
AOCL-Sparse

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FUNCTIONALITY API

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CHAPTER
ONE

INTRODUCTION

The AMD Optimized CPU Library AOCL-Sparse is a library that contains Basic Linear Algebra Subroutines for sparse matrices and vectors (Sparse BLAS) and is optimized for AMD EPYC and RYZEN family of CPU processors. It implements numerical algorithms in C++ while providing a public-facing C interface so it can be used with C, C++ and compatible languages.

The current functionality of AOCL-Sparse is organized in the following categories:

- **Sparse level 1** functions perform vector operations such as dot product, vector additions on sparse vectors, gather, scatter, and other similar operations.
- **Sparse level 2** functions describe the operations between a matrix in a sparse format and a vector in the dense format, including matrix-vector product (SpMV), triangular solve (TRSV) and similar.
- **Sparse level 3** functions describe the operations between a matrix in a sparse format and one or more dense/sparse matrices. The operations comprise of matrix additions (SpADD), matrix-matrix product (SpMM, Sp2M), and triangular solver with multiple right-hand sides (TRSM).
- **Iterative sparse solvers** based on Krylov subspace methods (CGM, GMRES) and preconditioners (such as, SymGS, ILU0).
- Sparse format conversion functions for translating matrices in a variety of sparse storage formats.
- Auxiliary functions to allow basic operations, including create, copy, destroy and modify matrix handles and descriptors.

Additional highlights:

- Supported data types: single, double, and the complex variants
- 0-based and 1-based indexing of sparse formats
- **Hint and optimize framework** to accelerate supported functions by a prior matrix analysis based on users' hints of expected operations.

NAMING CONVENTION

APIs in the library are formed by three sections: `aoclsparse` prefix, P data type precision, followed by an abbreviated form of the functionality. Data type precision P is a single letter indicating: s single, d double, c complex single, and z complex double floating point. Some illustrative examples follow.

Table 1: API naming convention examples

API	Precision P	Functionality
<code>aoclsparse_strsv(s)</code>		TRSV single precision linear system of equations TRiangular SolVer,
<code>aoclsparse_daxpy(d)</code>		AXPY perform a variant of the operation $a x + y$ in double precision,
<code>aoclsparse_cmv(c)</code>		SPMV sparse matrix-vector product using complex single precision,
<code>aoclsparse_ztrsm(z)</code>		TRSM complex double precision linear system of equations TRiangular Solver with Multiple right-hand sides.

A subset of APIs: `trsv`, `mv`, `create_csr`, `create_bsr`, and `sp2m` support C++ interfaces in the `aoclsparse::` namespace. These interfaces are templated to support the following data types: `float`, `double`, `std::complex<float>`, and `std::complex<double>`.

Throughout this document and where not ambiguous, if an API supports two or more data types described above, then it will be indicated by ? (question mark) in place of the data type single-letter abbreviation. As an example, `aoclsparse_?trsv()` references all supported data types for the TRSV solver, that is, `aoclsparse_strsv()`, `aoclsparse_dtrsv()`, `aoclsparse_ctrsv()`, and `aoclsparse_ztrsv()`; while `aoclsparse_?dotci()` references only `aoclsparse_cdotci()`, and `aoclsparse_zdotci()`.

2.1 Analysis Functions

2.1.1 `aoclsparse_optimize()`

`aoclsparse_status aoclsparse_optimize(aoclsparse_matrix mat)`

Performs analysis and possible data allocations and matrix restructuring operations to accelerate sparse operations involving matrices.

In `aoclsparse_optimize()` sparse matrices are restructured based on matrix analysis, into different storage formats to improve data access and thus performance.

Parameters

`mat` – [in] sparse matrix in CSR format and sparse format information inside

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – *m* is invalid.
- **aoclsparse_status_invalid_pointer** –
- **aoclsparse_status_internal_error** – an internal error occurred.

2.1.2 **aoclsparse_set_*_hint()**

aoclsparse_status aoclsparse_set_mv_hint(aoclsparse_matrix mat, aoclsparse_operation trans, const aoclsparse_mat_descr descr, aoclsparse_int expected_no_of_calls)

aoclsparse_status aoclsparse_set_sv_hint(aoclsparse_matrix mat, aoclsparse_operation trans, const aoclsparse_mat_descr descr, aoclsparse_int expected_no_of_calls)

aoclsparse_status aoclsparse_set_mm_hint(aoclsparse_matrix mat, aoclsparse_operation trans, const aoclsparse_mat_descr descr, aoclsparse_int expected_no_of_calls)

aoclsparse_status aoclsparse_set_2m_hint(aoclsparse_matrix mat, aoclsparse_operation trans, const aoclsparse_mat_descr descr, aoclsparse_int expected_no_of_calls)

Record hints of the expected number and types of calls to optimize the input matrix for.

Any of the *aoclsparse_set_*_hint* functions may be used to indicate that a given number of calls to the same Sparse BLAS API will be performed. When *aoclsparse_optimize()* is invoked, the input matrix might be tuned to accelerate the hinted calls.

Parameters

- **mat** – [in] Input sparse matrix to be tuned.
- **trans** – [in] Matrix operation to perform during the calls.
- **descr** – [in] Descriptor of the sparse matrix used during the calls.
- **expected_no_of_calls** – [in] A rough estimate of the number of the calls.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_value** – *mat*, *trans*, *descr* or *expected_no_of_calls* is invalid. Expecting *expected_no_of_calls* > 0.
- **aoclsparse_status_invalid_pointer** – *mat* or *descr* is invalid.
- **aoclsparse_status_memory_error** – internal memory allocation failure.

aoclsparse_status aoclsparse_set_lu_smoothening_hint(aoclsparse_matrix mat, aoclsparse_operation trans, const aoclsparse_mat_descr descr, aoclsparse_int expected_no_of_calls)

aoclsparse_status aoclsparse_set_symgs_hint(aoclsparse_matrix mat, aoclsparse_operation trans, const aoclsparse_mat_descr descr, aoclsparse_int expected_no_of_calls)

aoclsparse_status aoclsparse_set_dotmv_hint(aoclsparse_matrix mat, aoclsparse_operation trans, const aoclsparse_mat_descr descr, aoclsparse_int expected_no_of_calls)

Provides hints to optimize preconditioning matrices.

Set hints for analysis and optimization of preconditioning-related factorizations and/or accelerate the application of such preconditioner, this can also include hints for “fused” operations that accelerate two operations in a single call.

Parameters

- **mat** – [in] A sparse matrix
- **trans** – [in] Whether in transposed state or not. Transpose operation is not yet supported.
- **descr** – [in] Descriptor of the sparse matrix.
- **expected_no_of_calls** – [in] Expected number of call to an API that uses matrix **mat**.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – indicates that **mat** is invalid.
- **aoclsparse_status_invalid_pointer** – at least one of the input pointers is invalid.
- **aoclsparse_status_internal_error** – Indicates that an internal error occurred.

```
aoclsparse_status aoclsparse_set_sm_hint(aoclsparse_matrix mat, aoclsparse_operation trans, const  
                                  aoclsparse_mat_descr descr, const aoclsparse_order order, const  
                                  aoclsparse_int expected_no_of_calls)
```

Record a hint of the expected number of calls to *aoclsparse_strsm()* and variants to optimize the input matrix for the hinted operations.

aoclsparse_set_sm_hint() may be used to indicate that a given number of calls to the triangular solver *aoclsparse_strsm()* or other variant will be performed. When *aoclsparse_optimize()* is invoked, the input matrix might be tuned to accelerate the hinted calls. The hints include not only the estimated number of calls to the API solver, but also other (matrix) parameters. The hinted matrix should not be modified after the call to optimize and before the call to the solver.

Parameters

- **mat** – [in] Input sparse matrix to be tuned.
- **trans** – [in] Matrix operation to perform during the calls.
- **descr** – [in] Descriptor of the sparse matrix used during the calls.
- **order** – [in] Layout of the right-hand-side input matrix used during the calls, valid options are *aoclsparse_order_row* and *aoclsparse_order_column*.
- **expected_no_of_calls** – [in] A rough estimate of the number of the calls.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_value** – *expected_no_of_calls*, *order*, *mat*, *trans* or *descr* is invalid.
- **aoclsparse_status_invalid_pointer** – *mat* or *descr* is invalid.
- **aoclsparse_status_memory_error** – internal memory allocation failure.

```
aoclsparse_status aoclsparse_set_sorv_hint(aoclsparse_matrix mat, const aoclsparse_mat_descr descr, const  
                                         aoclsparse_sor_type type, const aoclsparse_int  
                                         expected_no_of_calls)
```

Record a hint of the expected number of aoclsparse_sorv() calls to optimize the input matrix for the hinted operations.

aoclsparse_set_sorv_hint may be used to indicate that a given number of calls to the SOR preconditioner aoclsparse_sorv() will be performed. When [aoclsparse_optimize\(\)](#) is invoked, the input matrix might be tuned to accelerate the hinted calls. The hints include not only the estimated number of the API calls but also their other parameters which should match the actual calls.

Parameters

- **mat** – [in] Input sparse matrix to be tuned.
- **descr** – [in] Descriptor of the sparse matrix used during the calls.
- **type** – [in] The operation to perform by the SOR preconditioner.
- **expected_no_of_calls** – [in] A rough estimate of the number of the calls.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_value** – expected_no_of_calls, descr, type or mat type is invalid.
- **aoclsparse_status_invalid_pointer** – mat or descr is NULL.
- **aoclsparse_status_memory_error** – internal memory allocation failure.

```
aoclsparse_status aoclsparse_set_memory_hint(aoclsparse_matrix mat, const aoclsparse_memory_usage  
                                              policy)
```

Record user's attitude to the memory consumption while optimizing the input matrix for the hinted operations.

aoclsparse_set_memory_hint may be used to indicate how much memory can be allocated during the optimization process of the input matrix for the previously hinted operations. In particular, [aoclsparse_memory_usage_minimal](#) suggests that the new memory should be only of order of vectors, whereas [aoclsparse_memory_usage_unrestricted](#) allows even new copies of the whole matrix. The unrestricted memory policy is the default. Any change to the memory policy applies only to any new optimizations for the new hints which have not been processed by [aoclsparse_optimize\(\)](#) yet. The optimizations from any previous calls are unaffected. Note that the memory policy is only an indication rather than rule.

Parameters

- **mat** – [in] Input sparse matrix to be tuned.
- **policy** – [in] Memory usage policy for future optimizations.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_value** – policy type is invalid.
- **aoclsparse_status_invalid_pointer** – pointer mat is invalid.

2.2 Auxiliary Functions

2.2.1 `aoclsparse_create_mat_descr()`

`aoclsparse_status aoclsparse_create_mat_descr(aoclsparse_mat_descr *descr)`

Create a matrix descriptor.

`aoclsparse_create_mat_descr` creates a matrix descriptor. It initializes `aoclsparse_matrix_type` to `aoclsparse_matrix_type_general` and `aoclsparse_index_base` to `aoclsparse_index_base_zero`. It should be destroyed at the end using `aoclsparse_destroy_mat_descr()`.

Parameters

`descr` – [out] the pointer to the matrix descriptor.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `descr` pointer is invalid.

2.2.2 `aoclsparse_destroy_mat_descr()`

`aoclsparse_status aoclsparse_destroy_mat_descr(aoclsparse_mat_descr descr)`

Destroy a matrix descriptor.

`aoclsparse_destroy_mat_descr` destroys a matrix descriptor and releases all resources used by the descriptor.

Parameters

`descr` – [in] the matrix descriptor.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `descr` is invalid.

2.2.3 `aoclsparse_copy_mat_descr()`

`aoclsparse_status aoclsparse_copy_mat_descr(aoclsparse_mat_descr dest, const aoclsparse_mat_descr src)`

Copy a matrix descriptor.

`aoclsparse_copy_mat_descr` copies a matrix descriptor. Both, source and destination matrix descriptors must be initialized prior to calling `aoclsparse_copy_mat_descr`.

Parameters

- `dest` – [out] the pointer to the destination matrix descriptor.
- `src` – [in] the pointer to the source matrix descriptor.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `src` or `dest` pointer is invalid.

2.2.4 `aoclsparse_create_?csr()`

```
aoclsparse_status aoclsparse_create_scsr(aoclsparse_matrix *mat, aoclsparse_index_base base,
                                         aoclsparse_int M, aoclsparse_int N, aoclsparse_int nnz,
                                         aoclsparse_int *row_ptr, aoclsparse_int *col_idx, float *val)

aoclsparse_status aoclsparse_create_dcsr(aoclsparse_matrix *mat, aoclsparse_index_base base,
                                         aoclsparse_int M, aoclsparse_int N, aoclsparse_int nnz,
                                         aoclsparse_int *row_ptr, aoclsparse_int *col_idx, double *val)

aoclsparse_status aoclsparse_create_ccsr(aoclsparse_matrix *mat, aoclsparse_index_base base,
                                         aoclsparse_int M, aoclsparse_int N, aoclsparse_int nnz,
                                         aoclsparse_int *row_ptr, aoclsparse_int *col_idx,
                                         aoclsparse_float_complex *val)

aoclsparse_status aoclsparse_create_zcsr(aoclsparse_matrix *mat, aoclsparse_index_base base,
                                         aoclsparse_int M, aoclsparse_int N, aoclsparse_int nnz,
                                         aoclsparse_int *row_ptr, aoclsparse_int *col_idx,
                                         aoclsparse_double_complex *val)
```

Creates a new `aoclsparse_matrix` based on CSR (Compressed Sparse Row) format.

`aoclsparse_create_?csr` creates `aoclsparse_matrix` and initializes it with input parameters passed. The input arrays are left unchanged by the library except for the call to `aoclsparse_order_mat()`, which performs ordering of column indices of the matrix, or `aoclsparse_sset_value()`, `aoclsparse_update_values()` and variants, which modify the values of a nonzero element. To avoid any changes to the input data, `aoclsparse_copy()` can be used. To convert any other format to CSR, `aoclsparse_convert_csr()` can be used. Matrix should be destroyed at the end using `aoclsparse_destroy()`.

Parameters

- `mat` – [out] the pointer to the CSR sparse matrix allocated in the API.
- `base` – [in] `aoclsparse_index_base_zero` or `aoclsparse_index_base_one`.
- `M` – [in] number of rows of the sparse CSR matrix.
- `N` – [in] number of columns of the sparse CSR matrix.
- `nnz` – [in] number of non-zero entries of the sparse CSR matrix.
- `row_ptr` – [in] array of `m+1` elements that point to the start of every row of the sparse CSR matrix.
- `col_idx` – [in] array of `nnz` elements containing the column indices of the sparse CSR matrix.
- `val` – [in] array of `nnz` elements of the sparse CSR matrix.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – at least one of `row_ptr`, `col_idx` or `val` pointer is NULL.
- `aoclsparse_status_invalid_size` – at least one of `M`, `N` or `nnz` has a negative value.
- `aoclsparse_status_invalid_index_value` – any `col_idx` value is not within `N`.
- `aoclsparse_status_memory_error` – memory allocation for matrix failed.

2.2.5 `aoclsparse::create_csr()`

```
template<typename T>
aoclsparse\_status aoclsparse::create_csr(aoclsparse\_matrix *mat, aoclsparse\_index\_base base,
                                         aoclsparse\_int M, aoclsparse\_int N, aoclsparse\_int nnz,
                                         aoclsparse\_int *row_ptr, aoclsparse\_int *col_idx, T *val, bool
                                         fast_chk = false)
```

`aoclsparse::create_csr` is the C++ interface to `aoclsparse_create_?csr` that creates `aoclsparse_matrix` and initializes it with provided input parameters.

