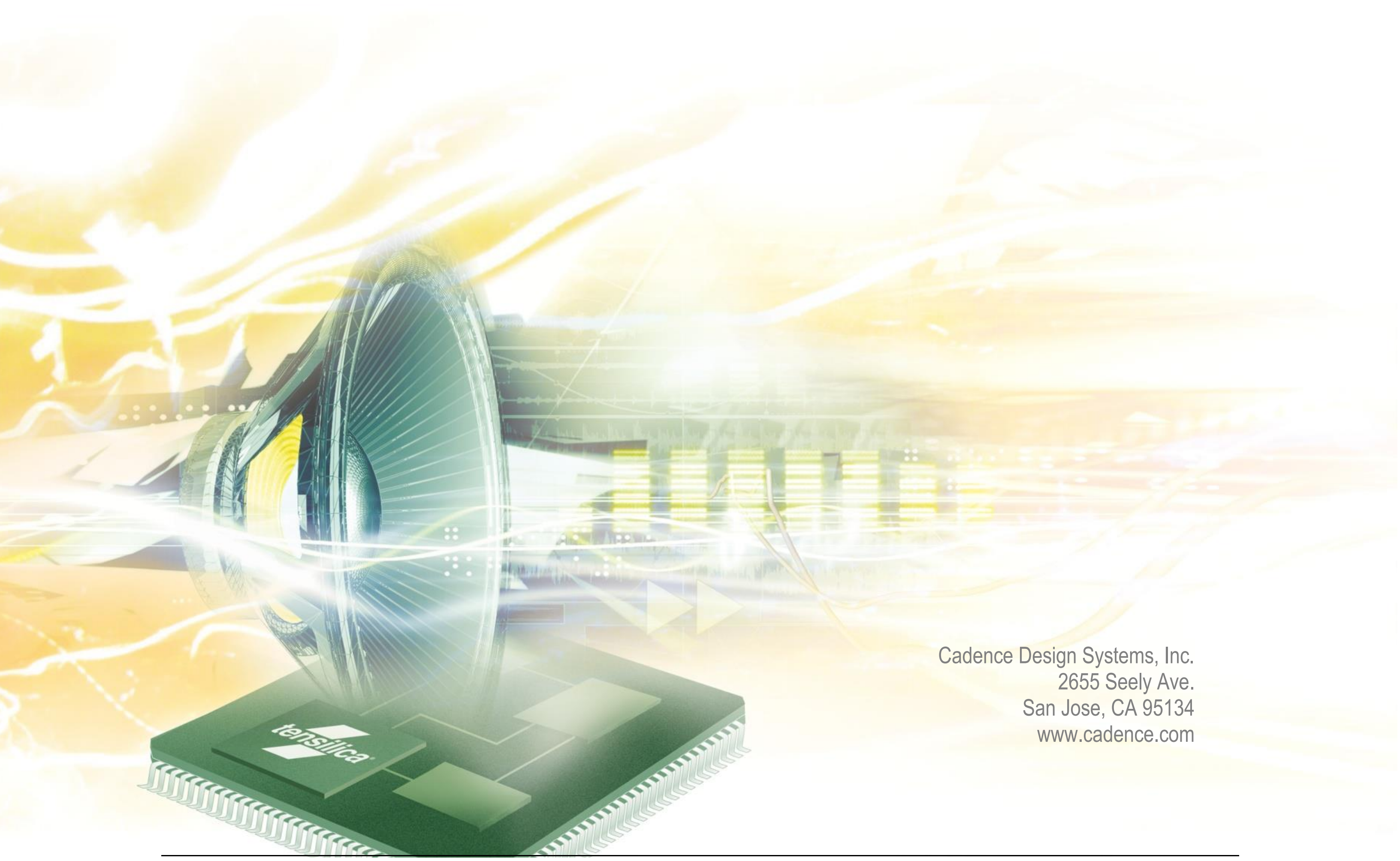
HiFi Neural Network Library

Programmer's Guide — API

For HiFi 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

Document Change History

Version	Changes
0.1	■ Initial release ■ Matrix X vector and activation function kernels added ■ GRU Layer (8x16, 16x16) added
1.0	■ GA release ■ Convolution, pooling kernels added ■ LSTM layer (8x16, 16x16) and CNN layer added
1.0.1	■ Some minor updates
2.0	■ Updated for HiFi NN Library v2.1.0 (Android NN support and TF Micro Lite Example)
2.1	■ Updated for HiFi NN Library v2.2.0
2.2	■ Updated performance tables
2.3	■ Added description of quantized 8-bit variants for standard convolution, depthwise convolution, fully connected and softmax kernels. ■ Added HiFi 3 to the list of supported cores. ■ Updated description of depthwise convolution, average pool and max pool kernels.
2.4	■ Added below kernels used for SVDF, quantize TFLM operators and pointwise convolution ○ xa_nn_dot_prod_16x16_asym8s ○ xa_nn_elm_quantize_asym16s_asym8s ○ xa_nn_matmul_per_chan_sym8sxasym8s_asym8s ○ xa_nn_matXvec_out_stride_sym8sxasym8s_16 ○ xa_nn_memmove_16
2.5	■ 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. ■ Added standard 2D convolution with Dilation. ■ Added matXvec batch kernels with accumulation. ■ Added 16-bit input/output kernels for sigmoid and tanh.

	■ Added following new kernels for int8 and quantized int8 datatypes: max, min, equal, notequal, greater, greaterequal, less, lessequal, add, sub, mul, elm_min_4D_Bcast, elm_max_4D_Bcast, elm_min_8D_Bcast, elm_max_8D_Bcast, logicaland, logicalor, logicalnot, broadcast, reduce_max_4D, reduce_mean_4D, tanh, sigmoid, leaky_relu, prelu, hard_swish, relu (asym8u and asym8s) and l2_norm. ■ Elementwise quantize kernels are renamed to elementwise requantize and two new variants are added. ■ Added Elementwise Dequantize kernels (quantized int8 to float32). ■ Added following float32 kernels: abs, sine, cosine, logn, sqrt, rsqrt, square, ceil, round and neg. ■ Added memory operation kernels: memset (float32) and memmove (asym8s). ■ Renamed the section "Miscellaneous Kernels" to "Basic Operations and Miscellaneous Kernels" ■ L2 normalization kernel description moved to "Normalization Kernels" section from older "Miscellaneous Kernels" section. ■ "Fully Connected Kernel" section is now moved to the section "HiFi NN Library – Low-Level Kernels" ■ Added 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 and norm testbench descriptions.
2.6	■ Created a separate performance document, and removed the performance data from this document.

1. Introduction to the HiFi NN Library

The HiFi 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, also 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. The HiFi NN Library also includes support for Android NN API v1.1 (Android P) NN operations.

This guide refers to the NN layers simply as layers, low level NN kernels as low-level kernels and the Android NN operations as ANN operations. The current version of the library implements GRU, LSTM (forward path), and CNN layers. It also implements matrix vector multiply, activation, pooling, normalization and convolution functions and some basic elementwise operations as low-level kernels.

Note This version of the HiFi NN Library is optimized for HiFi 4 DSP. The same library can be cross compiled for HiFi 1, HiFi 3, HiFi 3z, HiFi 5 DSP configurations and Fusion F1 DSP configurations with the AVS and the 16-bit Quad MAC unit options. To enable the cross compilation, a few HiFi 4 instructions that are not available in the other configurations are mapped to sequence of instructions available for the respective configuration.

Note The HiFi NN Library can be built for configurations with or without the optional Single Precision Vector Floating Point Unit (SP-VFPU). The floating-point variant of kernels can only be compiled when Core configurations is having SP-VFPU option.

Note The HiFi NN Library can be built for configurations with newlib or Xtensa C library. The ANN and respective supporting libraries need C++11 support and can be built for configurations with Xtensa C library only.

Note This version of the HiFi NN Library is tested with the xt-clang/xt-clang++ compilers using Xtensa Software Tools from RI-2021.6 release.

1.1 Organization of the HiFi 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).

[1] Refer to Section 2.1 Shape

[2] Refer to Section 2.2.3 Weights and Biases Memory

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

The HiFi NN library also 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 low level kernels support the datatypes required by the ANN operators from Android NN API v1.1. The HiFi NN Library package also includes a supporting library containing the HiFi implementation of the ANN operators. This library is referred to as ANN library. An application can use the ANN library along with the HiFi NN library to implement the Android NN API.

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 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 is generic and explained in Section 2. The low level NN kernels are explained in Section 3. The APIs for each layer are described in Section 4. Section 5 provides details about the included supporting libraries. Section 6 provides details about available sample testbenches. References are listed in Section 7.

1.2 HiFi 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 X Vector multiplication kernels
- Convolution kernels
- Activation kernels
- Pooling kernels
- Basic operations kernels
- Fully connected kernel
- Normalization kernels
- Reorg kernels

These kernels support fixed point 8-bit, 16-bit, single precision floating point and asymmetric 8-bit quantized datatypes for the weights, biases, input, and output.

They also support 8-bit quantized data types (asym8u/asym8 – 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 integer 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 range [0, 255] for unsigned type, in 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 zero point is 0, so all the calculation required due to zero point is 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].

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. Refer to Section 4 for details.

1.2.3 Support for TensorFlow Lite Micro Operators

The HiFi NN Library low level kernels can be used to implement the following operators of TensorFlow Lite Micro:

No.	Operator	Float32 Datatype Support	Uint8 (asymmetric quantized uint8) Datatype Support	Int8 (quantized int8) Datatype Support	Boolean (1 Byte) Datatype Support
1	FULLY_CONNECTED		Yes	Yes	
2	MAX_POOL_2D	Yes	Yes	Yes	
3	SOFTMAX		Yes	Yes	
4	LOGISTIC	Yes		Yes	
5	SVDF			Yes	
6	CONV_2D	Yes	Yes	Yes	
7	DEPTHWISE_CONV_2D	Yes	Yes	Yes	
8	AVERAGE_POOL_2D	Yes	Yes	Yes	
9	FLOOR	Yes			
10	RELU	Yes		Yes	
11	RELU6	Yes		Yes	
12	ADD	Yes		Yes	
13	MUL			Yes	
14	QUANTIZE[3]			Yes	
15	EQUAL			Yes	
16	GREATER			Yes	
17	GREATEREQUAL			Yes	
18	HARDSWISH			Yes	
19	LESS			Yes	
20	LESSEQUAL			Yes	
21	MAXIMUM			Yes	
22	MINIMUM			Yes	
23	NOTEQUAL			Yes	
24	PRELU			Yes	
25	SUB			Yes	
26	TANH			Yes	
27	LOGICALAND				Yes
28	LOGICALOR				Yes
29	LOGICALNOT				Yes
30	L2 NORM			Yes	

[3] QUANTIZE operator has different input and output quantized data types, HiFi 4 NN Library has kernels for Int16 to Int8, Int8 to Int32, Int16 to Int32.

No.	Operator	Float32 Datatype Support	Uint8 (asymmetric quantized uint8) Datatype Support	Int8 (quantized int8) Datatype Support	Boolean (1 Byte) Datatype Support
31	MEAN			Yes	
32	REDUCEMAX			Yes	
33	ABS	Yes			
34	SIN	Yes			
35	COS	Yes			
36	LOG	Yes			
37	SQRT	Yes			
38	RSQRT	Yes			
39	SQUARE	Yes			
40	FILL	Yes			
41	CEIL	Yes			
42	ROUND	Yes			
43	NEG	Yes			
45	DEQUANTIZE			Yes[4]	
47	LEAKY_RELU			Yes	
48	PAD			Yes	
49	PADV2			Yes	
50	CIRCULAR_BUFFER			Yes	
51	DEPTH_TO_SPACE			Yes	
52	BATCH_TO_SPACE_ND			Yes	
53	SPACE_TO_BATCH_ND			Yes	

The following TFLM operators get optimized out of box on HiFi 4 and do not require any HiFi 4 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			
3	RESHAPE[5]						
4	ELU			Yes			
5	SQUEEZE[5]						

[4] For TFLM DEQUANTIZE operator output is always single precision float whereas multiple input data types are supported. HiFi4 NN Library has kernel for quantized Int8 input data type.

[5] For RESHAPE and SQUEEZE datatype is not specified in TensorFlow Lite Micro.

1.2.4 Changes from the Previous Release

- Added support for quantized 8-bit variants for reorg, normalization, reduce, logical, compare, activations and basic operations
- Added support for single precision floating point variants for some basic operations.
- Added support for 16-bit input/output variants for sigmoid and tanh
- Added support for standard 2D convolution with dilation (with a change in API arguments)
- Added a variant for Matrix-Vector batch multiplication with accumulation
- Added support for TFLM Dequantize, and additional data types support for Requantize
- Added support for broadcast kernels for int8 datatype (with minimum/maximum variants)
- Enabled HiFi 1 cross compilation support.
- Improved performance and codesize for convolution, matXvec and matmul kernels.

2. Generic HiFi NN Layer API

Note This section explains an API standard which is evolving. 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.

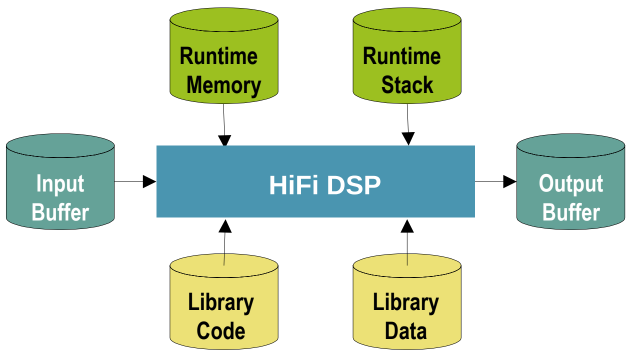

Figure 2-1 HiFi NN Layer Interfaces

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.

The output from one instance can be fed as input to the next instance if the precision and the dimension matches.

The data types, structures, and error codes explained in this section are declared/defined in `xa_nnlib_standard.h`. By default, the API header file of each layer will include this header file. The application need not include this file.

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_standard.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 inner most dimension, width is the middle dimension and height is the outer dimension. This type is also referred to as the NHWC 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 inner most 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, H = Height, W = Width).

