs_h	NA	NA	Pointer to bias vector bs_h.
xa_nnlib_shape_t	shape_bs_h	NA	NA	Shape information about bs_h.

Note GRU requires all weight matrices' and bias vectors' pointers to be 8 bytes aligned.

4.1.5 Enums Specific to GRU

Table 4-10 Enum xa_nnlib_gru_precision_t

Element	Description
XA_NNLIB_GRU_16bx16b	Coef: 16 bits, I/O: 16 bits Fixed Point
XA_NNLIB_GRU_8bx16b	Coef: 8 bits, I/O: 16 bits Fixed Point
XA_NNLIB_flt32xflt32	Coef: float32, I/O: float32
XA_NNLIB_GRU_8bx8b	Not supported
XA_NNLIB_flt16xflt16	Not supported

Note Currently, GRU only supports XA_NNLIB_GRU_16bx16b, XA_NNLIB_GRU_8bx16b precision setting.

Table 4-11 describes parameter IDs for parameters supported by GRU. It contains the following columns:

Parameter ID: Parameter identifier (`param_id`).

Value type: A pointer (`params`) to a variable of this type is to be passed.

RW: Indicates whether the parameter can be read (`get`) and/or written (`set`).

Range: Indicates valid values of the parameter.

Default: Default value of the parameter

Description: Brief description of the parameter.

Table 4-11 GRU Specific Parameters

Parameter ID	Value Type	RW	Range	Default	Description
XA_NNLIB_GRU_RESTORE_CONTEXT	vect_t []	*RW*	NA	NA	Set previous output. This can be used to set prev_h to specific context (size must be equal to number of output features). Upon set config, the buffer passed is copied to persistent memory; upon get config, it returns the prev_h state in the given buffer.
XA_NNLIB_GRU_WEIGHT	xa_nnlib_gru_weights_t	*RW*	NA	NA	Weight matrices, pointers to weight matrices along with shape information must be passed via xa_nnlib_gru_weights_t structure for set config. Upon get config, it returns pointers to weight matrices along with their shape information in same structure.
XA_NNLIB_GRU_BIAS	xa_nnlib_gru_	*RW*	NA	NA	Bias vectors, pointers to bias vectors along with shape information must be passed via

Parameter ID	Value Type	RW	Range	Default	Description
	biases_t				xa_nnlib_gru_biases_t structure for set config. Upon get config, it returns pointers to bias vectors along with their shape information in same structure.
XA_NNLIB_GRU_INPUT_SHAPE	xa_nnlib_shape_t	*R*	NA	NA	Input shape information, get information of the input shape expected by the layer.
XA_NNLIB_GRU_OUTPUT_SHAPE	xa_nnlib_shape_t	*R*	NA	NA	Output shape information, get information of the output shape expected by layer.

4.2 LSTM Layer

The LSTM APIs are defined in xa_nnlib_lstm_api.h.

4.2.1 LSTM Layer Specification

The LSTM layer implements the following forward path input-output equations:

$$f_f = sigmoid\left(w_{xf} * frame_f + prev\text{-}h * w_{hf} + b_f\right)$$
$$i_f = sigmoid\left(w_{xi} * frame_f + prev\text{-}h * w_{hi} + b_i\right)$$
$$c\text{-}hat_f = \tanh\left(w_{xc} * frame_f + prev\text{-}h * w_{hc} + b_c\right)$$
$$c_f = f_f.prev\text{-}c + i_f * c\text{-}hat_f$$
$$o_f = sigmoid\left(w_{xo} * frame_f + prev\text{-}h * w_{ho} + b_o\right)$$
$$h_f = o_f * \tanh\left(c_f\right)$$

i_f : input gate
h_t : output vector
$c\text{-}hat_f$: intermediate cell state vector
f_f : forget gate
$frame_f$: Input vector
w_x : weight matrices of input connections
$prev\text{-}h$: previous output vector
$prev$-c: previous cell output
b : bias vectors
o_f : output gate
c_f : cell state vector
w_h : weight matrices of recurrent connections

4.2.2 Error Codes Specific to LSTM

Other than common error codes explained in Section 2.3, the LSTM layer may also report the following error codes, which may be generated during the initialization stage:

XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_IN_FEATS[12]

Number of input features is not supported

XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_OUT_FEATS

Number of output features is not supported

XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_PRECISION

I/O precision is not supported

XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_COEFF_QFORMAT

Number of fractional bits for coefficients is not supported.

XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_CELL_QFORMAT

Number of fractional bits for cells is not supported

XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_IO_QFORMAT

[12] FEATS: = features

Number of fractional bits for input-output is not supported.

XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_MEMBANK_PADDING

Membank padding must be 0 or 1.

XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_PARAM_ID

Parameter identifier (param_id) is not valid

The following error codes may be generated during the execution stage.

XA_NNLIB_LSTM_EXECUTE_FATAL_INSUFFICIENT_DATA

Input data passed in insufficient

XA_NNLIB_LSTM_EXECUTE_FATAL_INSUFFICIENT_OUTPUT_BUFFER_SPACE

Output Buffer Size is not sufficient

4.2.3 API Functions Specific to LSTM

Query Functions

Table 4-12 LSTM Get Persistent Size Function

Function	`xa_nnlib_lstm_get_persistent_fast`
Syntax	`Int32 xa_nnlib_lstm_get_persistent_fast ( xa_nnlib_lstm_init_config_t *config)`
Description	Returns persistent memory size in bytes required by LSTM layer.
Parameters	Input: `config` Initial configuration parameters (see Table 4-18).
Errors	If the return value is less than 0 then it is an error. The following are the possible error codes: XA_NNLIB_FATAL_MEM_ALLOC XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_IN_FEATS Number of input features is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_OUT_FEATS Number of output features is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_PRECISION I/O precision is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_COEFF_QFORMAT Number of fractional bits for coefficients is not supported.

	XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_CELL_QFORMAT Number of fractional bits for cells is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_IO_QFORMAT Number of fractional bits for input-output is not supported. XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_MEMBANK_PADDING Membank padding must be 0 or 1.

Table 4-13 LSTM Get Scratch Size Function

Function	`xa_nnlib_lstm_get_scratch_fast`
Syntax	`Int32 xa_nnlib_lstm_get_scratch_fast (` `xa_nnlib_lstm_init_config_t *config)`
Description	Returns scratch memory size in bytes required by LSTM layer.
Parameters	Input: `config` Initial configuration parameters (see Table 4-18).
Errors	If the return value is less than 0 then it is an error. The possible error codes are: XA_NNLIB_FATAL_MEM_ALLOC XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_IN_FEATS Number of input features is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_OUT_FEATS Number of output features is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_PRECISION I/O precision is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_COEFF_QFORMAT Number of fractional bits for coefficients is not supported. XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_CELL_QFORMAT Number of fractional bits for cells is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_IO_QFORMAT Number of fractional bits for input-output is not supported. XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_MEMBANK_PADDING Membank padding must be 0 or 1.

Initialization Stage

Table 4-14 LSTM Init Function

Function	`xa_nnlib_lstm_init`

Syntax	`Int32`
	`xa_nnlib_lstm_init (`
	`xa_nnlib_handle_t handle,`
	`xa_nnlib_lstm_init_config_t *config)`

Description	Reset the LSTM layer API handle into its initial state. Set up the LSTM layer to the specified initial configuration parameters. This function sets prev_h vector and prev_c vector to 0; the user can enter the required values in prev_h and prev_c by using set config XA_NNLIB_LSTM_RESTORE_CONTEXT_OUTPUT and XA_NNLIB_LSTM_RESTORE_CONTEXT_CELL respectively (for more information, see Table 4-22).
Parameters	Input: `handle` Pointer to the component persistent memory. This is the opaque handle. Required size: see `xa_nnlib_lstm_get_persistent_fast`. Required alignment: 8 bytes. Input: `config` Initial configuration parameters (see Table 4-18). **Note:** The initial configuration parameters must be identical to those passed to query functions.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers is invalid. XA_NNLIB_FATAL_MEM_ALIGN One of the pointers is not properly aligned. XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_IN_FEATS Number of input features is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_OUT_FEATS Number of output features is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_PRECISION I/O precision is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_COEFF_QFORMAT Number of fractional bits for coefficients is not supported.

	XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_CELL_QFORMAT Number of fractional bits for cells is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_IO_QFORMAT Number of fractional bits for input-output is not supported XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_MEMBANK_PADDING Membank padding must be 0 or 1.

Execution Stage

Table 4-15 LSTM Execution Function

Function	`xa_nnlib_lstm_process`

Syntax	`Int32 xa_nnlib_lstm_process (`
	`xa_nnlib_handle_t handle,`
	`void *scratch,`
	`void *input,`
	`void *output,`
	`xa_nnlib_shape_t *p_in_shape,`
	`xa_nnlib_shape_t *p_out_shape)`

Description	Processes one input shape to generate one output shape.
Parameters	Input: `handle` The opaque component handle. Required alignment: 8 bytes. Input: `scratch` A pointer to the scratch buffer. Required alignment: 8 bytes. Input: `input` A pointer to the input buffer. The input buffer contains input data. Required alignment: 8 bytes. Output: `output` A pointer to the output buffer. The output is written to the output buffer. Required alignment: 8 bytes. Input/Output: `p_in_shape` Pointer to the shape containing input buffer dimensions. Contains the length of input data passed to LSTM layer. Required alignment: 4 bytes. Input/Output: `p_out_shape`

	Pointer to the shape for output buffer dimensions. On return, *p_out_shape is filled with the length of output generated by HiFi LSTM layer. Required alignment: 4 bytes.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers is NULL. XA_NNLIB_FATAL_MEM_ALIGN One of the pointers is not having proper alignment. XA_NNLIB_FATAL_INVALID_SHAPE Either input or output shape is invalid. XA_NNLIB_LSTM_EXECUTE_FATAL_INSUFFICIENT_DATA Input data passed in insufficient XA_NNLIB_LSTM_EXECUTE_FATAL_INSUFFICIENT_OUTPUT_BUFFER_SPACE Output Buffer Size is not sufficient

Table 4-16 LSTM Set Parameter Function Details

Function	xa_nnlib_lstm_set_config
Syntax	Int32 xa_nnlib_lstm_set_config (xa_nnlib_handle_t handle, xa_nnlib_lstm_param_id_t param_id, void *params)
Description	Sets the parameter specified by param_id to the value passed in the buffer pointed to by params.
Parameters	**Input:** handle The opaque component handle. Required alignment: 8 bytes. **Input:** param_id Identifies the parameter to be written. For more information on the list of supported parameters, see Table 4-11. **Input:** params A pointer to a buffer that contains the parameter value. Required alignment: 4 bytes.

Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers (`handle` or `params`) is `NULL`. XA_NNLIB_FATAL_MEM_ALIGN One of the pointers (`handle` or `params`) is not aligned correctly. XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (`param_id`) is not valid.

Table 4-17 LSTM Get Parameter Function Details

Function	`xa_nnlib_lstm_get_config`
Syntax	`Int32 xa_nnlib_lstm_get_config ( xa_nnlib_handle_t handle, xa_nnlib_lstm_param_id_t param_id, void *params)`
Description	Gets the value of the parameter specified by `param_id` in the buffer pointed to by `params`.
Parameters	**Input:** `handle` The opaque component handle. Required alignment: 8 bytes. **Input:** `param_id` Identifies the parameter to be read. For more information on the list of supported parameters, see Table 4-11. **Output:** `params` A pointer to a buffer that is filled with the parameter value when the function returns. Required alignment: 4 bytes.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers (`handle` or `params`) is `NULL`. XA_NNLIB_FATAL_MEM_ALIGN One of the pointers (`handle` or `params`) is not aligned correctly. XA_NNLIB_LSTM_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (`param_id`) is not valid.

4.2.4 Structures Specific to LSTM

Table 4-18 LSTM Config Structure xa_nnlib_lstm_init_config_t

Element Type	Element Name	Range	Default	Description
Int32	in_feats	4-2048	256	Number of input features (must be multiple of 4)
Int32	out_feats	4-2048	256	Number of output features (must be multiple of 4)
Int32	pad	0, 1	1	Padding 16 bytes for HiFi 5 DSP
Int32	mat_prec	8, 16	16	Matrix input precision
Int32	vec_prec	16	16	Vector input precision
xa_nnlib_lstm_precision_t	precision	XA_NNLIB_LSTM_16bx16b, XA_NNLIB_LSTM_8bx16b	XA_NNLIB_LSTM_16bx16b	Coef and I/O precision. **Note:** The current library supports only 16bx16b and 8bx16b precision for LSTM.
Int16	coeff_Qformat	0-15	15	Number of fractional bits for weights and biases
Int16	cell_Qformat	0-26		Number of fractional bits for cells.
Int16	io_Qformat	0-15	12	Number of fractional bits for input and output

Table 4-19 xa_nnlib_lstm_weights_t Parameter Type

Element Type	Element Name	Range	Default	Description
coeff_t *	w_xf	NA	NA	Pointer to coefficient matrix w_xf.
xa_nnlib_shape_t	shape_w_xf	NA	NA	Shape information about w_xf.
coeff_t *	w_xi	NA	NA	Pointer to coefficient matrix w_xi.
xa_nnlib_shape_t	shape_w_xi	NA	NA	Shape information about w_xi.
coeff_t *	w_xc	NA	NA	Pointer to coefficient matrix w_xc.
xa_nnlib_shape_t	shape_w_xc	NA	NA	Shape information about w_xc.
coeff_t *	w_xo	NA	NA	Pointer to coefficient matrix w_xo.
xa_nnlib_shape_t	shape_w_xo	NA	NA	Shape information about w_xo.
coeff_t *	w_hf	NA	NA	Pointer to coefficient matrix w_hf.

Element Type	Element Name	Range	Default	Description
xa_nnlib_shape_t	shape_w_hf	NA	NA	Shape information about w_hf.
coeff_t *	w_hi	NA	NA	Pointer to coefficient matrix w_hi.
xa_nnlib_shape_t	shape_w_hi	NA	NA	Shape information about w_hi.
coeff_t *	w_hc	NA	NA	Pointer to coefficient matrix w_hc.
xa_nnlib_shape_t	shape_w_hc	NA	NA	Shape information about w_hc.
coeff_t *	w_ho	NA	NA	Pointer to coefficient matrix w_ho.
xa_nnlib_shape_t	shape_w_ho	NA	NA	Shape information about w_ho.

Table 4-20 xa_nnlib_lstm_biases_t Parameter Type

Element Type	Element Name	Range	Default	Description
coeff_t *	b_f	NA	NA	Pointer to coefficient matrix b_f.
xa_nnlib_shape_t	shape_b_f	NA	NA	Shape information about b_f.
coeff_t *	b_i	NA	NA	Pointer to coefficient matrix b_i.
xa_nnlib_shape_t	shape_b_i	NA	NA	Shape information about b_i.
coeff_t *	b_c	NA	NA	Pointer to coefficient matrix b_c.
xa_nnlib_shape_t	shape_b_c	NA	NA	Shape information about b_c.
coeff_t *	b_o	NA	NA	Pointer to coefficient matrix b_o.
xa_nnlib_shape_t	shape_b_o	NA	NA	Shape information about b_o.

Note LSTM requires all weight matrices' and bias vectors' pointers to be 8 bytes aligned.

4.2.5 Enums Specific to LSTM

Table 4-21 Enum xa_nnlib_lstm_precision_t

Element	Description
XA_NNLIB_LSTM_16bx16b	Coef: 16 bits, I/O: 16 bits Fixed Point
XA_NNLIB_LSTM_8bx16b	Coef: 8 bits, I/O: 16 bits Fixed Point
XA_NNLIB_LSTM_8bx8b	Not supported
XA_NNLIB_flt16xflt16	Not supported

Note Currently, LSTM only supports the XA_NNLIB_LSTM_16bx16b, XA_NNLIB_LSTM_8bx16b precision setting.

Table 4-22 describes parameter IDs for parameters supported by LSTM. It contains the following columns:

Parameter ID: Parameter identifier (`param_id`).

Value type: A pointer (`params`) to a variable of this type is to be passed.

RW: Indicates whether the parameter can be read (`get`) and/or written (`set`).

Range: Indicates valid values of the parameter.

Default: Default value of the parameter.

Description: Brief description of the parameter.

