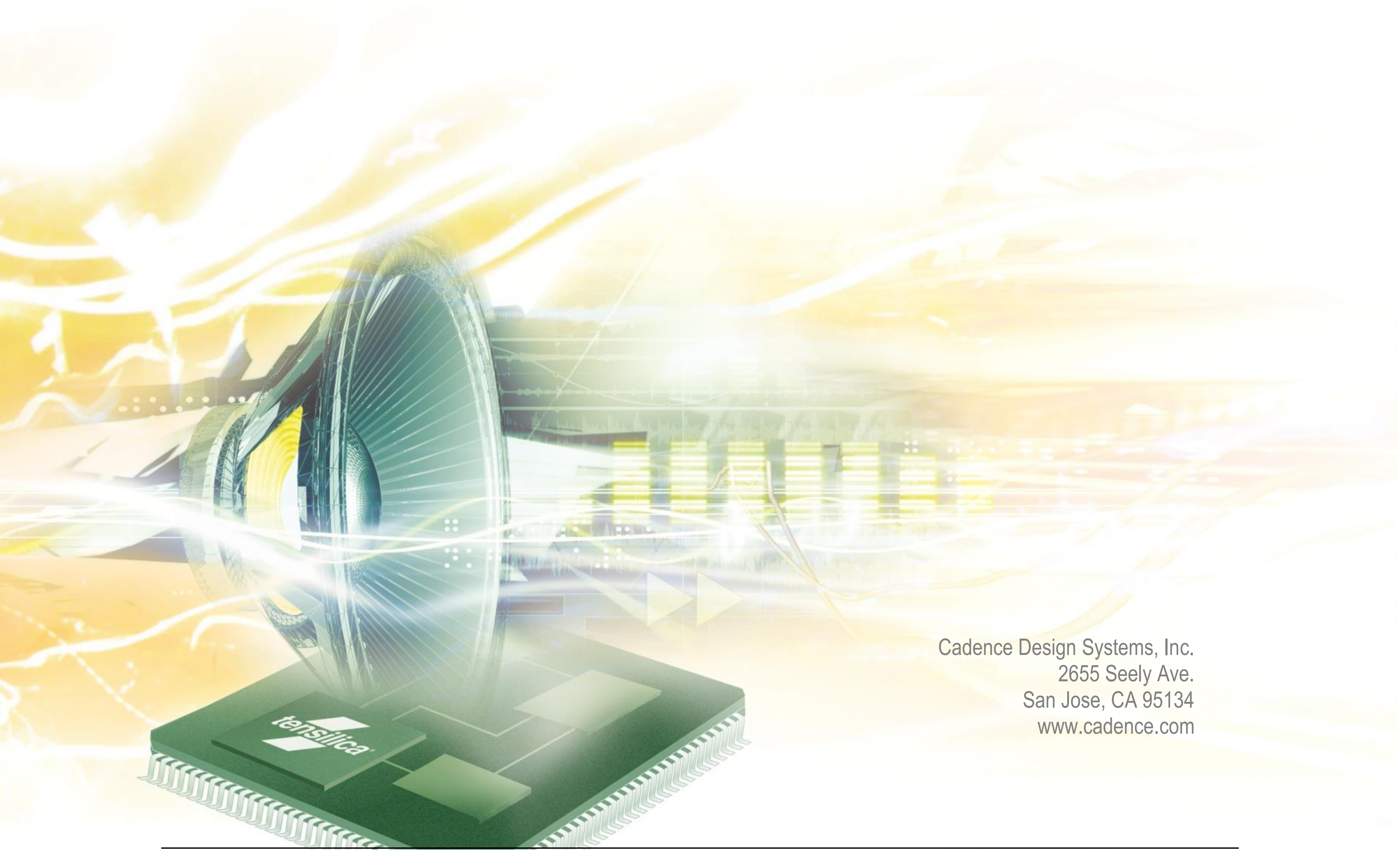
cādence®

HiFi Neural Network Library

Programmer's Guide

For HiFi DSPs



Cadence Design Systems, Inc.
2655 Seely Ave.
San Jose, CA 95134
www.cadence.com

Version 1.0
July 2019

Contents

1. Introduction to the HiFi NN Library ... 1
  1.1 Organization of the HiFi NN Library Package ... 1
    1.1.1 Document Overview ... 2
  1.2 HiFi NN Library Specification ... 2
    1.2.1 Low Level Kernels ... 2
    1.2.2 Layers ... 2
2. Generic HiFi NN Layer API ... 3
  2.1 Shape ... 3
  2.2 Memory Management ... 5
    2.2.1 API Handle / Persistent Memory ... 5
    2.2.2 Scratch Memory ... 5
    2.2.3 Weights and Biases Memory ... 5
    2.2.4 Input Buffer ... 5
    2.2.5 Output Buffer ... 5
  2.3 Generic API Errors ... 6
    2.3.1 Common API Errors ... 6
  2.4 C Language API ... 7
    2.4.1 Startup Functions ... 8
    2.4.2 Query Functions ... 9
    2.4.3 Initialization Functions ... 9
    2.4.4 Execution Functions ... 9
3. HiFi NN Library – Low-Level Kernels ... 10
  3.1 Matrix X Vector Multiplication Kernels ... 10
    3.1.1 Matrix X Vector Kernels ... 10
    3.1.2 Fused (Activation) Matrix X Vector Kernels ... 13
    3.1.3 Matrix X Vector Batch Kernels ... 17
  3.2 Convolution Kernels ... 19
    3.2.1 Standard 2D Convolution Kernel ... 19
    3.2.2 Standard 1D Convolution Kernel ... 23
    3.2.3 Depthwise Separable 2D Convolution Kernel ... 27
    3.2.3.1 Depthwise 2D Convolution Kernel ... 28
    3.2.3.2 Pointwise 2D Convolution Kernel ... 32
  3.3 Activation Kernels ... 35
    3.3.1 Sigmoid ... 35
    3.3.2 Tanh ... 36
    3.3.3 Rectifier Linear Unit (ReLU) ... 38
    3.3.4 Softmax ... 40
  3.4 Pooling Kernels ... 41