Template Parameters

`T` – Data type supported for `T` are double, float, std::complex<double> or std::complex<float>

2.2.6 `aoclsparse_create_?tcsr()`

```
aoclsparse\_status aoclsparse_create_stcsr(aoclsparse\_matrix *mat, const aoclsparse\_index\_base base, const
                                         aoclsparse\_int M, const aoclsparse\_int N, const aoclsparse\_int
                                         nnz, aoclsparse\_int *row_ptr_L, aoclsparse\_int *row_ptr_U,
                                         aoclsparse\_int *col_idx_L, aoclsparse\_int *col_idx_U, float
                                         *val_L, float *val_U)
```

```
aoclsparse\_status aoclsparse_create_dtcsr(aoclsparse\_matrix *mat, const aoclsparse\_index\_base base, const
                                         aoclsparse\_int M, const aoclsparse\_int N, const aoclsparse\_int
                                         nnz, aoclsparse\_int *row_ptr_L, aoclsparse\_int *row_ptr_U,
                                         aoclsparse\_int *col_idx_L, aoclsparse\_int *col_idx_U, double
                                         *val_L, double *val_U)
```

```
aoclsparse\_status aoclsparse_create_ctcsr(aoclsparse\_matrix *mat, const aoclsparse\_index\_base base, const
                                         aoclsparse\_int M, const aoclsparse\_int N, const aoclsparse\_int
                                         nnz, aoclsparse\_int *row_ptr_L, aoclsparse\_int *row_ptr_U,
                                         aoclsparse\_int *col_idx_L, aoclsparse\_int *col_idx_U,
                                         aoclsparse\_float\_complex *val_L, aoclsparse\_float\_complex
                                         *val_U)
```

```
aoclsparse\_status aoclsparse_create_ztcsr(aoclsparse\_matrix *mat, const aoclsparse\_index\_base base, const
                                         aoclsparse\_int M, const aoclsparse\_int N, const aoclsparse\_int
                                         nnz, aoclsparse\_int *row_ptr_L, aoclsparse\_int *row_ptr_U,
                                         aoclsparse\_int *col_idx_L, aoclsparse\_int *col_idx_U,
                                         aoclsparse\_double\_complex *val_L, aoclsparse\_double\_complex
                                         *val_U)
```

Creates a new `aoclsparse_matrix` based on TCSR (Triangular Compressed Sparse Row) format.

`aoclsparse_create_?tcsr` creates `aoclsparse_matrix` and initializes it with input parameters passed. Array data must not be modified by the user while matrix is being used as the pointers are copied, not the data. The input arrays are not modified by the library and the matrix should be destroyed at the end using `aoclsparse_destroy()`.

TCSR matrix structure holds lower triangular (L) and upper triangular (U) part of the matrix separately with diagonal (D) elements stored in both the parts. Both triangles (L+D and D+U) are stored like CSR and assumes partial sorting (L+D and D+U order is followed, but the indices within L or U group may not be sorted)

- One array with L elements potentially unsorted, followed by D elements in the L+D part for each row of the matrix.
- Another array with D elements, followed by U elements potentially unsorted in the D+U part for each row of the matrix.

- Currently TCSR storage format supports only square matrices with full(non-zero) diagonals.

Parameters

- **mat** – [out] The pointer to the TCSR sparse matrix.
- **base** – [in] *aoclsparse_index_base_zero* or *aoclsparse_index_base_one*.
- **M** – [in] Total number of rows in the **mat**.
- **N** – [in] Total number of columns in the **mat**.
- **nnz** – [in] Number of non-zero entries in the **mat**.
- **row_ptr_L** – [in] Array of lower triangular elements that point to the start of every row of the **mat** in **col_idx_L** and **val_L**.
- **row_ptr_U** – [in] Array of upper triangular elements that point to the start of every row of the **mat** in **col_idx_U** and **val_U**.
- **col_idx_L** – [in] Array of lower triangular elements containing column indices of the **mat**.
- **col_idx_U** – [in] Array of upper triangular elements containing column indices of the **mat**.
- **val_L** – [in] Array of lower triangular elements of the **mat**.
- **val_U** – [in] Array of upper triangular elements of the **mat**.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – Pointer given to API is invalid or nullptr.
- **aoclsparse_status_invalid_size** – M, N, nnz is invalid.
- **aoclsparse_status_invalid_index_value** – Index given for **mat** is out of matrix bounds depending on base given.
- **aoclsparse_status_invalid_value** – The coordinate **row_ptr** or **col_idx** is out of matrix bound or **mat** has duplicate diagonals or **mat** does not have full diagonals.
- **aoclsparse_status_unsorted_input** – The **mat** is unsorted. It supports only fully sorted and partially sorted matrix as input. The lower triangular part must not contain U elements, the upper triangular part must not contain L elements, and the position of the diagonal element must not be altered.
- **aoclsparse_status_memory_error** – Memory allocation for matrix failed.

2.2.7 *aoclsparse_create_?bsr()*

```
aoclsparse_status aoclsparse_create_sbsr(aoclsparse_matrix *mat, const aoclsparse_index_base base, const
                                         aoclsparse_order order, const aoclsparse_int bM, const
                                         aoclsparse_int bN, const aoclsparse_int block_dim, aoclsparse_int
                                         *row_ptr, aoclsparse_int *col_idx, float *val, bool fast_chk)
```

```
aoclsparse_status aoclsparse_create_dbsr(aoclsparse_matrix *mat, const aoclsparse_index_base base, const
                                         aoclsparse_order order, const aoclsparse_int bM, const
                                         aoclsparse_int bN, const aoclsparse_int block_dim, aoclsparse_int
                                         *row_ptr, aoclsparse_int *col_idx, double *val, bool fast_chk)
```

```
aoclsparse_status aoclsparse_create_cbsr(aoclsparse_matrix *mat, const aoclsparse_index_base base, const
                                         aoclsparse_order order, const aoclsparse_int bM, const
                                         aoclsparse_int bN, const aoclsparse_int block_dim, aoclsparse_int
                                         *row_ptr, aoclsparse_int *col_idx, aoclsparse_float_complex *val,
                                         bool fast_chk)

aoclsparse_status aoclsparse_create_zbsr(aoclsparse_matrix *mat, const aoclsparse_index_base base, const
                                         aoclsparse_order order, const aoclsparse_int bM, const
                                         aoclsparse_int bN, const aoclsparse_int block_dim, aoclsparse_int
                                         *row_ptr, aoclsparse_int *col_idx, aoclsparse_double_complex
                                         *val, bool fast_chk)
```

Creates a new *aoclsparse_matrix* based on BSR (Block-compressed Sparse Row) format.

aoclsparse_create_?bsr creates *aoclsparse_matrix* in BSR format and initializes it with input parameters passed. In BSR format, the matrix is split into a rectangular grid of square blocks of size *block_dim*, having *bM* blocks per row and *bN* blocks per column. Each block containing at least one non-zero is stored as a dense subblock, padded with zeros for the missing elements in the block. All such blocks are stored in the similar fashion to CSR where each element is a block. The elements inside each non-zero block are either stored in row-major or column-major order based on the *order* parameter. The input arrays are not modified by the library.

Parameters

- **mat** – [out] the pointer to the BSR matrix allocated in the API.
- **base** – [in] *aoclsparse_index_base_zero* or *aoclsparse_index_base_one*.
- **order** – [in] storage order of dense blocks. Possible options are *aoclsparse_order_row* and *aoclsparse_order_column*.
- **bM** – [in] number of block rows of the BSR matrix.
- **bN** – [in] number of block columns of the BSR matrix.
- **block_dim** – [in] size of the non-zero blocks of the BSR matrix.
- **row_ptr** – [in] array of *bM+1* elements that point to the start of every row block of the BSR matrix.
- **col_idx** – [in] array of elements containing the column block indices of the BSR matrix.
- **val** – [in] array containing the non-zero elements of the BSR matrix. The length of val array must be equal to the length of *col_idx* multiplied by *block_dim***block_dim*.
- **fast_chk** – [in] flag to perform a minimal and faster validation on the input matrix. If it is set to true, it skips the checks on diagonals/indices/sorting of the matrix.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_pointer** – at least one of *mat*, *row_ptr*, *col_idx* or *val* pointer is NULL.
- **aoclsparse_status_invalid_size** – at least one of *bM* or *bN* has an invalid size.
- **aoclsparse_status_invalid_value** – if *block_dim* has an invalid value.
- **aoclsparse_status_invalid_index_value** – either *col_idx* or *row_ptr* value is invalid.
- **aoclsparse_status_memory_error** – memory allocation for matrix failed.

2.2.8 `aoclsparse::create_bsr()`

```
template<typename T>
aoclsparse\_status aoclsparse::create_bsr(aoclsparse_matrix *mat, const aoclsparse_index_base base, const aoclsparse_order order, const aoclsparse_int bM, const aoclsparse_int bN, const aoclsparse_int block_dim, aoclsparse_int *row_ptr, aoclsparse_int *col_idx, T *val, bool fast_chk = false)
```

`aoclsparse::create_bsr` is the C++ interface to `aoclsparse_create_?bsr` that creates `aoclsparse_matrix` in BSR format and initializes it with the provided input parameters.

Template Parameters

`T` – Data type supported for `T` are double, float, std::complex<double> or std::complex<float>

2.2.9 `aoclsparse_create_?coo()`

```
aoclsparse\_status aoclsparse_create_scoo(aoclsparse_matrix *mat, const aoclsparse_index_base base, const aoclsparse_int M, const aoclsparse_int N, const aoclsparse_int nnz, aoclsparse_int *row_ind, aoclsparse_int *col_ind, float *val)
```

```
aoclsparse\_status aoclsparse_create_dcoo(aoclsparse_matrix *mat, const aoclsparse_index_base base, const aoclsparse_int M, const aoclsparse_int N, const aoclsparse_int nnz, aoclsparse_int *row_ind, aoclsparse_int *col_ind, double *val)
```

```
aoclsparse\_status aoclsparse_create_ccoo(aoclsparse_matrix *mat, const aoclsparse_index_base base, const aoclsparse_int M, const aoclsparse_int N, const aoclsparse_int nnz, aoclsparse_int *row_ind, aoclsparse_int *col_ind, aoclsparse_float_complex *val)
```

```
aoclsparse\_status aoclsparse_create_zcoo(aoclsparse_matrix *mat, const aoclsparse_index_base base, const aoclsparse_int M, const aoclsparse_int N, const aoclsparse_int nnz, aoclsparse_int *row_ind, aoclsparse_int *col_ind, aoclsparse_double_complex *val)
```

Creates a new `aoclsparse_matrix` based on COO (Co-ordinate format).

`aoclsparse_create_?coo` creates `aoclsparse_matrix` and initializes it with input parameters passed. Array data must not be modified by the user while matrix is alive as the pointers are copied, not the data. The input arrays are left unchanged by the library except for the call to `aoclsparse_sset_value()`, `aoclsparse_update_values()` and variants, which modify the value of a nonzero element. Matrix should be destroyed at the end using `aoclsparse_destroy()`.

Parameters

- `mat` – [inout] the pointer to the COO sparse matrix.
- `base` – [in] `aoclsparse_index_base_zero` or `aoclsparse_index_base_one` depending on whether the index first element starts from 0 or 1.
- `M` – [in] total number of rows of the sparse COO matrix.
- `N` – [in] total number of columns of the sparse COO matrix.
- `nnz` – [in] number of non-zero entries of the sparse COO matrix.
- `row_ind` – [in] array of `nnz` elements that point to the row of the element in co-ordinate Format.
- `col_ind` – [in] array of `nnz` elements that point to the column of the element in co-ordinate Format.

- **val** – [in] array of nnz elements of the sparse COO matrix.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_pointer** – pointer given to API is invalid or nullptr.
- **aoclsparse_status_invalid_size** – coo dimension of matrix or non-zero elements is invalid.
- **aoclsparse_status_invalid_index_value** – index given for coo is out of matrix bounds depending on base given
- **aoclsparse_status_memory_error** – memory allocation for matrix failed.

2.2.10 aoclsparse_create_?csc()

```
aoclsparse_status aoclsparse_create_scsc(aoclsparse_matrix *mat, aoclsparse_index_base base,
                                         aoclsparse_int M, aoclsparse_int N, aoclsparse_int nnz,
                                         aoclsparse_int *col_ptr, aoclsparse_int *row_idx, float *val)

aoclsparse_status aoclsparse_create_dcsc(aoclsparse_matrix *mat, aoclsparse_index_base base,
                                         aoclsparse_int M, aoclsparse_int N, aoclsparse_int nnz,
                                         aoclsparse_int *col_ptr, aoclsparse_int *row_idx, double *val)

aoclsparse_status aoclsparse_create_ccsc(aoclsparse_matrix *mat, aoclsparse_index_base base,
                                         aoclsparse_int M, aoclsparse_int N, aoclsparse_int nnz,
                                         aoclsparse_int *col_ptr, aoclsparse_int *row_idx,
                                         aoclsparse_float_complex *val)

aoclsparse_status aoclsparse_create_zcsc(aoclsparse_matrix *mat, aoclsparse_index_base base,
                                         aoclsparse_int M, aoclsparse_int N, aoclsparse_int nnz,
                                         aoclsparse_int *col_ptr, aoclsparse_int *row_idx,
                                         aoclsparse_double_complex *val)
```

Creates a new *aoclsparse_matrix* based on CSC (Compressed Sparse Column) format.

aoclsparse_create_?csc creates *aoclsparse_matrix* and initializes it with input parameters passed. The input arrays are left unchanged by the library except for the call to *aoclsparse_order_mat()*, which performs ordering of row indices of the matrix, or *aoclsparse_sset_value()*, *aoclsparse_update_values()* and variants, which modify the value of a nonzero element. To avoid any changes to the input data, *aoclsparse_copy()* can be used. Matrix should be destroyed at the end using *aoclsparse_destroy()*.

Parameters

- **mat** – [inout] the pointer to the CSC sparse matrix allocated in the API.
- **base** – [in] *aoclsparse_index_base_zero* or *aoclsparse_index_base_one*.
- **M** – [in] number of rows of the sparse CSC matrix.
- **N** – [in] number of columns of the sparse CSC matrix.
- **nnz** – [in] number of non-zero entries of the sparse CSC matrix.
- **col_ptr** – [in] array of n + 1 elements that points to the start of every column in row_idx array of the sparse CSC matrix.
- **row_idx** – [in] array of nnz elements containing the row indices of the sparse CSC matrix.
- **val** – [in] array of nnz elements of the sparse CSC matrix.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_pointer** – col_ptr, row_idx or val pointer is NULL.
- **aoclsparse_status_invalid_size** – M, N or nnz are negative values.
- **aoclsparse_status_invalid_index_value** – any row_idx value is not within M.
- **aoclsparse_status_memory_error** – memory allocation for matrix failed.

2.2.11 aoclsparse_destroy()

aoclsparse_status **aoclsparse_destroy**(*aoclsparse_matrix* *mat)

Destroy a sparse matrix structure.

aoclsparse_destroy destroys a structure that holds matrix **mat**.

Parameters

- **mat** – [in] the pointer to the sparse matrix.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_pointer** – matrix structure pointer is invalid.

2.2.12 aoclsparse_copy()

aoclsparse_status **aoclsparse_copy**(const *aoclsparse_matrix* src, const *aoclsparse_mat_descr* descr,
aoclsparse_matrix *dest)

Creates a copy of source *aoclsparse_matrix*.

aoclsparse_copy creates a deep copy of source *aoclsparse_matrix* (hints and optimized data are not copied). Matrix should be destroyed using *aoclsparse_destroy()*. *aoclsparse_convert_csr()* can also be used to create a copy of the source matrix while converting it in CSR format.

Parameters

- **src** – [in] the source *aoclsparse_matrix* to copy.
- **descr** – [in] the source matrix descriptor, this argument is reserved for future releases and it will not be referenced.
- **dest** – [out] pointer to the newly allocated copied *aoclsparse_matrix*.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_pointer** – src, dest or internal pointers are invalid. or dest points to src.
- **aoclsparse_status_memory_error** – memory allocation for matrix failed.
- **aoclsparse_status_invalid_value** – src matrix type is invalid.
- **aoclsparse_status_wrong_type** – src matrix data type is invalid.

2.2.13 `aoclsparse_order_mat()`

`aoclsparse_status aoclsparse_order_mat(aoclsparse_matrix mat)`

Performs ordering of index array of the matrix.

