Intel® Math Kernel Library Sparse Matrix Vector Multiply Format Prototype Package

Reference Manual

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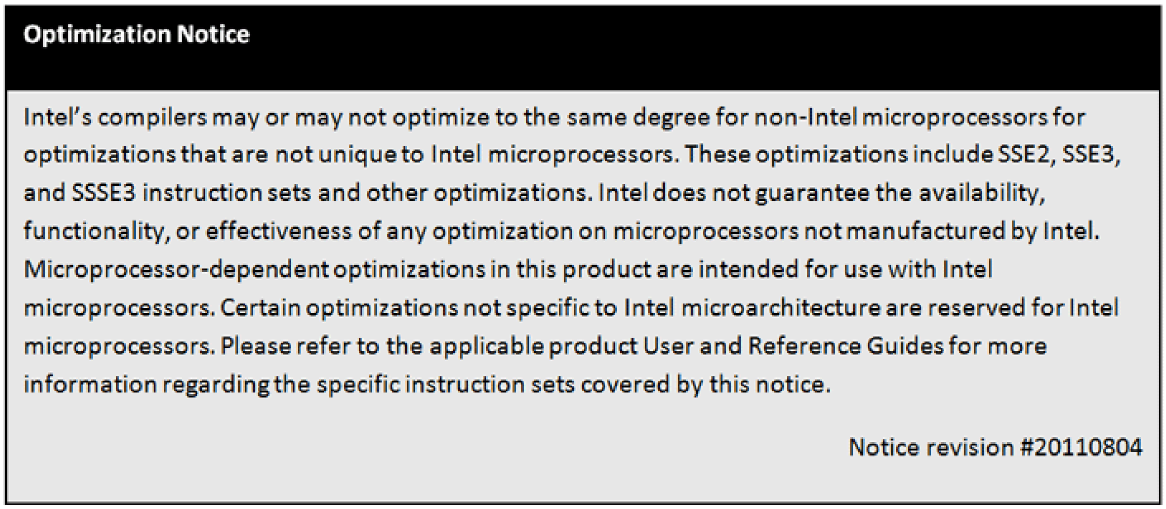

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1 Introducing the SpMV Format Package

The *Intel® Math Kernel Library Sparse Matrix Vector Multiply Format Prototype Package (Intel® MKL SpMV Format Prototype Package)* described in this document contains several implementations of SpMV routines which are optimized for Intel® Xeon Phi™ coprocessors. Interfaces for this library are mostly similar to NVIDIA* CUDA* Sparse Matrix library (CuSPARSE) interfaces [1].

Two sparse formats are currently supported in this library:

- CSR (Column Sparse-Row format), see Sparse Matrix Storage Formats section in [2] for details.
- ESB (ELLPACK Sparse Row format), see [3] for details.

The SpMV functionality implemented is the following general non-transposed case for double precision only:

y := *alpha*A*x+beta*y*,

where *alpha* and *beta* are scalars, *A* is a sparse matrix in the CSR or ESB format, and *x* and *y* are dense vectors.

The sparse matrix for this functionality is stored in an opaque structure passed by a handle, which can be created from an external sparse matrix in the CSR format. Note that the input data is duplicated in the internal array representation. An input matrix can use either 0-based or 1-based indexing.

The library currently provides only C interfaces.

2 Supported Data Types

The following table lists supported data types and possible values for each type:

Data Type	Possible Values	Description
`sparse Status_t`		A status that is returned by library functions.
	`SPARSE_STATUS_SUCCESS`	The operation completed successfully
	`SPARSE_STATUS_NOT_INITIALIZED`	Some of the structures were not created or initialized properly before use. Check the sequence of function calls and statuses of completed operations.
	`SPARSE_STATUS_ALLOC_FAILED`	Allocation of internal memory inside the library failed. A task which is too large is probably being solved or some memory was not released.
	`SPARSE_STATUS_INVALID_VALUE`	Some parameters in the function call have unsupported values. For example: the size of a matrix is negative.

	SPARSE_STATUS_EXECUTION_FAILED, SPARSE_STATUS_INTERNAL_ERROR	Usually it means that execution stopped due to unexpected values of some internal variables, which probably occurred as a result of the application of the wrong algorithm.
sparse Operation_t		A matrix operation
	SPARSE_OPERATION_NON_TRANSPOSE	Non-transposed matrix operation.
sparse Schedule_t		A workload scheduling algorithm
	SPARSE_SCHEDULE_STATIC	Statically distribute input data to threads
	SPARSE_SCHEDULE_DYNAMIC	Dynamically distribute input data to threads
	SPARSE_SCHEDULE_BLOCK	Distribute input data to threads as fixed-size blocks
sparseMatrix Type_t		A description of an input matrix
	SPARSE_MATRIX_TYPE_GENERAL	Input matrix is stored in the general representation.