Table 4-22 LSTM Specific Parameters

Parameter ID	Value Type	RW	Range	Default	Description
XA_NNLIB_LSTM_RESTORE_CONTEXT_OUTPUT	vect_t []	*RW*	NA	NA	Set previous output. This can be used to set prev_h to specific context (size must be equal to number of output features). Upon set config, the buffer passed is copied to persistent memory; upon get config, it returns the prev_h state in the given buffer.
XA_NNLIB_LSTM_RESTORE_CONTEXT_CELL	vect_t []	*RW*	NA	NA	Set previous cell state. This can be used to set prev_c to specific cell context (size must be equal to number of output features). Upon set config, the buffer passed is copied to persistent memory; upon get config, it returns the prev_c state in the given buffer.
XA_NNLIB_LSTM_WEIGHT	xa_nnlib_lstm_weights_t	*RW*	NA	NA	Weight matrices, pointers to weight matrices along with shape information needs to be passed via xa_nnlib_lstm_weights_t structure for set config. Upon get config, it returns pointers to weight matrices along with their shape information in same structure.
XA_NNLIB_LSTM_BIAS	xa_nnlib_lstm_biases_t	*RW*	NA	NA	Bias vectors, pointers to bias vectors along with shape information needs to be passed via xa_nnlib_lstm_biases_t structure for set config. Upon get config, it returns pointers to bias vectors along with their shape information in same structure.
XA_NNLIB_LSTM_INPUT_SHAPE	xa_nnlib_shape_t	*R*	NA	NA	Input shape information, get information of the input shape expected by the layer.
A_NNLIB_LSTM_OUTPUT_SHAPE	xa_nnlib_shape_t	*R*	NA	NA	Output shape information, get information of the output shape expected by layer.

4.3 CNN Layer

The CNN APIs are defined in `xa_nnlib_cnn_api.h`.

4.3.1 CNN Layer Specification

The CNN layer implements Standard 2D Convolution, Standard 1D Convolution, and Depthwise Separable 2D Convolution. For more information on the equations, see Section 3.2.1 for Standard 2D Convolution, Section 3.2.2 for Standard 1D Convolution, and Section 3.2.4 for Depthwise Separable 2D Convolution.

4.3.2 Error Codes Specific to CNN

Other than common error codes explained in Section 2.3, the CNN layer may also report the following error codes, which may be generated during the initialization stage.

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_ALGO

Algorithm is not supported

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PRECISION

I/O precision is not supported.

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_BIAS_SHIFT

Value of Bias shift is not supported

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_ACC_SHIFT

Value of Accumulator shift is not supported.

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_STRIDE

Value of strides is not supported

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PADDING

Value of padding is not supported.

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_INPUT_SHAPE

Input shape dimension is not supported.

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_OUTPUT_SHAPE

Out shape dimension is not supported.

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_KERNEL_SHAPE

Kernel shape dimension is not supported.

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_BIAS_SHAPE

Bias shape dimension is not supported.

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_ID

Parameter identifier (param_id) is not valid

XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_COMBINATION

Parameter combination (param_id) is not valid

The following error codes may be generated during the execution stage.

XA_NNLIB_CNN_EXECUTE_FATAL_INVALID_INPUT_SHAPE

Input shape passed during execution does not match with the input shape passed during initialization

4.3.3 API Functions Specific to CNN

Query Functions

Table 4-23 CNN Get Persistent Size Function

Function	`xa_nnlib_cnn_get_persistent_fast`
Syntax	`Int32 xa_nnlib_cnn_get_persistent_fast ( xa_nnlib_cnn_init_config_t *config)`
Description	Returns persistent memory size in bytes required by CNN layer.
Parameters	Input: `config` Initial configuration parameters (see Table 4-29).
Errors	If return value is less than 0, then it is an error. Following are the possible error codes: XA_NNLIB_FATAL_MEM_ALLOC XA_NNLIB_CNN_CONFIG_FATAL_INVALID_ALGO Algorithm is not supported XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PRECISION I/O precision is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_BIAS_SHIFT Value of Bias shift is not supported XA_NNLIB_CNN_CONFIG_FATAL_INVALID_ACC_SHIFT Value of Accumulator shift is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_STRIDE Value of strides is not supported XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PADDING Value of padding is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_INPUT_SHAPE

	Input shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_OUTPUT_SHAPE Out shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_KERNEL_SHAPE Kernel shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_BIAS_SHAPE Bias shape dimension is not supported XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (param_id) is not valid XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_COMBINATION Parameter combination (param_id) is not valid

Table 4-24 CNN Get Scratch Size Function

Function	`xa_nnlib_cnn_get_scratch_fast`
Syntax	`Int32 xa_nnlib_cnn_get_scratch_fast (` `xa_nnlib_cnn_init_config_t *config)`
Description	Returns scratch memory size in bytes required by CNN layer.
Parameters	Input: `config` Initial configuration parameters (see Table 4-29).
Errors	If return value is less than 0, then it is an error. Following are the possible error codes: XA_NNLIB_FATAL_MEM_ALLOC XA_NNLIB_CNN_CONFIG_FATAL_INVALID_ALGO Algorithm is not supported XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PRECISION I/O precision is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_BIAS_SHIFT Value of bias shift is not supported XA_NNLIB_CNN_CONFIG_FATAL_INVALID_ACC_SHIFT Value of Accumulator shift is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_STRIDE Value of strides is not supported XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PADDING Value of padding is not supported.

	XA_NNLIB_CNN_CONFIG_FATAL_INVALID_INPUT_SHAPE Input shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_OUTPUT_SHAPE Out shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_KERNEL_SHAPE Kernel shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_BIAS_SHAPE Bias shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (param_id) is not valid XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_COMBINATION Parameter combination (param_id) is not valid

Initialization Stage

Table 4-25 CNN Init Function

Function	`xa_nnlib_cnn_init`

Syntax	`int xa_nnlib_cnn_init (`
	`xa_nnlib_handle_t handle,`
	`xa_nnlib_cnn_init_config_t *config)`

Description	Reset the CNN layer API handle to its initial state. Set up the CNN layer to the specified initial configuration parameters.
Parameters	Input: `handle` Pointer to the component persistent memory. This is the opaque handle. Required size: see `xa_nnlib_cnn_get_persistent_fast`. Required alignment: 8 bytes. Input: `config` Initial configuration parameters (see Table 4-29). **Note:** The initial configuration parameters must be identical to those passed to query functions.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers is invalid. XA_NNLIB_FATAL_MEM_ALIGN

	One of the pointers is not properly aligned. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_ALGO Algorithm is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PRECISION I/O precision is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_BIAS_SHIFT Value of Bias shift is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_ACC_SHIFT Value of Accumulator shift is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_STRIDE Value of strides is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PADDING Value of padding is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_INPUT_SHAPE Input shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_OUTPUT_SHAPE Out shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_KERNEL_SHAPE Kernel shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_BIAS_SHAPE Bias shape dimension is not supported. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (param_id) is not valid. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_COMBINATION Parameter combination (param_id) is not valid.

Execution Stage

Table 4-26 CNN Execution Function

Function	`xa_nnlib_cnn_process`

Syntax	`int xa_nnlib_cnn_process (`
	`  xa_nnlib_handle_t handle,`
	`  void *scratch,`

	void *input, void *output, xa_nnlib_shape_t *p_in_shape, xa_nnlib_shape_t *p_out_shape)
Description	Processes one input shape to generate one output shape.
Parameters	Input: `handle` The opaque component handle. Required alignment: 8 bytes. Input: `scratch` A pointer to the scratch buffer. Required alignment: 8 bytes. Input: `input` A pointer to the input buffer. Input buffer contains input data. Required alignment: 8 bytes. Output: `output` A pointer to the output buffer. Output is written to the output buffer. Required alignment: 8 bytes. Input/Output: `p_in_shape` Pointer to the shape containing input buffer dimensions. Contains the length of input data passed to the CNN layer. Required alignment: 4 bytes. Output: `p_out_shape` Pointer to the shape for output buffer dimensions. Upon return, `*p_out_shape` is filled with the length of output generated by the CNN layer. Required alignment: 4 bytes.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers is NULL XA_NNLIB_FATAL_MEM_ALIGN One of the pointers is not having the required alignment XA_NNLIB_FATAL_INVALID_SHAPE Input shape passed during execution does not match with the input shape passed during initialization

Table 4-27 CNN Set Parameter Function Details

Function	`xa_nnlib_cnn_set_config`

Syntax	`int xa_nnlib_cnn_set_config (`
	`  xa_nnlib_handle_t handle,`
	`  xa_nnlib_cnn_param_id_t param_id,`
	`  void *params)`

Description	Sets the parameter specified by `param_id` to the value passed in the buffer pointed to by `params`.
Parameters	**Input:** `handle` The opaque component handle. Required alignment: 8 bytes. **Input:** `param_id` Identifies the parameter to be written. For the list of supported parameters, see Table 4-32. **Input:** `params` A pointer to a buffer that contains the parameter value. Required alignment: 4 bytes.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers (`handle` or `params`) is `NULL`. XA_NNLIB_FATAL_MEM_ALIGN One of the pointers (`handle` or `params`) is not aligned correctly. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (`param_id`) is not valid.