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

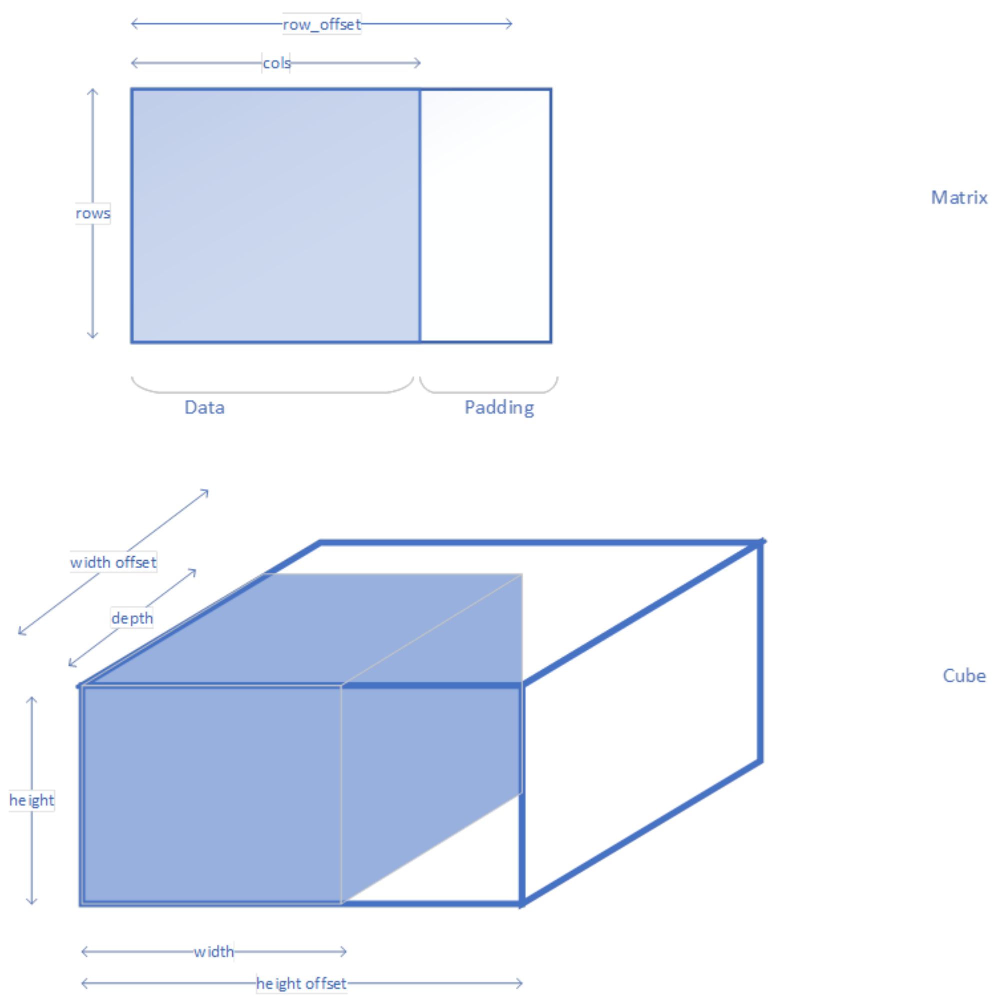

Figure 2-2 Matrix and Cube (SHAPE_CUBE_DWH_T) Shape Representation

2.2 Memory Management

The HiFi NN layer API supports a flexible memory scheme and a simple interface that eases the 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 the 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 via 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 used by the layer during a single frame processing call. The contents of this memory region should not be changed if the actual layer execution process is active; that is, if the thread running the layer is inside any API call. This region can be used freely by the system between successive calls to the layer.

2.2.3 Weights and Biases Memory

The weights or coefficients and biases should be managed by the application, and memory should not be requested by the API. 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 required, 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 should have an associated shape information to describe the input data format. The input buffer pointer can be changed by the application between calls to the layer, 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 should have an associated shape information to which the layer can describe the output data format. The output buffer pointer can be changed by the application between calls to the layer. This allows the layer to write directly to the input of another layer.

2.3 Generic API Errors

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

2.3.1 Common API Errors

The following errors are fatal and should not be encountered during normal application operation. They signal that a serious error has occurred in the application that is 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.

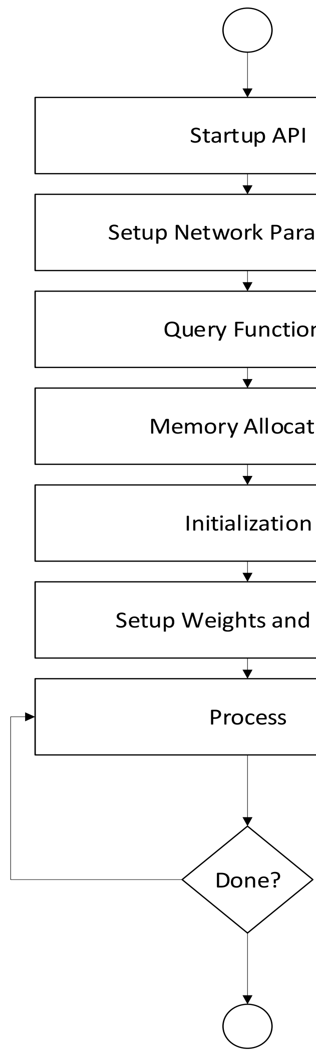

Figure 2-3 NN Layer Flow Overview

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 the memory allocation stages to obtain information about the memory requirements of the library.

Following is the naming convention for query functions:

```
xa_nnlib_<layer>_get_{persistent | scratch}_<placement>
```

Where:

<layer> indicates the module name (such as gru).

<placement> specifies fast or slow.

2.4.3 Initialization Functions

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

Following is the naming convention for initialization functions:

```
xa_nnlib_<layer>_init
```

2.4.4 Execution Functions

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

Following is the naming convention for execution functions:

```
xa_nnlib_<layer>_process
```

3. HiFi 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, simple interface.

The NN library is a single archive containing all low-level kernels and layers 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

These kernels perform the dual matXvec operation with bias addition; that is, `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`.

`bias_shift` and `acc_shift` arguments are provided in the kernel API to adjust 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 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 number of bits applied to the accumulator to obtain the output in desired Q format.

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

`row_stride1` and `row_stride2` arguments are provided in kernel API for row offsets of `mat1` and `mat2`, respectively. Note, input matrices are expected to be appropriately padded in case of `row_stride > cols`.

For conversion from higher precision accumulator to 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 asym8 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 asym8.

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

- `[p]`: Matrix precision in bits
- `[q]`: Vector precision in bits

- `[r]`: Output precision in bits

Precision

There are twelve variants available:

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

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 a 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_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,        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);
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);
```

Arguments

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

Type	Name	Size	Description
const UWORD8 *, const FLOAT32 *			
WORD16 *, WORD8 *, const UWORD8 *, const FLOAT32 *	p_mat2	rows*cols2	Input matrix 2, fixed or floating point, asym8u or sym8s
WORD16 *, WORD8 *, const UWORD8 *, const FLOAT32 *	p_vec1	cols1*1	Input vector 1, fixed or floating point, asym8u or sym8s
WORD16 *, WORD8 *, const UWORD8 *, const FLOAT32 *	p_vec2	cols2*1	Input vector 2, fixed or floating point, asym8u or sym8s
WORD16 *, WORD8 *, const WORD32 *, const FLOAT32 *	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 *, FLOAT32 *	p_out	rows*1	Output, fixed or floating point, asym8u or sym8s

Returns

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

Restrictions

Arguments	Restrictions
`row_stride1, row_stride2, cols1, cols2`	Multiples of 4 (1 for floating point and asym8)
`p_mat1, p_mat2, p_vec1, p_vec2`	Aligned on 4*(size of one element)-byte boundary ((size of one element)-byte only in case of floating point and asym8) Should not overlap
`p_bias, p_out`	Aligned on (size of one element)-byte boundary (for kernels supporting multiple bias precision maximum size of one element should be considered as the alignment requirement) Should not overlap
`p_mat1, p_vec1, p_out`	Cannot be NULL
`p_bias`	Cannot be NULL (except for sym8sxasym8s precision)
`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

These kernels perform the fused dual matXvec operation with an activation function i.e. `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`.

Intermediate output of `(mat1*vec1 + mat2*vec2 + bias)` is stored in temporary memory provided by the `p_scratch` argument to kernel API. Activation function is applied on this intermediate output to get final output. Note, for fixed point kernels, the activation function always takes input in Q6.25 format.

`bias_shift` and `acc_shift` arguments are provided in kernel API to adjust 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 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 matXvec multiplication – accumulation result. `acc_shift` is the shift in number of bits applied to the accumulator to obtain the intermediate output in Q6.25 format.

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

`row_stride1` and `row_stride2` arguments are provided in kernel API for row offsets of `mat1` and `mat2` respectively. Note, input matrices are expected to be appropriately padded in case of `row_stride > cols`.

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

Function variants available are `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

There are eight variants 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

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

In case of 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

Type	Name	Size	Description
`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
`cols1, cols2`	Multiples of 4
`row_stride1, row_stride2`	Multiples of 4 (2 in case of floating point)
`p_mat1, p_mat2, p_vec1, p_vec2, p_out`	Aligned on 8-byte boundary Should not overlap
`p_bias`	Aligned on (size of one element)-byte boundary (for kernels supporting multiple bias precision maximum size of one element should be considered as the alignment requirement) (Aligned on 8-byte for floating point kernels) Should not overlap
`p_scratch`	Cannot be NULL Aligned on 8-byte boundary Should not overlap
`p_mat1, p_vec1, p_bias, p_out`	Cannot be NULL
`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

These 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 resulting output vector sequence `z` have as many number of 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 vectors and output vectors are provided as array of pointers arguments to kernel API.

`bias_shift` and `acc_shift` arguments are provided in kernel API to adjust 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 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 number of bits applied to the accumulator to obtain the output in desired Q format.

Note, `acc_shift` and `bias_shift` are not relevant in case of floating point kernels.

The `row_stride1` argument is provided in kernel API for row offset of `mat1`. Note, input matrix is expected to be appropriately padded in case of `row_stride1 > cols1`.

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

Function variants available are `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

There are five variants 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

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

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

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);
WORD32 xa_nn_matXvec_batch_asym8uxasym8u_asym8u
(UWORD8 ** p_out,          UWORD8 * p_mat1,        UWORD8 ** p_vec1,
 WORD32 * p_bias,          WORD32 rows,            WORD32 cols1,
 WORD32 row_stride1,       WORD32 vec_count,       WORD32 mat1_zero_bias,
 WORD32 vec1_zero_bias,    WORD32 out_multiplier,  WORD32 out_shift,
 WORD32 out_zero_bias);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, UWORD8 *, FLOAT32 *	p_mat1	rows*cols1	Input matrix, fixed or floating point
WORD16 **, WORD8 **, UWORD8 **, FLOAT32 **	p_vec1	cols1*vec_count	Input vector pointers, fixed or floating point
WORD16 *, WORD8 *, WORD32 *, FLOAT32 *	p_bias	rows*1	Bias vector, fixed or floating point

Type	Name	Size	Description
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
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
Output			
WORD32 **, WORD64 **, UWORD8 **, 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	Aligned on 8-byte boundary Should not overlap Cannot be NULL
p_vec1	Aligned on 4-byte boundary Cannot be NULL Should not overlap p_vec1[0] to p_vec[vec_count-1] – Aligned on 4*(size of one element)-byte boundary (8-byte for floating point) Cannot be NULL Should not overlap
p_bias	Aligned on (size of one element)-byte boundary Cannot be NULL Should not overlap
p_out	Aligned on 4-byte boundary Cannot be NULL Should not overlap p_out[0] to p_out[vec_count-1] – Aligned on (size of one element)-byte boundary Cannot be NULL Should not overlap

Arguments	Restrictions
acc_shift, bias_shift, out_shift	{-31, …., 31}
vec_count	Greater than 0
mat1_zero_bias, vec1_zero_bias	{-255, …, 0}
out_multiplier	Greater than 0
out_zero_bias	{0, …, 255}

3.1.4 Matrix Multiplication Kernels

Description

These 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 should be stored in row major order and the second matrix should 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 i.e. the length of each vector in p_mat2. Bias and resulting output vector sequence z have as many numbers of 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 should be equal to cols, out_offset equal to 1 and out_stride should be equal to vec_count i.e. columns of mat2.

The bias_shift and acc_shift arguments are provided in kernel API to adjust 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.

The bias_shift is the shift in 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 desired Q format.

Note, the acc_shift and bias_shift arguments are not relevant in case of floating-point kernels and asymmetric 8-bit kernels.

The row_stride argument indicates the offset to 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 higher precision accumulator to lower precision output, symmetric rounding is used.

The arguments `mat1_zero_bias`, `mat2_zero_bias`, are provided to convert the asym8 inputs into their real values and perform matXvec batch operation. The `out_zero_bias`, `out_multiplier`, and `out_shift` values are used to quantize real values of output back to asym8.

Function variants available are `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 six variants available:

Type	Description
`16x16_16`	16-bit matrix inputs, 16-bit vector inputs, 16-bit output vectors
`8x16_16`	8-bit matrix inputs, 16-bit vector inputs, 16-bit output vectors
`8x8_8`	8-bit matrix inputs, 8-bit vector inputs, 8-bit output vectors
`f32xf32_f32`	float32 matrix inputs, float32 vector inputs, float32 output
`asym8uxasym8u_asym8u`	asym8u matrix inputs, asym8u vector inputs, asym8u output vectors
`per_chan_sym8sxasym8s_asym8s`	per channel quantized sym8s matrix inputs, asym8s vector inputs, asym8s output vectors

Algorithm

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

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

In case of floating-point and asym8 routine, `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_mat21,
 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,          WORD16 * 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 * p_out,         FLOAT32 * p_mat1,        FLOAT32 * p_mat2,
 FLOAT32 * 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_asym8uxasym8u_asym8u
(UWORD8 * p_out,          UWORD8 * p_mat1,         UWORD16 * p_mat2,
 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 mat2_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);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, UWORD8 *, FLOAT32 *	p_mat1	rows*cols	Input matrix, fixed or floating point
WORD16 *, WORD8 *, UWORD8 *, FLOAT32 *	p_mat2	Cols * vec_count	Input matrix, fixed or floating point
WORD16 *, WORD8 *, WORD32 *, FLOAT32 *	p_bias	rows*1	Bias vector, fixed or floating point
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

Type	Name	Size	Description
WORD32	vec_count		Number of input vectors
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 vector 1
WORD32 WORD32 *	out_multiplier, p_out_multiplier		Multiplier value of output, Pointer to output multiplier value
WORD32	out_shift, p_out_shift		Shift value of output, Pointer to output shift value
WORD32	out_zero_bias		Zero offset of output
Output			
WORD16 *, WORD8 *, UWORD8 *, FLOAT32 *	p_out	rows*vec_count	Output matrix, fixed or floating point

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 Cannot be NULL Should not overlap
p_bias	Aligned on (size of one element)-byte boundary
acc_shift, bias_shift, out_shift	{-31, …., 31}
vec_count	Greater than 0
vec_offset, out_offset, out_stride	Should not be 0
mat1_zero_bias, vec1_zero_bias	{-255, …, 0}
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}

3.1.5 Matrix X Vector Kernels with Output Stride

Description

These kernels 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`.

`row_stride1` is provided in kernel API for row offsets of `mat1`. Note, input matrices are expected to be appropriately padded in case of `row_stride > cols`.

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

The argument `out_stride` is helpful in storing 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 matXvec operation. The `out_multiplier` and `out_shift` values are used to convert real values of output to 16-bit.

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

- `[p]`: Matrix precision in bits
- `[q]`: Vector precision in bits
- `[r]`: Output precision in bits

Precision

There is one variant 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

These kernels 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 resulting output vector sequence `z` have as many numbers of 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, 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 row offset of `mat1`. Note, 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.

Function variants available are `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

There is one variant available:

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

Algorithm

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

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

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

Type	Name	Size	Description
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}

3.2 Convolution Kernels

3.2.1 Standard 2D Convolution Kernel

Description

These 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, 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.

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

`bias_shift` and `acc_shift` arguments are provided in kernel API to adjust 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 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 number of bits applied to the accumulator to obtain the output in desired Q format.

Note, `acc_shift` and `bias_shift` arguments are not relevant in case of floating point kernels and asymmetric 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 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).`

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

For the 8x16, 16x16 and the f32 variants 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, and 2 in case of floating-point variant.

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 should be queried using `xa_nn_conv2d_std_getsize()` helper API.

The arguments `input_zero_bias`, `kernel_zero_bias` are provided to convert the asym8 inputs into their real values and perform Standard 2D Convolution operation. The `out_zero_bias`, `out_multiplier`, and `out_shift` values are used to quantize real values of output back to asym8.

These kernels expect input, kernel, and bias cubes in SHAPE_CUBE_DWH_T shape type and can produce 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.

Function variants available are `xa_nn_conv2d_std_[p]`, where:

- [p]: precision in bits

Precision

There are six 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

Algorithm

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

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

In case of floating point and asym8 kernel, `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_channels,WORD32 kernel_height,
 WORD32 kernel_width,       WORD32 y_stride,      WORD32 y_padding,
 WORD32 out_height,         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,       FLOAT32 * p_inp,          FLOAT32 * p_ker,
 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_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 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_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);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, const UWORD8 *, const FLOAT32 *,	p_inp	input_height* input width* input_channels	Input cube, fixed, floating point, asym8u or asym8s, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, const UWORD8 *, const FLOAT32 *,	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 *, const WORD32 *, FLOAT32 *,	p_bias	out_channels	Bias vector, fixed or floating point
WORD32	input_height		Input height

Type	Name	Size	Description
`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_conv2d_std_getsize()`	Scratch memory pointer
Output			
`WORD16 *, WORD8 *, const UWORD8 *, FLOAT32 *,`	`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
	Should not overlap
	Aligned on 8-byte boundary (p_bias needs to be only 4-byte aligned for asym8 variant)
	For `p_scratch` – memory size >= size returned by `xa_nn_conv2d_std_getsize()`

Arguments	Restrictions
p_out, p_inp, p_bias	Cannot be NULL
	Should not overlap
	Aligned on (size of one element)-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	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
acc_shift,bias_shift, out_shift	{-31 …. 31} for fixed point APIs
input_zero_bias, kernel_zero_bias	{-255, …, 0}
out_multiplier	Greater than 0
out_zero_bias	{0 ..., 255}
out_data_format	Can be 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T

3.2.2 Standard 2D Convolution Kernel with Dilation

Description

These kernels 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 `out_channels` number of such 3D kernels, 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.

`bias_shift` and `acc_shift` arguments are provided in kernel API to adjust 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 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 number of bits applied to the accumulator to obtain the output in desired 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_padding = kernel_width_dilation + (out_width - 1) * x_stride - (x_padding + input_width)`.

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

For conversion from higher precision accumulator to 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 should 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 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.

Precision

Type	Description
`per_chan_sym8sxasym8s`	per channel quantized sym8s kernel, asym8s input, asym8s output

Algorithm

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

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

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,        WORD32 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);
```