`sparseIndexBase_t`		Indexing of a matrix
	`SPARSE_INDEX_BASE_ZERO`	The matrix has zero-based indexing.
	`SPARSE_INDEX_BASE_ONE`	The matrix has one-based indexing.

3 Auxiliary Functions

sparseCreateESBMatrix

Creates ESB internal matrix structure with default initial values.

Syntax

```
sparseStatus_t sparseCreateESBMatrix (sparseESBMatrix_t *esbA,
sparseSchedule_t schedule);
```

Include Files

`spmv_interface.h`

Input Parameters

`schedule`

Specifies the matrix scheduling algorithm.

Possible values:

`SPARSE_SCHEDULE_STATIC` – statically distribute the input data;

`SPARSE_SCHEDULE_DYNAMIC` – dyntamically distribute the input data.

Output Parameters

`esbA`

Pointer to the created ESB matrix structure.

Return Values

`Status`

Possible values:

`SPARSE_STATUS_SUCCESS` – ESB matrix structure is created successfully,

`SPARSE_STATUS_ALLOC_FAILED` – ESB matrix structure could not be allocated,

`SPARSE_STATUS_INVALID_VALUE` – the schedule parameter has an unsupported value.

Note: *The scheduling algorithm determines workload balancing for the input matrix. SPARSE_SCHEDULE_STATIC means that the input matrix is divided into small chunks which are assigned to threads statically. SPARSE_SCHEDULE_DYNAMIC means that these chunks are assigned to threads dynamically in run time.*

sparseDestroyESBMatrix

Releases memory used by the ESB matrix structure.

Syntax

```
sparseStatus_t sparseDestroyESBMatrix(sparseESBMatrix_t  esbA);
```

Include Files

```
spmv_interface.h
```

Input Parameters

esbA	the matrix for which to release the memory.

Return Values

Status

Possible values:

`SPARSE_STATUS_SUCCESS – ESB` matrix structure is released successfully,

`SPARSE_STATUS_NOT_INITIALIZED` – ESB matrix structure was not created.

sparseCreateCSRMatrix

Creates the CSR internal matrix structure with default initial values.

Syntax

```
sparseStatus_t sparseCreateCSRMatrix (sparseCSRMatrix_t *csrA,
sparseSchedule_t schedule);
```

Include Files

`spmv_interface.h`

Input Parameters

`schedule`

Specifies the matrix scheduling algorithm.

Possible values:

`SPARSE_SCHEDULE_STATIC` – statically distribute the input data;

`SPARSE_SCHEDULE_DYNAMIC` – dynamically distribute the input;

`SPARSE_SCHEDULE_BLOCK` – the input data will be distributed as fixed-size blocks.

Output Parameters

`csrA`

Pointer to the created CSR matrix structure.

Return Values

`Status`

Possible values:

`SPARSE_STATUS_SUCCESS` – CSR matrix structure is created successfully,

`SPARSE_STATUS_ALLOC_FAILED` – the memory for the CSR matrix structure could not be allocated,

`SPARSE_STATUS_INVALID_VALUE` – the schedule parameter has an unsupported value.

Note: *The scheduling algorithm determines workload balancing for the input matrix. SPARSE_SCHEDULE_STATIC means that the input matrix is divided into small chunks which are assigned to threads statically. SPARSE_SCHEDULE_DYNAMIC means that these chunks are assigned to threads dynamically in run time. SPARSE_SCHEDULE_BLOCK means that each thread processes one block of input matrix, all blocks have more or less equal numbers of non-zeroes.*

sparseDestroyCSRMatrix

Releases the memory used by the CSR matrix structure.

Syntax

```
sparseStatus_t sparseDestroyCSRMatrix(sparseCSRMatrix_t  csrA);
```

Include Files

```
spmv_interface.h
```

Input Parameters

`csrA` The matrix for which to release the memory.