Table 4-28 CNN Get Parameter Function Details

Function	`xa_nnlib_cnn_get_config`

Syntax	`int xa_nnlib_cnn_get_config(`
	`  xa_nnlib_handle_t handle,`
	`  xa_nnlib_cnn_param_id_t param_id,`
	`  void *params )`

Description	Gets the value of the parameter specified by `param_id` in the buffer pointed to by `params`.
Parameters	**Input:** `handle` The opaque component handle. Required alignment: 8 bytes. **Input:** `param_id` Identifies the parameter to be read. For the list of supported parameters, see Table 4-32. **Output:** `params` A pointer to a buffer that is filled with the parameter value when the function returns. Required alignment: 4 bytes.
Errors	If the return value is not XA_NNLIB_NO_ERROR, it implies that the function has encountered one of the following errors: XA_NNLIB_FATAL_MEM_ALLOC One of the pointers (`handle` or `params`) is `NULL`. XA_NNLIB_FATAL_MEM_ALIGN One of the pointers (`handle` or `params`) is not aligned correctly. XA_NNLIB_CNN_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (`param_id`) is not valid.

4.3.4 Structures Specific to CNN

Table 4-29 CNN Config Structure xa_nnlib_cnn_init_config_t

Element Type	Element Name	Range	Default	Description
xa_nnlib_ shape_t	input_ shape	NA	height = 16 width = 16 channels = 4	Input shape dimensions
Int32	output_ height	NA	16	Output height
Int32	output_ width	NA	16	Output width
Int32	output_ channels	NA	4	Output depth or channels
Int32	output_ format	0 or 1	0	Output data format 0: SHAPE_CUBE_DWH_T 1: SHAPE_CUBE_WHD_T
xa_nnlib_ shape_t	kernel_ std_shape	NA	height = 16 width = 16 channels = 4	Standard 1D/2D Convolution Kernel (Filter) shape dimensions output_channels indicate number of kernels
xa_nnlib_ shape_t	kernel_ ds_depth_ shape	NA	NA	Depthwise Separable 2D Convolution - Depthwise Kernel (filter) Dimensions
xa_nnlib_ shape_t	kernel_ds_ point_ shape	NA	NA	Depthwise Separable 2D Convolution - Pointwise Kernel (filter) Dimensions
xa_nnlib_ shape_t	bias_std_ shape	NA	channels = 4	Standard 1D/2D Convolution Bias dimensions
xa_nnlib_ shape_t	bias_ds_ depth_ shape	NA	NA	Depthwise Separable 2D Convolution - Depthwise Bias) Dimensions
xa_nnlib_ shape_t	bias_ds_ point_ shape	NA	NA	Depthwise Separable 2D Convolution – Pointwise Bias Dimensions
xa_nnlib_cnn _precision_t	precision	XA_NNLIB_ CNN_16bx1 6b, XA_NNLIB_ CNN_8bx16 b, XA_NNLIB_ CNN_8bx8b, XA_NNLIB_ CNN_f32xf3 2	XA_NNLIB_CNN_8b x16b	Kernel (filter), input, output precision setting
Int32	bias_ shift	-31 to 31	7	Q-format adjustment for bias before addition into accumulator, +/- value - left/right shift

Element Type	Element Name	Range	Default	Description
Int32	acc_shift	-31 to 31	-7	Q-format adjustment for accumulator before rounding to result, +/- value - left/right shift
Int32	channels_multiplier	NA	NA	Depthwise Separable 2D Convolution - channel multiplier. (channels_multiplier * input_channels) must be multiple of 4
Int32	x_padding	NA	2	Left side padding to be added to input
Int32	y_padding	NA	2	Top padding to be added to input
Int32	x_stride	NA	2	Strides over padded input in width dimension
Int32	y_stride	NA	2	Strides over padded input in height dimension
xa_nnlib_cnn_algo_t	algo	NA	XA_NNLIB_CNN_CONV2D_STD	Convolution algorithm

4.3.5 Enums Specific to CNN

Table 4-30 Enum xa_nnlib_cnn_precision_t

Element	Description
XA_NNLIB_CNN_16bx16b	Coef: 16 bits, I/O: 16 bits fixed point
XA_NNLIB_CNN_8bx16b	Coef: 8 bits, I/O: 16 bits fixed point
XA_NNLIB_CNN_8bx8b	Coef: 8 bits, I/O: 8 bits fixed point
XA_NNLIB_CNN_f32xf32	Coef: single precision float, I/O: single precision float

Table 4-31 Enum xa_nnlib_cnn_algo_t

Element	Description
XA_NNLIB_CNN_CONV1D_STD	Standard 1D Convolution
XA_NNLIB_CNN_CONV2D_STD	Standard 2D Convolution
XA_NNLIB_CNN_CONV2D_DS	Depthwise Separable 2D Convolution

Table 4-32 describes parameter IDs for parameters supported by CNN. It contains the following columns:

Parameter ID: Parameter identifier (`param_id`).

Value type: A pointer (`params`) to a variable of this type is to be passed.

RW: Indicates whether the parameter can be read (`get`) and/or written (`set`).

Range: Indicates valid values of the parameter.

Default: Default value of the parameter

Description: Brief description of the parameter.

Table 4-32 CNN Specific Parameters

Parameter ID	Value Type	RW	Range	Default	Description
XA_NNLIB_CNN_KERNEL	vect_t []	*RW*	NA	NA	Kernel shape information, get or set information of the kernel shape expected by the layer
XA_NNLIB_CNN_BIAS	vect_t []	*RW*	NA	NA	Bias shape information, get or set information of the bias shape expected by the layer
XA_NNLIB_CNN_INPUT_SHAPE	xa_nnlib_shape_t	*R*	NA	NA	Input shape information, get information of the input shape expected by the layer.
XA_NNLIB_CNN_OUTPUT_SHAPE	xa_nnlib_shape_t	*R*	NA	NA	Output shape information, get information of the output shape produced by layer.

5. Introduction to the Example Testbench

The HiFi 5 NN library is released as a .tgz file for linux/makefile based usage and a .xws file for Xtensa Xplorer based usage. Both the tgz and xws packages contain various testbenches in addition to the library. These testbenches demonstrate the usage of various APIs, and their performances. The details about building and running the library and testbenches are provided in the following sections.

5.1 Making the Library

If you have source code distribution (that is, .tgz), you must build the NN library before building the testbench. To do so, follow these steps:

1. Go to directory `libxa_nnlib/build`.
2. From the command prompt, enter:
   `xt-make -f makefile clean all install`

The NN library `xa_nnlib.a` is built and copied to the `lib` directory.

To create a debug build, pass DEBUG=1 makefile option in the make command.

The NN Library has TensorFlow Lite Micro double rounding as default option (SINGLE_ROUNDING=0, which is default for TensorFlow Lite Micro as well) and single rounding can be enabled by using the makefile option SINGLE_ROUNDING=1.[13]

The NN Library also supports improved optimizations using HiFi5 activation tie instructions for xa_nn_vec_[sigmoid|tanh]_[16|asym8s|sym16s]_[16|asym8s|sym16s] kernels which differs by 1-bit from Tensorflow Lite Micro implementation of corresponding operators, those optimizations are by default enabled for HiFi5 cores which has activation tie instructions, and can be disabled as follows (default is DISABLE_ACT_TIE=0):

```
xt-make -f makefile clean all install DISABLE_ACT_TIE=1
```

To create a CSTUB build, pass CPU=x86 makefile option in the make command.

To enable floating-point bit-exact code, pass AGGRESSIVE_FLOAT_OPT=0 makefile option in the make command.