`aoclsparse_order` orders column indices within a row for matrix in CSR format and row indices within a column for CSC format. It also adjusts value array accordingly. Ordering is implemented only for CSR and CSC format. `aoclsparse_copy()` can be used to get exact copy of data `aoclsparse_convert_csr()` can be used to convert any format to CSR. Matrix should be destroyed at the end using `aoclsparse_destroy()`.

Parameters

`mat` – [inout] pointer to matrix in either CSR or CSC format

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `mat` pointer is invalid.
- `aoclsparse_status_memory_error` – internal memory allocation failed.
- `aoclsparse_status_not_implemented` – matrix is not in CSR format.

2.2.14 `aoclsparse_?set_value()`

`aoclsparse_status aoclsparse_sset_value(aoclsparse_matrix A, aoclsparse_int row_idx, aoclsparse_int col_idx, float val)`

`aoclsparse_status aoclsparse_dset_value(aoclsparse_matrix A, aoclsparse_int row_idx, aoclsparse_int col_idx, double val)`

`aoclsparse_status aoclsparse_cset_value(aoclsparse_matrix A, aoclsparse_int row_idx, aoclsparse_int col_idx, aoclsparse_float_complex val)`

`aoclsparse_status aoclsparse_zset_value(aoclsparse_matrix A, aoclsparse_int row_idx, aoclsparse_int col_idx, aoclsparse_double_complex val)`

Set a new value to an existing nonzero in the matrix.

`aoclsparse_?set_value` modifies the value of an existing nonzero element specified by its coordinates. The row and column coordinates need to match the base (0 or 1-base) of the matrix. The change directly affects user's arrays if the matrix was created using `aoclsparse_create_scsr()`, `aoclsparse_create_scsc()`, `aoclsparse_create_scoo()` or other variants.

Note: The successful modification invalidates existing optimized data so it is desirable to call `aoclsparse_optimize()` once all modifications are performed.

Parameters

- `A` – [inout] The sparse matrix to be modified.
- `row_idx` – [in] The row index of the element to be updated.
- `col_idx` – [in] The column index of the element to be updated.
- `val` – [in] The value to be updated.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – The matrix handler A is invalid
- **aoclsparse_status_invalid_value** – The coordinate `row_idx` or `col_idx` is out of matrix bound
- **aoclsparse_status_wrong_type** – Matrix has different data type than the one used in API
- **aoclsparse_status_not_implemented** – Matrix format is not supported for this operation
- **aoclsparse_status_invalid_index_value** – The specified element does not exist in the matrix

2.2.15 `aoclsparse_?update_values()`

`aoclsparse_status aoclsparse_supdate_values(aoclsparse_matrix A, aoclsparse_int len, float *val)`

`aoclsparse_status aoclsparse_dupdate_values(aoclsparse_matrix A, aoclsparse_int len, double *val)`

`aoclsparse_status aoclsparse_cupdate_values(aoclsparse_matrix A, aoclsparse_int len,
aoclsparse_float_complex *val)`

`aoclsparse_status aoclsparse_zupdate_values(aoclsparse_matrix A, aoclsparse_int len,
aoclsparse_double_complex *val)`

Set new values to all existing nonzero element in the matrix.

`aoclsparse_?update_values` overwrites all existing nonzeros in the matrix with the new values provided in `val` array. The order of elements must match the order in the matrix. That would be either the order at the creation of the matrix or the sorted order if `aoclsparse_order_mat()` has been called. The change directly affects user's arrays if the matrix was created using `aoclsparse_create_scsr()`, `aoclsparse_create_scsc()`, `aoclsparse_create_scoo()` or other variants.

Note: The successful update invalidates existing optimized data so it is desirable to call `aoclsparse_optimize()` once all modifications are performed.

Parameters

- **A** – **[inout]** The sparse matrix to be modified.
- **len** – **[in]** Length of the `val` array and the number of nonzeros in the matrix.
- **val** – **[in]** Array with the values to be copied.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – The matrix A is invalid or `val` in NULL
- **aoclsparse_status_invalid_size** – `len` is not equal to `nnz` of matrix
- **aoclsparse_status_wrong_type** – Matrix has different data type than the one used in API
- **aoclsparse_status_not_implemented** – Matrix format is not supported for this operation

2.2.16 `aoclsparse_export_?csr()`

```
aoclsparse_status aoclsparse_export_scsr(const aoclsparse_matrix mat, aoclsparse_index_base *base,
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,
                                         aoclsparse_int **row_ptr, aoclsparse_int **col_ind, float **val)

aoclsparse_status aoclsparse_export_dcsr(const aoclsparse_matrix mat, aoclsparse_index_base *base,
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,
                                         aoclsparse_int **row_ptr, aoclsparse_int **col_ind, double **val)

aoclsparse_status aoclsparse_export_ccsr(const aoclsparse_matrix mat, aoclsparse_index_base *base,
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,
                                         aoclsparse_int **row_ptr, aoclsparse_int **col_ind,
                                         aoclsparse_float_complex **val)

aoclsparse_status aoclsparse_export_zcsr(const aoclsparse_matrix mat, aoclsparse_index_base *base,
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,
                                         aoclsparse_int **row_ptr, aoclsparse_int **col_ind,
                                         aoclsparse_double_complex **val)
```

Export a CSR matrix.

`aoclsparse_export_?csr` exposes the components defining the CSR matrix in `mat` structure by copying out the data pointers. No additional memory is allocated. User should not modify the arrays and once `aoclsparse_destroy()` is called to free `mat`, these arrays will become inaccessible. If the matrix is not in CSR format, an error is obtained. `aoclsparse_convert_csr()` can be used to convert non-CSR format to CSR format.

Parameters

- `mat` – [in] the pointer to the CSR sparse matrix.
- `base` – [out] `aoclsparse_index_base_zero` or `aoclsparse_index_base_one`.
- `m` – [out] number of rows of the sparse CSR matrix.
- `n` – [out] number of columns of the sparse CSR matrix.
- `nnz` – [out] number of non-zero entries of the sparse CSR matrix.
- `row_ptr` – [out] array of `m+1` elements that point to the start of every row of the sparse CSR matrix.
- `col_ind` – [out] array of `nnz` elements containing the column indices of the sparse CSR matrix.
- `val` – [out] array of `nnz` elements of the sparse CSR matrix.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `mat` or any of the output arguments are NULL.
- `aoclsparse_status_invalid_value` – `mat` is not in CSR format.
- `aoclsparse_status_wrong_type` – data type of `mat` does not match the function.

2.2.17 `aoclsparse_export_?csc()`

```
aoclsparse_status aoclsparse_export_scsc(const aoclsparse_matrix mat, aoclsparse_index_base *base,  
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,  
                                         aoclsparse_int **col_ptr, aoclsparse_int **row_ind, float **val)  
  
aoclsparse_status aoclsparse_export_dcsc(const aoclsparse_matrix mat, aoclsparse_index_base *base,  
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,  
                                         aoclsparse_int **col_ptr, aoclsparse_int **row_ind, double **val)  
  
aoclsparse_status aoclsparse_export_ccsc(const aoclsparse_matrix mat, aoclsparse_index_base *base,  
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,  
                                         aoclsparse_int **col_ptr, aoclsparse_int **row_ind,  
                                         aoclsparse_float_complex **val)  
  
aoclsparse_status aoclsparse_export_zcsc(const aoclsparse_matrix mat, aoclsparse_index_base *base,  
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,  
                                         aoclsparse_int **col_ptr, aoclsparse_int **row_ind,  
                                         aoclsparse_double_complex **val)
```

Export CSC matrix.

`aoclsparse_export_?csc` exposes the components defining the CSC matrix in `mat` structure by copying out the data pointers. No additional memory is allocated. User should not modify the arrays and once `aoclsparse_destroy()` is called to free `mat`, these arrays will become inaccessible. If the matrix is not in CSC format, an error is obtained.

Parameters

- `mat` – [in] the pointer to the CSC sparse matrix.
- `base` – [out] `aoclsparse_index_base_zero` or `aoclsparse_index_base_one`.
- `m` – [out] number of rows of the sparse CSC matrix.
- `n` – [out] number of columns of the sparse CSC matrix.
- `nnz` – [out] number of non-zero entries of the sparse CSC matrix.
- `col_ptr` – [out] array of `n+1` elements that point to the start of every col of the sparse CSC matrix.
- `row_ind` – [out] array of `nnz` elements containing the row indices of the sparse CSC matrix.
- `val` – [out] array of `nnz` elements of the sparse CSC matrix.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `mat` or any of the output arguments are invalid.
- `aoclsparse_status_invalid_value` – `mat` is not in CSC format.
- `aoclsparse_status_wrong_type` – data type of `mat` does not match the function data type.

2.2.18 `aoclsparse_export_?coo()`

```
aoclsparse_status aoclsparse_export_scoo(const aoclsparse_matrix mat, aoclsparse_index_base *base,
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,
                                         aoclsparse_int **row_ptr, aoclsparse_int **col_ptr, float **val)

aoclsparse_status aoclsparse_export_dcoo(const aoclsparse_matrix mat, aoclsparse_index_base *base,
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,
                                         aoclsparse_int **row_ptr, aoclsparse_int **col_ptr, double **val)

aoclsparse_status aoclsparse_export_ccoo(const aoclsparse_matrix mat, aoclsparse_index_base *base,
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,
                                         aoclsparse_int **row_ptr, aoclsparse_int **col_ptr,
                                         aoclsparse_float_complex **val)

aoclsparse_status aoclsparse_export_zcoo(const aoclsparse_matrix mat, aoclsparse_index_base *base,
                                         aoclsparse_int *m, aoclsparse_int *n, aoclsparse_int *nnz,
                                         aoclsparse_int **row_ptr, aoclsparse_int **col_ptr,
                                         aoclsparse_double_complex **val)
```

Export a COO matrix.

`aoclsparse_export_?coo` exposes the components defining the COO matrix in `mat` structure by copying out the data pointers. No additional memory is allocated. User should not modify the arrays and once `aoclsparse_destroy()` is called to free `mat`, these arrays will become inaccessible. If the matrix is not in COO format, an error is obtained.

Parameters

- `mat` – [in] the pointer to the COO sparse matrix.
- `base` – [out] `aoclsparse_index_base_zero` or `aoclsparse_index_base_one`.
- `m` – [out] number of rows of the sparse COO matrix.
- `n` – [out] number of columns of the sparse COO matrix.
- `nnz` – [out] number of non-zero entries of the sparse CSR matrix.
- `row_ptr` – [out] array of `nnz` elements containing the row indices of the sparse COO matrix.
- `col_ptr` – [out] array of `nnz` elements containing the column indices of the sparse COO matrix.
- `val` – [out] array of `nnz` elements of the sparse COO matrix.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `mat` or any of the output arguments are NULL.
- `aoclsparse_status_invalid_value` – `mat` is not in COO format.
- `aoclsparse_status_wrong_type` – data type of `mat` does not match the function.

2.2.19 `aoclsparse_get_mat_diag_type()`

`aoclsparse_diag_type aoclsparse_get_mat_diag_type(const aoclsparse_mat_descr descr)`

Get the matrix diagonal type of a matrix descriptor.

`aoclsparse_get_mat_diag_type` returns the matrix diagonal type of a matrix descriptor.

Parameters

`descr` – [in] the matrix descriptor.

Returns

`aoclsparse_diag_type_unit` or `aoclsparse_diag_type_non_unit` or `aoclsparse_diag_type_zero`.

2.2.20 `aoclsparse_get_mat_fill_mode()`

`aoclsparse_fill_mode aoclsparse_get_mat_fill_mode(const aoclsparse_mat_descr descr)`

Get the matrix fill mode of a matrix descriptor.

`aoclsparse_get_mat_fill_mode` returns the matrix fill mode of a matrix descriptor.

Parameters

`descr` – [in] the matrix descriptor.

Returns

`aoclsparse_fill_mode_lower` or `aoclsparse_fill_mode_upper`.

2.2.21 `aoclsparse_get_mat_index_base()`

`aoclsparse_index_base aoclsparse_get_mat_index_base(const aoclsparse_mat_descr descr)`

Get the index base of a matrix descriptor.

`aoclsparse_get_mat_index_base` returns the index base of a matrix descriptor.

Parameters

`descr` – [in] the matrix descriptor.

Returns

`aoclsparse_index_base_zero` or `aoclsparse_index_base_one`.

2.2.22 `aoclsparse_get_mat_type()`

`aoclsparse_matrix_type aoclsparse_get_mat_type(const aoclsparse_mat_descr descr)`

Get the matrix type of a matrix descriptor.

`aoclsparse_get_mat_type` returns the matrix type of a matrix descriptor.

Parameters

`descr` – [in] the matrix descriptor.

Returns

`aoclsparse_matrix_type_general`, `aoclsparse_matrix_type_symmetric`,
`aoclsparse_matrix_type_hermitian` or `aoclsparse_matrix_type_triangular`.

2.2.23 `aoclsparse_get_version()`

`const char *aoclsparse_get_version()`

Get AOCL-Sparse Library version.

Returns

AOCL-Sparse Library version number in the format “AOCL-Sparse <major>.<minor>.<patch>”

2.2.24 `aoclsparse_set_mat_diag_type()`

`aoclsparse_status aoclsparse_set_mat_diag_type(aoclsparse_mat_descr descr, aoclsparse_diag_type diag_type)`

Specify the matrix diagonal type of a matrix descriptor.

`aoclsparse_set_mat_diag_type` sets the matrix diagonal type of a matrix descriptor. Valid diagonal types are `aoclsparse_diag_type_unit`, `aoclsparse_diag_type_non_unit` or `aoclsparse_diag_type_zero`.

Parameters

- **descr** – [inout] the matrix descriptor.
- **diag_type** – [in] `aoclsparse_diag_type_unit` or `aoclsparse_diag_type_non_unit` or `aoclsparse_diag_type_zero`.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – descr pointer is invalid.
- `aoclsparse_status_invalid_value` – diag_type is invalid.

2.2.25 `aoclsparse_set_mat_fill_mode()`

`aoclsparse_status aoclsparse_set_mat_fill_mode(aoclsparse_mat_descr descr, aoclsparse_fill_mode fill_mode)`

Specify the matrix fill mode of a matrix descriptor.

`aoclsparse_set_mat_fill_mode` sets the matrix fill mode of a matrix descriptor. Valid fill modes are `aoclsparse_fill_mode_lower` or `aoclsparse_fill_mode_upper`.

Parameters

- **descr** – [inout] the matrix descriptor.
- **fill_mode** – [in] `aoclsparse_fill_mode_lower` or `aoclsparse_fill_mode_upper`.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – descr pointer is invalid.
- `aoclsparse_status_invalid_value` – fill_mode is invalid.

2.2.26 `aoclsparse_set_mat_index_base()`

`aoclsparse_status aoclsparse_set_mat_index_base(aoclsparse_mat_descr descr, aoclsparse_index_base base)`

Specify the index base of a matrix descriptor.

`aoclsparse_set_mat_index_base` sets the index base of a matrix descriptor. Valid options are `aoclsparse_index_base_zero` or `aoclsparse_index_base_one`.

Parameters

- `descr` – [inout] the matrix descriptor.
- `base` – [in] `aoclsparse_index_base_zero` or `aoclsparse_index_base_one`.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `descr` pointer is invalid.
- `aoclsparse_status_invalid_value` – `base` is invalid.

2.2.27 `aoclsparse_set_mat_type()`

`aoclsparse_status aoclsparse_set_mat_type(aoclsparse_mat_descr descr, aoclsparse_matrix_type type)`

Specify the matrix type of a matrix descriptor.

`aoclsparse_set_mat_type` sets the matrix type of a matrix descriptor. Valid matrix types are `aoclsparse_matrix_type_general`, `aoclsparse_matrix_type_symmetric`, `aoclsparse_matrix_type_hermitian` or `aoclsparse_matrix_type_triangular`.

Parameters

- `descr` – [inout] the matrix descriptor.
- `type` – [in] `aoclsparse_matrix_type_general`, `aoclsparse_matrix_type_symmetric`, `aoclsparse_matrix_type_hermitian` or `aoclsparse_matrix_type_triangular`.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `descr` pointer is invalid.
- `aoclsparse_status_invalid_value` – `type` is invalid.