Arguments

Type	Name	Size	Description
Input			
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

Type	Name	Size	Description
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
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
	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

Arguments	Restrictions
`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 Kernel

Description

These 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 `out_channels` number of such 3D kernels, 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 input and kernel must be identical, and width dimension (`input_width`) of input and kernel also must be identical for 1D convolution.

`bias_shift` and `acc_shift` arguments are provided in kernel API to adjust 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 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 number of bits applied to the accumulator to obtain the output in desired Q format.

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

The `y_stride` argument to kernel API defines the step size of the kernel when traversing the input in 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_padding = kernel_height + (out_height – 1) * y_stride – (y_padding + input_height).`

For conversion from higher precision accumulator to 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 case of floating-point variant.

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 should be queried using `xa_nn_conv1d_std_getsize()` helper API.

The arguments `input_zero_bias, kernel_zero_bias` are provided to convert the asym8 inputs into their real values and perform Standard 1D Convolution operation. The `out_zero_bias, out_multiplier` and `out_shift` values are used to quantize real values of output back to asym8.

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

Function variants available are `xa_nn_conv1d_std_[p]`, where:

- `[p]`: precision in bits

Precision

There are five 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

Algorithm

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

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

In case of floating-point and asym8 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);
WORD32 xa_nn_conv1d_std_asym8uxasym8u
(UWORD8* p_out,           UWORD8* p_inp,        UWORD8* p_kernel,
 WORD32* 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 input_zero_bias,  WORD32 kernel_zero_bias, WORD32 out_multiplier,
 WORD32 out_shift,        WORD32 out_zero_bias,    WORD32 out_data_format,
 VOID *p_scratch);
```

Arguments

Type	Name	Size	Description
Input			
`WORD16 *,` `WORD8 *,` `const UWORD8 *,` `FLOAT32 *,`	`p_inp`	`input_height* input width* input_channels`	Input cube, fixed or floating point, in SHAPE_CUBE_DWH_T
`WORD16 *,` `WORD8 *,` `const UWORD8 *,` `FLOAT32 *,`	`p_ker`	`out_channels* (kernel_height* input width* input_channels)`	Kernel cube, fixed or floating point, in SHAPE_CUBE_DWH_T

Type	Name	Size	Description
WORD16 *, WORD8 *, const WORD32 *, 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	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 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 *, const UWORD8 *, 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 8-byte boundary
	For p_scratch – memory size >= size returned by xa_nn_conv1d_std_getsize()

Arguments	Restrictions
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, out_shift	{-31 …. 31} for fixed point APIs
input_zero_bias, kernel_zero_bias	{-255, …., 0}
out_multiplier	Greater than 0
out_zero_bias	{0, ..., 255}
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 Kernel

Depthwise Separable 2D Convolution is computed in two steps using 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 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 output cube (`out_height x out_width x (channels_multiplier * input_channels)`) of 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, 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`.

Note, for depthwise separable 2D convolution, (`channels_multiplier * input_channels`) must be multiple of 4 (see Section 3.2.4.2 for details).

Following are the descriptions for these two low level kernels.

3.2.4.1 Depthwise 2D Convolution Kernel

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 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`).

`bias_shift` and `acc_shift` arguments are provided in kernel API to adjust 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 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 number of bits applied to the accumulator to obtain the output in desired Q format.

Note, `acc_shift` and `bias_shift` arguments are not relevant in case of floating-point kernels and asymmetric 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_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)`.

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

These kernels require a temporary buffer for convolution computation. This temporary buffer is provided by the `p_scratch` argument of kernel API. The size of temporary buffer should be queried using `xa_nn_conv2d_depthwise_getsize()` helper API.

The arguments `input_zero_bias`, `kernel_zero_bias` are provided to convert the asym8 inputs into their real values and perform Depthwise 2D Convolution operation. The `out_zero_bias`, `out_multiplier`, and `out_shift` values are used to quantize real values of output back to asym8.

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 type 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 output cube shape.

Function variants available are `xa_nn_conv2d_depthwise_[p]`, where:

- `[p]`: precision in bits

Precision

There are six 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

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 and asym8 kernel, `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_width,         WORD32 kernel_height,  WORD32 kernel_width,
 WORD32 x_stride,            WORD32 y_stride        WORD32 x_padding,
 WORD32 output_width,        WORD32 circ_buf_bytewidth);
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 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 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 out_data_format,     VOID   * p_scratch);
WORD32 xa_nn_conv2d_depthwise_f32
(FLOAT32 * p_out,            FLOAT32 * p_ker,         FLOAT32 * p_inp,
 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 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);
```

Arguments

Type	Name	Size	Description
Input			
const WORD16 *, const WORD8 *, const UWORD8 *, const FLOAT32 *,	p_ker	kernel_height* kernel width* input_channels* channels_multiplier	Kernel cube, fixed or floating point, asym8u or sym8s, in SHAPE_CUBE_DWH or SHAPE_CUBE_WHD_T
const WORD16 *, const WORD8 *, const UWORD8 *, const FLOAT32 *,	p_inp	input_height* input width* input_channels	Input cube, fixed or floating point, asym8u or asym8s in SHAPE_CUBE_DWH or SHAPE_CUBE_WHD_T
const WORD16 *, const WORD8 *, const WORD32 *, const FLOAT32 *,	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
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

Type	Name	Size	Description
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
Output			
WORD16 *, WORD8 *, const UWORD8 *, FLOAT32 *,	p_out	out_height* out width* input_channels* channels_multiplier	Output cube, fixed or floating point, asym8u or asym8s, in SHAPE_CUBE_DWH_T

Returns

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

Restrictions

Arguments	Restrictions
p_kernel, p_inp	Cannot be NULL
	Should not overlap
	Aligned on 8-byte boundary
p_out, p_bias	Cannot be NULL
	Should not overlap
	Aligned on (size of one element)-byte boundary
p_scratch	Cannot be NULL
	Should not overlap
	Aligned on 8-byte boundary
	memory size >= size returned by xa_nn_conv2d_depthwise_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}
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

Arguments	Restrictions
acc_shift,bias_shift, out_shift	{-31 …. 31} for fixed point APIs
input_zero_bias	{-255,….., 0} for asym8u input, {-127….., 128} for asym8s input
Kernel_zero_bias	{-255……, 0} for asym8u kernel
out_multiplier	Greater than 0
out_zero_bias	{0,........,255} for asym8u output, {-128….., 127} for asym8s output
inp_data_format	can be 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T
out_data_format	must be 0: SHAPE_CUBE_DWH_T

3.2.4.2 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, 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 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 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 number of bits applied to the accumulator to obtain the output in desired Q format.

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

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

The arguments `input_zero_bias`, `kernel_zero_bias` are provided to convert the asym8 inputs into their real values and perform Pointwise 2D Convolution operation. The `out_zero_bias`, `out_multiplier`, and `out_shift` values are used to quantize real values of output back to asym8.

The pointwise kernels expect input cube in SHAPE_CUBE_DWH_T shape type, kernel as matrix, bias as vector and produce output cube in SHAPE_CUBE_DWH_T or SHAPE_CUBE_WHD_T shape type as per the `out_data_format` argument value 0 or 1 to kernel API.

Function variants available are `xa_nn_conv2d_pointwise_[p]`, where:

- `[p]`: precision in bits

Precision

There are six 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
`sym8xasym8`	sym8s kernel, asym8s input, asym8s 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 and asym8 kernel, `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,            FLOAT32 * p_ker,       FLOAT32 *  p_inp,
 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
(pUWORD8 p_out               pUWORD8 p_kernel,     pUWORD8 p_inp,
 pWORD32 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);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *, const UWORD8 *, const WORD8 *	p_ker	out_channels * input_channels	Kernel matrix, fixed or floating point
WORD16 *, WORD8 *, FLOAT32 *, const UWORD8 *, const WORD8 *	p_inp	input_height* input width* input_channels	Input cube, fixed or floating point, 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	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_biast		Zero offset of output
WORD32	out_data_format		Output data format 0:SHAPE_CUBE_DWH_T 1:SHAPE_CUBE_WHD_T
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
input_height, input_width	Greater than or equal to 1
input_channels, out_channels	Greater than or equal to 1
acc_shift, bias_shift	{-31 …. 31} for fixed point APIs
input_zero_bias, kernel_zero_bias	{-255, …, 0}
out_multiplier	Greater than 0
out_zero_bias	{0,........,255}
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

These kernels perform the sigmoid operation on input vector `x` and give 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 give output in Q15 (16-bit) format.

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

The 16-bit fixed point variant and the quantized 8-bit variants of sigmoid are based on TensorFlow implementations.

The `input_range_radius` argument for quantized 8-bit variants 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_sigmoid_[p]_[q]`, where:

- `[p]`: Input precision in bits

- `[q]`: Output precision in bits

Precision

There are seven variants available.

Type	Description
32_32	32-bit input, 32-bit output
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
asym8uxasym8u	asym8u input, asym8u output
asym8sxasym8s	asym8s input, asym8s 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_32
(WORD32 * p_out,            const WORD32 * p_vec,    WORD32 vec_length);
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);
```

Arguments

Type	Name	Size	Description
Input			
const WORD32 *, const WORD16 *, const UWORD8 *, const FLOAT32 *, const WORD8 *	p_vec	vec_length	Input vector, Q6.25, Q3.12, floating point, asym8u or asym8s

Type	Name	Size	Description
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 or asym8s

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 asym8u [-128, 127] for asym8s
input_range_radius	[0, 255]
input_left_shift	[-31, 31]
input_multiplier	Should not be less than 0.
vec_length	Greater than 0

3.3.2 Tanh

Description

These kernels perform the hyperbolic tangent operation on input vector `x` and give 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`), output is given in Q15 (16-bit) format.

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

The 16-bit fixed point variant and the quantized 8-bit variants of tanh are based on TensorFlow implementations.

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 six variants available:

Type	Description
32_32	32-bit input, 32-bit output
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
asym8sxasym8s	asym8s input, asym8s output

Algorithm

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

Prototype

```
WORD32 xa_nn_vec_tanh_32_32
(WORD32 * p_out,            const WORD32 * p_vec,    WORD32 vec_length);
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);
```

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 or asym8s
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 or asym8s

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	[0, 255]
input_multiplier	Should not be less than 0
vec_length	Greater than 0
integer_bits	[0, 6]

3.3.3 Rectifier Linear Unit (ReLU)

Description

These kernels compute the rectifier linear unit function of input vector `x` and give 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 gives 32-bit output in Q16.15 format.

The `threshold` argument to `relu` kernel API allows to set upper threshold for proper compression of 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
`32_32`	32-bit input, 32-bit output
`f32_f32`	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

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

K represents `threshold`

Prototype

```
WORD32 xa_nn_vec_relu_32_32
(WORD32 * p_out,     const WORD32 * p_vec,    WORD32 threshold,
 WORD32 vec_length);
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_32_32
(WORD32 * p_out,      const WORD32 * p_vec,   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_32_32
(WORD32 * p_out,      const WORD32 * 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_multiplier		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
WORD32 FLOAT32	threshold		threshold, fixed or floating point

Type	Name	Size	Description
WORD16 WORD8			
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

These kernels compute the Softmax (normalized exponential function) of input vector `x` and give 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 and asym8s kernels, both the input and output are of the same precision.