Return Values

`Status` Possible values:

`SPARSE_STATUS_SUCCESS` – the CSR matrix structure is released successfully, SPARSE_STATUS_NOT_INITIALIZED – the CSR matrix structure was not created.

sparseCreateMatDescr

Creates a matrix descriptor and initializes it with default values using the SPARSE_MATRIX_TYPE_GENERAL *and* SPARSE_INDEX_BASE_ZERO *settings.*

Syntax

```
sparseStatus_t sparseCreateMatDescr  (sparseMatDescr_t *descrA);
```

Include Files

```
 spmv_interface.h
```

Output Parameters

descrA	Pointer to the created matrix descrtiptor.

Return Values

Status	Possible values: SPARSE_STATUS_SUCCESS – the matrix descriptor structure is created successfully, SPARSE_STATUS_ALLOC_FAILED – the memory for the matrix descriptor structure could not be allocated.

sparseDestroyMatDescr

Releases the memory used by the matrix descriptor structure.

Syntax

```
sparseStatus_t sparseDestroyMatDescr (sparseMatDescr_t  descrA);
```

Include Files

```
spmv_interface.h
```

Input Parameters

descrA	The matrix descriptor for which to release the memory.

Return Values

Status	Possible values: `SPARSE_STATUS_SUCCESS` – the matrix descriptor is released successfully, `SPARSE_STATUS_NOT_INITIALIZED` – the matrix descriptor was not previously created.

sparseSetMatType

Sets the MatrixType value in the matrix descriptor.

Syntax

```
sparseStatus_t      sparseSetMatType(sparseMatDescr_t descrA,
sparseMatrixType_t type);
```

Include Files

```
spmv_interface.h
```

Input Parameters

descrA	The matrix descriptor to be modified.

`type`	The matrix type. Possible value: `SPARSE_MATRIX_TYPE_GENERAL`, default.

Output Parameters

`descrA`	The matrix descriptor.

Return Values

`descrA`	The matrix descriptor.
`Status`	Possible values: `SPARSE_STATUS_SUCCESS` – *MatrixType* was set successfully, `SPARSE_STATUS_NOT_INITIALIZED` – the *descrA* matrix structure was not initialized properly.

sparseGetMatType

Get the MatrixType value from the matrix descriptor.

Syntax

```
sparseMatrixType_t  sparseGetMatType(const sparseMatDescr_t descrA);
```

Include Files

```
spmv_interface.h
```

Input Parameters

descrA	The matrix descriptor.

Return Values

MatrixType	The value of the matrix type from the matrix descriptor. Possible value: `SPARSE_MATRIX_TYPE_GENERAL`, default.

sparseSetMatIndexBase

Sets the indexing base value in the matrix descriptor.

Syntax

```
sparseStatus_t      sparseSetMatIndexBase(sparseMatDescr_t descrA,
sparseIndexBase_t base);
```

Include Files

```
spmv_interface.h
```

Input Parameters

descrA	The matrix descriptor to be modified.
base	The base to use for indexing arrays. Possible values: `SPARSE_INDEX_BASE_ZERO` (default) and `SPARSE_INDEX_BASE_ONE`.

Output Parameters

descrA	The matrix descriptor.

Return Values

Status

Possible values:

SPARSE_STATUS_SUCCESS – the indexing base was set successfully,

SPARSE_STATUS_NOT_INITIALIZED – the *descrA* matrix structure was not initialized properly.

sparseGetMatIndexBase

Get the indexing base value from the matrix descriptor.

Syntax

```
sparseIndexBase_t   sparseGetMatIndexBase(const sparseMatDescr_t
descrA);
```

Include Files

```
spmv_interface.h
```

Input Parameters

descrA

The matrix descriptor.

Returned Values

IndexBase

The base used for indexing arrays.

Note:

If *descrA* was not initialized, SPARSE_INDEX_BASE_ZERO is returned.

sparseDcsr2esb

Creates the internal ESB matrix structure from the input matrix in the CSR format, described by the descrA descriptor. It also analyzes the sparsity structure of the matrix and prepares data for workload scheduling algorithms.

Syntax

```
sparseStatus_t sparseDcsr2esb(   int m, int n, const sparseMatDescr_t
descrA, const double *csrValA, const int *csrRowPtrA,  const int
*csrColIndA, sparseESBMatrix_t  esbA );
```

Include Files

`spmv_interface.h`

Input Parameters

m

The number of rows of the input matrix *A*.

n

The number of columns of the input matrix *A*.

descrA

The descriptor of the matrix *A*.

csrValA

Array of length *csrRowPtrA [m]* - *csrRowPtrA [0]*. Contains non-zero elements of the matrix A. See the description of the values array in CSR Format for more details.

csrRowPtrA

Array of length *m* + 1. Contains indices of elements in the *csrValA* array such that *csrRowPtrA[I]* is the index in the *csrValA* array of the first non-zero element in the row I. The value of *csrRowPtrA [m] - csrRowPtrA [0]* is equal to the number of non-zero elements. See the description of the rowIndex array in CSR Format for more details.

csrColIndA

Array of length equal to the length of the *csrValA* array. Contains the column indices for each non-zero element of the matrix *A*. See the description of the columns array in CSR Format for more details.