2.3 Conversion Functions

`aoclsparse_convert.h` provides sparse format conversion functions.

2.3.1 `aoclsparse_csr2ell_width()`

```
aoclsparse_status aoclsparse_csr2ell_width(aoclsparse_int m, aoclsparse_int nnz, const aoclsparse_int
                                            *csr_row_ptr, aoclsparse_int *ell_width)
```

Convert a sparse CSR matrix into a sparse ELL matrix.

`aoclsparse_csr2ell_width` computes the maximum of the per row non-zero elements over all rows, the ELL width, for a given CSR matrix.

Parameters

- **m** – [in] number of rows of the sparse CSR matrix.
- **nnz** – [in] number of non-zero entries of the sparse CSR matrix.
- **csr_row_ptr** – [in] array of $m + 1$ elements that point to the start of every row of the sparse CSR matrix.
- **ell_width** – [out] pointer to the number of non-zero elements per row in ELL storage format.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – m is invalid.
- **aoclsparse_status_invalid_pointer** – `csr_row_ptr`, or `ell_width` pointer is invalid.
- **aoclsparse_status_internal_error** – an internal error occurred.

2.3.2 `aoclsparse_?csr2ell()`

```
aoclsparse_status aoclsparse_scsr2ell(aoclsparse_int m, const aoclsparse_mat_descr descr, const
                                         aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind, const
                                         float *csr_val, aoclsparse_int *ell_col_ind, float *ell_val,
                                         aoclsparse_int ell_width)
```

```
aoclsparse_status aoclsparse_dcsr2ell(aoclsparse_int m, const aoclsparse_mat_descr descr, const
                                         aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind, const
                                         double *csr_val, aoclsparse_int *ell_col_ind, double *ell_val,
                                         aoclsparse_int ell_width)
```

Convert a sparse CSR matrix into a sparse ELLPACK matrix.

`aoclsparse_?csr2ell` converts a CSR matrix into an ELL matrix. It is assumed, that `ell_val` and `ell_col_ind` are allocated. Allocation size is computed by the number of rows times the number of ELL non-zero elements per row, such that nnz_{ELL} is equal to m times `ell_width`. The number of ELL non-zero elements per row is obtained by `aoclsparse_csr2ell_width()`. The index base is preserved during the conversion.

Parameters

- **m** – [in] number of rows of the sparse CSR matrix.
- **descr** – [in] descriptor of the input sparse CSR matrix. Only the base index is used in the conversion process, the remaining descriptor elements are ignored.
- **csr_val** – [in] array containing the values of the sparse CSR matrix.
- **csr_row_ptr** – [in] array of $m + 1$ elements that point to the start of every row of the sparse CSR matrix.

- **csr_col_ind** – [in] array containing the column indices of the sparse CSR matrix.
- **ell_width** – [in] number of non-zero elements per row in ELL storage format.
- **ell_val** – [out] array of m times **ell_width** elements of the sparse ELL matrix.
- **ell_col_ind** – [out] array of m times **ell_width** elements containing the column indices of the sparse ELL matrix.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_handle** – the library context was not initialized.
- **aoclsparse_status_invalid_size** – m or **ell_width** is invalid.
- **aoclsparse_status_invalid_pointer** – **csr_val**, **csr_row_ptr**, **csr_col_ind**, **ell_val** or **ell_col_ind** pointer is invalid.

2.3.3 **aoclsparse_csr2dia_ndiag()**

```
aoclsparse_status aoclsparse_csr2dia_ndiag(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr  
                                         descr, aoclsparse_int nnz, const aoclsparse_int *csr_row_ptr,  
                                         const aoclsparse_int *csr_col_ind, aoclsparse_int  
                                         *dia_num_diag)
```

Convert a sparse CSR matrix into a sparse DIA matrix.

aoclsparse_csr2dia_ndiag computes number of diagonals for a given CSR matrix.

Parameters

- **m** – [in] number of rows of the sparse CSR matrix.
- **n** – [in] number of columns of the sparse CSR matrix.
- **descr** – [in] descriptor of the input sparse CSR matrix. Only the base index is used in computing the diagonals, the remaining descriptor elements are ignored.
- **nnz** – [in] number of non-zero entries of the sparse CSR matrix.
- **csr_row_ptr** – [in] array of $m + 1$ elements that point to the start of every row of the sparse CSR matrix.
- **csr_col_ind** – [in] array containing the column indices of the sparse CSR matrix.
- **dia_num_diag** – [out] pointer to the number of diagonals with non-zeroes in DIA storage format.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – m is invalid.
- **aoclsparse_status_invalid_pointer** – **csr_row_ptr**, or **ell_width** pointer is invalid.
- **aoclsparse_status_internal_error** – an internal error occurred.

2.3.4 `aoclsparse_?csr2dia()`

```
aoclsparse_status aoclsparse_scsr2dia(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr descr,
                                         const aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind,
                                         const float *csr_val, aoclsparse_int dia_num_diag, aoclsparse_int
                                         *dia_offset, float *dia_val)
```

```
aoclsparse_status aoclsparse_dcsr2dia(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr descr,
                                         const aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind,
                                         const double *csr_val, aoclsparse_int dia_num_diag, aoclsparse_int
                                         *dia_offset, double *dia_val)
```

Convert a sparse CSR matrix into a sparse DIA matrix.

`aoclsparse_?csr2dia` converts a CSR matrix into an DIA matrix. It is assumed, that `dia_val` and `dia_offset` are allocated. Allocation size is computed by the number of rows times the number of diagonals. The number of DIA diagonals is obtained by `aoclsparse_csr2dia_ndiag()`. The index base is preserved during the conversion.

Parameters

- `m` – [in] number of rows of the sparse CSR matrix.
- `n` – [in] number of cols of the sparse CSR matrix.
- `descr` – [in] descriptor of the input sparse CSR matrix. Only the base index is used in the conversion process, the remaining descriptor elements are ignored.
- `csr_row_ptr` – [in] array of `m + 1` elements that point to the start of every row of the sparse CSR matrix.
- `csr_col_ind` – [in] array containing the column indices of the sparse CSR matrix.
- `csr_val` – [in] array containing the values of the sparse CSR matrix.
- `dia_num_diag` – [in] number of diaognals in ELL storage format.
- `dia_offset` – [out] array of `dia_num_diag` elements containing the diagonal offsets from main diagonal.
- `dia_val` – [out] array of `m` times `dia_num_diag` elements of the sparse DIA matrix.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_handle` – the library context was not initialized.
- `aoclsparse_status_invalid_size` – `m` or `ell_width` is invalid.
- `aoclsparse_status_invalid_pointer` – `csr_val`, `csr_row_ptr`, `csr_col_ind`, `ell_val` or `ell_col_ind` pointer is invalid.

2.3.5 `aoclsparse_csr2bsr_nnz()`

```
aoclsparse_status aoclsparse_csr2bsr_nnz(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr  
                                         descr, const aoclsparse_int *csr_row_ptr, const aoclsparse_int  
                                         *csr_col_ind, aoclsparse_int block_dim, aoclsparse_int  
                                         *bsr_row_ptr, aoclsparse_int *bsr_nnz)
```

`aoclsparse_csr2bsr_nnz` computes the number of nonzero block columns per row and the total number of nonzero blocks in a sparse BSR matrix given a sparse CSR matrix as input.

Parameters

- **m** – [in] number of rows of the sparse CSR matrix.
- **n** – [in] number of columns of the sparse CSR matrix.
- **descr** – [in] descriptor of the input sparse CSR matrix. Only the base index is used in computing the nnz blocks, the remaining descriptor elements are ignored.
- **csr_row_ptr** – [in] integer array containing $m + 1$ elements that point to the start of each row of the CSR matrix
- **csr_col_ind** – [in] integer array of the column indices for each non-zero element in the CSR matrix
- **block_dim** – [in] the block dimension of the BSR matrix. Between 1 and $\min(m, n)$
- **bsr_row_ptr** – [out] integer array containing $mb + 1$ elements that point to the start of each block row of the BSR matrix
- **bsr_nnz** – [out] total number of nonzero elements in device or host memory.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – m or n or $block_dim$ is invalid.
- **aoclsparse_status_invalid_pointer** – `csr_row_ptr` or `csr_col_ind` or `bsr_row_ptr` or `bsr_nnz` pointer is invalid.

2.3.6 `aoclsparse_?csr2bsr()`

```
aoclsparse_status aoclsparse_scsr2bsr(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr descr,  
                                         const aoclsparse_order block_order, const float *csr_val, const  
                                         aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind,  
                                         aoclsparse_int block_dim, float *bsr_val, aoclsparse_int *bsr_row_ptr,  
                                         aoclsparse_int *bsr_col_ind)
```

```
aoclsparse_status aoclsparse_dcsr2bsr(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr descr,  
                                         const aoclsparse_order block_order, const double *csr_val, const  
                                         aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind,  
                                         aoclsparse_int block_dim, double *bsr_val, aoclsparse_int  
                                         *bsr_row_ptr, aoclsparse_int *bsr_col_ind)
```

Convert a sparse CSR matrix into a sparse BSR matrix.

`aoclsparse_?csr2bsr` converts a CSR matrix into a BSR matrix. It is assumed, that `bsr_val`, `bsr_col_ind` and `bsr_row_ptr` are allocated. Allocation size for `bsr_row_ptr` is computed as $mb + 1$ where mb is the number of block rows in the BSR matrix. Allocation size for `bsr_val` and `bsr_col_ind` is computed using this function which also fills in `bsr_row_ptr`. The index base is preserved during the conversion.

Parameters

- **m** – [in] number of rows in the sparse CSR matrix.
- **n** – [in] number of columns in the sparse CSR matrix.
- **descr** – [in] descriptor of the input sparse CSR matrix. Only the base index is used in the conversion process, the remaining descriptor elements are ignored.
- **block_order** – [in] storage order of the elements inside the blocks. Possible options are `aoclsparse_order_row` and `aoclsparse_order_column`.
- **csr_val** – [in] array of nnz elements containing the values of the sparse CSR matrix.
- **csr_row_ptr** – [in] array of $m+1$ elements that point to the start of every row of the sparse CSR matrix.
- **csr_col_ind** – [in] array of nnz elements containing the column indices of the sparse CSR matrix.
- **block_dim** – [in] size of the blocks in the sparse BSR matrix.
- **bsr_val** – [out] array of $nnzb * block_dim * block_dim$ containing the values of the sparse BSR matrix.
- **bsr_row_ptr** – [out] array of $mb+1$ elements that point to the start of every block row of the sparse BSR matrix.
- **bsr_col_ind** – [out] array of $nnzb$ elements containing the block column indices of the sparse BSR matrix.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_size` – m, or n, or `block_dim` is invalid.
- `aoclsparse_status_invalid_pointer` – `bsr_val`, `bsr_row_ptr`, `bsr_col_ind`, `csr_val`, `csr_row_ptr` or `csr_col_ind` pointer is invalid.

2.3.7 `aoclsparse_?csr2csc()`

```
aoclsparse_status aoclsparse_scsr2csc(aoclsparse_int m, aoclsparse_int n, aoclsparse_int nnz, const
                                         aoclsparse_mat_descr descr, aoclsparse_index_base baseCSC, const
                                         aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind, const
                                         float *csr_val, aoclsparse_int *csc_row_ind, aoclsparse_int
                                         *csc_col_ptr, float *csc_val)

aoclsparse_status aoclsparse_dcsr2csc(aoclsparse_int m, aoclsparse_int n, aoclsparse_int nnz, const
                                         aoclsparse_mat_descr descr, aoclsparse_index_base baseCSC, const
                                         aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind, const
                                         double *csr_val, aoclsparse_int *csc_row_ind, aoclsparse_int
                                         *csc_col_ptr, double *csc_val)

aoclsparse_status aoclsparse_ccsr2csc(aoclsparse_int m, aoclsparse_int n, aoclsparse_int nnz, const
                                         aoclsparse_mat_descr descr, aoclsparse_index_base baseCSC, const
                                         aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind, const
                                         aoclsparse_float_complex *csr_val, aoclsparse_int *csc_row_ind,
                                         aoclsparse_int *csc_col_ptr, aoclsparse_float_complex *csc_val)
```

```
aoclsparse_status aoclsparse_zcsr2csc(aoclsparse_int m, aoclsparse_int n, aoclsparse_int nnz, const  
aoclsparse_mat_descr descr, aoclsparse_index_base baseCSC, const  
aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind, const  
aoclsparse_double_complex *csr_val, aoclsparse_int *csc_row_ind,  
aoclsparse_int *csc_col_ptr, aoclsparse_double_complex *csc_val)
```

Convert a sparse CSR matrix into a sparse CSC matrix.

`aoclsparse_?csr2csc` converts a CSR matrix into a CSC matrix. These functions can also be used to convert a CSC matrix into a CSR matrix. The index base can be modified during the conversion.

Note: The resulting matrix can also be seen as the transpose of the input matrix.

Parameters

- `m` – [in] number of rows of the sparse CSR matrix.
- `n` – [in] number of columns of the sparse CSR matrix.
- `nnz` – [in] number of non-zero entries of the sparse CSR matrix.
- `descr` – [in] descriptor of the input sparse CSR matrix. Only the base index is used in the conversion process, the remaining descriptor elements are ignored.
- `baseCSC` – [in] the desired index base (zero or one) for the converted matrix.
- `csr_val` – [in] array of `nnz` elements of the sparse CSR matrix.
- `csr_row_ptr` – [in] array of `m+1` elements that point to the start of every row of the sparse CSR matrix.
- `csr_col_ind` – [in] array of `nnz` elements containing the column indices of the sparse CSR matrix.
- `csc_val` – [out] array of `nnz` elements of the sparse CSC matrix.
- `csc_row_ind` – [out] array of `nnz` elements containing the row indices of the sparse CSC matrix.
- `csc_col_ptr` – [out] array of `n+1` elements that point to the start of every column of the sparse CSC matrix. `aoclsparse_csr2csc_buffer_size()`.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_size` – `m, n` or `nnz` is invalid.
- `aoclsparse_status_invalid_pointer` – `csr_val, csr_row_ptr, csr_col_ind, csc_val, csc_row_ind, csc_col_ptr` is invalid.

2.3.8 `aoclsparse_?csr2dense()`

```
aoclsparse_status aoclsparse_scsr2dense(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr
                                         descr, const float *csr_val, const aoclsparse_int *csr_row_ptr, const
                                         aoclsparse_int *csr_col_ind, float *A, aoclsparse_int ld,
                                         aoclsparse_order order)
```

```
aoclsparse_status aoclsparse_dcsr2dense(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr
                                         descr, const double *csr_val, const aoclsparse_int *csr_row_ptr,
                                         const aoclsparse_int *csr_col_ind, double *A, aoclsparse_int ld,
                                         aoclsparse_order order)
```

```
aoclsparse_status aoclsparse_ccsr2dense(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr
                                         descr, const aoclsparse_float_complex *csr_val, const aoclsparse_int
                                         *csr_row_ptr, const aoclsparse_int *csr_col_ind,
                                         aoclsparse_float_complex *A, aoclsparse_int ld, aoclsparse_order
                                         order)
```

```
aoclsparse_status aoclsparse_zcsr2dense(aoclsparse_int m, aoclsparse_int n, const aoclsparse_mat_descr
                                         descr, const aoclsparse_double_complex *csr_val, const
                                         aoclsparse_int *csr_row_ptr, const aoclsparse_int *csr_col_ind,
                                         aoclsparse_double_complex *A, aoclsparse_int ld, aoclsparse_order
                                         order)
```

This function converts the sparse matrix in CSR format into a dense matrix.

Parameters

- **m** – [in] number of rows of the dense matrix A.
- **n** – [in] number of columns of the dense matrix A.
- **descr** – [in] the descriptor of the dense matrix A, the supported matrix type is `aoclsparse_matrix_type_general`. Base index from the descriptor is used in the conversion process.
- **csr_val** – [in] array of size at least nnz nonzero elements of matrix A.
- **csr_row_ptr** – [in] CSR row pointer array of size (m + 1).
- **csr_col_ind** – [in] An array of CSR column indices of at least nnz column indices of the nonzero elements of matrix A.
- **A** – [out] array of dimensions (lda, n)
- **ld** – [in] leading dimension of dense array A.
- **order** – [in] memory layout of a dense matrix A. It can be either `aoclsparse_order_column` or `aoclsparse_order_row`.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_size` – m or n or ld is invalid.
- `aoclsparse_status_invalid_pointer` – A, csr_val, csr_row_ptr, or csr_col_ind pointers are invalid.