3.4.1 Average Pool Kernel 41
3.4.2 Max Pool Kernel 44
3.4.3 Fully Connected Kernel 47
3.5 Miscellaneous Kernels 49
3.5.1 Interpolation Kernel 49
4. HiFi NN Library – Layers 51
4.1 GRU Layer 51
4.1.1 GRU Layer Specification 51
4.1.2 Error Codes Specific to GRU 52
4.1.3 API Functions Specific to GRU 53
4.1.3.1 Query Functions 53
4.1.3.2 Initialization Stage 55
4.1.3.3 Execution Stage 56
4.1.4 Structures Specific to GRU 59
4.1.5 Enums Specific to GRU 60
4.2 LSTM Layer 62
4.2.1 LSTM Layer Specification 62
4.2.2 Error Codes Specific to LSTM 62
4.2.3 API Functions Specific to LSTM 64
4.2.3.1 Query Functions 64
4.2.3.2 Initialization Stage 66
4.2.3.3 Execution Stage 67
4.2.4 Structures Specific to LSTM 71
4.2.5 Enums Specific to LSTM 72
4.3 CNN Layer 74
4.3.1 CNN Layer Specification 74
4.3.2 Error Codes Specific to CNN 74
4.3.3 API Functions Specific to CNN 75
4.3.3.1 Query Functions 75
4.3.3.2 Initialization Stage 78
4.3.3.3 Execution Stage 80
4.3.4 Structures Specific to CNN 83
4.3.5 Enums Specific to CNN 84
5. Introduction to the Example Testbench 86
5.1 Making the Library 86
5.2 Making the Executable 86
5.3 Sample Testbench for Matrix X Vector Multiplication Kernels 87
5.3.1 Usage 87
5.4 Sample Testbench for Convolution Kernels 88
5.4.1 Usage 88
5.5 Sample Testbench for Activation Kernels 90
5.5.1 Usage 90
5.6 Sample Testbench for Pooling Kernels 91

5.6.1 Usage 91
5.7 Sample Testbench for GRU Layer 92
5.7.1 Usage 92
5.8 Sample Testbench for LSTM Layer 93
5.8.1 Usage 93
5.9 Sample Testbench for CNN Layer 94
5.9.1 Usage 94
5.10 Sample Testbenches for Neural Network Examples 96
5.10.1 Usage 97
6. References 98

Figures

Figure 2-1 HiFi NN Layer Interfaces 3
Figure 2-2 Matrix and Cube (SHAPE_CUBE_DWH_T) Shape Representation 4
Figure 2-3 NN Layer Flow Overview... 7

Tables

Table 2-1 Library Identification Functions 8
Table 4-1 GRU Get Persistent Size Function 53
Table 4-2 GRU Get Scratch Size Function 54
Table 4-3 GRU Init Function 55
Table 4-4 GRU Execution Function 56
Table 4-5 GRU Set Parameter Function Details 57
Table 4-6 GRU Get Parameter Function Details 58
Table 4-7 GRU Config Structure xa_nnlib_gru_init_config_t 59
Table 4-8 xa_nnlib_gru_weights_t Parameter Type 59
Table 4-9 xa_nnlib_gru_biases_t Parameter Type 60
Table 4-10 Enum xa_nnlib_gru_precision_t 60
Table 4-11 GRU Specific Parameters 61
Table 4-12 LSTM Get Persistent Size Function 64
Table 4-13 LSTM Get Scratch Size Function 65
Table 4-14 LSTM Init Function 66
Table 4-15 LSTM Execution Function 67
Table 4-16 LSTM Set Parameter Function Details 69
Table 4-17 LSTM Get Parameter Function Details 70
Table 4-18 LSTM Config Structure xa_nnlib_lstm_init_config_t 71
Table 4-19 xa_nnlib_lstm_weights_t Parameter Type 71
Table 4-20 xa_nnlib_lstm_biases_t Parameter Type 72
Table 4-21 Enum xa_nnlib_lstm_precision_t 72
Table 4-22 LSTM Specific Parameters 73
Table 4-23 CNN Get Persistent Size Function 75
Table 4-24 CNN Get Scratch Size Function 76
Table 4-25 CNN Init Function 78

Table 4-26 CNN Execution Function 80
Table 4-27 CNN Set Parameter Function Details........ 81
Table 4-28 CNN Get Parameter Function Details 82
Table 4-29 CNN Config Structure xa_nnlib_cnn_init_config_t 83
Table 4-30 Enum xa_nnlib_cnn_precision_t 84
Table 4-31 Enum xa_nnlib_cnn_algo_t 84
Table 4-32 CNN Specific Parameters........ 85

Document Change History

Version	Changes
1.0	Initial version

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.

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

Note	This version of the library supports HiFi 5 DSPs with the NN Extension enabled. The SP-VFPU (Single Precision Vector Floating Point Unit) is optional. The library can be compiled for HiFi 5 DSPs with or without the SP-VFPU enabled.

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).

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

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

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] Refer to Section 2.1 Shape

[2] Refer to Section 2.2.3 Weights and Biases Memory

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 available sample testbenches. References are listed in Section 6.

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

These kernels support fixed point 8 bit, 16 bit, and single precision floating point data types for weights or coefficients, biases, input, and output. Refer to Section 3 for details.

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.

2. Generic HiFi NN Layer API

Note This section explains an API standard that 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.

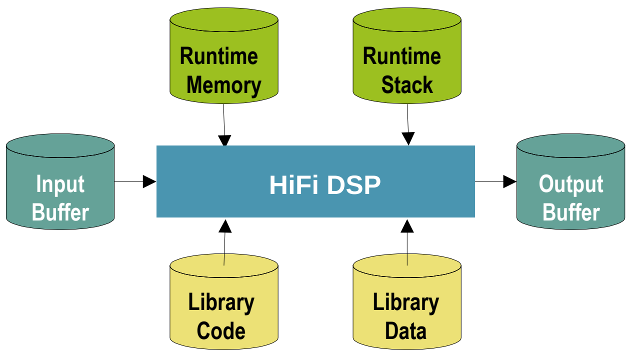


Figure 2-1 HiFi NN Layer Interfaces

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, width, and height order; that is, elements with the same height and width indices are stored consecutively.
  - SHAPE_CUBE_WHD_T

    This assumes that elements are stored in width, height, and depth order; that is, elements with the same height and depth are stored consecutively.