5.1.1 Controlling Library Code Size

The HiFi NN Library code size can be reduced by discarding unused functions at the time of linking.

[13] For XTENSA workspaces, the single-rounding option can be enabled by defining TFLITE_SINGLE_ROUNDING=1 in Build Properties of libxa_nnlib.

The library is compiled with the `'-ffunction-sections'` option. With this option, the compiler puts each function in a separate section. This enables the linker to discard unused functions when linking the executable, using the `'-Wl,-gc-sections'` linker option.

Additionally, to remove unused function sections during the library creation, the `'-Wl,-gc-sections'` linker option is enabled while building the testbench. The list of required functions is provided in the linker script file `build/ldscript_nnlib.txt`. While building the library, the linker discards functions not listed as 'EXTERN' in the linker script file. By appropriately modifying the linker script, the library can be built with only the kernels required for particular application.

5.2 Making the Executable

To build the testbenches, follow these steps:

1. Go to `test/build`.
2. In the command-line prompt, enter:
   `xt-make -f makefile_testbench_sample clean all`

This builds the example testbenches for all the kernels and layers.

The following header files are common and used by all testbenches.

Testbench header files (`test/include`)

- `xt_profiler.h`
- `cmdline_parser.h`
- `file_io.h`
- `xt_manage_buffers.h`

To build and execute the example testbenches from xws based release package, check the readme.html files available in the imported example testbench projects.

The following sections describe each low-level kernel and layer testbench.

5.2.1 Controlling Executable Code Size

The code size of the executable binaries can be reduced by discarding unused functions at the time of linking.

The library is compiled with the `'-ffunction-sections'` option. With this option, the compiler puts each function in a separate section. This enables the linker to discard unused functions when linking the executable, using the `'-Wl,-gc-sections'` linker option.

5.3 Sample Testbench for Matrix X Vector Multiplication Kernels

The NN library Matrix X Vector Multiplication Kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- `xa_nn_matXvec_testbench.c`

5.3.1 Usage

The NN library Matrix X Vector Multiplication Kernels executable can be run with the command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_matXvec_test [options]
```

The following options are available:

Option	Description	Additional Information
`-rows`	Rows of mat1 (Default=32)	
`-cols1`	Columns of mat1 and rows of mat2 (Default=32)	Columns of mat1 must be multiple of 4 (except for quantized datatype kernels)
`-cols2`	Columns of mat2 (Default=32)	Columns of mat2 must be multiple of 4 ((except for quantized datatype kernels)
`-row_stride1`	Row stride for mat1(Default=32)	
`-row_stride2`	Row stride for mat2(Default=32)	
`-vec_count`	Vec count for Time batching (Default=1)	
`-acc_shift`	Accumulator left shift (Default=0)	
`-bias_shift`	Bias left shift (Default=0)	
`-mat_precision`	8, 16, -1(single precision float), -2(half precision float), -3 (asym8u), -13 (asym4s) or -5 (sym8s); (Default=16)	
`-inp_precision`	8, 16, -1(single precision float), -2(half precision float), -3(asym8u,-8(sym16s) or-4 (asym8s); (Default=16)	
`-out_precision`	8, 16, 32, 64, -1(single precision float), - 2(half precision float), -3(asym8u), -4 (asym8s), -8(sym16s) or -7 (asym16s); (Default=16)	
`-bias_precision`	8, 16, 64, -1(single precision float), -2(half precision float), 32(asym8); (Default=16)	
`-mat1_zero_bias`	Matrix1 zero bias for quantized 8-bit, -255 to 0 for asym8u, ignored for sym8s; Default=-128	
`-mat2_zero_bias`	Matrix2 zero bias for quantized 8-bit, -255 to 0 for asym8u, ignored for sym8s; Default=-128	

Option	Description	Additional Information
-inp1_zero_bias	Input1 zero bias for quantized 8-bit, -255 to 0 for asym8u, -127 to 128 for asym8s, 0 for sym16s, ; Default=-128	
-inp2_zero_bias	Input2 zero bias for quantized 8-bit, -255 to 0 for asym8u, -127 to 128 for asym8s, 0 for sym16s; Default=-128	
-out_multiplier	Output multiplier in Q31 format for quantized 8-bit, 0x0 to 0x7fffffff; Default=0x40000000	
-out_shift	Output shift for quantized 8-bit (asym8u and asym8s) 31 to -31; Default=-8	
-out_zero_bias	Output zero bias for quantized 8-bit, 0 to 255 for asym8u, -128 to 127 for asym8s, 0 for sym16s; Default=128	
-out_stride	Stride for storing the output; Default=1	
-membank_padding	0, 1 (Default=1)	
-frames	Positive number; (Default=2)	
-activation	Sigmoid, tanh (Default= bypass, that is, no activation for output)	
-write_file	Set to 1 to write input and output vectors to file; (Default=0)	
-read_inp_file_name	Full filename for reading inputs (order - mat1, vec1, mat2, vec2, bias)	
-read_ref_file_name	Full filename for reading reference output	
-write_inp_file_name	Full filename for writing inputs (order - mat1, vec1, mat2, vec2, bias)	
-write_out_file_name	Full filename for writing output	
-verify	Verify output against provided reference	0: Disable, 1: Bit exact match (Default=1)
-batch	Flag to execute time batching kernels	0: Disable, 1: Enable (Default=0)
-matmul	Flag to execute matmul kernels	0: Disable, 1: Enable (Default=0)
-fc	Flag to execute fully connected kernels	0: Disable, 1: Enable (Default=0)
-v2	Flag for _v2 kernel	0: Disable, 1: Enable (Default=0)
-batch_matmul	Flag for batch_matmul, xa_nn_batch_matmul_[asym8sxasym8s_asym8s|sym16sx sym16s_sym16s];	0: Disable, 1: Enable; Default=0
-mat1_shape	Takes the matrix 1 shape dimensions for batch_matmul	
-inp1_shape	Takes the input 1 or matrix 2 shape dimensions for batch_matmul	
-out_shape	Takes the output shape dimensions for batch_matmul	
-mat1_transpose:	Flag for matrix 1 transpose, applicable only when batch_matmul is 1	0: Disable, 1: Enable; Default=0
-inp1_transpose:	Flag for input 1 transpose, applicable only when batch_matmul is 1;	0: Disable, 1: Enable; Default=0
--help, -help, -h	Prints help	

If no command-line arguments are given, the Matrix X Vector Multiplication Kernels sample testbench runs with default values from the paramfile (paramfilesimple_matXvec.txt).

5.4 Sample Testbench for Convolution Kernels

The NN library Convolutional Kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- `xa_nn_conv_testbench.c`

5.4.1 Usage

The NN Library Convolutional Kernels executable can be run with the command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_conv_test [options]
```

The following options are available:

Option	Description
`-input_height`	Input height (Default=16)
`-input_width`	Input width (Default=16)
`-input_channels`	Input channels (Default=4); Not required for group convolution.
`-kernel_height`	Kernel height (Default=3)
`-kernel_width`	Kernel width (Default=3)
`-kernel_channels`	kernel channels (Default=4)
`-out_channels`	Out channels (Default=4)
`-channels_multiplier`	Channel Multiplier (Default=1)
`-x_stride`	Stride in width dimension (Default=2)
`-y_stride`	Stride in height dimension (Default=2)
`-x_padding`	Left padding in width dimension (Default=2)
`-y_padding`	Top padding in height dimension (Default=2)
`-dilation_height`	Dilation in height dimension (Default=1)
`-dilation_width`	Dilation in width dimension (Default=1)
`-out_height`	Output height (Default=16)
`-out_width`	Output width (Default=16)
`-bias_shift`	Bias left shift (Default=7)
`-groups`	Number of groups; Default=1. This parameter is unused in the Testbench.
`-acc_shift`	Accumulator left shift (Default=-7)
`-inp_data_format`	Input data format, 0 (DWH), 1 WHD) Default=1(WHD), ignored for conv2d_std and conv1d_std kernels
`-out_data_format`	Output data format, 0 (DWH), 1 (WHD) Default=0 (DWH)
`-inp_precision`	8, 16, -1(single precision float), -2(half precision float), -3(asymmetric 8-bit unsigned), -8 (sym16s) or -4 (asymmetric 8-bit signed); (Default=16)