2.3.9 `aoclsparse_convert_csr()`

```
aoclsparse_status aoclsparse_convert_csr(const aoclsparse_matrix src_mat, const aoclsparse_operation op,  
                                         aoclsparse_matrix *dest_mat)
```

Convert internal representation of matrix into a sparse CSR matrix.

`aoclsparse_convert_csr` converts any supported matrix format into a CSR format matrix and returns it as a new `aoclsparse_matrix`. The new matrix can also be transposed, or conjugated and transposed during the conversion. It should be freed by calling `aoclsparse_destroy()`. The source matrix needs to be initialized using e.g. `aoclsparse_create_scoo()`, `aoclsparse_create_scsr()`, `aoclsparse_create_scsc()` or any of their variants.

Parameters

- `src_mat` – [in] source matrix used for conversion.
- `op` – [in] operation to be performed on destination matrix
- `dest_mat` – [out] destination matrix output in CSR Format of the `src_mat`.

Return values

- `aoclsparse_status_success` – the operation completed successfully
- `aoclsparse_status_invalid_size` – matrix dimension are invalid
- `aoclsparse_status_invalid_value` – `src_mat` contains invalid value type
- `aoclsparse_status_invalid_pointer` – pointers in `src_mat` or `dest_mat` are invalid
- `aoclsparse_status_not_implemented` – conversion of the `src_mat` format given is not implemented
- `aoclsparse_status_memory_error` – memory allocation for destination matrix failed

2.3.10 `aoclsparse_convert_bsr()`

```
aoclsparse_status aoclsparse_convert_bsr(const aoclsparse_matrix src_mat, aoclsparse_int block_dim,  
                                         aoclsparse_order block_order, aoclsparse_operation op,  
                                         aoclsparse_matrix *dest_mat)
```

Convert internal representation of matrix into a sparse BSR matrix.

`aoclsparse_convert_bsr` converts the supported matrix format into a BSR format and returns it as a new `aoclsparse_matrix`. The input matrix can also be transposed, or conjugated and transposed before the conversion. The newly created matrix should be freed by calling `aoclsparse_destroy()`. Currently, the API supports a source matrix stored in CSR storage format with the matrix type `aoclsparse_matrix_type_general`. The source matrix needs to be initialized using `aoclsparse_create_csr()`.

Parameters

- `src_mat` – [in] source matrix used for conversion.
- `block_dim` – [in] size of the non-zero blocks of the BSR matrix.
- `block_order` – [in] storage order of the elements inside the blocks. Possible options are `aoclsparse_order_row` and `aoclsparse_order_column`.
- `op` – [in] operation to be performed on the input matrix.
- `dest_mat` – [out] output destination matrix in BSR format.

Return values

- `aoclsparse_status_success` – the operation completed successfully

- **aoclsparse_status_invalid_size** – matrix dimensions are invalid
- **aoclsparse_status_invalid_value** – `src_mat` or `block_dim` contains invalid value
- **aoclsparse_status_invalid_pointer** – pointers in `src_mat` or `dest_mat` are invalid
- **aoclsparse_status_not_implemented** – conversion of the `src_mat` format given is not implemented
- **aoclsparse_status_memory_error** – memory allocation for destination matrix failed

2.4 Sparse BLAS level 1, 2, and 3 functions

`aoclsparse_functions.h` provides AMD CPU hardware optimized level 1, 2, and 3 Sparse Linear Algebra Subprograms (Sparse BLAS).

2.4.1 Level 1

The sparse level 1 routines describe operations between a vector in sparse format and a vector in dense format.

This section describes all provided level 1 sparse linear algebra functions.

`aoclsparse_?axpyi()`

`aoclsparse_status aoclsparse_saxpyi`(const `aoclsparse_int nnz`, const float `a`, const float *`x`, const `aoclsparse_int *indx`, float *`y`)

`aoclsparse_status aoclsparse_daxpyi`(const `aoclsparse_int nnz`, const double `a`, const double *`x`, const `aoclsparse_int *indx`, double *`y`)

`aoclsparse_status aoclsparse_caxpyi`(const `aoclsparse_int nnz`, const void *`a`, const void *`x`, const `aoclsparse_int *indx`, void *`y`)

`aoclsparse_status aoclsparse_zaxpyi`(const `aoclsparse_int nnz`, const void *`a`, const void *`x`, const `aoclsparse_int *indx`, void *`y`)

A variant of sparse vector-vector addition between compressed sparse vector and dense vector.

`aoclsparse_?axpyi` adds a scalar multiple of compressed sparse vector to a dense vector.

Let $y \in R^m$ (or C^m) be a dense vector, x be a compressed sparse vector and I_x be the nonzero indices set for x of length at least `nnz` described by `indx`, then

$$y_{I_{x_i}} = a x_i + y_{I_{x_i}}, \quad i \in \{1, \dots, nnz\}.$$

Example (tests/examples/sample_axpyi.cpp)

Note: The contents of the vectors are not checked for NaNs.

Parameters

- **nnz** – [in] The number of elements in x and indx .
- **a** – [in] Scalar value.
- **x** – [in] Sparse vector stored in compressed form of at least nnz elements.
- **indx** – [in] Nonzero indices set, I_x , of x described by this array of length at least nnz . The elements in this vector are only checked for non-negativity. The caller should make sure that all indices are less than the size of y . Array is assumed to be in zero base.
- **y** – [inout] Array of at least $\max(I_{x_i}, i \in \{1, \dots, \text{nnz}\})$ elements.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – At least one of the pointers x , indx , y is invalid.
- **aoclsparse_status_invalid_size** – Indicates that provided nnz is less than zero.
- **aoclsparse_status_invalid_index_value** – At least one of the indices in indx is negative.

aoclsparse_?dotci()

aoclsparse_status **aoclsparse_cdotci**(const *aoclsparse_int* nnz, const void **x*, const *aoclsparse_int* **indx*, const void **y*, void **dot*)

aoclsparse_status **aoclsparse_zdotci**(const *aoclsparse_int* nnz, const void **x*, const *aoclsparse_int* **indx*, const void **y*, void **dot*)

Sparse conjugate dot product for single and double data precision complex types.

aoclsparse_cdotci() (complex float) and *aoclsparse_zdotci()* (complex double) compute the dot product of the conjugate of a complex vector stored in a compressed format and a complex dense vector. Let x and y be respectively a sparse and dense vectors in C^m with indx (I_x) the nonzero indices array of x of length at least nnz that is used to index into the entries of dense vector y , then these functions return

$$\text{dot} = \sum_{i=0}^{\text{nnz}-1} \overline{x_i} \cdot y_{I_{x_i}}.$$

Example (tests/examples/sample_dotp.cpp)

Note: The contents of the vectors are not checked for NaNs.

Parameters

- **nnz** – [in] The number of elements (length) of vectors x and indx .
- **x** – [in] Array of at least nnz complex elements.

- **indx – [in]** Nonzero indices set, I_x , of x described by this array of length at least **nnz**. Each entry must contain a valid index into y and be unique. The entries of **indx** are not checked for validity.
- **y – [in]** Array of at least $\max(I_{x_i}, i \in \{1, \dots, \text{nnz}\})$ complex elements.
- **dot – [out]** The dot product of the conjugate of x and y when $\text{nnz} > 0$. If $\text{nnz} \leq 0$, **dot** is set to 0.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – At least one of the pointers **x**, **indx**, **y**, **dot** is invalid.
- **aoclsparse_status_invalid_size** – Indicates that the provided **nnz** is not positive.

aoclsparse_?dotui()

aoclsparse_status **aoclsparse_cdotui**(const *aoclsparse_int* nnz, const void **x*, const *aoclsparse_int* **indx*, const void **y*, void **dot*)

aoclsparse_status **aoclsparse_zdotui**(const *aoclsparse_int* nnz, const void **x*, const *aoclsparse_int* **indx*, const void **y*, void **dot*)

Sparse dot product for single and double data precision complex types.

aoclsparse_cdotui() (complex float) and *aoclsparse_zdotui()* (complex double) compute the dot product of a complex vector stored in a compressed format and a complex dense vector. Let x and y be respectively a sparse and dense vectors in C^m with **indx** (I_x) the nonzero indices array of x of length at least **nnz** that is used to index into the entries of dense vector y , then these functions return

$$\text{dot} = \sum_{i=0}^{\text{nnz}-1} x_i \cdot y_{I_{x_i}}.$$

Example (tests/examples/sample_dotp.cpp)

Note: The contents of the vectors are not checked for NaNs.

Parameters

- **nnz – [in]** The number of elements (length) of vectors x and *indx*.
- **x – [in]** Array of at least **nnz** complex elements.
- **indx – [in]** Nonzero indices set, I_x , of x described by this array of length at least **nnz**. Each entry must contain a valid index into y and be unique. The entries of **indx** are not checked for validity.
- **y – [in]** Array of at least $\max(I_{x_i}, i \in \{1, \dots, \text{nnz}\})$ complex elements.
- **dot – [out]** The dot product of x and y when $\text{nnz} > 0$. If $\text{nnz} \leq 0$, **dot** is set to 0.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – At least one of the pointers **x**, **indx**, **y**, **dot** is invalid.
- **aoclsparse_status_invalid_size** – Indicates that the provided **nnz** is not positive.

aoclsparse_?doti()

```
float aoclsparse_sdoti(const aoclsparse_int nnz, const float *x, const aoclsparse_int *indx, const float *y)  
double aoclsparse_ddoti(const aoclsparse_int nnz, const double *x, const aoclsparse_int *indx, const double  
*y)
```

Sparse dot product for single and double data precision real types.

aoclsparse_sdoti() and *aoclsparse_ddoti()* compute the dot product of a real vector stored in a compressed format and a real dense vector. Let x and y be respectively a sparse and dense vectors in R^m with **indx** (I_x) an indices array of length at least **nnz** that is used to index into the entries of dense vector y , then these functions return

$$\text{dot} = \sum_{i=0}^{\text{nnz}-1} x_i \cdot y_{I_{x_i}}.$$

Note: The contents of the vectors are not checked for NaNs.

Parameters

- **nnz** – [in] The number of elements to access in vectors **x** and **indx**.
- **x** – [in] Array of at least **nnz** elements.
- **indx** – [in] Nonzero indices set, I_x , of **x** described by this array of length at least **nnz**. Each entry must contain a valid index into **y** and be unique. The entries of **indx** are not checked for validity.
- **y** – [in] Array of at least $\max(I_{x_i}, i \in \{1, \dots, \text{nnz}\})$ elements.

Return values

dot – Value of the dot product if **nnz** is positive, otherwise returns 0.

aoclsparse_?sctr()

```
aoclsparse_status aoclsparse_ssctr(const aoclsparse_int nnz, const float *x, const aoclsparse_int *indx, float  
*y)
```

```
aoclsparse_status aoclsparse.dsctr(const aoclsparse_int nnz, const double *x, const aoclsparse_int *indx,  
double *y)
```

```
aoclsparse_status aoclsparse.csctr(const aoclsparse_int nnz, const void *x, const aoclsparse_int *indx, void  
*y)
```

`aoclsparse_status aoclsparse_zsctr(const aoclsparse_int nnz, const void *x, const aoclsparse_int *indx, void *y)`

Sparse scatter for single and double precision real and complex types.

`aoclsparse_?sctr` scatter the elements of a compressed sparse vector into a dense vector.

Let $y \in R^m$ (or C^m) be a dense vector, and x be a compressed sparse vector with I_x be its nonzero indices set of length at least `nnz` and described by the array `indx`, then

$$y_{I_{x_i}} = x_i, \quad i \in \{1, \dots, \text{nnz}\}.$$

Example (tests/examples/sample_sctr.cpp)

Note: The contents of the vectors are not checked for NaNs.

Parameters

- **nnz** – [in] The number of elements to use from x and `indx`.
- **x** – [in] Dense array of at least size `nnz`. The first `nnz` elements are to be scattered.
- **indx** – [in] Nonzero index set for x of size at least `nnz`. The first `nnz` indices are used for the scattering. The elements in this vector are only checked for non-negativity. The user should make sure that index is less than the size of y .
- **y** – [out] Array of at least $\max(I_{x_i}, i \in \{1, \dots, \text{nnz}\})$ elements.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – At least one of the pointers `x`, `indx`, `y` is invalid.
- **aoclsparse_status_invalid_size** – Indicates that provided `nnz` is less than zero.
- **aoclsparse_status_invalid_index_value** – At least one of the indices in `indx` is negative.

sparse_?sctrs()

`aoclsparse_status aoclsparse_ssctrs(const aoclsparse_int nnz, const float *x, aoclsparse_int stride, float *y)`

`aoclsparse_status aoclsparse_dsctrs(const aoclsparse_int nnz, const double *x, aoclsparse_int stride, double *y)`

`aoclsparse_status aoclsparse_csctrs(const aoclsparse_int nnz, const void *x, aoclsparse_int stride, void *y)`

`aoclsparse_status aoclsparse_zsctrs`(const `aoclsparse_int` nnz, const void *x, `aoclsparse_int` stride, void *y)

Sparse scatter with stride for real/complex single and double data precisions.

`aoclsparse_?sctrs` scatters the elements of a compressed sparse vector into a dense vector using a stride.

Let y be a dense vector of length $n > 0$, x be a compressed sparse vector with $\text{nnz} > 0$ nonzeros, and `stride` be a striding distance, then

$$y_{\text{stride} \times i} = x_i, \quad i \in \{1, \dots, \text{nnz}\}.$$

Note: Contents of the vector x are accessed but not checked.

Parameters

- `nnz` – [in] Number of nonzero elements to access in x .
- `x` – [in] Array of at least `nnz` elements. The first `nnz` elements are to be scattered into y .
- `stride` – [in] (Positive) striding distance used to store elements in vector y .
- `y` – [out] Array of size at least `stride` \times `nnz`.

Return values

- `aoclsparse_status_success` – The operation completed successfully.
- `aoclsparse_status_invalid_pointer` – At least one of the pointers `x`, `y` is invalid.
- `aoclsparse_status_invalid_size` – Indicates that one or more of the values provided in `nnz` or `stride` is not positive.

`aoclsparse_?roti()`

`aoclsparse_status aoclsparse_sroti`(const `aoclsparse_int` nnz, float *x, const `aoclsparse_int` *indx, float *y,
const float c, const float s)

`aoclsparse_status aoclsparse_droti`(const `aoclsparse_int` nnz, double *x, const `aoclsparse_int` *indx, double *y,
const double c, const double s)

Apply Givens rotation to single or double precision real vectors.

`aoclsparse_sroti()` and `aoclsparse_droti()` apply the Givens rotation on elements of two real vectors.

Let $y \in R^m$ be a vector in full storage form, x be a vector in a compressed form and I_x its nonzero indices set of length at least `nnz` described by the array `indx`, then

$$x_i = c * x_i + s * y_{I_{x_i}},$$

$$y_{I_{x_i}} = c * y_{I_{x_i}} - s * x_i,$$

for $i \in 1, \dots, \text{nnz}$. The elements `c`, `s` are scalars.

Example (tests/examples/sample_roti.cpp)

Note: The contents of the vectors are not checked for NaNs.