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

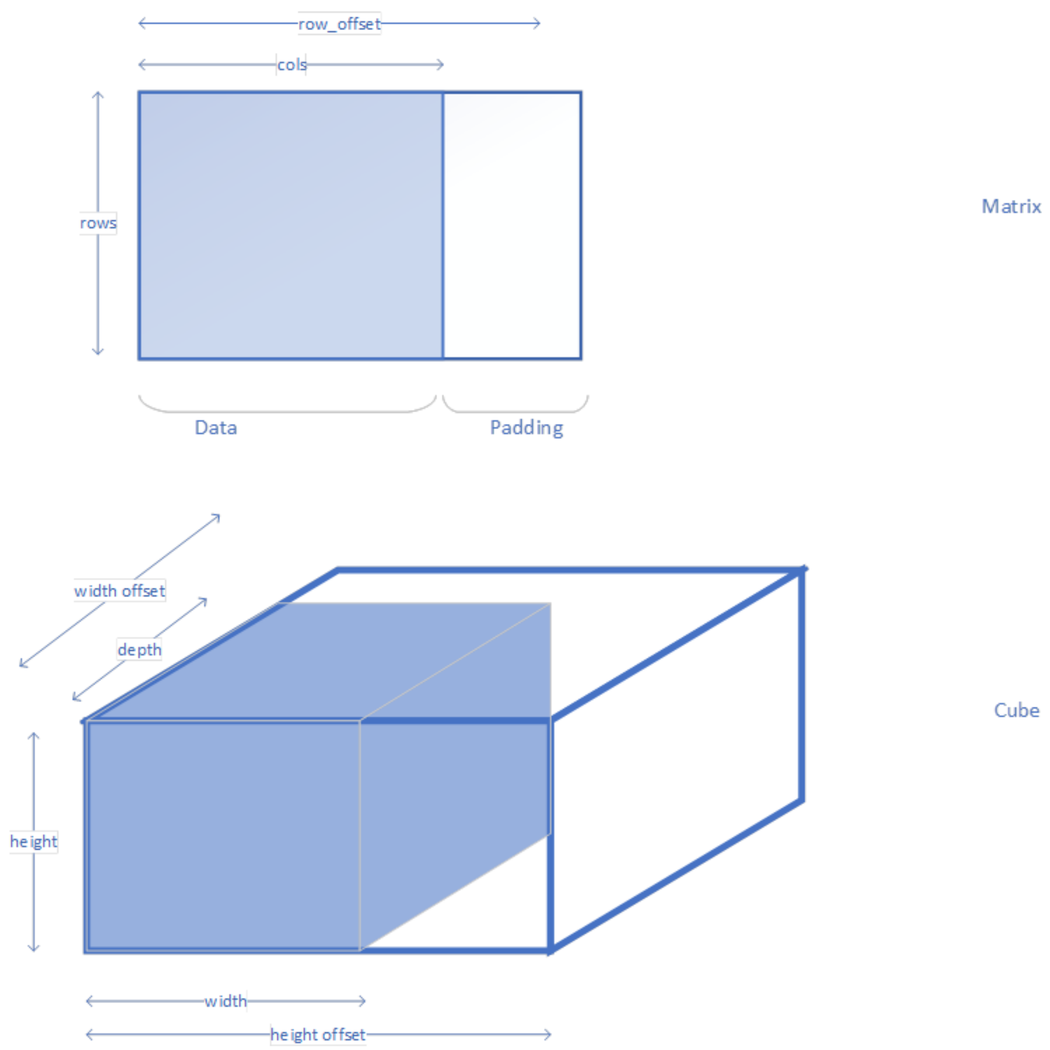


Figure 2-2 Matrix and Cube (SHAPE_CUBE_DWH_T) Shape Representation

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.

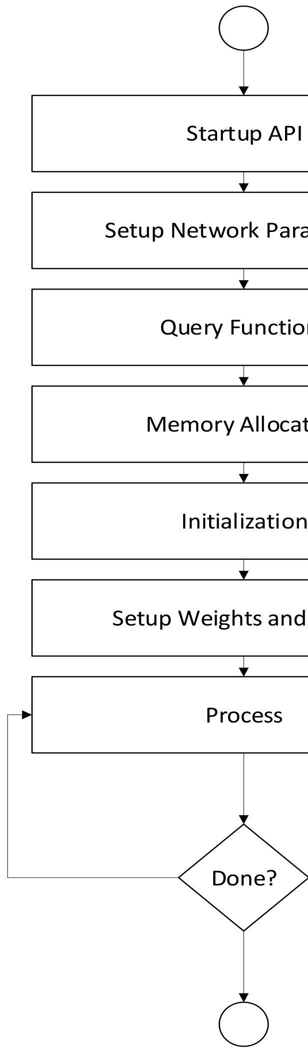


Figure 2-3 NN Layer Flow Overview

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` 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]`, where:

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

Precision

There are ten 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

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);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *	p_mat1	rows*cols1	Input matrix 1, fixed or floating point
WORD16 *, WORD8 *, FLOAT32 *	p_mat2	rows*cols2	Input matrix 2, fixed or floating point
WORD16 *, WORD8 *, FLOAT32 *	p_vec1	cols1*1	Input vector 1, fixed or floating point
WORD16 *, WORD8 *, FLOAT32 *	p_vec2	cols2*1	Input vector 2, fixed or floating point
WORD16 *, WORD8 *, 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

Type	Name	Size	Description
WORD32	acc_shift		Shift applied to accumulator
WORD32	bias_shift		Shift applied to bias
Output			
WORD8 *, WORD16 *, WORD32 *, WORD64 *, FLOAT32 *	p_out	rows*1	Output, fixed or floating point

Returns

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

Restrictions

Arguments	Restrictions
row_stride1, row_stride2, cols1, cols2	Multiples of 4 (2 in case of floating point)
p_mat1, p_mat2, p_vec1, p_vec2, p_bias, p_out	Aligned on 16-byte boundary Should not overlap
p_mat1, p_vec1, p_bias, p_out	Cannot be NULL
acc_shift, bias_shift	{-31, …., 31}

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` 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

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

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
WORD16 *, WORD8 *, FLOAT32 *	p_vec1	cols1*1	Input vector 1, fixed or floating point
WORD16 *, WORD8 *, FLOAT32 *	p_vec2	cols2*1	Input vector 2, fixed or floating point
VOID *, FLOAT32 *	p_bias	rows*1	Bias vector, fixed or floating point
WORD32	rows		Number of rows in matrix 1,2, bias and output
WORD32	cols1		Number of columns in matrix 1 and rows in vector 1
WORD32	cols2		Number of columns in matrix 2 and rows in vector 2
WORD32	row_stride1		Row offset of matrix 1
WORD32	row_stride2		Row offset of matrix 2
WORD32	acc_shift		Shift applied to accumulator
WORD32	bias_shift		Shift applied to bias
WORD32	bias_precision		Precision of bias in bytes
Output			
WORD8 *, WORD16 *, FLOAT32 *	p_out	rows*1	Output, fixed (Q7, Q15) or floating point
Temporary			
VOID *, FLOAT32 *	p_scratch	rows*4	Scratch (temporary) memory pointer