Option	Description
-kernel_precision	8, 16, -1(single precision float), -2(half precision float), -3(asymmetric 8-bit unsigned) or -5 (symmetric 8-bit signed), -12(Symmetric 4-bit signed); (Default=8)
-out_precision	8, 16, -1(single precision float), -2(half precision float), -3(asymmetric 8-bit unsigned), -8 (sym16s) or -4 (asymmetric 8-bit signed); (Default=16)
-bias_precision	8, 16, -1(single precision float), -2(half precision float), 32(for quantized 8-bit kernels); (Default=16)
-input_zero_bias	Input zero bias for quantized 8-bit, -255 to 0 for asymmetric 8 bit unsigned, -127 to 128 for asymmetric 8 bit signed, ignored for symmetric 16-bit signed; Default=-127
-kernel_zero_bias	Kernel zero_bias for quantized 8-bit, -255 to 0 for asymmetric 8 bit unsigned, ignored for symmetric 8 bit signed; Default=-127
-out_multiplier	Output multiplier in Q31 format for quantized 8 bit, 0x0 to 0x7fffffff; Default=0x40000000
-out_shift	Output shift for quantized 8-bit(asym8u and asym8s), 31 to -31; Default=-8
-out_zero_bias	Output zero bias for quantized 8-bit, 0 to 255 for asym8u, -128 to 127 for asym8s, ignored for symmetric 16-bit signed; Default=128
-frames	Positive number (Default=2)
-kernel_name	conv2d_std, dilated_conv2d_std, conv2d_depth, conv2d_point, conv1d_std, transpose_conv, dilated_conv2d_depth, conv2d_group; Default= : conv2d_std
-pointwise_profile_only	Applicable only when kernel_name is conv2d_depth, 0 (print conv2d depthwise and pointwise profile info), 1(print only conv2d pointwise profile info); Default=0
-write_file	Set to 1 to write input and output vectors to file; (Default=0)
-read_inp_file_name	Full filename for reading inputs (order - input, kernel, bias, (pointwise kernel, pointwise bias for depth separable))
-read_ref_file_name	Full filename for reading reference output
-write_inp_file_name	Full filename for writing inputs (order - input, kernel, bias, (pointwise kernel, pointwise bias for depth separable))
-write_out_file_name	Full filename for writing output
-verify	Verify output against provided reference; 0: Disable, 1: Bit exact match (Default=1)
-v2	Flag for v2 kernels; 0: Disable, 1: Enable; Default=0. Uses _v2 API, if set to 1.
-out_activation_min	Lower range of fused min/max activation
-out_activation_max	Higher range of fused min/max activation
-num_groups	Number of groups along depth dimension; Default=1
--help, -help, -h	Prints help

If no command-line arguments are given, the Convolutional Kernels sample testbench runs with default values from the paramfile (paramfilesimple_conv.txt).

5.5 Sample Testbench for Activation Kernels

The NN library activation kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- `xa_nn_activations_testbench.c`

5.5.1 Usage

The NN library activation kernels executable can be run with the command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_activation_test [options]
```

The following options are available:

Option	Description
`-num_elements`	Number of elements (Default=32)
`-relu_threshold`	Threshold for relu in Q16.15 (Default= 32768, that is, =1 in Q16.15)
`-inp_precision`	8,16, 32, -1(single precision float), -3(asym8u) -4 (asym8s), -7 (asym16s) or -8 (sym16s); (Default=32)
`-out_precision`	8,16, 32, -1(single precision float), -3(asym8u) or -4 (asym8s), -7 (asym16s) or -8 (sym16s); (Default=32)
`-integer_bits`	Number of integer bits in input for tanh_16_16(0 to 6) (Default = 3)
`-frames`	Positive number (Default=2)
`-activation`	Sigmoid, tanh, relu, relu_std, relu1, relu6, activation_min_max, softmax, hard_swish, prelu or leaky_relu (Default= sigmoid)
`-write_file`	Set to 1 to write input and output vectors to file; (Default=0)
`-read_inp_file_name`	Full filename for reading input
`-read_ref_file_name`	Full filename for reading reference output
`-write_inp_file_name`	Full filename for writing input
`-write_out_file_name`	Full filename for writing output
`-verify`	Verify output against provided reference; 0: Disable, 1: Bit exact match (Default=1)
Quantized 8-bit specific parameters	
`-diffmin`	Diffmin; Default=-15
`-input_left_shift`	Input_left_shift; Default=27
`-input_multiplier`	Input_multiplier; Default=2060158080
`-activation_max`	asym8u/asym8s/16/8 input data activation max; Default=0
`-activation_min`	asym8u/asym8s/16/8 input data activation min; Default=0
`-activation_max_f32`	Float input data activation max (Default=0)

Option	Description
-activation_min_f32	Float input data activation min (Default=0)
-input_range_radius	sigmoid_asym8u/s input parameter; Default=128
-zero_point	sigmoid_asym8u/s input parameter; Default=0
-input_zero_bias	Zero bias value for input (Default =0)
-alpha_zero_bias	Prelu parameter - Zero bias value for alpha Default=0
-alpha_multiplier	Leaky Relu and Prelu parameter - Multiplier value for alpha Default=0x40000000
-alpha_shift	Leaky Relu and Prelu parameter - Shift value for alpha Default=0
-reluish_multiplier	Hard Swish parameter - Multiplier value for relu scale Default=0x40000000
-reluish_shift	Hard Swish parameter - Shift value for relu scale Default=0
-out_multiplier	Multiplier value for output Default=0x40000000
-out_shift	Shift value for output Default=0
-out_zero_bias	Zero bias value for output Default=0
--help, -help, -h	Prints help

If no command-line arguments are given, the Activation Kernels sample testbench runs with default values from the paramfile (paramfilesimple_activations.txt).

5.6 Sample Testbench for Pooling Kernels

The NN library pooling kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- `xa_nn_pool_testbench.c`

5.6.1 Usage

The NN library pooling kernels executable can be run with the command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_pool_test [options]
```

The following options are available:

Option	Description
-inp_data_format	Input data format, 0 (SHAPE_CUBE_DWH_T), 1 SHAPE_CUBE_WHD_T); (Default=1 (SHAPE_CUBE_WHD_T))

Option	Description
-out_data_format	Output data format, 0 (SHAPE_CUBE_DWH_T), 1 SHAPE_CUBE_WHD_T); (Default=1 (SHAPE_CUBE_WHD_T))
-input_height	Input height (Default=16)
-input_width	Input width (Default=16)
-input_channels	Input channels (Default=4)
-kernel_height	Kernel height (Default=3)
-kernel_width	Kernel width (Default=3)
-x_stride	Stride in width dimension (Default=2)
-y_stride	Stride in height dimension (Default=2)
-x_padding	Left padding in width dimension (Default=2)
-y_padding	Top padding in height dimension (Default=2)
-out_height	Output height (Default=16)
-out_width	Output width (Default=16)
-acc_shift	Accumulator left shift (Default=-7)
-inp_precision	8, 16, -1(single precision float), -3(asym8); (Default=16)
-out_precision	8, 16, -1(single precision float), -3(asym8); (Default=16)
-frames	Positive number (Default=2)
-kernel_name	avgpool, maxpool (Default= avgpool)
-write_file	set to 1 to write input and output vectors to file; (Default=0)
-read_inp_file_name	Full filename for reading inputs (order - inp)
-read_ref_file_name	Full filename for reading reference output
-write_inp_file_name	Full filename for writing inputs (order - inp)
-write_out_file_name	Full filename for writing output
-verify	Verify output against provided reference; 0: Disable, 1: Bit exact match (Default=1)
--help, -help, -h	Prints help

If no command-line arguments are given, the Pooling Kernels sample testbench runs with default values from the paramfile (paramfilesimple_pool.txt).