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

- `[p]`: Input precision in bits
- `[q]`: Output precision in bits

Precision

There are four variants available:

Type	Description
`32_32`	32-bit input, 32-bit output
`f32_f32`	float32 input, float32 output
`asym8u_asym8u`	asym8u input, asym8u output
`asym8s_asym8s`	asym8s input, asym8s output

Algorithm

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

Prototype

```
WORD32 xa_nn_vec_softmax_32_32
(WORD32 * p_out,               const WORD32 * p_vec,   WORD32 vec_length);
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);
```

Arguments

Type	Name	Size	Description
Input			
`const WORD32 *, const UWORD8 *, const FLOAT32 *`	`p_vec`	`vec_length`	Input vector, Q6.25, floating point, 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 *, UWORD8 *, FLOAT32 *`	`p_out`	`vec_length`	Output vector, Q16.15, floating point, asym8u or asym8s
Temporary			
`VOID *, FLOAT32 *`	`p_scratch`		Scratch (temporary) memory pointer

Returns

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

Restrictions

Arguments	Restrictions
Input_left_shift	{-31, … ,31}
input_multiplier	Greater than zero
vec_length	Greater than Zero
`p_vec, p_out`	Should not overlap
	Cannot be NULL

3.3.5 Activation Min Max

Description

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

The routine accepts asym8u or float32 input and gives asym8u or float32 output.

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

There are four variants 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 lower threshold.

activation–max represents 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 or fixed point.
WORD32, FLOAT32	activation_max		Upper threshold value, floating-point 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

These kernels compute the hard-swish function of input vector `x` and give 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

There is one variant 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_multiplier		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

These kernels compute the Parametric ReLU function of input vector `x` and give 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

There is one variant available:

Type	Description
`asym8s_asym8s`	asym8s input, asym8s 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 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_multiplier		Fixed-point multiplier value for alpha input.
WORD32	alpha_shift		Shift value for alpha input.
WORD16	out_multiplier		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

These kernels compute the Leaky ReLU function of input vector `x` and give 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

There is one variant available:

Type	Description
`asym8s_asym8s`	asym8s input, asym8s 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);
```

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`	`alpha_multiplier`		Fixed-point multiplier value for alpha input.
`WORD32`	`alpha_shift`		Shift value for alpha input.

Type	Name	Size	Description
WORD16	out_multiplier		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	{-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}

3.4 Pooling Kernels

3.4.1 Average Pool Kernel

Description

These kernels compute 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 pooling region is covering input plane then only average of those elements is calculated and the denominator is the number of elements from input in current pooling region.

The average pool kernels accept input as 8-bit, 16-bit integer, asym8 or single precision floating point format and give output in same precision as input.

These kernels require temporary buffer for average pool computation. This temporary buffer is provided by the `p_scratch` argument of kernel API. The size of temporary buffer should be queried using `xa_nn_avgpool_getsize()` helper API.

The average pool 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 and SHAPE_CUBE_WHD_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

There are four variants 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

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

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

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			
WORD8 *, 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			

Type	Name	Size	Description
WORD8 *, WORD16 *, UWORD8 *, FLOAT32 *	p_out	out_height * out_width * input_channels	Output
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
	Aligned on 8-byte boundary
	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 Kernel

Description

These kernels perform 2D max pooling operation over a set of input planes x and give 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 8-bit, 16-bit integer, or single precision floating point format and give output in the same precision as input.

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

The max pool 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 and SHAPE_CUBE_WHD_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 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

There are four variants 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

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

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,           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_maxpool_16
(WORD16 * p_out,          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_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 inp_data_format, 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			
WORD8 *, 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

Type	Name	Size	Description
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
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
p_scratch	Cannot be NULL
	Aligned on 8-byte boundary
	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 Kernel

Description

These kernels perform the operation of multiplication of weight matrix with input vectors in a fully connected neural network layer i.e. `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 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 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 number of bits applied to the accumulator to obtain the output in desired Q format.

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

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

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

The arguments `input_zero_bias`, `weight_zero_bias` are provided to convert the asym8 inputs into their real values and perform Fully Connected kernel operation. The `out_zero_bias`, `out_multiplier`, and `out_shift` values are used to quantize real values of output back to asym8.

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 six variants available:

Type	Description
`16x16_16`	16-bit matrix inputs, 16-bit vector inputs, 16-bit output
`8x16_16`	8-bit matrix inputs, 16-bit vector inputs, 16-bit output
`8x8_8`	8-bit matrix inputs, 8-bit vector inputs, 8-bit output
`f32`	float32 matrix inputs, float32 vector inputs, float32 output
`asym8uxasym8u_asym8u`	asym8u matrix inputs, asym8u vector inputs, asym8u output
`sym8sxasym8s_asym8s`	sym8s weight matrix, asym8s input vector, asym8s output

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 asym8 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);
```

Arguments

Type	Name	Size	Description
Input			
`WORD16 *, WORD8 *, const UWORD8 *, const FLOAT32 *`	`p_weight`	`out_depth* weight_depth`	Weight matrix, fixed, floating point, asym8u or sym8s
`WORD16 *, WORD8 *, const UWORD8 *, const FLOAT32 *`	`p_inp`	`weight_depth* 1`	Input vector, fixed, floating point, asym8u or asym8s

Type	Name	Size	Description
WORD16 *, WORD8 *, const WORD32 *, const FLOAT32 *	p_bias	out_depth*1	Bias vector, fixed or floating point
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
Output			
WORD8 *, WORD16 *, UWORD8 *, FLOAT32 *	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 (1 in case of floating point and asym8)
p_weight, p_inp, p_out	Aligned on 8-byte boundary (Aligned on (size of one element)-byte boundary for floating point and asym8)
	Should not overlap
	Cannot be NULL
p_bias	Cannot be NULL (except for sym8sxasym8s precision)
out_depth	Greater than or equal to 1
acc_shift, bias_shift, out_shift	{-31, ….,31}
input_zero_bias	{-255, ….,0} for asym8u, {-127, ….,128} for asym8s
weight_zero_bias	{-255, ….,0}
out_multiplier	Greater than 0
out_zero_bias	{-255, ….,0} for asym8u, {-127, ….,128} for asym8s

3.6 Basic Operations and Miscellaneous Kernels

3.6.1 Interpolation Kernel

Description

This 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 Elementwise Requantize Kernels

Description

These kernels perform the requantization operation of the `p_inp1` input vector elements to get the output vector `p_out`. 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)

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

Precision

Type	Description
asym8s_asym32s	asym8s input, asym32s output
asym16s_asym8s	asym16s input, asym8s output
asym16s_asym32s	asym16s input, asym32s output

Prototype

```
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_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_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);
```

Arguments

Type	Name	Size	Description
Input			
const WORD16 *, const WORD8 *	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 *, 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	{-32768….,32767} for inp type asym16s {-128,….,127} for inp type asym8s
out_zero_bias	{-128….,127} for out type asym8s Signed 32-bit integer value for out type asym32s

3.6.3 Elementwise Dequantize Kernels

Description

These kernels perform the dequantization operation of the `p_inp1` input vector elements to get the output vector `p_out`. 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

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);
```

Arguments

Type	Name	Size	Description
Input			
`const WORD8 *`	`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

3.6.4 Elementwise Comparison Kernels

Description

These 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 requires 1-byte space. The supported precisions are: asym8s.

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

- `[o]`: Operations: `elm_equal, elm_notequal, elm_greater, elm_greaterequal, elm_less, elm_lessequal`
- `[p]`: Input Precision in bits- input1xinput2

Precision

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

Algorithm

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

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);
```

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.
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}

3.6.5 Basic Kernels

Description

These 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 and inverse square-root. The supported precisions are: 8-bit, float32 and asym8s.

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

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
- [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
asym8sxasym8s_asym8s	2 asym8s inputs, asym8s output

Algorithm

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

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

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

elm_floor: $z_n = \lfloor x_n \rfloor$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$

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

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

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

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

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

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

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

elm_round[6]: $z_n = \mathrm{round}(x_n)$, $n = 0 \ldots, \overline{num\text{-}elm - 1}$

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

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

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

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

x_n represents first input, y_n represents second input.

z_n represents output.

Prototype

```
WORD32 xa_nn_elm_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,
 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_min_8x8_8
```

[6] The round variant is banker's rounding. It is also called as "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

```
(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_add_f32xf32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp1,
const FLOAT32 * __restrict__ p_inp2, WORD32  num_elm);

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_rsqrt_f32_f32
(FLOAT32 * __restrict__ p_out,  const FLOAT32 * __restrict__ p_inp,   WORD32  num_elm);
```

Arguments

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

Type	Name	Size	Description
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.
Output			
WORD8 * FLOAT32 *	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 …. 31} for fixed point and quantized 8-bit APIs
left_shift	{0 …. 31}
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

3.6.6 Basic Kernels with Broadcasting

Description

These kernels 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 be have their shapes extended[4.1] 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

$$p\text{-}out[i_0][i_1]\ldots[i_N] =$$
$$[op](\,p\text{-}in1(\,[i_0\ i_1\ \ldots\ i_N]\cdot[s1_0\ s1_1\ \ldots\ s1_N])\ ,\ p\text{-}in2(\,[i_0\ i_1\ \ldots\ i_N]\cdot[s2_0\ s2_1\ \ldots\ s2_N]\,))$$

Where,

- $i_n \in (0\ \text{out\_extents}[n]]$, and, $n \in (0\ \ 4]$ for 4D tensors, or,
  $(0\ \ 8]$ for 8D Tensors
- $s1_n = \text{in1\_strides}[n]$, with n defined the same as above
- $s2_n = \text{in2\_strides}[n]$, 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` `p_out`	Aligned on byte boundary Cannot be NULL
`out_extents, in1_strides, in2_strides`	Positive integers

3.6.7 Elementwise Logical Kernels

Description

These 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 requires 1-byte space each. The supported precisions are: 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 first input, y_n represents 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

3.6.8 Reduce Kernels

Description

These 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. 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 should 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 same. Thus, the API does not include quantization specific multiplier, shift and zero bias arguments. For the dimensions mentioned in the axis vector, 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, mean operation is carried out thereby reducing the dimension size to 1.

Note The total number of elements in axis dimensions i.e. the values which are to be reduced should not be more than 127 for the reduce_mean kernel.

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 should be queried using `xa_nn_reduce_getsize_nhwc()` helper API. The `reduce_ops` argument accepts an enumerator that will state 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 dimentions: `4D`
- `[p]`: Input Precision in bits- `input_output`

Precision

Type	Description
`asym8s_asym8s`	asym8s input, asym8s output

Algorithm

Reduce Max:

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

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

Where,

- The values of output dimensions(N, H, W, C) if reduced will be equal to 1
- $\boldsymbol{r} \in$ 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:

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

- Then, we compute the mean

  $$Z_{N,H,W,C} = \frac{1}{\prod nElem_r} S_{N,H,W,C}$$

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 .

- r_i and r_j are the elements in the input shape along the r dimension.
- $\Pi\, nElem_r$ is the product of number of elements in every r dimension.

$S_{N,H,W,C}$ 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_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);
```

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 *	p_inp	Product of all dims in p_inp_shape	Input vector, asym8s
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			

Type	Name	Size	Description
WORD8 *	p_out	Product of all dims in p_out_shape	Output vector, asym8s

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 should be between 0 and (num_inp_dims – 1).
p_inp_shape,p_out_shape	The shape values should be greater than 0.
p_out_shape	The output length i.e the product of all the shape values must be <= 127.
inp_zero_bias out_zero_bias	{-128….,127} for asym8s
out_multiplier	Greater than 0
out_shift	{-31, …, 31}

3.6.9 Broadcast Kernel

Description

This kernel broadcasts 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 at 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 3-1 shows a simple illustration for broadcasting a 1x4x1 tensor into 1x4x3 and 2x4x3.

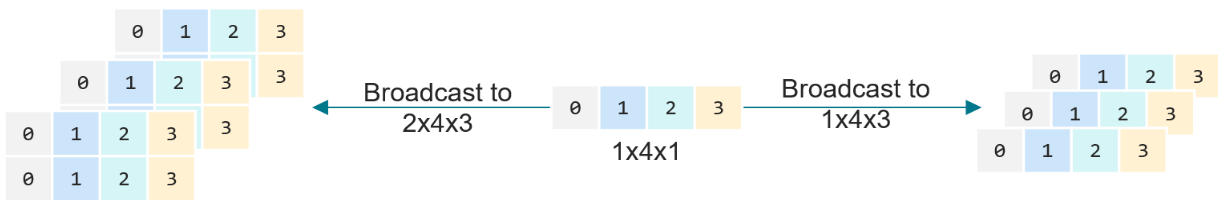

Figure 3-1 Broadcasting a 1x4x1 Tensor to 1x4x3 and 2x4x3

Precision

Type	Description
8_8	8-bit input, 8-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);
```

Arguments

Type	Name	Size	Description
Input			
const WORD8 *	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 *	p_out	$\prod_{i=0}^{i=num\text{-}dims-1} out\text{-}shape[i]$	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 should be greater than zero

Arguments	Restrictions
	inp_shape[i] should be either equal to out_shape[i] or 1 for i = [0, numDims-1]
`num_dims`	In the range [1, 8]

3.6.10 Memory Operation Kernels

Description

These kernels perform basic memory related operations. The supported precision for memmove are 8-bit and 16-bit. For memset, it is float32.

Memmove kernel does element level transfer and accepts pointers to 8/16-bit input/output memory locations and `num_elm` should be set to the number of elements to be transferred.

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

- `[o]`: Operations: `memmove, memset`
- `[p]`: Input Precision in bits
- `[q]`: Output Precision in bits. (If `[q]` is absent, output precision is the same as `[p]`)

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

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

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, psrc	num_elm or n	First input vector
FLOAT32	val		Memset value
WORD32	num_elm, n		Number of elements
Output			
FLOAT32 * void *	p_out, pdst	num_elm or n	Output vector

Returns

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

Restrictions:

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

3.6.11 Dot Product Kernels

Description

These kernels perform the dot product operations between two sets of input vectors `p_inp1` and `p_inp2` to get output vector `p_out`. The supported precisions are: f32xf32_f32 and 16x16_asym8s.