Returns

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

Restrictions

Arguments	Restrictions
row_stride1, row_stride2, cols1, cols2	Multiples of 4 (2 in case of floating point)
p_mat1, p_mat2, p_vec1, p_vec2, p_bias, p_out	Aligned on 16-byte boundary Should not overlap
p_mat1, p_vec1, p_bias, p_out	Cannot be NULL
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 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 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 four 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

Algorithm

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

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

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

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

Prototype

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

Arguments

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

Type	Name	Size	Description
Output			
`WORD32 **`, `WORD64 **`, `FLOAT32 **`	`p_out`	`rows*vec_count`	Output vector pointers, fixed or floating point

Returns

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

Restrictions

Arguments	Restrictions
`row_stride1, cols1`	Multiples of 4 (2 in case of floating point)
`p_mat1, p_vec1, p_bias, p_out`	Aligned on 16-byte boundary Should not overlap Cannot be NULL
`acc_shift, bias_shift`	{-31, …., 31}

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 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.

Note: `acc_shift` and `bias_shift` are not relevant in case of floating point 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_paddding = kernel_width + (out_width – 1) * x_stride – (x_padding + input_width)`.

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

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

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.

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.

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

- [p]: precision in bits

Precision

There are four 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

Algorithm

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

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

In case of floating point 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);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *,	p_inp	input_height* input width* input_channels	Input cube, fixed or floating point, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *,	p_ker	out_channels* (kernel_height* kernel width* input_channels)	Kernel cube, fixed or floating point, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *,	p_bias	out_channels	Bias vector, fixed or floating point
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of input channels
WORD32	kernel_height		Kernel height
WORD32	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	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 *, FLOAT32 *,	p_out	(out_height* out_width)* out_channels	Output cube, fixed or floating point, as per the out_data_format argument.

Returns

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

Restrictions

Arguments	Restrictions
p_out, p_inp, p_ker, p_bias, p_scratch	Cannot be NULL
	Should not overlap
	Aligned on 16-byte boundary
	For p_scratch – memory size >= size returned by xa_nn_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	{1, 2, ..., kernel_width}
y_stride	Greater than or equal to 1
x_padding, y_padding	Greater than or equal to 0
out_height, out_width	Greater than or equal to 1
acc_shift, bias_shift	{-31 …. 31} for fixed point APIs
out_data_format	Can be 0: SHAPE_CUBE_DWH_T or 1: SHAPE_CUBE_WHD_T

3.2.2 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` are not relevant in case of floating point 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_paddding = 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.

These kernels expect input and kernel 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 four 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

Algorithm

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

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

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

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

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

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

b denotes the `bias` shape.

Prototype

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

WORD32 xa_nn_conv1d_std_16x16
(WORD16 * p_out,        WORD16 * p_inp,       WORD16 * p_ker,
 WORD16 * p_bias,       WORD32 input_height,  WORD32 input_width,
 WORD32 input_channels, WORD32 kernel_height, WORD32 out_channels,
 WORD32 y_stride,       WORD32 y_padding,     WORD32 out_height,
 WORD32 bias_shift,     WORD32 acc_shift,     WORD32 out_data_format,
 VOID   * p_scratch);
WORD32 xa_nn_conv1d_std_8x16
(WORD16 * p_out,        WORD16 * p_inp,       WORD8  * p_ker,
 WORD16 * p_bias,       WORD32 input_height,  WORD32 input_width,
 WORD32 input_channels, WORD32 kernel_height, WORD32 out_channels,
 WORD32 y_stride,       WORD32 y_padding,     WORD32 out_height,
 WORD32 bias_shift,     WORD32 acc_shift,     WORD32 out_data_format,
 VOID   * p_scratch);
WORD32 xa_nn_conv1d_std_8x8
(WORD8  * p_out,        WORD8  * p_inp,       WORD8  * p_ker,
 WORD8  * p_bias,       WORD32 input_height,  WORD32 input_width,
 WORD32 input_channels, WORD32 kernel_height, WORD32 out_channels,
 WORD32 y_stride,       WORD32 y_padding,     WORD32 out_height,
 WORD32 bias_shift,     WORD32 acc_shift,     WORD32 out_data_format,
 VOID   * p_scratch);
WORD32 xa_nn_conv1d_std_f32
(FLOAT32 * p_out,         FLOAT32 * p_inp,        FLOAT32 * p_ker,
 FLOAT32 * p_bias,        WORD32 input_height,    WORD32 input_width,
 WORD32 input_channels,   WORD32 kernel_height,   WORD32 out_channels,
 WORD32 y_stride,         WORD32 y_padding,       WORD32 out_height,
 WORD32 out_data_format,  VOID   * p_scratch);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *,	p_inp	input_height* input width* input_channels	Input cube, fixed or floating point, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *,	p_ker	out_channels* (kernel_height* input width* input_channels)	Kernel cube, fixed or floating point, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *,	p_bias	out_channels	Bias vector, fixed or floating point
WORD32	input_height		Input height
WORD32	input_width		Input width
WORD32	input_channels		Number of input channels
WORD32	kernel_height		Kernel height
WORD32	out_channels		Number of output channels
WORD32	y_stride		Vertical stride over input
WORD32	y_padding		Top padding height on input
WORD32	out_height		Output height
WORD32	bias_shift		Shift applied to bias
WORD32	acc_shift		Shift applied to accumulator
WORD32	out_data_format		Output matrix order 0: out_height x out_channels 1: out_channels x out_height
VOID *	p_scratch	xa_nn_conv1d_std_getsize()	Scratch memory pointer
Output			
WORD16 *, WORD8 *, FLOAT32 *,	p_out	out_height* out_channels	Output matrix, fixed or floating point, as per the out_data_format argument.

Returns

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

Restrictions

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

3.2.3 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 3.2.3.2 for details).

Following are the descriptions for these two low level kernels.

3.2.3.1 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 are not relevant in case of floating point kernels.

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

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

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

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

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

The kernel is expected to be padded in the width dimension if the kernel_width is not a multiple of 4.

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.