Parameters

- **nnz** – [in] The number of elements to use from x and indx .
- **x** – [inout] Array x of at least nnz elements in compressed form. The elements of the array are updated after applying the Givens rotation.
- **indx** – [in] Nonzero index set of x , I_x , with at least nnz elements. The first nnz elements are used to apply the Givens rotation. The elements in this vector are only checked for non-negativity. The caller should make sure that each entry is less than the size of y and are all distinct.
- **y** – [inout] Dense array of at least $\max(I_{x_i}, \text{for } i \in \{1, \dots, \text{nnz}\})$ elements in full storage form. The elements of the array are updated after applying the Givens rotation.
- **c** – [in] A scalar.
- **s** – [in] A scalar.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – At least one of the pointers x , indx , y is invalid.
- **aoclsparse_status_invalid_size** – Indicates that provided nnz is less than zero.
- **aoclsparse_status_invalid_index_value** – At least one of the indices in indx is negative. With this error, the values of vectors x and y are undefined.

aoclsparse_?gthr()

```
aoclsparse_status aoclsparse_sgthr(aoclsparse_int nnz, const float *y, float *x, const aoclsparse_int *indx)
aoclsparse_status aoclsparse_dgthr(aoclsparse_int nnz, const double *y, double *x, const aoclsparse_int *indx)
aoclsparse_status aoclsparse_cgthr(aoclsparse_int nnz, const void *y, void *x, const aoclsparse_int *indx)
aoclsparse_status aoclsparse_zgthr(aoclsparse_int nnz, const void *y, void *x, const aoclsparse_int *indx)
```

Gather elements from a dense vector and store them into a sparse vector.

The `aoclsparse_?gthr` is a group of functions that gather the elements indexed in `indx` from the dense vector `y` into the sparse vector `x`.

Let $y \in R^m$ (or C^m) be a dense vector, x be a sparse vector from the same space and I_x be a set of indices of size $0 < \text{nnz} \leq m$ described by `indx`, then

$$x_i = y_{I_{x_i}}, i \in \{1, \dots, \text{nnz}\}.$$

For double precision complex vectors use `aoclsparse_zgthr()` and for single precision complex vectors use `aoclsparse_cgthr()`.

Example - Complex space (tests/examples/sample_zgthr.cpp)

Note: These functions assume that the indices stored in `indx` are less than m without duplicate elements, and that `x` and `indx` are pointers to vectors of size at least `nnz`.

Parameters

- `nnz` – [in] number of non-zero entries of x . If `nnz` is zero, then none of the entries of vectors `x`, `y`, and `indx` are touched.
- `y` – [in] pointer to dense vector y of size at least m .
- `x` – [out] pointer to sparse vector x with at least `nnz` non-zero elements.
- `indx` – [in] index vector of size `nnz`, containing the indices of the non-zero values of x . Indices should range from 0 to $m - 1$, need not be ordered. The elements in this vector are only checked for non-negativity. The user should make sure that no index is out-of-bound and that it does not contains any duplicates.

Return values

- `aoclsparse_status_success` – the operation completed successfully
- `aoclsparse_status_invalid_size` – `nnz` parameter value is negative
- `aoclsparse_status_invalid_pointer` – at least one of the pointers `y`, `x` or `indx` is invalid
- `aoclsparse_status_invalid_index_value` – at least one of the indices in `indx` is negative

`aoclsparse_?gthrz()`

```
aoclsparse_status aoclsparse_sgthrz(aoclsparse_int nnz, float *y, float *x, const aoclsparse_int *indx)
aoclsparse_status aoclsparse_dgthrz(aoclsparse_int nnz, double *y, double *x, const aoclsparse_int *indx)
aoclsparse_status aoclsparse_cgthrz(aoclsparse_int nnz, void *y, void *x, const aoclsparse_int *indx)
aoclsparse_status aoclsparse_zgthrz(aoclsparse_int nnz, void *y, void *x, const aoclsparse_int *indx)
```

Gather and zero out elements from a dense vector and store them into a sparse vector.

The `aoclsparse_?gthrz` is a group of functions that gather the elements

indexed in `indx` from the dense vector `y` into the sparse vector `x`. The gathered elements in `y` are replaced by zero.

Let $y \in R^m$ (or C^m) be a dense vector, x be a sparse vector from the same space and I_x be a set of indices of size $0 < \text{nnz} \leq m$ described by `indx`, then

$$x_i = y_{I_{x_i}}, i \in \{1, \dots, \text{nnz}\}, \text{ and after the assignment, } y_{I_{x_i}} = 0, i \in \{1, \dots, \text{nnz}\}.$$

For double precision complex vectors use `aoclsparse_zgthrz()` and for single precision complex vectors use `aoclsparse_cgthrz()`.

Note: These functions assume that the indices stored in `indx` are less than m without duplicate elements, and that `x` and `indx` are pointers to vectors of size at least `nnz`.

Parameters

- **nnz** – [in] number of non-zero entries of x . If nnz is zero, then none of the entries of vectors x , y , and $indx$ are touched.
- **y** – [in] pointer to dense vector y of size at least m .
- **x** – [out] pointer to sparse vector x with at least nnz non-zero elements.
- **indx** – [in] index vector of size nnz , containing the indices of the non-zero values of x . Indices should range from 0 to $m - 1$, need not be ordered. The elements in this vector are only checked for non-negativity. The user should make sure that no index is out-of-bound and that it does not contain any duplicates.

Return values

- **aoclsparse_status_success** – the operation completed successfully
- **aoclsparse_status_invalid_size** – nnz parameter value is negative
- **aoclsparse_status_invalid_pointer** – at least one of the pointers y , x or $indx$ is invalid
- **aoclsparse_status_invalid_index_value** – at least one of the indices in $indx$ is negative

aoclsparse_?gthrs()

```
aoclsparse_status aoclsparse_sgthrs(aoclsparse_int nnz, const float *y, float *x, aoclsparse_int stride)
aoclsparse_status aoclsparse_dgthrs(aoclsparse_int nnz, const double *y, double *x, aoclsparse_int stride)
aoclsparse_status aoclsparse_cgthrs(aoclsparse_int nnz, const void *y, void *x, aoclsparse_int stride)
aoclsparse_status aoclsparse_zgthrs(aoclsparse_int nnz, const void *y, void *x, aoclsparse_int stride)
```

Gather elements from a dense vector using a stride and store them into a sparse vector.

The **aoclsparse_?gthrs** is a group of functions that gather the elements from the dense vector y using a fixed stride distance and copies them into the sparse vector x .

Let $y \in R^m$ (or C^m) be a dense vector, x be a sparse vector from the same space and **stride** be a (positive) striding distance, then $x_i = y_{\text{stride} \times i}$, $i \in \{1, \dots, nnz\}$.

Parameters

- **nnz** – [in] Number of non-zero entries of x . If nnz is zero, then none of the entries of vectors x and y are accessed. Note that nnz must be such that **stride** \times nnz must be less or equal to m .
- **y** – [in] Pointer to dense vector y of size at least m .
- **x** – [out] Pointer to sparse vector x with at least nnz non-zero elements.
- **stride** – [in] Striding distance used to access elements in the dense vector y . It must be such that **stride** \times nnz is less or equal to m .

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – at least one of the parameters nnz or **stride** has a negative value.
- **aoclsparse_status_invalid_pointer** – at least one of the pointers y , or x is invalid.

2.4.2 Level 2

This module holds all sparse level 2 routines.

The sparse level 2 routines describe operations between a matrix in sparse format and a vector in dense or sparse format.

aoclsparse_?mv()

```
aoclsparse_status aoclsparse_smv(aoclsparse_operation op, const float *alpha, aoclsparse_matrix A, const  
aoclsparse_mat_descr descr, const float *x, const float *beta, float *y)  
  
aoclsparse_status aoclsparse_dmv(aoclsparse_operation op, const double *alpha, aoclsparse_matrix A, const  
aoclsparse_mat_descr descr, const double *x, const double *beta, double *y)  
  
aoclsparse_status aoclsparse_cmv(aoclsparse_operation op, const aoclsparse_float_complex *alpha,  
aoclsparse_matrix A, const aoclsparse_mat_descr descr, const  
aoclsparse_float_complex *x, const aoclsparse_float_complex *beta,  
aoclsparse_float_complex *y)  
  
aoclsparse_status aoclsparse_zmv(aoclsparse_operation op, const aoclsparse_double_complex *alpha,  
aoclsparse_matrix A, const aoclsparse_mat_descr descr, const  
aoclsparse_double_complex *x, const aoclsparse_double_complex *beta,  
aoclsparse_double_complex *y)
```

Compute sparse matrix-vector multiplication for real/complex single and double data precisions.

The `aoclsparse_?mv` perform sparse matrix-vector products of the form

$$y = \alpha op(A) x + \beta y,$$

where, x and y are dense vectors, α and β are scalars, and A is a sparse matrix structure. The matrix operation `op()` is defined as:

$$op(A) = \begin{cases} A, & \text{if } op = \text{aoclsparse_operation_none} \\ A^T, & \text{if } op = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } op = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Example - C++ (tests/examples/sample_mv_cpp.cpp)

Example - C (tests/examples/sample_spmv_c.c)

Parameters

- **op** – [in] Matrix operation, `op` can be one of `aoclsparse_operation_none`, `aoclsparse_operation_transpose`, or `aoclsparse_operation_conjugate_transpose`.
- **alpha** – [in] Scalar α .
- **A** – [in] The sparse matrix created using e.g. `aoclsparse_create_scsr()` or other variant. Matrix is considered of size m by n .
- **descr** – [in] Descriptor of the matrix. These functions support the following `aoclsparse_matrix_type` types: `aoclsparse_matrix_type_general`, `aoclsparse_matrix_type_triangular`, `aoclsparse_matrix_type_symmetric`, and `aoclsparse_matrix_type_hermitian`. Both base-zero and base-one are supported, however, the index base needs to match with the one defined in matrix A.

- **x – [in]** An array of **n** elements if $op(A) = A$; or of **m** elements if $op(A) = A^T$ or $op(A) = A^H$.
- **beta – [in]** Scalar β .
- **y – [inout]** An array of **m** elements if $op(A) = A$; or of **n** elements if $op(A) = A^T$ or $op(A) = A^H$.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_size** – The value of **m**, **n** or **nnz** is invalid.
- **aoclsparse_status_invalid_pointer** – **descr**, **alpha**, internal structures related to the sparse matrix **A**, **x**, **beta** or **y** has an invalid pointer.
- **aoclsparse_status_not_implemented** – The requested functionality is not implemented.

aoclsparse::mv()

```
template<typename T>
aoclsparse_status aoclsparse::mv(aoclsparse_operation op, const T *alpha, aoclsparse_matrix A, const
                                  aoclsparse_mat_descr descr, const T *x, const T *beta, T *y)
```

C++ function to compute sparse matrix-vector multiplication for real/complex single and double data precisions.

`aoclsparse::mv` is the C++ interface to `aoclsparse_?mv` that computes sparse matrix-vector multiplication using the provided input parameters.

Example - C++ (tests/examples/sample_mv_cpp.cpp)

Template Parameters

T – Data type supported for **T** are double, float, std::complex<double> and std::complex<float>

aoclsparse_?trsv()

```
aoclsparse_status aoclsparse_strsv(aoclsparse_operation trans, const float alpha, aoclsparse_matrix A, const
                                    aoclsparse_mat_descr descr, const float *b, float *x)
```

```
aoclsparse_status aoclsparse_dtrsv(aoclsparse_operation trans, const double alpha, aoclsparse_matrix A, const
                                    aoclsparse_mat_descr descr, const double *b, double *x)
```

```
aoclsparse_status aoclsparse_ctrsv(aoclsparse_operation trans, const aoclsparse_float_complex alpha,
                                    aoclsparse_matrix A, const aoclsparse_mat_descr descr, const
                                    aoclsparse_float_complex *b, aoclsparse_float_complex *x)
```

```
aoclsparse_status aoclsparse_ztrsv(aoclsparse_operation trans, const aoclsparse_double_complex alpha,
                                    aoclsparse_matrix A, const aoclsparse_mat_descr descr, const
                                    aoclsparse_double_complex *b, aoclsparse_double_complex *x)
```

Sparse triangular solver for real/complex single and double data precisions.

The function `aoclsparse_strsv()` and variants solve sparse lower (or upper) triangular linear system of equations. The system is defined by the sparse $m \times m$ matrix A , the dense solution m -vector x , and the right-hand side dense m -vector b . Vector b is multiplied by α . The solution x is estimated by solving

$$op(L) \cdot x = \alpha \cdot b, \quad \text{or} \quad op(U) \cdot x = \alpha \cdot b,$$

where $L = \text{tril}(A)$ is the lower triangle of matrix A , similarly, $U = \text{triu}(A)$ is the upper triangle of matrix A . The operator $op()$ is regarded as the matrix linear operation,

$$op(A) = \begin{cases} A, & \text{if } \text{trans} = \text{aoclsparse_operation_none} \\ A^T, & \text{if } \text{trans} = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } \text{trans} = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Notes

1. This routine supports sparse matrices in CSR, CSC, and TCSR formats.
2. If the matrix descriptor `descr` specifies that the matrix A is to be regarded as having a unitary diagonal, then the main diagonal entries of matrix A are not accessed and are all considered to be unitary.
3. The input matrix need not be (upper or lower) triangular matrix, in the `descr`, the `fill_mode` entity specifies which triangle to consider, namely, if `fill_mode = aoclsparse_fill_mode_lower`, then

$$op(L) \cdot x = \alpha \cdot b,$$

otherwise, if `fill_mode = aoclsparse_fill_mode_upper`, then

$$op(U) \cdot x = \alpha \cdot b,$$

is solved.

4. To increase performance and if the matrix A is to be used more than once to solve for different right-hand sides b , then it is encouraged to provide hints using `aoclsparse_set_sv_hint()` and `aoclsparse_optimize()`, otherwise, the optimization for the matrix will be done by the solver on entry.
5. There is a `kid` (Kernel ID) variation of TRSV, namely with a suffix of `_kid`, `aoclsparse_strsv_kid()` (and variations) where it is possible to specify the TRSV kernel to use (if possible).

Example - Real space (tests/examples/sample_dtrsv.cpp)

Example - Complex space (tests/examples/sample_tcsr_ztrsv.cpp)

Parameters

- **trans** – [in] matrix operation type, either `aoclsparse_operation_none`, `aoclsparse_operation_transpose`, or `aoclsparse_operation_conjugate_transpose`.
- **alpha** – [in] scalar α , used to multiply right-hand side vector b .
- **A** – [inout] matrix containing data used to represent the $m \times m$ triangular linear system to solve.
- **descr** – [in] matrix descriptor. Supported matrix types are `aoclsparse_matrix_type_symmetric` and `aoclsparse_matrix_type_triangular`.
- **b** – [in] array of m elements, storing the right-hand side.
- **x** – [out] array of m elements, storing the solution if solver returns `aoclsparse_status_success`.

Return values

- **aoclsparse_status_success** – the operation completed successfully and x contains the solution to the linear system of equations.
- **aoclsparse_status_invalid_size** – matrix A or $op(A)$ is invalid.

- **aoclsparse_status_invalid_pointer** – One or more of A, descr, x, b are invalid pointers.
- **aoclsparse_status_internal_error** – an internal error occurred.
- **aoclsparse_status_not_implemented** – the requested operation is not yet implemented.
- **other** – possible failure values from a call to *aoclsparse_optimize*.

aoclsparse_status **aoclsparse_trsv_strided**(*aoclsparse_operation* trans, const float alpha, *aoclsparse_matrix* A, const *aoclsparse_mat_descr* descr, const float *b, const *aoclsparse_int* incb, float *x, const *aoclsparse_int* incx)

aoclsparse_status **aoclsparse_dtrsv_strided**(*aoclsparse_operation* trans, const double alpha, *aoclsparse_matrix* A, const *aoclsparse_mat_descr* descr, const double *b, const *aoclsparse_int* incb, double *x, const *aoclsparse_int* incx)

aoclsparse_status **aoclsparse_ctrsv_strided**(*aoclsparse_operation* trans, const *aoclsparse_float_complex* alpha, *aoclsparse_matrix* A, const *aoclsparse_mat_descr* descr, const *aoclsparse_float_complex* *b, const *aoclsparse_int* incb, *aoclsparse_float_complex* *x, const *aoclsparse_int* incx)

aoclsparse_status **aoclsparse_ztrsv_strided**(*aoclsparse_operation* trans, const *aoclsparse_double_complex* alpha, *aoclsparse_matrix* A, const *aoclsparse_mat_descr* descr, const *aoclsparse_double_complex* *b, const *aoclsparse_int* incb, *aoclsparse_double_complex* *x, const *aoclsparse_int* incx)

This is a variation of TRSV, namely with a suffix of _strided, allows to set the stride for the dense vectors b and x.