Function variants available are `xa_nn_elm_quantize_[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

Prototype

```
WORD32 xa_nn_dot_prod_f32xf32_f32(FLOAT32 * __restrict__ p_out,
    const FLOAT32 * __restrict__ p_inp1, const FLOAT32 * __restrict__ p_inp2,
    WORD32 vec_length, WORD32 num_vecs);
WORD32 xa_nn_dot_prod_16x16_asym8s(WORD8 * __restrict__ p_out,
    const WORD16 * __restrict__ p_inp1_start,
    const WORD16 * __restrict__ p_inp2_start,
    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	
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 vectors in each input
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

3.7 Normalization Kernels

3.7.1 L2 Normalization Kernel

Description

This kernel performs L2 normalization of an input vector `x` to get output vector `z`, which 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.

Precision

Type	Description
`f32`	float32 input, float32 output
`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_f32
 (FLOAT32 * p_out,  const FLOAT32 * p_inp,                    WORD32 num_elm);

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 FLOAT32 *,` `const WORD8 *`	`p_inp`	`num_elm`	Input vector
`WORD32`	`zero_point`		Zero point
`WORD32`	`num_elm`		Number of elements
Output			
`WORD16 *`	`p_out`	`num_elm`	Output vector

Returns

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

Restrictions

Arguments	Restrictions
`p_inp, p_out`	Aligned on input element size boundary
	Should not overlap
	Cannot be NULL
`num_elm`	Greater than 0
`zero_point`	{-128….., 127}

3.8 Reorg Kernels

3.8.1 Depth to Space Kernels

Description

These kernels convert 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 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 3-2.

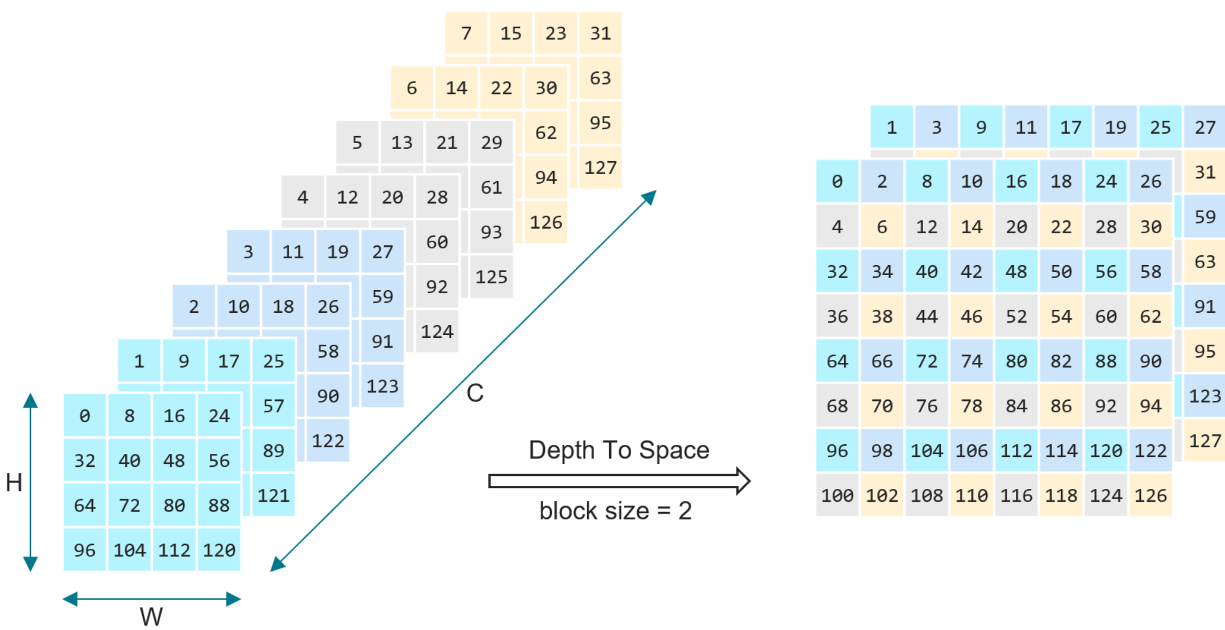

Figure 3-2 Depth to Space Conversion for 4x4x8 Input with Block Size of 2

Given an input cube of shape HxWxC and a `block_size` of K, this kernel will output cube of dimensions HKxWKxC/K^2. The specified output shape i.e `out_height/width/channels` must therefore equal HK, WK, and C/K^2 respectively.

Because the elements collected from one dimension must be spread across two, the input depth dimension C (i.e. `input_channels`) must be divisible by K^2 (i.e. `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

These 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 kernel]s which is illustrated in Figure 3-3.

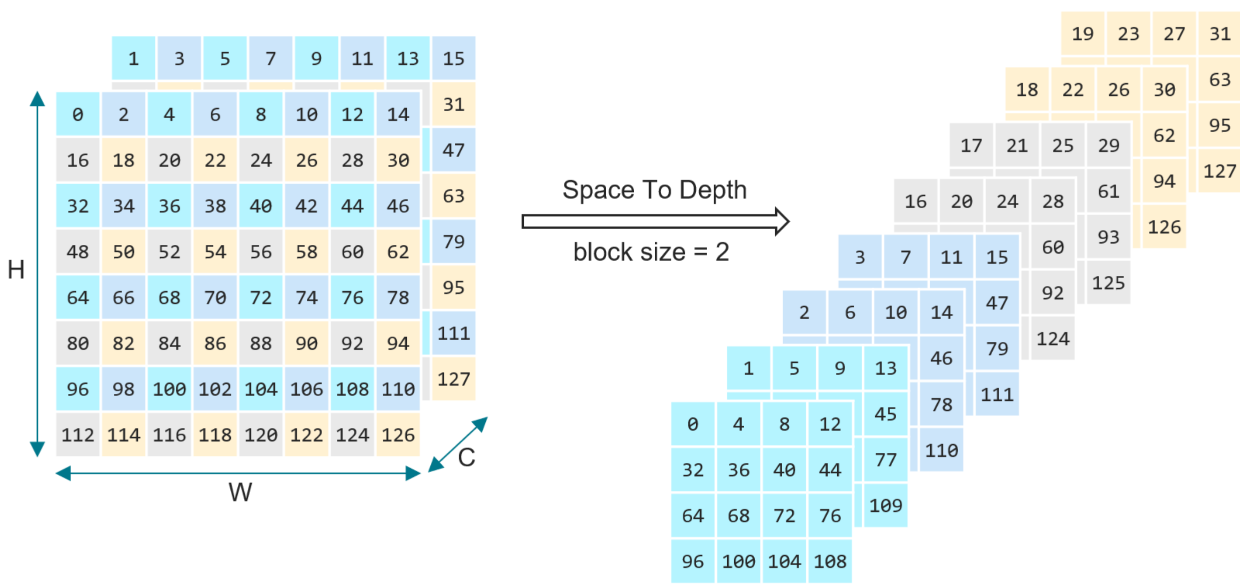

Figure 3-3 Space to Depth Conversion for a 8x8x2 Input with a Block Size of 2

Given an input of shape HxWxC with a block_size of K, this kernel will collect KxKxC elements from the input cube and serialize 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 in 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 Kernel

Description

This kernel pads an input with 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 will contain a pair of values which will 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 will be scaled up to 4D. Output dimension must be equal to input dimension. Size of p_pad_values should be exactly (2 * input_dimensions). The value to be padded can be given through pad_value.

Naming convention used for pad kernel is:

xa_nn_pad_[p]

Where [p] = [input_precision]_[out_precision]

Precision

Type	Description
8_8	Signed 8-bit input, signed 8-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 will be:

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);
```

Arguments

Type	Name	Size	Description
Input			
`const WORD32 *const`	`p_out_shape`	`num_out_dims`	Shape of output
`const WORD8 *`	`p_inp`	$\prod_{i=0}^{i=num\text{-}inp\text{-}dims-1} p\text{-}inp\text{-}shape[i]$	Input (set of cubes)
`const WORD32 *const`	`p_inp_shape`	`num_inp_dims`	Shape of input
`const WORD32 *`	`p_pad_values`	$\prod_{i=0}^{i=num\text{-}pad\text{-}dims-1} p\text{-}pad\text{-}shape[i]$	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 *`	`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
	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 should be greater than zero
p_pad_values	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements should 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

These kernels performs 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, 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 `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.

Naming convention used for batch_to_space_nd kernels is:

`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.

Refer to Figure 3-4 for visualization of batch to space conversion.

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`	$\prod_{i=0}^{i=num\text{-}inp\text{-}dims-1} p\text{-}inp\text{-}shape[i]$	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.

Type	Name	Size	Description
`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`	$\prod_{i=0}^{i=num\text{-}out\text{-}dims-1} p\text{-}out\text{-}shape[i]$	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
	Should not overlap
`p_out_shape, p_inp_shape`	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap
	All elements should be greater than zero
	p_out_shape[num_out_dims – 1] == p_inp_shape[num_inp_dims – 1] (depth for input and output should be equal.
`p_block_sizes`	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements should be greater than zero
	p_inp_shape[0] == p_out_shape[0]*p_block_sizes[0]*p_block_sizes[1][7]
`p_crop_sizes`	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements should be greater than or equal to zero
`num_out_dims`	Must be equal to 4
`num_inp_dims`	Must be in range {3, 4}

[7] 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]

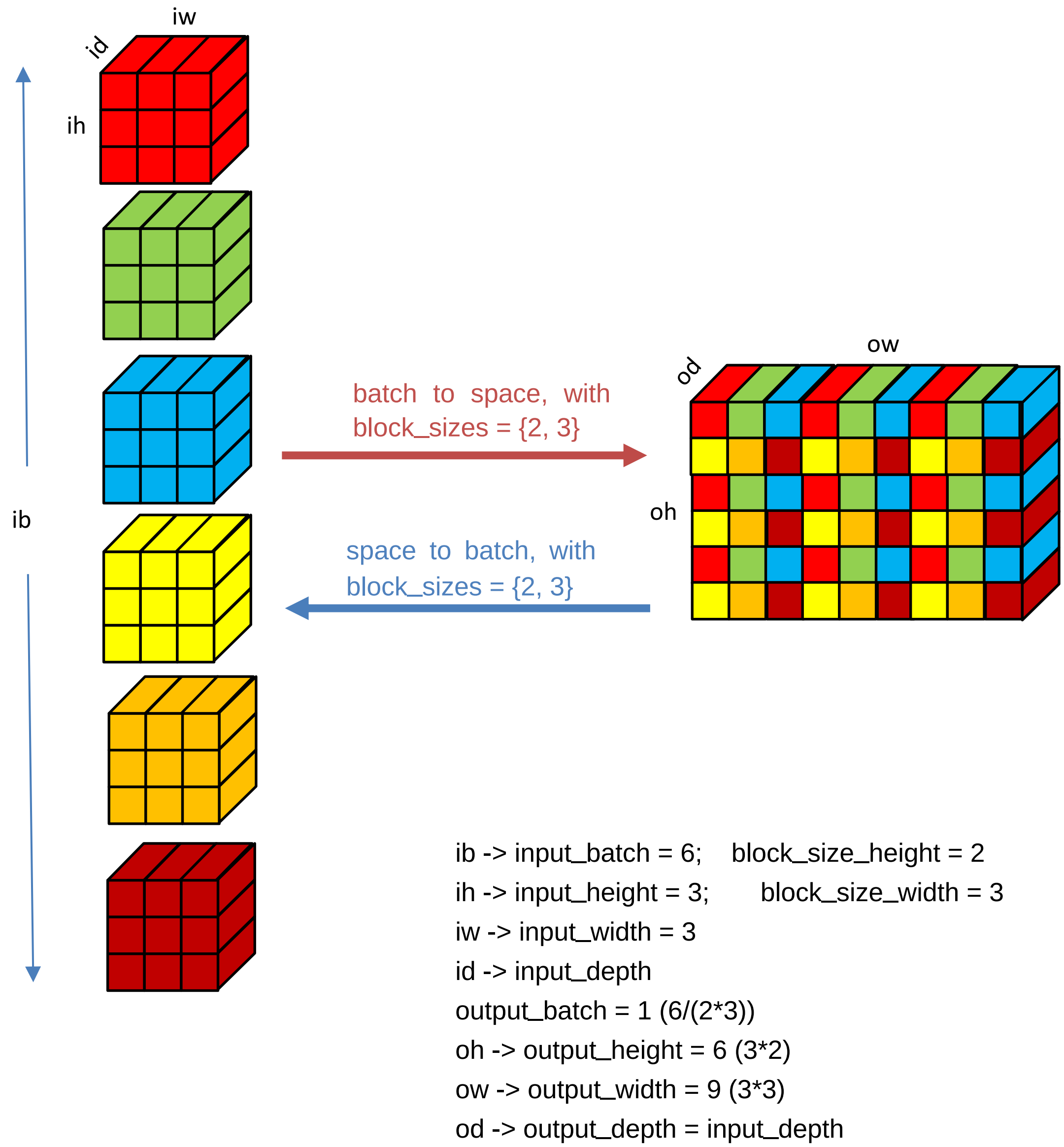

Figure 3-4 batch_to_space and space to batch Conversion

For simplicity, crop_sizes and pad_sizes are assumed to be 0.

3.8.5 Space to Batch Kernels

Description

These kernels performs space to batch 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 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 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, 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`.

Naming convention used for space_to_batch_nd kernels is:

`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 3-4 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	$\prod_{i=0}^{i=num\text{-}inp\text{-}dims-1} p\text{-}inp\text{-}shape[i]$	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	$\prod_{i=0}^{i=num\text{-}out\text{-}dims-1} p\text{-}out\text{-}shape[i]$	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
	Should not overlap
p_out_shape, p_inp_shape	Aligned on 4-byte boundary
	Cannot be NULL

Arguments	Restrictions
	Should not overlap
	All elements should be greater than zero
	p_out_shape[num_out_dims – 1] == p_inp_shape[num_inp_dims – 1] (depth for input and output should be equal.
`p_block_sizes`	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements should be greater than zero
	p_out_shape[0] == p_inp_shape[0]*p_block_sizes[0]*p_block_sizes[1][8]
`p_pad_sizes`	Aligned on 4-byte boundary
	Cannot be NULL
	Should not overlap with other buffers
	All elements should 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]

[8] 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]

4. HiFi 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 [1]:

$$
\begin{aligned}
&z_t = sigmoid(W_z * \ x_t + U_z * prev\text{-}h + b_z)\\
&r_t = sigmoid(W_r * x_t + U_r * \ prev\text{-}h + b_r)\\
&g = \tanh(W_h * x_t + U_h * (r_t \cdot prev\text{-}h) + b_h)\\
&y_t = \ h_t = z_t \cdot g + (1 - z_t) \cdot prev\text{-}h\\
&prev\text{-}h = h_t
\end{aligned}
$$

x_t : input vector
$y_t, \ h_t$: output vector
W, U : weight matrices
$prev\text{-}h$: previous output vector

z_t : update gate vector
r_t : reset gate vector
b : bias vectors

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[9]

  Number of input features is not supported

- XA_NNLIB_GRU_CONFIG_FATAL_INVALID_OUT_FEATS

  Number of output features is not supported

[9] FEATS := features

- 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 should be 0 or 1.
- XA_NNLIB_GRU_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_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

4.1.3 API Functions Specific to GRU

4.1.3.1 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 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_IN_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_IN_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

4.1.3.2 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 put the desired values in prev_h by using set config XA_NNLIB_GRU_RESTORE_CONTEXT (refer to Table 4-11 for more information).
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 that 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_IN_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.