These kernels expect input and kernel cubes in SHAPE_CUBE_WHD_T shape type, bias as vector and produce output cube in SHAPE_CUBE_DWH_T shape type. `out_data_format` argument to kernel API must always be 0 to indicate output cube shape type as SHAPE_CUBE_DWH_T.

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

- `[p]`: precision in bits

Precision

There are four 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

Algorithm

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

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

In case of floating point 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);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *,	p_ker	kernel_height* kernel width* input_channels* channels_multiplier	Kernel cube, fixed or floating point, in SHAPE_CUBE_WHD_T
WORD16 *, WORD8 *, FLOAT32 *,	p_inp	input_height* input width* input_channels	Input cube, fixed or floating point, in SHAPE_CUBE_WHD_T
WORD16 *, WORD8 *, 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

Type	Name	Size	Description
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	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 *, FLOAT32 *,	p_out	out_height* out width* input_channels* channels_multiplier	Output cube, fixed or floating point, in SHAPE_CUBE_DWH_T

Returns

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

Restrictions

Arguments	Restrictions
p_out, p_ker, p_inp, p_bias, p_scratch	Cannot be NULL
	Should not overlap
	Aligned on 16-byte boundary
	For p_scratch – memory size >= size returned by xa_nn_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
acc_shift, bias_shift	{-31 .... 31} for fixed point APIs
out_data_format	must be 0: SHAPE_CUBE_DWH_T

3.2.3.2 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` are not relevant in case of floating point kernels.

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

These kernels expect input cube in SHAPE_CUBE_DWH_T shape type, kernel as matrix, bias as vector and produce output cube in SHAPE_CUBE_WHD_T shape type. `out_data_format` argument to kernel API must be always 1 to indicate output cube shape type as SHAPE_CUBE_WHD_T.

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

- `[p]`: precision in bits

Precision

There are four 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

Algorithm

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

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

In case of floating point kernel, `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);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, FLOAT32 *,	p_ker	out_channels * input_channels	Kernel matrix, fixed or floating point (out_channels x input_channels)
WORD16 *, WORD8 *, FLOAT32 *,	p_inp	input_height* input width* input_channels	Input cube, fixed or floating point, in SHAPE_CUBE_DWH_T
WORD16 *, WORD8 *, FLOAT32 *,	p_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	out_data_format		Output data format 1:SHAPE_CUBE_WHD_T

Returns

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

Restrictions

Arguments	Restrictions
p_out, p_ker, p_inp, p_bias	Cannot be NULL
	Should not overlap
	Aligned on 16-byte boundary
input_height, input_width	Greater than or equal to 1
input_channels	Greater than or equal to 4, multiple of 4
out_channels	Greater than or equal to 1
acc_shift, bias_shift	{-31 …. 31} for fixed point APIs
out_data_format	Must be 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 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.

Function variants available are `xa_nn_vec_sigmoid_[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
32_16	32-bit input, 16-bit output
32_8	32-bit input, 8-bit output
f32_f32	float32 input, float32 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);
```

Arguments

Type	Name	Size	Description
Input			
WORD32 *, FLOAT32 *	p_vec	vec_length	Input vector, Q6.25 or floating point
WORD32	vec_length		Length of input vector
Output			
WORD32 *, WORD16 *, WORD8 *, FLOAT32 *	p_out	vec_length	Output vector, fixed (Q16.15, Q15, Q7) or floating point

Returns

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

Restrictions

Arguments	Restrictions
p_vec, p_out	Should not overlap
	Cannot be NULL

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 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.

Function variants available are `xa_nn_vec_tanh_[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
32_16	32-bit input, 16-bit output
32_8	32-bit input, 8-bit output
f32_f32	float32 input, float32 output

Algorithm

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

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);
```

Arguments

Type	Name	Size	Description
Input			
WORD32 *, FLOAT32 *	p_vec	vec_length	Input vector, Q6.25 or floating point
WORD32	vec_length		Length of input vector
Output			
WORD32 *, WORD16 *, WORD8 *, FLOAT32 *	p_out	vec_length	Output vector, fixed (Q16.15, Q15, Q7) or floating point

Returns

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

Restrictions

Arguments	Restrictions
p_vec, p_out	Should not overlap
	Cannot be NULL

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.

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 two variants available:

Type	Description
`32_32`	32-bit input, 32-bit output
`f32_f32`	float32 input, float32 output

Algorithm

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

K represents `threshold`

Prototype

```
WORD32 xa_nn_vec_relu_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_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);
```

Arguments

Type	Name	Size	Description
Input			
WORD32 *, FLOAT32 *	p_vec	vec_length	Input vector, Q6.25 or floating point
WORD32	vec_length		length of input vector
WORD32	threshold		threshold, Q16.15 or floating point
Output			
WORD32 *, FLOAT32 *	p_out	vec_length	Output vector, Q16.15 or floating point

Returns

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

Restrictions

Arguments	Restrictions
p_vec, p_out	Should not overlap
	Cannot be NULL

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.

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

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

Precision

There are two variants available:

Type	Description
32_32	32-bit input, 32-bit output
f32_f32	float32 input, float32 output

Algorithm

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

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);
```

Arguments

Type	Name	Size	Description
Input			
WORD32 *, FLOAT32 *	p_vec	vec_length	Input vector, Q6.25 or floating point
WORD32	vec_length		Length of input vector
Output			
WORD32 *, FLOAT32 *	p_out	vec_length	Output vector, Q16.15 or floating point

Returns

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

Restrictions

Arguments	Restrictions
p_vec, p_out	Should not overlap
	Cannot be NULL

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 the 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 or single precision floating point format and give output in the 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 the temporary buffer should be queried using xa_nn_avgpool_getsize() helper API.

These kernels expect input cube in SHAPE_CUBE_WHD_T shape type and produce output cube in SHAPE_CUBE_WHD_T shape type. The `out_data_format` argument to kernel API must always be 1 to indicate output cube shape type as SHAPE_CUBE_WHD_T.

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

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

Precision

There are three variants available:

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

Algorithm

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

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

in denotes padded input cube, z denotes output

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

Prototype

```
WORD32 xa_nn_avgpool_getsize
(WORD32 inp_precision,    WORD32 input_width,     WORD32 kernel_height,
 WORD32 kernel_width,     WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,        WORD32 out_height,      WORD32 out_width);