For full details refer to *aoclsparse_?trsv()*.

Parameters

- **trans** – [in] matrix operation type, either *aoclsparse_operation_none*, *aoclsparse_operation_transpose*, or *aoclsparse_operation_conjugate_transpose*.
- **alpha** – [in] scalar α , used to multiply right-hand side vector b.
- **A** – [inout] matrix containing data used to represent the $m \times m$ triangular linear system to solve.
- **descr** – [in] matrix descriptor. Supported matrix types are *aoclsparse_matrix_type_symmetric* and *aoclsparse_matrix_type_triangular*.
- **b** – [in] array of m elements, storing the right-hand side.
- **incb** – [in] a positive integer holding the stride value for b vector.
- **x** – [out] array of m elements, storing the solution if solver returns *aoclsparse_status_success*.
- **incx** – [in] a positive integer holding the stride value for x vector.

aoclsparse_status **aoclsparse_trsv_kid**(*aoclsparse_operation* trans, const float alpha, *aoclsparse_matrix* A, const *aoclsparse_mat_descr* descr, const float *b, float *x, *aoclsparse_int* kid)

aoclsparse_status **aoclsparse_dtrsv_kid**(*aoclsparse_operation* trans, const double alpha, *aoclsparse_matrix* A, const *aoclsparse_mat_descr* descr, const double *b, double *x, *aoclsparse_int* kid)

```
aoclsparse_status aoclsparse_ctrsv_kid(aoclsparse_operation trans, const aoclsparse_float_complex alpha,  
aoclsparse_matrix A, const aoclsparse_mat_descr descr, const  
aoclsparse_float_complex *b, aoclsparse_float_complex *x,  
aoclsparse_int kid)
```

```
aoclsparse_status aoclsparse_ztrsv_kid(aoclsparse_operation trans, const aoclsparse_double_complex alpha,  
aoclsparse_matrix A, const aoclsparse_mat_descr descr, const  
aoclsparse_double_complex *b, aoclsparse_double_complex *x,  
aoclsparse_int kid)
```

Sparse triangular solver for real/complex single and double data precisions (kernel flag variation).

For full details refer to [aoclsparse_?trsv\(\)](#).

This variation of TRSV, namely with a suffix of _kid, allows to choose which TRSV kernel to use (if possible). Currently the possible choices are:

kid=0

Reference implementation (No explicit AVX instructions).

kid=1

Alias to kid=2 (Kernel Template AVX 256-bit implementation)

kid=2

Kernel Template version using AVX2 extensions.

kid=3

Kernel Template version using AVX512F+ CPU extensions.

Any other Kernel ID value will default to kid = 0.

Parameters

- **trans** – [in] matrix operation type, either `aoclsparse_operation_none`, `aoclsparse_operation_transpose`, or `aoclsparse_operation_conjugate_transpose`.
- **alpha** – [in] scalar α , used to multiply right-hand side vector b .
- **A** – [inout] matrix containing data used to represent the $m \times m$ triangular linear system to solve.
- **descr** – [in] matrix descriptor. Supported matrix types are `aoclsparse_matrix_type_symmetric` and `aoclsparse_matrix_type_triangular`.
- **b** – [in] array of m elements, storing the right-hand side.
- **x** – [out] array of m elements, storing the solution if solver returns `aoclsparse_status_success`.
- **kid** – [in] Kernel ID, hints a request on which TRSV kernel to use.

aoclsparse::trsv()

```
template<typename T>
aoclsparse\_status aoclsparse::trsv(const aoclsparse\_operation trans, const T alpha, aoclsparse\_matrix A, const
                                         aoclsparse\_mat\_descr descr, const T *b, const aoclsparse\_int incb, T *x,
                                         const aoclsparse\_int incx, aoclsparse\_int kid = -1)
```

`aoclsparse::trsv` is the C++ interface to `aoclsparse_?trsv` and it performs a sparse triangular solve using the provided input parameters.

Example - Complex space (tests/examples/sample_trsv_cpp.cpp)

Template Parameters

`T` – Data type supported for `T` are double, float, `std::complex<double>` or `std::complex<float>`

aoclsparse_?dotmv()

```
aoclsparse\_status aoclsparse_sdotmv(const aoclsparse\_operation op, const float alpha, aoclsparse\_matrix A,
                                         const aoclsparse\_mat\_descr descr, const float *x, const float beta, float *y,
                                         float *d)
```

```
aoclsparse\_status aoclsparse_ddotmv(const aoclsparse\_operation op, const double alpha, aoclsparse\_matrix A,
                                         const aoclsparse\_mat\_descr descr, const double *x, const double beta,
                                         double *y, double *d)
```

```
aoclsparse\_status aoclsparse_cdotmv(const aoclsparse\_operation op, const aoclsparse\_float\_complex alpha,
                                         aoclsparse\_matrix A, const aoclsparse\_mat\_descr descr, const
                                         aoclsparse\_float\_complex *x, const aoclsparse\_float\_complex beta,
                                         aoclsparse\_float\_complex *y, aoclsparse\_float\_complex *d)
```

```
aoclsparse\_status aoclsparse_zdotmv(const aoclsparse\_operation op, const aoclsparse\_double\_complex alpha,
                                         aoclsparse\_matrix A, const aoclsparse\_mat\_descr descr, const
                                         aoclsparse\_double\_complex *x, const aoclsparse\_double\_complex beta,
                                         aoclsparse\_double\_complex *y, aoclsparse\_double\_complex *d)
```

Performs sparse matrix-vector multiplication followed by vector-vector multiplication.

`aoclsparse_?dotmv` multiplies the scalar α with a sparse $m \times n$ matrix, defined in a sparse storage format, and the dense vector x and adds the result to the dense vector y that is multiplied by the scalar β , such that

$$y := \alpha op(A) x + \beta y, \quad \text{with} \quad op(A) = \begin{cases} A, & \text{if } op = \text{aoclsparse_operation_none} \\ A^T, & \text{if } op = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } op = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

followed by dot product of dense vectors x and y such that

$$d = \begin{cases} \sum_{i=0}^{\min(m,n)-1} x_i y_i, & \text{real case} \\ \sum_{i=0}^{\min(m,n)-1} \bar{x}_i y_i, & \text{complex case} \end{cases}$$

Example (tests/examples/sample_dotmv.cpp)

Parameters

- `op` – [in] matrix operation type.

- **alpha** – [in] scalar α .
- **A** – [in] the sparse $m \times n$ matrix structure that is created using `aoclsparse_create_scsr()` or other variation.
- **descr** – [in] descriptor of the sparse CSR matrix. Both base-zero and base-one are supported, however, the index base needs to match the one used when `aoclsparse_matrix` was created.
- **x** – [in] array of atleast **n** elements if $op(A) = A$ or at least **m** elements if $op(A) = A^T$ or A^H .
- **beta** – [in] scalar β .
- **y** – [inout] array of atleast **m** elements if $op(A) = A$ or at least **n** elements if $op(A) = A^T$ or A^H .
- **d** – [out] dot product of y and x.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_size` – **m**, **n** or **nnz** is invalid.
- `aoclsparse_status_invalid_value` – (base index is neither `aoclsparse_index_base_zero` nor `aoclsparse_index_base_one`, or matrix base index and descr base index values do not match).
- `aoclsparse_status_invalid_pointer` – descr, internal structures related to the sparse matrix A, x, y or d are invalid pointer.
- `aoclsparse_status_wrong_type` – matrix data type is not supported.
- `aoclsparse_status_not_implemented` – `aoclsparse_matrix_type` is `aoclsparse_matrix_type_hermitian` or, `aoclsparse_matrix_format_type` is not `aoclsparse_csr_mat`

`aoclsparse_?ellmv()`

```
aoclsparse_status aoclsparse_sellmv(aoclsparse_operation trans, const float *alpha, aoclsparse_int m,  
                                     aoclsparse_int n, aoclsparse_int nnz, const float *ell_val, const  
                                     aoclsparse_int *ell_col_ind, aoclsparse_int ell_width, const  
                                     aoclsparse_mat_descr descr, const float *x, const float *beta, float *y)
```

```
aoclsparse_status aoclsparse_dellmv(aoclsparse_operation trans, const double *alpha, aoclsparse_int m,  
                                     aoclsparse_int n, aoclsparse_int nnz, const double *ell_val, const  
                                     aoclsparse_int *ell_col_ind, aoclsparse_int ell_width, const  
                                     aoclsparse_mat_descr descr, const double *x, const double *beta, double  
                                     *y)
```

Real single and double precision sparse matrix vector product using ELL storage format.

`aoclsparse_?ellmv` multiplies the scalar α with a sparse $m \times n$ matrix, defined in ELL storage format, and the dense vector x and adds the result to the dense vector y that is multiplied by the scalar β , such that

$$y = \alpha op(A) x + \beta y,$$

with

$$op(A) = \begin{cases} A, & \text{if } \text{trans} = \text{aoclsparse_operation_none} \\ A^T, & \text{if } \text{trans} = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } \text{trans} = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Note: Currently, only `trans = aoclsparse_operation_none` is supported.

Parameters

- **trans** – [in] matrix operation type.
- **alpha** – [in] scalar α .
- **m** – [in] number of rows of the sparse ELL matrix.
- **n** – [in] number of columns of the sparse ELL matrix.
- **nnz** – [in] number of non-zero entries of the sparse ELL matrix.
- **descr** – [in] descriptor of the sparse ELL matrix. Both, base-zero and base-one input arrays of ELL matrix are supported
- **ell_val** – [in] array that contains the elements of the sparse ELL matrix. Padded elements should be zero.
- **ell_col_ind** – [in] array that contains the column indices of the sparse ELL matrix. Padded column indices should be -1.
- **ell_width** – [in] number of non-zero elements per row of the sparse ELL matrix.
- **x** – [in] array of **n** elements ($op(A) = A$) or **m** elements ($op(A) = A^T$ or $op(A) = A^H$).
- **beta** – [in] scalar β .
- **y** – [inout] array of **m** elements ($op(A) = A$) or **n** elements ($op(A) = A^T$ or $op(A) = A^H$).

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – **m**, **n** or **ell_width** is invalid.
- **aoclsparse_status_invalid_pointer** – **descr**, **alpha**, **ell_val**, **ell_col_ind**, **x**, **beta** or **y** pointer is invalid.
- **aoclsparse_status_not_implemented** – **trans** is not `aoclsparse_operation_none`, or `aoclsparse_matrix_type` is not `aoclsparse_matrix_type_general`.

aoclsparse_?diamv()

```
aoclsparse_status aoclsparse_sdiamv(aoclsparse_operation trans, const float *alpha, aoclsparse_int m,
                                     aoclsparse_int n, aoclsparse_int nnz, const float *dia_val, const
                                     aoclsparse_int *dia_offset, aoclsparse_int dia_num_diag, const
                                     aoclsparse_mat_descr descr, const float *x, const float *beta, float *y)
```

```
aoclsparse_status aoclsparse_ddiamv(aoclsparse_operation trans, const double *alpha, aoclsparse_int m,
                                     aoclsparse_int n, aoclsparse_int nnz, const double *dia_val, const
                                     aoclsparse_int *dia_offset, aoclsparse_int dia_num_diag, const
                                     aoclsparse_mat_descr descr, const double *x, const double *beta, double
                                     *y)
```

Real single and double precision sparse matrix vector product using DIA storage format.

`aoclsparse_?diamv` multiplies the scalar α with a sparse $m \times n$ matrix, defined in DIA storage format, and the dense vector x and adds the result to the dense vector y that is multiplied by the scalar β , such that

$$y = \alpha op(A) x + \beta y,$$

with

$$op(A) = \begin{cases} A, & \text{if } trans = \text{aoclsparse_operation_none} \\ A^T, & \text{if } trans = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } trans = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Note: Currently, only `trans = aoclsparse_operation_none` is supported.

Parameters

- **trans** – [in] matrix operation type.
- **alpha** – [in] scalar α .
- **m** – [in] number of rows of the matrix.
- **n** – [in] number of columns of the matrix.
- **nnz** – [in] number of non-zero entries of the matrix.
- **descr** – [in] descriptor of the sparse DIA matrix.
- **dia_val** – [in] array that contains the elements of the matrix. Padded elements should be zero.
- **dia_offset** – [in] array that contains the offsets of each diagonal of the matrix.
- **dia_num_diag** – [in] number of diagonals in the matrix.
- **x** – [in] array of n elements ($op(A) = A$) or m elements ($op(A) = A^T$ or $op(A) = A^H$).
- **beta** – [in] scalar β .
- **y** – [inout] array of m elements ($op(A) = A$) or n elements ($op(A) = A^T$ or $op(A) = A^H$).

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – m, n or ell_width is invalid.
- **aoclsparse_status_invalid_pointer** – descr, alpha, ell_val, ell_col_ind, x, beta or y pointer is invalid.
- **aoclsparse_status_not_implemented** – trans is not `aoclsparse_operation_none`, or `aoclsparse_matrix_type` is not `aoclsparse_matrix_type_general`.

aoclsparse_?bsrmv()

`aoclsparse_status aoclsparse_sbsrmv(aoclsparse_operation trans, const float *alpha, aoclsparse_int mb,
aoclsparse_int nb, aoclsparse_int bsr_dim, const float *bsr_val, const
aoclsparse_int *bsr_col_ind, const aoclsparse_int *bsr_row_ptr, const
aoclsparse_mat_descr descr, const float *x, const float *beta, float *y)`

`aoclsparse_status aoclsparse_dbsrmv(aoclsparse_operation trans, const double *alpha, aoclsparse_int mb,
aoclsparse_int nb, aoclsparse_int bsr_dim, const double *bsr_val, const
aoclsparse_int *bsr_col_ind, const aoclsparse_int *bsr_row_ptr, const
aoclsparse_mat_descr descr, const double *x, const double *beta, double
*y)`

Real single and double precision matrix vector product using BSR storage format.

`aoclsparse_?bsrmv` multiplies the scalar α with a sparse `mb` times `bsr_dim` by `nb` times `bsr_dim` matrix, defined in BSR storage format, and the dense vector x and adds the result to the dense vector y that is multiplied by the scalar β , such that

$$y = \alpha op(A) x + \beta y,$$

with

$$op(A) = \begin{cases} A, & \text{if } \text{trans} = \text{aoclsparse_operation_none} \\ A^T, & \text{if } \text{trans} = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } \text{trans} = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Note: Only `trans = aoclsparse_operation_none` is supported.

Parameters

- **trans** – [in] matrix operation type.
- **mb** – [in] number of block rows of the sparse BSR matrix.
- **nb** – [in] number of block columns of the sparse BSR matrix.
- **alpha** – [in] scalar α .
- **descr** – [in] descriptor of the sparse BSR matrix. Both, base-zero and base-one input arrays of BSR matrix are supported.
- **bsr_val** – [in] array of `nnzb` blocks of the sparse BSR matrix.
- **bsr_row_ptr** – [in] array of `mb+1` elements that point to the start of every block row of the sparse BSR matrix.
- **bsr_col_ind** – [in] array of `nnz` containing the block column indices of the sparse BSR matrix.
- **bsr_dim** – [in] block dimension of the sparse BSR matrix.
- **x** – [in] array of `nb` times `bsr_dim` elements ($op(A) = A$) or `mb` times `bsr_dim` elements ($op(A) = A^T$ or $op(A) = A^H$).
- **beta** – [in] scalar β .
- **y** – [inout] array of `mb` times `bsr_dim` elements ($op(A) = A$) or `nb` times `bsr_dim` elements ($op(A) = A^T$ or $op(A) = A^H$).