4.1.3.3 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. Input buffer contains input data. Required alignment: 8 bytes. Output: `output` A pointer to the output buffer. Output is written to 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.

<table>
<tr><td></td><td>

XA_NNLIB_FATAL_INVALID_SHAPE
Either input or output shape is invalid.
XA_NNLIB_GRU_EXECUTE_FATAL_INSUFFICIENT_DATA
Input data passed in insufficient.
XA_NNLIB_GRU_EXECUTE_FATAL_INSUFFICIENT_OUTPUT_BUFFER_SPACE
Output buffer size is not sufficient.

</td></tr>
</table>

Table 4-5 GRU Set Parameter Function Details

<table>
<tr><td>Function</td><td><code>xa_nnlib_gru_set_config</code></td></tr>
<tr><td>Syntax</td><td><pre>Int32
xa_nnlib_gru_set_config (
      xa_nnlib_handle_t handle,
      xa_nnlib_gru_param_id_t param_id,
      void *params)</pre></td></tr>
<tr><td>Description</td><td>Sets the parameter specified by <code>param_id</code> to the value passed in the buffer pointed to by <code>params</code>.</td></tr>
<tr><td>Parameters</td><td>Input: <code>handle</code>
The opaque component handle.
Required alignment: 8 bytes.

Input: <code>param_id</code>
Identifies the parameter to be written. Refer to Table 4-11 for the list of supported parameters.

Input: <code>params</code>
A pointer to a buffer that contains the parameter value.
Required alignment: 4 bytes.</td></tr>
<tr><td>Errors</td><td>If the return value is not XA_NNLIB_NO_ERROR, it implies that function has encountered one of the following errors:

XA_NNLIB_FATAL_MEM_ALLOC
One of the pointers (<code>handle</code> or <code>params</code>) is <code>NULL</code>.
XA_NNLIB_FATAL_MEM_ALIGN
One of the pointers (<code>handle</code> or <code>params</code>) is not aligned correctly.
XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PARAM_ID
Parameter identifier (<code>param_id</code>) is not valid.

</td></tr>
</table>

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. Refer to Table 4-11 for the list of supported parameters. **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 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 8 bytes for HiFi4
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_16bx16b	Coef and I/O precision. Note: Current library supports only 16bx16b and 8bx16b 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

Table 4-8 xa_nnlib_gru_weights_t Parameter Type

Element Type	Element Name	Range	Default	Description
coeff_t *	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 *	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 *	w_r	NA	NA	Pointer to coefficient matrix w_r.
xa_nnlib_shape_t	shape_w_r	NA	NA	Shape information about w_r.
coeff_t *	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 *	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 *	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
coeff_t *	b_z	NA	NA	Pointer to coefficient matrix b_z.
xa_nnlib_shape_t	shape_b_z	NA	NA	Shape information about b_z.
coeff_t *	b_r	NA	NA	Pointer to coefficient matrix b_r.
xa_nnlib_shape_t	shape_b_r	NA	NA	Shape information about b_r.
coeff_t *	b_h	NA	NA	Pointer to coefficient matrix b_h.
xa_nnlib_shape_t	shape_b_h	NA	NA	Shape information about b_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_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 should 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_biases_t	*RW*	NA	NA	Bias vectors, pointers to bias vectors along with shape information must be passed via 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:

$$f_f = sigmoid\left(w_{xf} * frame_f + prev\text{-}h * w_{hf} + b_f\right)$$
$$i_f = sigmoid\left(w_{xi} * frame_f + prev\text{-}h * w_{hi} + b_i\right)$$
$$c\text{-}hat_f = \tanh(w_{xc} * frame_f + prev\text{-}h * w_{hc} + b_c)$$
$$c_f = f_f . prev\text{-}c + i_f * c\text{-}hat_f$$
$$o_f = sigmoid\left(w_{xo} * frame_f + prev\text{-}h * w_{ho} + b_o\right)$$
$$h_f = o_f * \tanh(c_f)$$

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[10]

  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

[10] FEATS: = features

- 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 should 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

4.2.3.1 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 return value is less than 0 then it is an error. 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 should 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 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 should be 0 or 1.

4.2.3.2 Initialization Stage

Table 4-14 LSTM Init Function

<table>
<tr><td>Function</td><td><code>xa_nnlib_lstm_init</code></td></tr>
<tr><td>Syntax</td><td><code>Int32
xa_nnlib_lstm_init (
      xa_nnlib_handle_t handle,
      xa_nnlib_lstm_init_config_t *config)</code></td></tr>
<tr><td>Description</td><td>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 put the desired 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 (refer to Table 4-22 for more information).</td></tr>
<tr><td>Parameters</td><td>Input: <code>handle</code>
Pointer to the component persistent memory. This is the opaque handle.
Required size: see <code>xa_nnlib_lstm_get_persistent_fast</code>.
Required alignment: 8 bytes.

Input: <code>config</code>
Initial configuration parameters (see Table 4-18). Note that the initial configuration parameters MUST be identical to those passed to query functions.</td></tr>
<tr><td>Errors</td><td>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.</td></tr>
</table>

	■ 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 should be 0 or 1.

4.2.3.3 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. 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 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. Refer to Table 4-11 for the list of supported parameters. **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. Refer to Table 4-11 for the list of supported parameters. **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 8 bytes for HiFi 4 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.
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.

Element Type	Element Name	Range	Default	Description
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 should 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 should 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. Refer to the equations in Section 3.2.1 for Standard 2D Convolution, Section 3.2.3 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_CONFIG_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

4.3.3.1 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

4.3.3.2 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 into 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 that 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.

4.3.3.3 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 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. Refer to Table 4-32 for the list of supported parameters. **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. Refer to Table 4-32 for the list of supported parameters. **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_ s hape_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

Element Type	Element Name	Range	Default	Description
				accumulator, +/- value - left/right shift
`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_ST`	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. Additional Supporting Libraries

The HiFi NN library package includes a library, `xa_annlib`, that demonstrates the implementation of Android NN API v1.1 using the HiFi NN library. The below sections describe the main features and the operations supported by the `xa_annlib` library.

5.1 xa_annlib Features

- All the Android NN operations from Android NN API v1.1 are supported in the library
- Majority of the operations are supported using HiFi 4 optimized low level kernels while providing API similar to that of the reference Android NN implementation.
- The library is tested using the testcases provided in the Android CTS tests for Android NN API v1.1.

5.2 xa_annlib Operations

The xa_annlib includes functions that support easy integration with the Android NN API v1.1. The library supports all operations of the Android NN API v1.1 **[3]**.

These functions are provided with similar API and the same functionality as that of the reference implementation. In few cases, the operations need additional scratch memory for the optimizations. In such cases, the APIs are modified accordingly. Refer to the reference ANN API implementation, documentation, and the provided sample testbench for more details.

An example testbench that demonstrates the usage and testing of these operations is also provided, as described in Section 6.13. The operations are tested using the testcases provided with the reference implementation as part of the Android CTS test suite.

The rest of this section describes the individual ANN functions. The related function prototypes are provided in the header files included in '`test/android_nn/include/xa_nnlib_ann_api.h`'.

5.2.1 Relu operations

Description

These functions perform elementwise rectified linear activation on the input. They are implemented using the HiFi optimized low-level kernels.

Algorithm

```
Relu: output = max(0, input)
```

```
Relu1: output = min(1.f, max(-1.f, input))
Relu6: output = min(6, max(0, input))
```

Prototype

```
bool genericActivationPrepare(const Shape& input, Shape* output,
           const Operation& operation, int32_t& scratch_size);

bool reluFloat32(const float* inputData, const Shape& inputShape,
                 float* outputData, const Shape& outputShape);
bool relu1Float32(const float* inputData, const Shape& inputShape,
                  float* outputData, const Shape& outputShape);
bool relu6Float32(const float* inputData, const Shape& inputShape,
                  float* outputData, const Shape& outputShape);

bool reluQuant8(const uint8_t* inputData, const Shape& inputShape,
                uint8_t* outputData, const Shape& outputShape);
bool relu1Quant8(const uint8_t* inputData, const Shape& inputShape,
                 uint8_t* outputData, const Shape& outputShape);
bool relu6Quant8(const uint8_t* inputData, const Shape& inputShape,
                 uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const float * uint8_t *	inputData	Pointer to the input operand
const Shape &	inputShape	Shape of the input operand
Output		
float * uint8_t *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.2 Tanh

Description

This function performs elementwise hyperbolic tangent operation on the input. This function is implemented using the HiFi optimized low-level kernel.

Algorithm

```
output = tanh(input)
```

Prototype

```
bool genericActivationPrepare(const Shape& input, Shape* output,
           const Operation& operation, int32_t& scratch_size);

bool tanhFloat32(const float* inputData, const Shape& inputShape,
                 float* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const float *	inputData	Pointer to the input operand
const Shape &	inputShape	Shape of the input operand
Output		
float *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.3 Logistic

Description

These functions perform elementwise logistic or sigmoid operation on the input. They are implemented using the HiFi optimized low-level kernels.

Algorithm

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

Prototype

```
bool genericActivationPrepare(const Shape& input, Shape* output,
           const Operation& operation, int32_t& scratch_size);

bool logisticFloat32(const float* inputData, const Shape& inputShape,
                 float* outputData, const Shape& outputShape);

bool logisticQuant8(const uint8_t* inputData, const Shape& inputShape,
                uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const float * uint8_t *	inputData	Pointer to the input operand
const Shape &	inputShape	Shape of the input operand
Output		
float * uint8_t *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.4 Softmax

Description

These functions perform elementwise softmax operation on the input. They are implemented using the HiFi optimized low-level kernels.

Algorithm

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

Prototype

```
bool genericActivationPrepare(const Shape& input, Shape* output,
           const Operation& operation, int32_t& scratch_size);

bool softmaxFloat32(const float* inputData, const Shape& inputShape,
                    const float beta, float* outputData,
                    const Shape& outputShape);

bool softmaxQuant8(const uint8_t* inputData, const Shape& inputShape,
                   const float beta, uint8_t* outputData,
                   const Shape& outputShape, void *p_scratch);
```

Arguments

Type	Name	Description
Input		
`const float *` `uint8_t *`	`inputData`	Pointer to the input operand
`const Shape &`	`inputShape`	Shape of the input operand
`const float`	`beta`	Input multiplier
`const Operation&`	`operation`	Operation
Output		
`float *` `uint8_t *`	`outputData`	Pointer to the output
`const Shape &`	`outputShape`	Shape of the output
Temporary		
`int32_t&`	`scratch_size`	Size of the required scratch memory
`void *`	`p_scratch`	Pointer to scratch memory

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.5 Concatenation

Description

These functions perform concatenation of input tensors along the given dimension. These functions are included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool concatenationPrepare(const std::vector<Shape>& inputShapes,
                          int32_t axis,
                          Shape* output);

bool concatenationFloat32(const std::vector<const float*>& inputDataPtrs,
               const std::vector<Shape>& inputShapes, int32_t axis,
                float* outputData, const Shape& outputShape);

bool concatenationQuant8(const std::vector<const uint8_t*>& inputDataPtrs,
               const std::vector<Shape>& inputShapes, int32_t axis,
                uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const float * uint8_t *	inputDataPtrs	Pointer to the array of pointers to input operands
const Shape &	inputShapes	Pointer to Shape of the input operand
int32_t	axis	Concatenation axis
Output		
float * uint8_t *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.6 Convolution Operation

Description

These functions perform 2D convolution on the input data. These functions are implemented using the HiFi optimized low-level kernels.

Prototype

```
bool convPrepare(const Shape& input,
                 const Shape& filter,
                 const Shape& bias,
                 int32_t padding_left, int32_t padding_right,
                 int32_t padding_top, int32_t padding_bottom,
                 int32_t stride_width, int32_t stride_height,
                 Shape* output, int32_t& scratch_size);

bool convFloat32(const float* inputData, const Shape& inputShape,
                 const float* filterData, const Shape& filterShape,
                 const float* biasData, const Shape& biasShape,
                 int32_t padding_left, int32_t padding_right,
                 int32_t padding_top, int32_t padding_bottom,
                 int32_t stride_width, int32_t stride_height,
                 int32_t activation, float* outputData,
                 const Shape& outputShape, void *p_scratch);

bool convQuant8(const uint8_t* inputData, const Shape& inputShape,
                const uint8_t* filterData, const Shape& filterShape,
                const int32_t* biasData, const Shape& biasShape,
                int32_t padding_left, int32_t padding_right,
                int32_t padding_top, int32_t padding_bottom,
```

```
int32_t stride_width, int32_t stride_height,
int32_t activation, uint8_t* outputData,
const Shape& outputShape, void *p_scratch);
```

Arguments

Type	Name	Description
Input		
`const float *` `const uint8_t *`	`inputData,` `filterData,` `biasData`	Pointer to the input, filter and bias operands
`const Shape &`	`inputShape,` `filterShape,` `biasShape`	Pointer to Shape of the input, filter and bias operands
`int32_t`	`padding_left,` `padding_right,` `padding_top,` `padding_bottom`	Padding values.
`int32_t`	`stride_width,` `stride_height`	Stride values
`int32_t`	`activation`	Fused activation function selection
Output		
`float *` `uint8_t *`	`outputData`	Pointer to the output
`const Shape &`	`outputShape`	Shape of the output
Temporary		
`int32_t&`	`scratch_size`	Size of the required scratch memory
`void *`	`p_scratch`	Pointer to scratch memory

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.7 Depth-wise Convolution Operation

Description

These functions perform depth-wise 2D convolution on the input data. They are implemented using the HiFi optimized low-level kernels.

Prototype

```
bool depthwiseConvPrepare(const Shape& input,
                          const Shape& filter,
                          const Shape& bias,
                          int32_t padding_left, int32_t padding_right,
                          int32_t padding_top, int32_t padding_bottom,
                          int32_t stride_width, int32_t stride_height,
                          Shape* output, int32_t& scratch_size);
```

```
bool depthwiseConvFloat32(const float* inputData, const Shape& inputShape,
                          const float* filterData, const Shape& filterShape,
                          const float* biasData, const Shape& biasShape,
                          int32_t padding_left, int32_t padding_right,
                          int32_t padding_top, int32_t padding_bottom,
                          int32_t stride_width, int32_t stride_height,
                          int32_t depth_multiplier, int32_t activation,
                          float* outputData, const Shape& outputShape, void* p_scratch);

bool depthwiseConvQuant8(const uint8_t* inputData, const Shape& inputShape,
                         const uint8_t* filterData, const Shape& filterShape,
                         const int32_t* biasData, const Shape& biasShape,
                         int32_t padding_left, int32_t padding_right,
                         int32_t padding_top, int32_t padding_bottom,
                         int32_t stride_width, int32_t stride_height,
                         int32_t depth_multiplier, int32_t activation,
                         uint8_t* outputData, const Shape& outputShape,
                          void *p_scratch);
```

Arguments

Type	Name	Description
Input		
const float * const uint8_t *	inputData, filterData, biasData	Pointer to the input, filter and bias operands
const Shape &	inputShape, filterShape, biasShape	Pointer to Shape of the input, filter and bias operands
int32_t	padding_left, padding_right, padding_top, padding_bottom	Padding values.
int32_t	stride_width, stride_height	Stride values
int32_t	depth_multiplier	Depthwise multiplier
int32_t	activation	Fused activation function selection
Output		
float * uint8_t *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output
Temporary		
int32_t&	scratch_size	Size of the required scratch memory
void *	p_scratch	Pointer to scratch memory

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.8 Fully Connected

Description

These functions perform multiplication of the weight matrix with the input vectors in a fully connected neural network layer i.e. `z = weight*input + bias.` They are implemented using the HiFi optimized low-level kernels.

Prototype

```
bool fullyConnectedPrepare(const Shape& input,
                           const Shape& weights,
                           const Shape& bias,
                           Shape* output);

bool fullyConnectedFloat32(const float* inputData, const Shape& inputShape,
                           const float* weights, const Shape& weightsShape,
                           const float* biasData, const Shape& biasShape,
                           int32_t activation, float* outputData,
                           const Shape& outputShape);

bool fullyConnectedQuant8(const uint8_t* inputData, const Shape& inputShape,
                          const uint8_t* weights, const Shape& weightsShape,
                          const int32_t* biasData, const Shape& biasShape,
                          int32_t activation, uint8_t* outputData,
                          const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const float * uint8_t *	inputData, weights, biasData	Pointer to the input operands
const Shape &	inputShape, weightsShape, biasShape	Shape of the input operand
int32_t	activation	Fused activation function selection
Output		
float * uint8_t *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.9 L2 Normalization

Description

These functions perform l2 normalization on the input to get output which has unity l2-norm. They are included as is from the reference implementation without any HiFi optimization.