5.7 Sample Testbench for Basic Operations Kernels

The NN library basic kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (test/src)

- xa_nn_basic_testbench.c

5.7.1 Usage

The NN library basic kernels executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_basic_test [options]
```

The following options are available:

Option	Description
-io_length	Input/output vector length; Default=1024
-num_inp_dims	Number of input dimensions(Default =4)
-num_axis_dims	Number of axis dimensions(Default =4)
-num_output_dims	Number of output dimensions(Default =4)
-inp_precision	8, 16, 32, -3 (asym8u), -1 (single prec float), -4(asym8s), -7(asym16s) , -8(sym16s), 1(bool); Default=-1
-out_precision	8, 16, 32, -3 (asym8u), -1 (single prec float), -4(asym8s) , -7(asym16s) , -8(sym16s), 1(bool), -10(asym32s); Default=-1
-vec_count	Number of input vectors; Default=1
-frames	Positive number; Default=2
-kernel_name	elm_add, elm_sub, elm_mul, elm_floor, dot_prod, elm_min and elm_max, elm_equal, elm_notequal, elm_greater, elm_greaterequal, elm_less, elm_lessequal, elm_logicaland, elm_logicalor, elm_logicalnot, reduce_max_4D, reduce_mean_4D, elm_min_4D_Bcast, elm_max_4D_Bcast, elm_sine, elm_cosine, elm_logn, elm_abs, elm_ceil, elm_round, elm_neg, elm_square, elm_sqrt, elm_rsqrt, broadcast, elm_requantize, elm_dequantize, elm_quantize, memmove,memset, elm_add_broadcast_4D, elm_sub_broadcast_4D, elm_mul_broadcast_4D, elm_squared_diff_broadcast_4D, elm_div_broadcast_4D, elm_sel, elm_clamp, elm_sel_broadcast_4D, elm_compare, elm_compare_Bcast; Default=elm_add
-write_file	Set to 1 to write input and output vectors to file; Default=0
-read_inp1_file_name	Full filename for reading inputs (order - inp)
-read_inp2_file_name	Full filename for reading inputs (order - inp)
-read_inp3_file_name	Full filename for reading inputs (order - inp)
-read_ref_file_name	Full filename for reading reference output
-write_inp1_file_name	Full filename for writing inputs (order - inp)
-write_inp2_file_name	Full filename for writing inputs (order - inp)
-write_inp3_file_name	Full filename for writing inputs (order - inp)
-write_out_file_name	Full filename for writing output
-verify	Verify output against provided reference; 0: Disable, 1: Bit exact match; Default=1
-read_inp_shape_str	Takes the input shape dimensions(space ' ' separated) as a string

Option	Description
-read_inp1_shape_str	Takes the input1 shape dimensions(space ' ' separated) as a string
-read_inp2_shape_str	Takes the input2 shape dimensions(space ' ' separated) as a string
-read_inp3_shape_str	Takes the input3 shape dimensions(space ' ' separated) as a string
-read_out_shape_str	Takes the output shape dimensions(space ' ' separated) as a string
-read_axis_data_str	Takes the axis data (space ' ' separated) as a string
-kernel_type	Positive number between 0 to 5; Default=0
Broadcast specific parameters	
-input1_numElements	Number of elements in input (order - inp)
-input2_numElements	Number of elements in input(order – inp)
-input1_strides	Input strides (order – inp)
-input2_strides	Input strides (order – inp)
Quantized data types specific parameters	
-output_zero_bias	Output zero bias; Default=127
-output_left_shift	Output_left_shift; Default=0
-output_multiplier	Output_multiplier; Default=0x7fff
-output_activation_min	Output_activation_min; Default=0
-output_activation_max	Output_activation_max; Default = 225
-input1_zero_bias	Input1 zero bias; Default=-127
-input1_left_shift	Input1 left shift; Default=0
-input1_multiplier	Input1 multiplier; Default=0x7fff
-input2_zero_bias	Input2 zero bias; Default=-127
-input2_left_shift	Input2 left shift; Default=0
-input2_multiplier	Input2 multiplier; Default=0x7fff
-left_shift	Global left shift; Default=0
-input1_scale	Input scale; Default=0.5
-val_memset	input_memset(Float value. Needed in memset operation); Default=0.0
--help, -help, -h	Prints help

If no command-line arguments are given, the Basic Kernels sample testbench runs with default values from the paramfile (paramfilesimple_basic.txt).

5.8 Sample Testbench for Normalization Kernels

The NN library Normalization Kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- `xa_nn_norm_testbench.c`

5.8.1 Usage

The NN library Normalization Kernels executable can be run with the command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_norm_test [options]
```

The following options are available:

Option	Description
`-num_elms`	Number of elements; Default=256
`-inp_precision`	-4(asym8s) and -1(float32); Default=16
`-out_precision`	-4(asym8s) and -1(float32); Default=16
`-frames`	Positive number; Default=2
`-kernel_name`	L2_norm, norm_calc_3D, norm_apply_3D; Default=l2_norm
`-zero_point`	Input Zero point; Default = 0
`-write_file`	Set to 1 to write input and output vectors to file; Default=0
`-read_inp_file_name`	Full filename for reading inputs (order - inp)
`-read_ref_file_name`	Full filename for reading reference output
`-write_inp_file_name`	Full filename for writing inputs (order - inp)
`-write_out_file_name`	Full filename for writing output
`-verify`	Verify output against provided reference; 0: Disable, 1: Bit exact match; Default=1
`-renorm_scale`	Scale for renormalization; Default=1
`-renorm_shift`	Right shift for renormalization; Default=0
`-input_zero_bias`	Zero bias of input ; Default=0
`-output_zero_bias`	Zero bias of output ; Default=0
`-across_depth_flag`	Across depth flag for 3D input; Default=1
`-rsqrt_shift`	applies to index in calc-norm API, and to table value in apply-norm API; Default=2
`-rsqrt_table_len`	Reciprocal sqrt table length; Default=4096
`-recip_shift`	Reciprocal shift value; Default=12
`-per_chan_flag`	Per channel flag; Default=1
`--help, -help, -h`	Prints help

If no command-line arguments are given, the Normalization Kernels sample testbench runs with default values from the paramfile (paramfilesimple_norm.txt).

5.9 Sample Testbench for Reorg Kernels

The NN library reorg kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- `xa_nn_reorg_testbench.c`

5.9.1 Usage

The NN library reorg kernels executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_reorg_test [options]
```

The following options are available:

Option	Description
`-inp_data_format`	Data format of input and output, 0 for nhwc; Default=0
`-num_inp_dims`	Number of input dimensions; Default=4
`-num_pad_dims`	Number of pad dimensions; Default=2
`-num_out_dims`	Number of output dimensions; Default=4
`-num_ouputs`	Number of outputs for split_v kernel; Default=1
`-axis`	Axis dimension for concat or split_v kernel; Default=0
`-split_v_outs_shape`	Output shape dimensions for all outputs in split_v kernel
`-pad_value`	Input to be padded with this pad value; Default=0
`-permute_vec`	Permutation values of dimensions for transpose
`-input_height`	Input height; Default=16
`-input_width`	Input width; Default=16
`-input_channels`	Input channels; Default=16
`-block_size`	Block size; Default=2
`-out_height`	Output height; Default=16
`-out_width`	Output width; Default=16
`-out_channels`	Output channels; Default=4
Strided slice specific parameters	
`-start_0`	begin point for dimension 0; Default=0
`-start_1`	begin point for dimension 1; Default=0
`-start_2`	begin point for dimension 2; Default=0
`-start_3`	begin point for dimension 3; Default=0
`-start_4`	begin point for dimension 4; Default=0
`-stop_0`	end point for dimension 0; Default=1
`-stop_1`	end point for dimension 1; Default=1
`-stop_2`	end point for dimension 2; Default=1
`-stop_3`	end point for dimension 3; Default=1

Option	Description
-stop_4	end point for dimension 4; Default=1
-stride_0	stride for dimension 0; Default=1
-stride_1	stride for dimension 1; Default=1
-stride_2	stride for dimension 2; Default=1
-stride_3	stride for dimension 3; Default=1
-stride_4	stride for dimension 4; Default=1
-inp_precision	8, 16, 32; Default=8
-out_precision	8, 16, 32; Default=8
-frames	Positive number; Default=2
-kernel_name	depth_to_space, space_to_depth, pad, batch_to_space_nd, space_to_batch_nd, strided_slice, transpose, concat; Default=depth_to_space
-write_file	Set to 1 to write input and output vectors to file; Default=0
-read_inp_file_name	Full filename for reading inputs (order - inp)
-read_ref_file_name	Full filename for reading reference output
-write_inp_file_name	Full filename for writing inputs (order - inp)
-write_out_file_name	Full filename for writing output
-verify	Verify output against provided reference; 0
-inp_shape	Takes the input shape dimensions (num_inp_dims values space ' ' separated)
-pad_shape	Takes the pad shape dimensions (num_pad_dims values space ' ' separated)
-out_shape	Takes the output shape dimensions (num_out_dims values space ' ' separated)
-pad_values	Takes the pad values(prod(pad_shape) values space ' ' separated)
-block_sizes	Takes the block sizes ((num_inp_dims-2) values space ' ' separated) for batch_to_space_nd and space_to_batch_nd kernels
-crop_or_pad_sizes	Takes the crop sizes for batch_to_space_nd or pad sizes for space_to_batch_nd (2*(num_inp_dims-2) values space ' ' separated)
-interleave_group	Number of groups to interleave in shuffle; Default=1
--help, -help, -h	Prints help.

If no command-line arguments are given, the Reorg Kernels sample testbench runs with default values from the paramfile (paramfilesimple_reorg.txt).

5.10 Sample Testbench for RNN Kernels

The NN library RNN kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- xa_nn_rnn_testbench.c

5.10.1 Usage

The NN library RNN kernels executable can be run with the command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_rnn_test [options]
```