WORD32 xa_nn_avgpool_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 out_data_format,
 VOID * p_scratch);
WORD32 xa_nn_avgpool_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 out_data_format,
 VOID * p_scratch);
WORD32 xa_nn_avgpool_f32
(FLOAT32 * p_out,         FLOAT32 * p_inp,        WORD32 input_height,
 WORD32 input_width,      WORD32 input_channels,  WORD32 kernel_height,
```

```
WORD32 kernel_width,     WORD32 x_stride,         WORD32 y_stride,
WORD32 x_padding,        WORD32 y_padding,        WORD32 out_height,
WORD32 out_width,        WORD32 out_data_format,
VOID * p_scratch);
```

Arguments

Type	Name	Size	Description
Input			
WORD8 *, WORD16 *, 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	out_data_format		Output data format: SHAPE_CUBE_WHD_T
Output			
WORD8 *, WORD16 *, 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
	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
out_data_format	Must be 1 (value of 1 implies SHAPE_CUBE_WHD_T)

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 the temporary buffer should be queried using the xa_nn_maxpool_getsize() helper API.

These kernels expect input cube in SHAPE_CUBE_WHD_T shape type and produce output cube in SHAPE_CUBE_WHD_T shape type. The out_data_format argument to kernel API must be always 1 to indicate output cube shape type as SHAPE_CUBE_WHD_T.

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

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

Precision

There are three variants available:

Type	Description
`8`	8-bit input, 8-bit output
`16`	16-bit input, 16-bit output
`f32`	float32 input, float32 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 inp_precision,    WORD32 input_width,     WORD32 kernel_height,
 WORD32 kernel_width,     WORD32 x_stride,        WORD32 y_stride,
 WORD32 x_padding,        WORD32 out_width);

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

Arguments

Type	Name	Size	Description
Input			
WORD8 *, WORD16 *, 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	out_data_format		Output data format: SHAPE_CUBE_WHD_T
Output			
WORD8 *, WORD16 *, 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
	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
`out_data_format`	Must be 1 (value of 1 implies SHAPE_CUBE_WHD_T)

3.4.3 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 numbers 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` are not relevant in the case of floating point 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.

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 four 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

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 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);
```

Arguments

Type	Name	Size	Description
Input			
WORD16 *, WORD8 *, pFLOAT32	p_weight	out_depth* weight_depth	Weight matrix, fixed or floating point
WORD16 *, WORD8 *, pFLOAT32	p_inp	weight_depth *1	Input vector, fixed or floating point
WORD16 *, WORD8 *, pFLOAT32	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
Output			
WORD8 *, WORD16 *, pFLOAT32	p_out	out_depth*1	Output vector, fixed or floating point

Returns

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

Restrictions

Arguments	Restrictions
weight_depth	Multiple of 4 (2 in case of floating point)
p_weight, p_inp, p_bias, p_out	Aligned on 16-byte boundary
	Should not overlap
	Cannot be NULL
out_depth	Greater than or equal to 1
acc_shift, bias_shift	{-31, ….,31}

3.5 Miscellaneous Kernels

3.5.1 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

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[3]

  Number of input features is not supported
- XA_NNLIB_GRU_CONFIG_FATAL_INVALID_OUT_FEATS

  Number of output features is not supported
- XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PRECISION

  I/O precision is not supported
- XA_NNLIB_GRU_CONFIG_FATAL_INVALID_COEFF_QFORMAT

  Number of fractional bits for coefficients is not supported.
- XA_NNLIB_GRU_CONFIG_FATAL_INVALID_IO_QFORMAT

  Number of fractional bits for input-output is not supported.
- XA_NNLIB_GRU_CONFIG_FATAL_INVALID_MEMBANK_PADDING

  Membank padding 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

[3] FEATS := features

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

<table>
<tr><td>Function</td><td><code>xa_nnlib_gru_process</code></td></tr>
<tr><td>Syntax</td><td><pre>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)</pre></td></tr>
<tr><td>Description</td><td>Processes one input shape to generate one output shape.</td></tr>
<tr><td>Parameters</td><td>Input: <code>handle</code>
The opaque component handle.
Required alignment: 8 bytes.

Input: <code>scratch</code>
A pointer to the scratch buffer.
Required alignment: 8 bytes.

Input: <code>input</code>
A pointer to the input buffer. Input buffer contains input data.
Required alignment: 8 bytes.

Output: <code>output</code>
A pointer to the output buffer. Output is written to output buffer.
Required alignment: 8 bytes.

Input/Output: <code>p_in_shape</code>
Pointer to the shape containing input buffer dimensions. Contains the length of input data passed to GRU layer.
Required alignment: 4 bytes.

Input/Output: <code>p_out_shape</code>
Pointer to the shape for output buffer dimensions. On return, *<code>p_out_shape</code> is filled with the length of output generated by HiFi GRU Layer.
Required alignment: 4 bytes.</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 NULL.
XA_NNLIB_FATAL_MEM_ALIGN
One of the pointers is not properly aligned.</td></tr>
</table>

	■ 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.

Table 4-5 GRU Set Parameter Function Details

Function	`xa_nnlib_gru_set_config`

Syntax	`Int32`
	`xa_nnlib_gru_set_config (`
	`xa_nnlib_handle_t handle,`
	`xa_nnlib_gru_param_id_t param_id,`
	`void *params)`

Description	Sets the parameter specified by `param_id` to the value passed in the buffer pointed to by `params`.
Parameters	**Input:** `handle` The opaque component handle. Required alignment: 8 bytes. **Input:** `param_id` Identifies the parameter to be written. 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 function has encountered one of the following errors: ■ XA_NNLIB_FATAL_MEM_ALLOC One of the pointers (`handle` or `params`) is `NULL`. ■ XA_NNLIB_FATAL_MEM_ALIGN One of the pointers (`handle` or `params`) is not aligned correctly. ■ XA_NNLIB_GRU_CONFIG_FATAL_INVALID_PARAM_ID Parameter identifier (`param_id`) is not valid.