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

```
bool l2normFloat32(const float* inputData, const Shape& inputShape,
                   float* outputData, const Shape& outputShape);

bool l2normQuant8(const uint8_t* inputData, const Shape& inputShape,
                  uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const float * uint8_t *	inputData	Pointer to the input operand
const Shape &	inputShape	Shape of the input operand
Output		
float *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.10 Pooling operations

Description

Pooling functions perform 2D pooling (average, max, L2) on the input data. They are implemented using the HiFi optimized low-level kernels.

Prototype

```
bool genericPoolingPrepare(const Shape& input,
                           int32_t padding_left, int32_t padding_right,
                           int32_t padding_top, int32_t padding_bottom,
                           int32_t stride_width, int32_t stride_height,
                           int32_t filter_width, int32_t filter_height,
                           Shape* output, const Operation& operation,
                            int32_t& scratch_size);

bool averagePoolFloat32(const float* inputData, const Shape& inputShape,
                        int32_t padding_left, int32_t padding_right,
                        int32_t padding_top, int32_t padding_bottom,
                        int32_t stride_width, int32_t stride_height,
                        int32_t filter_width, int32_t filter_height, int32_t activation,
                        float* outputData, const Shape& outputShape, void* p_scratch);

bool averagePoolQuant8(const uint8_t* inputData, const Shape& inputShape,
                       int32_t padding_left, int32_t padding_right,
                       int32_t padding_top, int32_t padding_bottom,
                       int32_t stride_width, int32_t stride_height,
                       int32_t filter_width, int32_t filter_height, int32_t activation,
                       uint8_t* outputData, const Shape& outputShape, void* p_scratch);

bool l2PoolFloat32(const float* inputData, const Shape& inputShape,
                   int32_t padding_left, int32_t padding_right,
                   int32_t padding_top, int32_t padding_bottom,
                   int32_t stride_width, int32_t stride_height,
                   int32_t filter_width, int32_t filter_height, int32_t activation,
                   float* outputData, const Shape& outputShape);

bool maxPoolFloat32(const float* inputData, const Shape& inputShape,
                    int32_t padding_left, int32_t padding_right,
                    int32_t padding_top, int32_t padding_bottom,
                    int32_t stride_width, int32_t stride_height,
                    int32_t filter_width, int32_t filter_height, int32_t activation,
                    float* outputData, const Shape& outputShape, void* p_scratch);

bool maxPoolQuant8(const uint8_t* inputData, const Shape& inputShape,
                   int32_t padding_left, int32_t padding_right,
                   int32_t padding_top, int32_t padding_bottom,
                   int32_t stride_width, int32_t stride_height,
                   int32_t filter_width, int32_t filter_height, int32_t activation,
                   uint8_t* outputData, const Shape& outputShape, void* p_scratch);
```

Arguments

Type	Name	Description
Input		
const float *	inputData	Pointer to the input, filter and bias operands

Type	Name	Description
uint8_t *		
const Shape &	inputShape	Pointer to Shape of the input, filter and bias operands
int32_t	padding_left, padding_right, padding_top, padding_bottom	Padding values.
int32_t	stride_width, stride_height	Stride values
int32_t	filter_width, filter_height	Filter dimensions
int32_t	activation	Fused activation function selection
Output		
float * uint8_t *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output
Temporary		
int32_t&	scratch_size	Size of the required scratch memory
void *	p_scratch	Pointer to scratch memory

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.11 Basic operations

Description

These functions perform basic elementwise operations. They are implemented using the HiFi optimized low-level kernels.

Prototype

```
bool addFloat32(const float* in1, const Shape& shape1,
                const float* in2, const Shape& shape2,
                int32_t activation,
                float* out, const Shape& shapeOut);

bool addQuant8(const uint8_t* in1, const Shape& shape1,
               const uint8_t* in2, const Shape& shape2,
               int32_t activation,
               uint8_t* out, const Shape& shapeOut);

bool mulFloat32(const float* in1, const Shape& shape1,
                const float* in2, const Shape& shape2,
                int32_t activation,
                float* out, const Shape& shapeOut);
```

```
bool mulQuant8(const uint8_t* in1, const Shape& shape1,
               const uint8_t* in2, const Shape& shape2,
               int32_t activation,
               uint8_t* out, const Shape& shapeOut);

bool floorFloat32(const float* inputData,
                  float* outputData,
                  const Shape& shape);

bool subFloat32(const float* in1, const Shape& shape1,
                const float* in2, const Shape& shape2,
                int32_t activation,
                float* out, const Shape& shapeOut);

bool divFloat32(const float* in1, const Shape& shape1,
                const float* in2, const Shape& shape2,
                int32_t activation,
                float* out, const Shape& shapeOut);
```

Arguments

Type	Name	Description
Input		
const float *	in1, in2	Pointer to the input operand
const Shape &	shape1, shape2	Shape of the input operand
Output		
float *	out	Pointer to the output
const Shape &	shapeOut	Shape of the output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.12 Local Response Norm

Description

This function performs local response normalization along the depth dimension of a 4-D tensor.

It is implemented using the HiFi optimized low-level kernels.

Prototype

```
bool localResponseNormFloat32(const float* inputData, const Shape& inputShape,
                              int32_t radius, float bias, float alpha, float beta,
                              float* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const float *	inputData	Pointer to the input operand
const Shape &	inputShape	Shape of the input operand
int32_t	radius	Depth radius
float	bias	Bias value that is added to product of squared sum and multiplication factor.
float	alpha	Multiplication factor of squared sum
float	Beta	Power factor
Output		
float *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.13 Reshape Generic

Description

This function reshapes a tensor in newly specified shape. It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool reshapePrepare(const Shape& input,
                    const int32_t* targetDims,
                    const int32_t targetDimsSize,
                    Shape* output);

bool reshapeGeneric(const void* inputData, const Shape& inputShape,
                    void* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const void *	inputData	Pointer to input operands
const Shape &	inputShape	Shape of the input operand
int32_t *	targetDims	Pointer to target dimension.
int32_t	targetDimsSize	Target dimension size
Output		
void *	outputData	Pointer to the output

Type	Name	Description
const Shape &	outputShape	Shape of the output
Shape *	output	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.14 Resize Bilinear

Description

This function resizes images using bilinear interpolation. It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool resizeBilinearPrepare(const Shape& input,
                           int32_t height,
                           int32_t width,
                           Shape* output);

bool resizeBilinearFloat32(const float* inputData,
                           const Shape& inputShape,
                           float* outputData,
                           const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const float *	inputData	Pointer to input operands
const Shape &	inputShape	Shape of the input operand
int32_t	height	Target height.
int32_t	width	Target width.
Output		
float *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output
Shape *	output	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.15 Depth to Space

Description

This function rearranges data from depth to spatial blocks. It unfolds depth data into non-overlapping spatial blocks of size blockSize * blockSize. It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool depthToSpacePrepare(const Shape& input,
                         int32_t blockSize,
                         Shape* output);

bool depthToSpaceGeneric(const uint8_t* inputData, const Shape& inputShape,
                         int32_t blockSize,
                         uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const float *	inputData	Pointer to input operands
const Shape &	inputShape	Shape of the input operand
int32_t	blockSize	Target blocksize.
Output		
float *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output
Shape *	Output	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.16 Space to Depth

Description

This function rearranges data from spatial blocks to depth. It folds non-overlapping spatial blocks of size blockSize * blockSize into depth data. It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool spaceToDepthPrepare(const Shape& input,
                         int32_t blockSize,
```

```
                          Shape* output);

bool spaceToDepthGeneric(const uint8_t* inputData, const Shape& inputShape,
                          int32_t blockSize,
                          uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
`const float *`	`inputData`	Pointer to input operands
`const Shape &`	`inputShape`	Shape of the input operand
`int32_t`	`blockSize`	Target blocksize.
Output		
`float *`	`outputData`	Pointer to the output
`const Shape &`	`outputShape`	Shape of the output
`Shape *`	`Output`	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.17 Pad

Description

This operation pads input with zeros according to the specified paddings.

Prototype

```
bool padPrepare(const Shape& input,
                const int32_t* paddingsData,
                const Shape& paddingsShape,
                Shape* output);

bool padGeneric(const uint8_t* inputData, const Shape& inputShape,
                const int32_t* paddings,
                uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
`const float *`	`inputData`	Pointer to input operands
`const Shape &`	`inputShape, paddingsShape`	Shape of the input operand
`int32_t *`	`paddingsShape, paddings`	Target padding

Type	Name	Description
Output		
float *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output
Shape *	Output	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.18 Batch to Space

Description

BatchToSpace for N-dimensional tensors.

This operation reshapes the batch dimension (dimension 0) into M + 1 dimensions of shape block_shape + [batch], interleaves these blocks back into the grid defined by the spatial dimensions [1, ..., M], to obtain a result with the same rank as the input.

This is the reverse of SpaceToBatch.

It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool batchToSpacePrepare(const Shape& input,
                         const int32_t* blockSizeData,
                         const Shape& blockSizeShape,
                         Shape* output);

bool batchToSpaceGeneric(const uint8_t* inputData, const Shape& inputShape,
                         const int32_t* blockSize,
                         uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const uint8_t *	inputData	Pointer to input operands
const Shape &	inputShape, blockSizeShape	Shape of the input operand
Const int32_t *	blockSize, blockSizeData	Target block size.
Output		
uint8_t *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output

Type	Name	Description
`Shape *`	`Output`	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.19 Space to Batch

Description

SpaceToBatch for N-Dimensional tensors.

This operation divides "spatial" dimensions [1, ..., M] of the input into a grid of blocks of shape block_shape, and interleaves these blocks with the "batch" dimension (0) such that in the output, the spatial dimensions [1, ..., M] correspond to the position within the grid, and the batch dimension combines both the position within a spatial block and the original batch position. Prior to division into blocks, the spatial dimensions of the input are optionally zero padded according to paddings.

It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool spaceToBatchPrepare(const Shape& input,
                         const int32_t* blockSizeData,
                         const Shape& blockSizeShape,
                         const int32_t* paddingsData,
                         const Shape& paddingsShape,
                         Shape* output);

bool spaceToBatchGeneric(const uint8_t* inputData, const Shape& inputShape,
                         const int32_t* blockSize,
                         const int32_t* padding, const Shape& paddingShape,
                         uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
`const uint8_t *`	`inputData`	Pointer to input operands
`const Shape &`	`inputShape, paddingShape`	Shape of the input operand
`const int32_t *`	`blockSize, blockSizeData`	Target block size.
`const int32_t *`	`Padding, paddingsData`	Target Padding.
Output		
`uint8_t *`	`outputData`	Pointer to the output

Type	Name	Description
const Shape &	outputShape	Shape of the output
Shape *	Output	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.20 Squeeze

Description

This function removes dimensions of size 1 from the input tensor.

It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool squeezePrepare(const Shape& input,
                    const int32_t* squeezeDims,
                    const Shape& squeezeDimsShape,
                    Shape* output);

bool squeezeGeneric(const void* inputData, const Shape& inputShape,
                    void* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const void *	inputData	Pointer to input operands
const Shape &	inputShape, squeezeDimsShape	Shape of the input operand
const int32_t *	squeezeDims	Target squeeze dimension.
Output		
void *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output
Shape *	Output	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.21 Transpose

Description

This function transposes the input tensor according to permute tensor.

It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool transposePrepare(const Shape& input,
                      const int32_t* permData,
                      const Shape& permShape,
                      Shape* output);

bool transposeGeneric(const uint8_t* inputData, const Shape& inputShape,
                      const int32_t* perm, const Shape& permShape,
                      uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const uint8_t *	inputData	Pointer to input operands
const Shape &	inputShape, permShape	Shape of the input operand
const int32_t *	permData, perm	Target permutation.
Output		
uint8_t *	outputData	Pointer to the output
const Shape &	outputShape	Shape of the output
Shape *	Output	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.22 Mean

Description

Computes the mean of elements across dimensions of a tensor.

Reduces the input tensor along the given dimensions to reduce. Unless keep_dims is true, the rank of the tensor is reduced by 1 for each entry in axis. If keep_dims is true, the reduced dimensions are retained with length 1.

It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool meanPrepare(const Shape& input,
                 const int32_t* axisData,
                 const Shape& axisShape,
                 bool keepDims,
                 Shape* output);

bool meanGeneric(const uint8_t* inputData, const Shape& inputShape,
                 const int32_t* axis, const Shape& axisShape, bool keepDims,
                 uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
`const uint8_t *`	`inputData`	Pointer to input operands
`const Shape &`	`inputShape, axisShape`	Shape of the input operand
`const int32_t *`	`axis, axisData`	Mean axis.
`bool`	`keepDims`	Flag: true if dimension to be retained, false if output dimension is to be reduced.
Output		
`uint8_t *`	`outputData`	Pointer to the output
`const Shape &`	`outputShape`	Shape of the output
`Shape *`	`Output`	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.23 Strided Slice

Description

This function extracts a strided slice of a tensor.

More specifically this operation extracts a slice of size (end - begin) / stride from the given input tensor. Starting at the location specified by begin the slice continues by adding stride to the index until all dimensions are not less than end. Note that a stride can be negative, which causes a reverse slice.

It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool stridedSlicePrepare(const Shape& input,
                         const int32_t* beginData, const Shape& beginShape,
                         const int32_t* endData, const Shape& endShape,
                         const int32_t* stridesData, const Shape& stridesShape,
                         int32_t beginMask, int32_t endMask, int32_t shrinkAxisMask,
                         Shape* output);

bool stridedSliceGeneric(const uint8_t* inputData, const Shape& inputShape,
                         const int32_t* beginData, const int32_t* endData,
                         const int32_t* stridesData,
                         int32_t beginMask, int32_t endMask, int32_t shrinkAxisMask,
                         uint8_t* outputData, const Shape& outputShape);
```