Option	Description	Additional Information
-ker_precision	Kernel precision; Default=-5	Must be -5
-io_precision	Input/output precision; Default=-4	Must be -4
-cell_precision	Cell precision; Default=16	Must be 16
-input_zero_bias	Input zero point; Default=0	
-frames	Positive number; Default=2	
-kernel_name	lstm; Default=lstm	
-hidden_zero_bias	Hidden layer Zero point; Default = 0	
-write_file	Set to 1 to write input and output vectors to file; Default=0	
-read_inp_file_name	Full filename for reading inputs	
-read_ref_file_name	Full filename for reading reference output	
-write_inp_file_name	Full filename for writing inputs	
-write_out_file_name	Full filename for writing output	
-verify	Verify output against provided reference; 0: Disable, 1: Bit exact match; Default=1	
-hidden_shift	Hidden Layer shift; Default=0	
-hidden_multiplier	Hidden layer multiplier; Default=0x40000000	
-quantized_cell_clip	Clip value for quantized cell; Default=32767	
-cell_state_scale	Cell state scale; Default=-12	
-inp_size	Number of features in input; Default=128	
-n_itr	Number of time iterations; Default=64	
-n_batch	Number of elements in batch dimension; Default=16	
-n_cell	Number of elements in cell state; Default=96	
-time_major	Order of input and output 1: time is outer most dimension, 0: batch is outer most dimension Default=0	
--help, -help, -h	Prints help	

If no command-line arguments are given, the RNN sample testbench runs with default values from the paramfile (paramfilesimple_rnn.txt)

5.11 Sample Testbench for GRU Layer

The NN library GRU layer is provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- `xa_nn_gru_testbench.c`

5.11.1 Usage

The NN library GRU executable can be run with the command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_gru_test [options]
```

The following options are available:

Option	Description	Additional Information
`--in_feats`	Input length (Default=256)	Range: 4-2048 **Note:** Input length must be multiple of 4
`--out_feats`	Output length (Default=256)	Range: 4-2048 **Note:** Output length must be multiple of 4
`--membank_padding`	Memory bank padding (Default=1)	Must be 0 or 1
`--split_bias`	Split Bias option (Default=0)	Must be 0 or 1
`--mat_prec`	Coefficient precision (Default=16)	Must be 8 or 16
`--vec_prec`	Input precision (Default=16)	Must be 16
`--verify`	Verify output against ref output (Default=1)	Supported values: 0: Disable, 1: Enable
`--input_file`	Input file name	
`--filter_path`	Path where file containing filter are stored	
`--output_file`	File to which output is written	
`--prev_h_file`	File containing context data	
`--ref_file`	File which has ref output	
`--help, -help, -h`	Prints help	

If no command-line arguments are given, the GRU sample testbench runs with default values from the paramfile (paramfilesimple_gru.txt).

5.12 Sample Testbench for LSTM Layer

The NN library LSTM layer is provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- `xa_nn_lstm_testbench.c`

5.12.1 Usage

The NN library LSTM executable can be run with the command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_lstm_test [options]
```

The following options are available:

Option	Description	Additional Information
`--in_feats`	Input length (Default=256)	Range: 4-2048 **Note:** Input length must be multiple of 4
`--out_feats`	Output length (Default=256)	Range: 4-2048 **Note:** Output length must be multiple of 4
`--membank_padding`	Memory bank padding (Default=1)	Must be 0 or 1
`--mat_prec`	Coefficient precision (Default=16)	Must be 8 or 16
`--vec_prec`	Input precision (Default=16)	Must be 16
`--verify`	Verify output against ref output (Default=1)	Supported values: 0: Disable, 1: Enable
`--input_file`	File containing input shape	
`--filter_path`	Path where file containing filter are stored	
`--output_file`	File to which output is written	
`--output_cell_file`	File to which cell output is written	
`--prev_h_file`	File containing context (previous output) data	
`--prev_c_file`	File containing context (previous cell state) data	
`--ref_file`	File which has ref output	
`--ref_cell_file`	File which has ref cell output	
`--help, -help, -h`	Prints help	

If no command-line arguments are given, the LSTM sample testbench runs with default values from the paramfile (paramfilesimple_lstm.txt).

5.13 Sample Testbench for CNN Layer

The NN library CNN layer is provided with a sample testbench application. The supplied testbench consists of the following files:

Testbench source files (`test/src`)

- `xa_nn_cnn_testbench.c`

5.13.1 Usage

The NN Library CNN executable can be run with the command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_cnn_test [options]
```

The following options are available:

Option	Description
`-input_height`	Input height (Default=16)
`-input_width`	Input width (Default=16)
`-input_channels`	Input channels (Default=4)
`-kernel_height`	Kernel height (Default=3)
`-kernel_width`	Kernel width (Default=3)
`-out_channels`	Out channels (Default=4)
`-channels_multiplier`	Channel Multiplier (Default=1)
`-x_stride`	Stride in width dimension (Default=2)
`-y_stride`	Stride in height dimension (Default=2)
`-x_padding`	Left padding in width dimension (Default=2)
`-y_padding`	Top padding in height dimension (Default=2)
`-out_height`	Output height (Default=16)
`-out_width`	Output width (Default=16)
`-bias_shift`	Bias shift (Default=7)
`-acc_shift`	Accumulator shift (Default=-7)
`-out_data_format`	Output data format, 0 (SHAPE_CUBE_DWH_T), 1 (SHAPE_CUBE_WHD_T); (Default=0)
`-inp_precision`	8, 16, -1(single precision float); (Default=16)
`-kernel_precision`	8, 16, -1(single precision float); (Default=8)
`-out_precision`	8, 16, -1(single precision float); (Default=16)
`-bias_precision`	8, 16, -1(single precision float); (Default=16)
`-frames`	Positive number; (Default=2)
`-kernel_name`	conv2d_std, conv2d_depth, conv1d_std; (Default= conv2d_std)

Option	Description
`-write_file`	Set to 1 to write input and output vectors to file; (Default=0)
`-read_inp_file_name`	Full filename for reading inputs (order - input, kernel, bias, (pointwise kernel, pointwise bias for depth separable))
`-read_ref_file_name`	Full filename for reading reference output
`-write_inp_file_name`	Full filename for writing inputs (order - input, kernel, bias, (pointwise kernel, pointwise bias for depth separable))
`-write_out_file_name`	Full filename for writing output
`-verify`	Verify output against provided reference; 0: Disable, 1: Bit exact match; Default=1
`--help, -help, -h`	Prints help

If no command-line arguments are given, the CNN sample testbench runs with default values from the paramfile (paramfilesimple_cnn.txt).

6. References

[1] Reference Wiki page for GRU. https://en.wikipedia.org/wiki/Gated_recurrent_unit

[2] TF Micro Lite speech recognition example: https://github.com/tensorflow/tensorflow/tree/r2.3/tensorflow/lite/micro/examples/micro_speech

[3] TensorFlow Lite for Microcontrollers

[4] TensorFlow XLA Documentation: https://www.tensorflow.org/xla/broadcasting
NumPy Theory: https://numpy.org/devdocs/user/basics.broadcasting.html
General Broadcasting syntax: https://www.tensorflow.org/guide/tensor#broadcasting

[5] 'strides' as defined in the structure 'NDArrayDesc' at https://github.com/tensorflow/tensorflow/blob/master/tensorflow/lite/kernels/internal/common.h