Table 4-6 GRU Get Parameter Function Details

Function	`xa_nnlib_gru_get_config`

Syntax	`Int32 xa_nnlib_gru_get_config (`
	`xa_nnlib_handle_t handle,`
	`xa_nnlib_gru_param_id_t param_id,`
	`void *params)`

Description	Gets the value of the parameter specified by `param_id` in the buffer pointed to by `params`.
Parameters	**Input:** `handle` The opaque component handle. Required alignment: 8 bytes. **Input:** `param_id` Identifies the parameter to be read. 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 16 bytes for HiFi 5
Int32	mat_prec	8, 16	16	Matrix input precision
Int32	vec_prec	16	16	Vector input precision
xa_nnlib_gru_precision_t	precision	XA_NNLIB_GRU_16bx16b, XA_NNLIB_GRU_8bx16b	XA_NNLIB_GRU_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:

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

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[4]

  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

[4] 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

Function	`xa_nnlib_lstm_init`

Syntax	`Int32`
	`xa_nnlib_lstm_init (`
	`    xa_nnlib_handle_t handle,`
	`    xa_nnlib_lstm_init_config_t *config)`

Description	Reset the LSTM layer API handle into its initial state. Set up the LSTM layer to the specified initial configuration parameters. This function sets prev_h vector and prev_c vector to 0; the user can 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).
Parameters	Input: `handle` Pointer to the component persistent memory. This is the opaque handle. Required size: see `xa_nnlib_lstm_get_persistent_fast`. Required alignment: 8 bytes. Input: `config` Initial configuration parameters (see Table 4-18). Note 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_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.

4.2.3.3 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 16 bytes for HiFi 5 DSP
Int32	mat_prec	8, 16	16	Matrix input precision
Int32	vec_prec	16	16	Vector input precision
xa_nnlib_lstm_precision_t	precision	XA_NNLIB_LSTM_16bx16b, XA_NNLIB_LSTM_8bx16b	XA_NNLIB_LSTM_16bx16b	Coef and I/O precision. Note: The current library supports only 16bx16b and 8bx16b precision for LSTM.
Int16	coeff_Qformat	0-15	15	Number of fractional bits for weights and biases
Int16	cell_Qformat	0-26		Number of fractional bits for cells.
Int16	io_Qformat	0-15	12	Number of fractional bits for input and output

Table 4-19 xa_nnlib_lstm_weights_t Parameter Type

Element Type	Element Name	Range	Default	Description
coeff_t *	w_xf	NA	NA	Pointer to coefficient matrix w_xf.
xa_nnlib_shape_t	shape_w_xf	NA	NA	Shape information about w_xf.
coeff_t *	w_xi	NA	NA	Pointer to coefficient matrix w_xi.
xa_nnlib_shape_t	shape_w_xi	NA	NA	Shape information about w_xi.
coeff_t *	w_xc	NA	NA	Pointer to coefficient matrix w_xc.
xa_nnlib_shape_t	shape_w_xc	NA	NA	Shape information about w_xc.
coeff_t *	w_xo	NA	NA	Pointer to coefficient matrix w_xo.
xa_nnlib_shape_t	shape_w_xo	NA	NA	Shape information about w_xo.
coeff_t *	w_hf	NA	NA	Pointer to coefficient matrix w_hf.
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 3.2.2 for Standard 1D Convolution, and Section 3.2.3 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_shape_t	bias_ds_depth_shape	NA	NA	Depthwise Separable 2D Convolution - Depthwise Bias) Dimensions
xa_nnlib_shape_t	bias_ds_point_shape	NA	NA	Depthwise Separable 2D Convolution – Pointwise Bias Dimensions
xa_nnlib_cnn_precision_t	precision	XA_NNLIB_CNN_16bx16b, XA_NNLIB_CNN_8bx16b, XA_NNLIB_CNN_8bx8b, XA_NNLIB_CNN_f32xf32	XA_NNLIB_CNN_8bx16b	Kernel (filter), input, output precision setting
Int32	bias_shift	-31 to 31	7	Q-format adjustment for bias before addition into accumulator, +/- value - left/right shift

Element Type	Element Name	Range	Default	Description
`Int32`	`acc_shift`	-31 to 31	-7	Q-format adjustment for accumulator before rounding to result, +/- value - left/right shift
`Int32`	`channels_multiplier`	NA	NA	Depthwise Separable 2D Convolution - channel multiplier. (`channels_multiplier * input_channels`) must be multiple of 4
`Int32`	`x_padding`	NA	2	Left side padding to be added to input
`Int32`	`y_padding`	NA	2	Top padding to be added to input
`Int32`	`x_stride`	NA	2	Strides over padded input in width dimension
`Int32`	`y_stride`	NA	2	Strides over padded input in height dimension
`xa_nnlib_cnn_algo_t`	`algo`	NA	XA_NNLIB_CNN_CONV2D_STD	Convolution algorithm

4.3.5 Enums Specific to CNN

Table 4-30 Enum xa_nnlib_cnn_precision_t

Element	Description
`XA_NNLIB_CNN_16bx16b`	Coef: 16 bits, I/O: 16 bits fixed point
`XA_NNLIB_CNN_8bx16b`	Coef: 8 bits, I/O: 16 bits fixed point
`XA_NNLIB_CNN_8bx8b`	Coef: 8 bits, I/O: 8 bits fixed point
`XA_NNLIB_CNN_f32xf32`	Coef: single precision float, I/O: single precision float

Table 4-31 Enum xa_nnlib_cnn_algo_t

Element	Description
`XA_NNLIB_CNN_CONV1D_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. Introduction to the Example Testbench

5.1 Making the Library

If you have source code distribution, you must build the NN library before you can build the testbench. To do so, follow these steps:

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

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

5.2 Making the Executable

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 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`

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

5.3 Sample Testbench for Matrix X Vector Multiplication Kernels

The NN library Matrix X Vector Multiplication Kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

- Testbench source files (`test/src`)
  - `xa_nn_matXvec_testbench.c`

5.3.1 Usage

The NN library Matrix X Vector Multiplication Kernels executable can be run with 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.	
`-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 shift(Default=-7)	
`-bias_shift`	Bias shift(Default=7)	
`-mat_precision`	8, 16, -1(single precision float); (Default=16)	
`-inp_precision`	8, 16, -1(single precision float); (Default=16)	
`-out_precision`	8, 16, 32, 64 -1(single precision float); (Default=16)	
`-bias_precision`	16, 64 -1(single precision float); (Default=16)	
`-membank_padding`	0 or 1 (Default=1)	
`-frames`	Positive number; (Default=2)	
`-activation`	Sigmoid, tanh, relu or softmax (Default= bypass i.e. no activation for output)	
`-write_file`	Set to 1 to write input and output vectors to file; (Default=0)	

Option	Description	Additional Information
`-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`	Prints help	

If no command line arguments are given, the Matrix X Vector Multiplication Kernels sample testbench runs with default values.