Arguments

Type	Name	Description
Input		
const uint8_t *	inputData	Pointer to input operands
const Shape &	inputShape, beginShape, endShape, stridesShape	Shape of the operands
const int32_t *	beginData, endData, stridesData	Pointer to the begin, end and stride values
int32_t	beginMask, endMask, shrinkAxisMask	Begin, end and shrink mask values
Output		
uint8_t *	outputData	Pointer to the output
Shape *	Output	Pointer to output shape
const Shape &	outputShape	Shape of the output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.24 Dequantize Quant8 to Float32

Description

This function performs dequantization of quant8 format to float32 data. It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool dequantizePrepare(const Shape& input, Shape* output);

bool dequantizeQuant8ToFloat32(const uint8_t* inputData,
                               float* outputData,
                               const Shape& shape);
```

Arguments

Type	Name	Description
Input		
const uint8_t *	inputData	Pointer to the input operand
const Shape &	shape, input	Shape of the input operand
Output		
float *	outputData	Pointer to the output
Shape *	output	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.25 Embedding Lookup

Description

This module implements the embedded lookup operation as specified in the Android NN API v1.1 reference implementation. It concatenates sub-tensors from the given input tensor according to the given indices tensor. It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool embeddingLookupPrepare(const Shape &valueShape,
                            const Shape &lookupShape,
                            Shape *outputShape);
EmbeddingLookup::EmbeddingLookup(
      const android::hardware::neuralnetworks::V1_1::Operation &operation,
      std::vector<RunTimeOperandInfo> &operands);

bool EmbeddingLookup::Eval()
```

Arguments

Type	Name	Description
Input		
`const Shape &`	`valueShape, lookupShape`	Reference to input and lookup shape.
`std::vector<RunTimeOperandInfo> &`	`operands`	List of operands specified as `RunTimeOperandInfo`
Output		
`Shape *`	`outputShape`	Pointer to outputShape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.26 Hashtable Lookup

Description

This module implements the hashtable lookup operation as specified in the Android NN API v1.1 reference implementation. It concatenates sub-tensors from the given input tensor according to the given key-value map. It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
bool hashtableLookupPrepare(const Shape &lookupShape,
                            const Shape &keyShape,
                            const Shape &valueShape,
                            Shape *outputShape,
                            Shape *hitShape);

HashtableLookup::HashtableLookup(
      const android::hardware::neuralnetworks::V1_1::Operation &operation,
      std::vector<RunTimeOperandInfo> &operands);

bool HashtableLookup::Eval()
```

Arguments

Type	Name	Description
Input		
`Operation &`	`operation`	ANN operation structure instance of the type LSH_PROJECTION
`const Shape &`	`lookupShape, keyShape, valueShape`	Shapes of the inputs: lookup, key and values
`std::vector<RunTimeOperandInfo> &`	`operands`	List of operands specified as `RunTimeOperandInfo`
Output		
`Shape *`	`outputShape`	Pointer to output shape
`Shape *`	`hitShape`	Pointer to the hits output

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.27 LSH Projection

Description

This module implements the LSH projection operation as specified in the Android NN API v1.1 reference implementation. It projects an input to a bit vector using locality sensitive hashing. It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
LSHProjection::LSHProjection(
      const android::hardware::neuralnetworks::V1_1::Operation &operation,
      std::vector<RunTimeOperandInfo> &operands);

bool LSHProjection::Prepare(
      const android::hardware::neuralnetworks::V1_1::Operation &operation,
      std::vector<RunTimeOperandInfo>& operands,
      Shape *outputShape);

bool LSHProjection::Eval();
```

Arguments

Type	Name	Description
Input		
`Operation &`	`operation`	ANN operation structure instance of the type LSH_PROJECTION
`std::vector<RunTimeOperandInfo> &`	`operands`	List of operands specified as `RunTimeOperandInfo`
Output		
`Shape *`	`outputShape`	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.28 LSTM

Description

These functions perform a single time step in a LSTM layer as specified in the Android NN API v1.1 reference implementation. They are implemented using the HiFi optimized low-level kernels.

Prototype

```
LSTMCell::LSTMCell(const android::hardware::neuralnetworks::V1_1::Operation &operation,
           std::vector<RunTimeOperandInfo> &operands);

static bool LSTMCell::Prepare(const android::hardware::neuralnetworks::V1_1::Operation &operation,
                      std::vector<RunTimeOperandInfo> &operands,
                      Shape *scratchShape,
                      Shape *outputStateShape,
                      Shape *cellStateShape,
                      Shape *outputShape);

bool LSTMCell::Eval();
```

Arguments

Type	Name	Description
Input		
Operation	operation	ANN operation instance of the type LSTM
std::vector<RunTimeOperandInfo> &	operands	List of operands specified as RunTimeOperandInfo
Shape *	cellStateShape	Pointer to cell state shape
Output		
Shape *	outputShape	Pointer to output shape
Shape *	outputStateShape	Pointer to output state shape
Temporary		
Shape *	scratchShape	Pointer to scratch shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.29 RNN

Description

These functions implement a basic recurrent neural network as specified in the Android NN API v1.1 reference implementation. They are implemented using the HiFi optimized low-level kernels.

Prototype

```
RNN::RNN(const android::hardware::neuralnetworks::V1_1::Operation &operation,
      std::vector<RunTimeOperandInfo> &operands);

bool RNN::Prepare(const android::hardware::neuralnetworks::V1_1::Operation &operation,
                      std::vector<RunTimeOperandInfo> &operands,
                      Shape *hiddenStateShape,
                      Shape *outputShape);
bool RNN::Eval();
```

Arguments

Type	Name	Description
Input		
Operation	operation	ANN operation instance of the type RNN
std::vector<RunTimeOperandInfo> &	operands	List of operands specified as RunTimeOperandInfo
Shape *	hiddenStateShape	Pointer to shape of the state
Output		
Shape *	outputShape	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

5.2.30 SVDF

Description

This module implements the SVDF operation as specified in the Android NN API v1.1 reference implementation. It is included as is from the reference implementation without any HiFi optimization.

Prototype

```
SVDF::SVDF(const android::hardware::neuralnetworks::V1_1::Operation &operation,
         std::vector<RunTimeOperandInfo>& operands);

bool SVDF::Prepare(
        const hardware::neuralnetworks::V1_1::Operation &operation,
        std::vector<RunTimeOperandInfo> &operands, Shape *stateShape,
        Shape *outputShape);

bool SVDF::Eval();
```

Arguments

Type	Name	Description
Input		
`Operation`	`operation`	ANN operation instance of the type SVDF
`std::vector<RunTimeOperandInfo> &`	`operands`	List of operands specified as `RunTimeOperandInfo`
`Shape *`	`stateShape`	Pointer to state shape
Output		
`Shape *`	`outputShape`	Pointer to output shape

Returns

- 1 (true): no error
- 0 (false): error, invalid parameters

6. Introduction to the Example Testbench

The HiFi NN library is released as .tgz file for linux/makefile based usage and .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 sections below.

6.1 Making the Library

If you have source code distribution (i.e. .tgz), you must build the NN library before building the testbench. To do so, follow these steps:

1. Go to `libxa_nnlib/build`.
2. From the command prompt, enter:
   `xt-make -f makefile detected_core=hifi4 clean all install`

The NN library `xa_nnlib.a` will be built and copied to the `lib` directory.

6.1.1 Controlling Library Code Size

The HiFi NN Library code size 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.

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.

6.2 Making the Executable

To build and execute the application from Xtensa Xplorer workspace (.xws) based release package, please refer to the readme.html file available in the imported application project.

To build the library in makefile based (.tgz) package, the following steps are required.

To build the testbenches, follow these steps:

1. Go to `test/build`.
2. From the command-line prompt, enter:
   `xt-make –f makefile_testbench_sample detected_core=hifi4 clean all`

This will build 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`

6.2.1 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.

The following sections describe each low-level kernel and layer testbench.

6.3 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`

6.3.1 Usage

The NN library Matrix X Vector Multiplication Kernels executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_matXvec_test [options]
```

Following are available options:

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
`-cols2`	Columns of mat2 (Default=32)	Columns of mat2 must be multiple of 4
`-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), -3 (asym8u) or -5 (sym8s); (Default=16)	
`-inp_precision`	8, 16, -1(single precision float), -3(asym8u) or -4 (asym8s); (Default=16)	
`-out_precision`	8, 16, 32, 64, -1(single precision float), -3(asym8u), -4 (asym8s) or -7 (asym16s); (Default=16)	
`-bias_precision`	8, 16, 64, -1(single 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	
`-inp1_zero_bias`	Input1 zero bias for quantized 8-bit, -255 to 0 for asym8u, -127 to 128 for asym8s; Default=-128	
`-inp2_zero_bias`	Input2 zero bias for quantized 8-bit, -255 to 0 for asym8u, -127 to 128 for asym8s; 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	

Option	Description	Additional Information
`-out_zero_bias`	Output zero bias for quantized 8-bit, 0 to 255 for asym8u, -128 to 127 for asym8s; 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 i.e. 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)
`-fc`	Flag to execute fully connected kernels	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).

6.4 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`

6.4.1 Usage

The NN Library Convolutional Kernels executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_conv_test [options]
```

Following are available options:

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)
`-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)
`-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), -3(asymmetric 8-bit unsigned) or -4 (asymmetric 8-bit signed); (Default=16)
`-kernel_precision`	8, 16, -1(single precision float), -3(asymmetric 8-bit unsigned) or -5 (symmetric 8-bit signed); (Default=8)
`-out_precision`	8, 16, -1(single precision float), -3(asymmetric 8-bit unsigned) or -4 (asymmetric 8-bit signed); (Default=16)
`-bias_precision`	8, 16, -1(single 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

Option	Description
	asymmetric 8 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; Default=128
`-frames`	Positive number (Default=2)
`-kernel_name`	conv2d_std, conv2d_depth, conv1d_std or dilated_conv2d_std; (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)
`--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).

6.5 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`

6.5.1 Usage

The NN library Activation Kernels executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_activation_test [options]
```

Following are available options:

Option	Description
`-num_elements`	Number of elements (Default=32)
`-relu_threshold`	Threshold for relu in Q16.15 (Default= 32768 i.e. =1 in Q16.15)
`-inp_precision`	8,16, 32, -1(single precision float), -3(asym8u) or -4 (asym8s); (Default=32)
`-out_precision`	8,16, 32, -1(single precision float), -3(asym8u) or -4 (asym8s); (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

Option	Description
`-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)
`-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).

6.6 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`

6.6.1 Usage

The NN library Pooling Kernels executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_pool_test [options]
```

Following are available options:

Option	Description
`-inp_data_format`	Input data format, 0 (SHAPE_CUBE_DWH_T), 1 SHAPE_CUBE_WHD_T); (Default=1 (SHAPE_CUBE_WHD_T))
`-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)

Option	Description
-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).

6.7 Sample Testbench for Basic 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`

6.7.1 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]
```

Following are available options:

Option	Description
-io_length	Input/output vector length; Default=1024
-num_inp_dims	Number of input dimensions(Default =4)

Option	Description
`-num_axis_dims`	Number of axis dimensions(Default =4)
`-num_output_dims`	Number of output dimensions(Default =4)
`-inp_precision`	16, -3 (asym8u), -1 (single prec float), -4(asym8s), 1(bool); Default=-1
`-out_precision`	-3 (asym8u), -1 (single prec float), -4(asym8s) , 1(bool), -10(asym32s); 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, elm_requantize, elm_dequantize, memmove,memset; 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_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_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_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
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=1
`-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).

6.8 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`

6.8.1 Usage

The NN library Normalization Kernels executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_norm_test [options]
```

Following are available options:

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; 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
`--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).

6.9 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`

6.9.1 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]
```

Following are available options:

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
`-pad_value`	Input to be padded with this pad value; Default=0
`-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
`-inp_precision`	8; Default=8
`-out_precision`	8; Default=8
`-frames`	Positive number; Default=2
`-kernel_name`	depth_to_space, space_to_depth, pad, batch_to_space_nd, space_to_batch_nd; 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)

Option	Description
`-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)
`--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).

6.10 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`

6.10.1 Usage

The NN library GRU executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_gru_test [options]
```

Following are available options:

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`	Input file name	
`--filter_path`	Path where file containing filter are stored	
`--output_file`	File to which output will be 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).

6.11 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`

6.11.1 Usage

The NN library LSTM executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_lstm_test [options]
```

Following are available options:

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 will be written	
`--output_cell_file`	File to which cell output will be 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).

6.12 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`

6.12.1 Usage

The NN Library CNN executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_cnn_test [options]
```

Following are available options:

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)
-write_file	Set to 1 to write input and output vectors to file; (Default=0)

Option	Description
-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).

6.13 Sample Testbench for ANN Operations

The NN library package is provided with a sample testbench application for the ANN operations. This testbench is based on the test application provided in the Android NN API reference implementation in the Android Open Source Project **[3][4]**. It builds and runs the tests given in the reference implementation using the ANN operations provided by the library. The supplied testbench consists of the following files:

- Testbench source files (`test/android_nn`)
  - `runtime/…` The test application derived from ANN reference
  - `common/…` Supporting files for the ANN test application
  - `android_deps/…` Supporting files for the ANN test application
  - `tools/…` Supporting files for the ANN test application

6.13.1 Usage

The ANN testbench executable can be run with command-line options as follows.

```
$ xt-run [--mem_model] [--turbo] xa_nn_ann_test
```

Currently the testbench does not accept any command line options. The test to run is selected at compile time through a preprocessor definition of testcase identifier. For e.g. defining "`HIFI_ADD`" selects the ANN testcase for ADD operation.

The file "`test/android_nn/runtime/test/generated/all_generated_tests_hifi.cpp`" contains the list of all ANN testcase identifiers and testcase specification (model, input and output).

To run a test, the executable should be built with the corresponding test case identifier defined.

7. 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/theory.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