Output Parameters

esbA

The ESB matrix descriptor.

Return Values

Status

See the type description for possible values.

sparseDcsr2csr

Creates the internal CSR matrix structure from the input matrix in the CSR format, described by the descrA descriptor. It also analyzes the sparsity structure of the matrix and prepares data for workload scheduling algorithms.

Syntax

```
sparseStatus_t sparseDcsr2csr( int m, int n, const sparseMatDescr_t
descrA,const double *csrValA, const int *csrRowPtrA, const int
*csrColIndA, sparseCSRMatrix_t  csrA );
```

Include Files

```
spmv_interface.h
```

Input Parameters

m

The number of rows of the input matrix *A*.

n

The number of columns of the input matrix *A*.

descrA

The descriptor of the matrix *A*.

csrValA

Array of length *csrRowPtrA [m]* - *csrRowPtrA [0]*. Contains non-zero elements of the matrix *A*. See the description of the values array in CSR Format for more details.

csrRowPtrA

Array of length *m* + 1. Contains indices of elements in the array *csrValA* such that *csrRowPtrA[I]* is the index in the array *csrValA* of the first non-zero element in the row I. The value of *csrRowPtrA [m] – csrRowPtrA [0]* is equal to the number of non-zero elements. See the description of the rowIndex array in CSR Format for more details.

csrColIndA

Array of length equal to the length of the array *csrValA*. Contains the column indices for each non-zero element of the matrix *A*. See the description of the columns array in CSR Format for more details.

Output Parameters

csrA

CSR matrix descriptor.

Return Values

Status

See the type description for possible values.

4 Computational Functions

sparseDesbmv

*Performs the matrix-vector operation y:= alpha*A*x+beta*y, where alpha and beta are scalars, x and y are dense vectors, and A is a sparse m-by-n matrix in the internal ESB format.*

Syntax

```
sparseStatus_t sparseDesbmv( sparseOperation_t transA, const double
*alpha, const sparseESBMatrix_t  esbA, const double *x, const double
*beta, double *y);
```

Include Files

```
spmv_interface.h
```

Input Parameters

transA Descriptor of the matrix operation. Only non-transposed operation is currently supported.

alpha The scalar parameter *alpha*.

esbA Sparse matrix in the ESB format. Use the sparseDcsr2esb() convertor to initialize the esbA structure.

x Array of dimension at least *n*. Contains the dense vector *x*.

beta The scalar parameter *beta*.

y Array of dimension at least *m*. Contains the input vector *y*.

Output Parameters

y	Array of dimension at least m. Contains the resulting vector *y*.

Return Values

Status	See the type description for possible values.

sparseDcsrmv

*Performs the matrix-vector operation y:= alpha*A*x+beta*y, where alpha and beta are scalars, x and y are dense vectors and A is a sparse m-by-n matrix in the internal CSR format.*

Syntax

```
sparseStatus_t sparseDcsrmv( sparseOperation_t transA, const double
*alpha, const sparseCSRMatrix_t  csrA, const double *x, const double
*beta, double *y);
```

Include Files

```
spmv_interface.h
```

Input Parameters

transA	The descriptor of the matrix operation. Only non-transposed operation is currently supported.
alpha	The scalar parameter *alpha*.
csrA	Sparse matrix in the CSR format. Use the sparseDcsr2csr() convertor to initialize the csrA

structure.

`x` Array of dimension at least *n*. Contains the vector *x*.

`beta` The scalar parameter beta.

`y` Array of dimension at least *m*. Contains the input vector *y*.

Output Parameters

`y` Array of dimension at least *m*. Contains the resulting vector *y*.

Return Values

`Status` See the type description for possible values.

BIBLIOGRAPHY

1. The NVIDIA CuSPARSE* library documentation
2. Intel® Math Kernel Library Reference Manual
3. Xing Liu, Mikhail Smelyanskiy, Edmond Chow, Pradeep Dubey. “Efficient Sparse Matrix-Vector Multiplication on x86-Based Many-Core Processors”. ICS’13, June 10–14, 2013, Eugene, Oregon, USA