5.4 Sample Testbench for Convolution Kernels

The NN library Convolutional Kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

- Testbench source files (`test/src`)
  - `xa_nn_conv_testbench.c`

5.4.1 Usage

The NN Library Convolutional Kernels executable can be run with 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)

Option	Description
`-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`	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)
`-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`	Prints help

If no command line arguments are given, the Convolutional Kernels sample testbench runs with default values.

5.5 Sample Testbench for Activation Kernels

The NN library Activation kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

- Testbench source files (`test/src`)
  - `xa_nn_activations_testbench.c`

5.5.1 Usage

The NN library Convolutional 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`	16, 32, -1 (single precision float) (Default=32)
`-out_precision`	16, 32, -1(single precision float) (Default=32)
`-frames`	Positive number (Default=2)
`-activation`	Sigmoid, tanh, relu, relu1, relu6 or softmax (Default= sigmoid)
`-write_file`	Set to 1 to write input and output vectors to file; (Default=0)
`-read_inp_file_name`	Full filename for reading input
`-read_ref_file_name`	Full filename for reading reference output
`-write_inp_file_name`	Full filename for writing input
`-write_out_file_name`	Full filename for writing output
`-verify`	Verify output against provided reference; 0: Disable, 1: Bit exact match (Default=1)
`-help`	Prints help

If no command line arguments are given, the Activation Kernels sample testbench runs with default values.

5.6 Sample Testbench for Pooling Kernels

The NN library Pooling Kernels are provided with a sample testbench application. The supplied testbench consists of the following files:

- Testbench source files (`test/src`)
  - `xa_nn_pool_testbench.c`

5.6.1 Usage

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

```
$ xt-run [--mem_model] [--turbo] xa_nn_pool_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)
`-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 shift (Default=-7)
`-out_data_format`	Data format (Default=1 (SHAPE_CUBE_WHD_T))
`-inp_precision`	8, 16, -1(single precision float) (Default=16)
`-out_precision`	8, 16, -1(single precision float) (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)

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: Disable, 1: Bit exact match (Default=1)
`-help`	Prints help

If no command line arguments are given, the Pooling Kernels sample testbench runs with default values.

5.7 Sample Testbench for GRU Layer

The NN library GRU layer is provided with a sample testbench application. The supplied testbench consists of the following files:

- Testbench source files (`test/src`)
  - `xa_nn_gru_testbench.c`

5.7.1 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	

Option	Description	Additional Information
`--output_file`	File to which output will be written	
`--prev_h_file`	File containing context data	
`--ref_file`	File which has ref output	
`-help`	Prints help	

If no command line arguments are given, the GRU sample testbench runs with default values.

5.8 Sample Testbench for LSTM Layer

The NN library LSTM layer is provided with a sample testbench application. The supplied testbench consists of the following files:

- Testbench source files (`test/src`)
  - `xa_nn_lstm_testbench.c`

5.8.1 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	

Option	Description	Additional Information
`--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`	Prints help	

If no command line arguments are given, the LSTM sample testbench runs with default values.

5.9 Sample Testbench for CNN Layer

The NN library CNN layer is provided with a sample testbench application. The supplied testbench consists of the following files:

- Testbench source files (`test/src`)
  - `xa_nn_cnn_testbench.c`

5.9.1 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)

Option	Description
`-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)
`-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`	Prints help

If no command line arguments are given, the CNN sample testbench runs with default values.

5.10 Sample Testbenches for Neural Network Examples

Along with the NN library this package includes two samples testbenches for NN use-case examples, `xa_nn_model_conv_test` and `xa_nn_model_tiny_conv_test`. Both the applications consist of a pre-trained neural network model stored as read-only data. The testbenches use the NN library kernels for inference of the pre-trained neural network. The neural networks were trained using the Simple Audio Recognition tutorial in TensorFlow [2]. The test application uses a small convolutional neural network to recognize a word from the input spectrogram given as input. Currently, only single precision float processing is used. The input spectrogram is generated externally by extracting the speech features from an audio file(.wav) and they are stored as the `.bin` input files. The information related to the details of the NN model has been given in the testbench. Both the applications can work as a yes-no recognizer or a ten-word recognizer based on the selected model (`-model`).

The `xa_nn_model_tiny_conv_test` application consists of the following layers:

- Input
- Standard 2D Convolution
- ReLU
- Fully Connected
- Softmax

The `xa_nn_model_conv_test` application consists of the following layers:

- Input
- Standard 2D Convolution
- ReLU
- Maxpool
- Standard 2D Convolution
- ReLU
- Fully Connected
- Softmax

The supplied testbenches consist of the following files:

- Testbench source files (`test/src`)
  - `xa_nn_model_tiny_conv_testbench.c`
  - `xa_nn_model_conv_testbench.c`
- Testbench source files containing weights of the models (`test/src`)
  - `tiny_conv2d_ker_bias.c`
  - `tiny_fc_ker_bias.c`

  - conv_conv2d_ker_bias.c
  - conv_fc_ker_bias.c
- Additional Testbench include files (test/include)
  - tiny_conv2d_ker_bias.h
  - tiny_fc_ker_bias.h
  - conv_conv2d_ker_bias.h
  - conv_fc_ker_bias.h
- Testbench input files (test/test_inp)

  Following is the naming convention for the input files:
- [NN model]_[word model]_[input word(s)].bin
  - tiny_conv_Ten_Word_stop.bin
  - tiny_conv_Ten_Word_stop_right.bin
  - tiny_conv_Yes_No_yes.bin
  - tiny_conv_Yes_No_yes_no.bin
  - conv_Ten_Word_down_on.bin
  - conv_Ten_Word_off.bin
  - conv_Yes_No_no.bin
  - conv_Yes_No_no_no.bin

5.10.1 Usage

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

```
$ xt-run [--mem_model] [--turbo] xa_nn_model_conv_test [options]
$ xt-run [--mem_model] [--turbo] xa_nn_model_tiny_conv_test
[options]
```

Following are available options:

Option	Description
-read_inp_file_name	Full filename for reading input spectrogram.
-model	Yes_No, Ten_Word; (Default= Yes_No)
-precision	-1 for FLOAT32; (Default=-1 FLOAT32)
-frames	Data frames to be processed. Should be a positive number. (Default=1)
-help	Shows help

6. References

[1] Reference Wiki page for GRU. https://en.wikipedia.org/wiki/Gated_recurrent_unit

[2] Simple Audio Recognition tutorial in TensorFlow:
https://www.tensorflow.org/tutorials/sequences/audio_recognition