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_handle** – the library context was not initialized.
- **aoclsparse_status_invalid_size** – `mb`, `nb`, `nnzb` or `bsr_dim` is invalid.
- **aoclsparse_status_invalid_pointer** – `descr`, `alpha`, `bsr_val`, `bsr_row_ind`, `bsr_col_ind`, `x`, `beta` or `y` pointer is invalid.
- **aoclsparse_status_arch_mismatch** – the device is not supported.
- **aoclsparse_status_not_implemented** – `trans` is not `aoclsparse_operation_none`, or `aoclsparse_matrix_type` is not `aoclsparse_matrix_type_general`.

aoclsparse_?csrmv()

```
aoclsparse_status aoclsparse_scsrmv(aoclsparse_operation trans, const float *alpha, aoclsparse_int m,  
                                     aoclsparse_int n, aoclsparse_int nnz, const float *csr_val, const  
                                     aoclsparse_int *csr_col_ind, const aoclsparse_int *csr_row_ptr, const  
                                     aoclsparse_mat_descr descr, const float *x, const float *beta, float *y)
```

```
aoclsparse_status aoclsparse_dcsrmv(aoclsparse_operation trans, const double *alpha, aoclsparse_int m,  
                                     aoclsparse_int n, aoclsparse_int nnz, const double *csr_val, const  
                                     aoclsparse_int *csr_col_ind, const aoclsparse_int *csr_row_ptr, const  
                                     aoclsparse_mat_descr descr, const double *x, const double *beta, double  
                                     *y)
```

Real single and double precision sparse matrix-vector multiplication using CSR storage format.

`aoclsparse_?csrmv` multiplies the scalar α with a sparse $m \times n$ matrix, defined in CSR storage format, and the dense vector x and adds the result to the dense vector y that is multiplied by the scalar β , such that

$$y = \alpha op(A) x + \beta y,$$

with

$$op(A) = \begin{cases} A, & \text{if } \text{trans} = \text{aoclsparse_operation_none} \\ A^T, & \text{if } \text{trans} = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } \text{trans} = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Parameters

- **trans** – [in] matrix operation type.
- **alpha** – [in] scalar α .
- **m** – [in] number of rows of the sparse CSR matrix.
- **n** – [in] number of columns of the sparse CSR matrix.
- **nnz** – [in] number of non-zero entries of the sparse CSR matrix.
- **csr_val** – [in] array of nnz elements of the sparse CSR matrix.
- **csr_col_ind** – [in] array of nnz elements containing the column indices of the sparse CSR matrix.
- **csr_row_ptr** – [in] array of $m+1$ elements that point to the start of every row of the sparse CSR matrix.
- **descr** – [in] descriptor of the sparse CSR matrix. Currently, only `aoclsparse_matrix_type_general` and `aoclsparse_matrix_type_symmetric` is supported.
- **x** – [in] array of n elements ($op(A) = A$) or m elements ($op(A) = A^T$ or $op(A) = A^H$).
- **beta** – [in] scalar β .
- **y** – [inout] array of m elements ($op(A) = A$) or n elements ($op(A) = A^T$ or $op(A) = A^H$).

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – m, n or nnz is invalid.
- **aoclsparse_status_invalid_pointer** – `descr`, `alpha`, `csr_val`, `csr_row_ptr`, `csr_col_ind`, `x`, `beta` or `y` pointer is invalid.

- **aoclsparse_status_not_implemented** – `trans` is not `aoclsparse_operation_none` and `trans` is not `aoclsparse_operation_transpose`. `aoclsparse_matrix_type` is not `aoclsparse_matrix_type_general`, or `aoclsparse_matrix_type` is not `aoclsparse_matrix_type_symmetric`.

aoclsparse_?csrsv()

`aoclsparse_status aoclsparse_scsrsv(aoclsparse_operation trans, const float *alpha, aoclsparse_int m, const float *csr_val, const aoclsparse_int *csr_col_ind, const aoclsparse_int *csr_row_ptr, const aoclsparse_mat_descr descr, const float *x, float *y)`

`aoclsparse_status aoclsparse_dcsrsv(aoclsparse_operation trans, const double *alpha, aoclsparse_int m, const double *csr_val, const aoclsparse_int *csr_col_ind, const aoclsparse_int *csr_row_ptr, const aoclsparse_mat_descr descr, const double *x, double *y)`

Sparse triangular solve using CSR storage format for single and double data precisions.

Deprecated:

This API is superseded by `aoclsparse_strsv()` and `aoclsparse_dtrsv()`.

`aoclsparse_?csrsv` solves a sparse triangular linear system of a sparse $m \times m$ matrix, defined in CSR storage format, a dense solution vector y and the right-hand side x that is multiplied by α , such that

$$op(A) y = \alpha x,$$

with

$$op(A) = \begin{cases} A, & \text{if } \text{trans} = \text{aoclsparse_operation_none} \\ A^T, & \text{if } \text{trans} = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } \text{trans} = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Note: Only `trans = aoclsparse_operation_none` is supported.

Note: The input matrix has to be sparse upper or lower triangular matrix with unit or non-unit main diagonal. Matrix has to be sorted. No diagonal element can be omitted from a sparse storage if the solver is called with the non-unit indicator.

Parameters

- **trans** – [in] matrix operation type.
- **alpha** – [in] scalar α .
- **m** – [in] number of rows of the sparse CSR matrix.
- **csr_val** – [in] array of nnz elements of the sparse CSR matrix.
- **csr_row_ptr** – [in] array of $m+1$ elements that point to the start of every row of the sparse CSR matrix.
- **csr_col_ind** – [in] array of nnz elements containing the column indices of the sparse CSR matrix.

- **descr** – [in] descriptor of the sparse CSR matrix.
- **x** – [in] array of m elements, holding the right-hand side.
- **y** – [out] array of m elements, holding the solution.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – m is invalid.
- **aoclsparse_status_invalid_pointer** – **descr**, **alpha**, **csr_val**, **csr_row_ptr**, **csr_col_ind**, **x** or **y** pointer is invalid.
- **aoclsparse_status_internal_error** – an internal error occurred.
- **aoclsparse_status_not_implemented** – $-\text{trans} = \text{ao-clsparse_operation_conjugate_transpose}$ or $\text{trans} = \text{aoclsparse_operation_transpose}$ or **aoclsparse_matrix_type** is not **aoclsparse_matrix_type_general**.

2.4.3 Level 3

This module holds all sparse level 3 routines.

The sparse level 3 routines describe operations between matrices.

aoclsparse_?trsm()

```
aoclsparse_status aoclsparse_strsm(const aoclsparse_operation trans, const float alpha, aoclsparse_matrix A,  
const aoclsparse_mat_descr descr, aoclsparse_order order, const float *B,  
aoclsparse_int n, aoclsparse_int ldb, float *X, aoclsparse_int ldx)
```

```
aoclsparse_status aoclsparse_dtrsm(const aoclsparse_operation trans, const double alpha, aoclsparse_matrix A,  
const aoclsparse_mat_descr descr, aoclsparse_order order, const double  
*B, aoclsparse_int n, aoclsparse_int ldb, double *X, aoclsparse_int ldx)
```

```
aoclsparse_status aoclsparse_ctrsm(aoclsparse_operation trans, const aoclsparse_float_complex alpha,  
aoclsparse_matrix A, const aoclsparse_mat_descr descr, aoclsparse_order  
order, const aoclsparse_float_complex *B, aoclsparse_int n, aoclsparse_int  
ldb, aoclsparse_float_complex *X, aoclsparse_int ldx)
```

```
aoclsparse_status aoclsparse_ztrsm(aoclsparse_operation trans, const aoclsparse_double_complex alpha,  
aoclsparse_matrix A, const aoclsparse_mat_descr descr, aoclsparse_order  
order, const aoclsparse_double_complex *B, aoclsparse_int n,  
aoclsparse_int ldb, aoclsparse_double_complex *X, aoclsparse_int ldx)
```

Solve sparse triangular linear system of equations with multiple right hand sides for real/complex single and double data precisions.

aoclsparse_?trsm solves a sparse triangular linear system of equations with multiple right hand sides, of the form

$$\text{op}(A) X = \alpha B,$$

where A is a sparse matrix of size m , $\text{op}()$ is a linear operator, X and B are rectangular dense matrices of appropriate size, while α is a scalar. The sparse matrix A can be interpreted either as a lower triangular or upper triangular. This is indicated by **fill_mode** from the matrix descriptor **descr** where either upper or lower triangular portion of the matrix is only referenced. The matrix can also be of class symmetric in which case only

the selected triangular part is used. Matrix A must be of full rank, that is, the matrix must be invertible. The linear operator $op()$ can define the transposition or Hermitian transposition operations. By default, no transposition is performed. The right-hand-side matrix B and the solution matrix X are dense and must be of the correct size, that is m by n , see `ldb` and `ldx` input parameters for further details.

Explicitly, this kernel solves

$$op(A) X = \alpha B, \text{ with solution } X = \alpha (op(A)^{-1}) B,$$

where

$$op(A) = \begin{cases} A, & \text{if } \text{trans} = \text{aoclsparse_operation_none} \\ A^T, & \text{if } \text{trans} = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } \text{trans} = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

If a linear operator is applied then, the possible problems solved are

$$A^T X = \alpha B, \text{ with solution } X = \alpha A^{-T} B, \text{ and } A^H X = \alpha B, \text{ with solution } X = \alpha A^{-H} B.$$

Notes

1. If the matrix descriptor `descr` specifies that the matrix A is to be regarded as having a unitary diagonal, then the main diagonal entries of matrix A are not accessed and are considered to all be ones.
2. If the matrix A is described as upper triangular, then only the upper triangular portion of the matrix is referenced. Conversely, if the matrix A is described lower triangular, then only the lower triangular portion of the matrix is used.
3. This set of APIs allocates work array of size m for each case where the matrices B or X are stored in row-major format (ref `aoclsparse_order_row`).
4. A subset of kernels are parallel (on parallel builds) and can be expected potential acceleration in the solve. These kernels are available when both dense matrices X and B are stored in column-major format (ref `aoclsparse_order_column`) and thread count is greater than 1 on a parallel build.
5. There is `aoclsparse_trsm_kid` (Kernel ID) variation of TRSM, namely with a suffix of `_kid`, this solver allows to choose which underlying TRSV kernels to use (if possible). Currently, all the existing kernels available in `aoclsparse_trsv_kid` are supported.
6. This routine supports only sparse matrices in CSR format.

Example - Real space (tests/examples/sample_dtrsm.cpp)

Example - Complex space (tests/examples/sample_ztrsm.cpp)

Parameters

- **`trans`** – [in] matrix operation to perform on A . Possible values are `aoclsparse_operation_none`, `aoclsparse_operation_transpose`, and `aoclsparse_operation_conjugate_transpose`.
- **`alpha`** – [in] scalar α .
- **`A`** – [in] sparse matrix A of size m .
- **`descr`** – [in] descriptor of the sparse matrix A .
- **`order`** – [in] storage order of dense matrices B and X . Possible options are `aoclsparse_order_row` and `aoclsparse_order_column`.

- **B** – [in] dense matrix, potentially rectangular, of size $m \times n$.
- **n** – [in] n , number of columns of the dense matrix B .
- **ldb** – [in] leading dimension of B . Eventhough the matrix B is considered of size $m \times n$, its memory layout may correspond to a larger matrix (ldb by $N > n$) in which only the submatrix B is of interest. In this case, this parameter provides means to access the correct elements of B within the larger layout.

matrix layout	row count	column count
<i>aoclsparse_order_row</i>	m	ldb with $\text{ldb} \geq n$
<i>aoclsparse_order_column</i>	ldb with $\text{ldb} \geq m$	n

- **X** – [out] solution matrix X , dense and potentially rectangular matrix of size $m \times n$.
- **ldx** – [in] leading dimension of X . Eventhough the matrix X is considered of size $m \times n$, its memory layout may correspond to a larger matrix (ldx by $N > n$) in which only the submatrix X is of interest. In this case, this parameter provides means to access the correct elements of X within the larger layout.

matrix layout	row count	column count
<i>aoclsparse_order_row</i>	m	ldx with $\text{ldx} \geq n$
<i>aoclsparse_order_column</i>	ldx with $\text{ldx} \geq m$	n

Return values

- **aoclsparse_status_success** – indicates that the operation completed successfully.
- **aoclsparse_status_invalid_size** – informs that either m , n , nnz , ldb or ldx is invalid.
- **aoclsparse_status_invalid_pointer** – informs that either **descr**, **alpha**, **A**, **B**, or **X** pointer is invalid.
- **aoclsparse_status_not_implemented** – this error occurs when the provided matrix *aoclsparse_matrix_type* is *aoclsparse_matrix_type_general* or *aoclsparse_matrix_type_hermitian* or when matrix **A** is not in CSR, CSC, TCSR format.

aoclsparse_status aoclsparse_strsm_kid(const *aoclsparse_operation* trans, const float alpha, *aoclsparse_matrix* A, const *aoclsparse_mat_descr* descr, *aoclsparse_order* order, const float *B, *aoclsparse_int* n, *aoclsparse_int* ldb, float *X, *aoclsparse_int* ldx, const *aoclsparse_int* kid)

aoclsparse_status aoclsparse_dtrsm_kid(const *aoclsparse_operation* trans, const double alpha, *aoclsparse_matrix* A, const *aoclsparse_mat_descr* descr, *aoclsparse_order* order, const double *B, *aoclsparse_int* n, *aoclsparse_int* ldb, double *X, *aoclsparse_int* ldx, const *aoclsparse_int* kid)

aoclsparse_status aoclsparse_ctrsm_kid(*aoclsparse_operation* trans, const *aoclsparse_float_complex* alpha, *aoclsparse_matrix* A, const *aoclsparse_mat_descr* descr, *aoclsparse_order* order, const *aoclsparse_float_complex* *B, *aoclsparse_int* n, *aoclsparse_int* ldb, *aoclsparse_float_complex* *X, *aoclsparse_int* ldx, const *aoclsparse_int* kid)

```
aoclsparse_status aoclsparse_ztrsm_kid(aoclsparse_operation trans, const aoclsparse_double_complex alpha,
                                         aoclsparse_matrix A, const aoclsparse_mat_descr descr,
                                         aoclsparse_order order, const aoclsparse_double_complex *B,
                                         aoclsparse_int n, aoclsparse_int ldb, aoclsparse_double_complex *X,
                                         aoclsparse_int ldx, const aoclsparse_int kid)
```

Solve sparse triangular linear system of equations with multiple right hand sides for real/complex single and double data precisions (kernel flag variation).

For full details refer to [aoclsparse_?trsm\(\)](#).

This variation of TRSM, namely with a suffix of _kid, allows to choose which underlying TRSV kernels to use (if possible). Currently, all the existing kernels supported by [aoclsparse_?trsv_kid\(\)](#) are available here as well.

Parameters

- **trans** – [in] matrix operation to perform on A . Possible values are [aoclsparse_operation_none](#), [aoclsparse_operation_transpose](#), and [aoclsparse_operation_conjugate_transpose](#).
- **alpha** – [in] scalar α .
- **A** – [in] sparse matrix A of size m .
- **descr** – [in] descriptor of the sparse matrix A .
- **order** – [in] storage order of dense matrices B and X . Possible options are [aoclsparse_order_row](#) and [aoclsparse_order_column](#).
- **B** – [in] dense matrix, potentially rectangular, of size $m \times n$.
- **n** – [in] n , number of columns of the dense matrix B .
- **ldb** – [in] leading dimension of B . Eventhough the matrix B is considered of size $m \times n$, its memory layout may correspond to a larger matrix (ldb by $N > n$) in which only the submatrix B is of interest. In this case, this parameter provides means to access the correct elements of B within the larger layout.

matrix layout	row count	column count
aoclsparse_order_row	m	ldb with $ldb \geq n$
aoclsparse_order_column	ldb with $ldb \geq m$	n

- **X** – [out] solution matrix X , dense and potentially rectangular matrix of size $m \times n$.
- **ldx** – [in] leading dimension of X . Eventhough the matrix X is considered of size $m \times n$, its memory layout may correspond to a larger matrix (ldx by $N > n$) in which only the submatrix X is of interest. In this case, this parameter provides means to access the correct elements of X within the larger layout.

matrix layout	row count	column count
aoclsparse_order_row	m	ldx with $ldx \geq n$
aoclsparse_order_column	ldx with $ldx \geq m$	n

- **kid** – [in] kernel ID, hints which kernel to use.

aoclsparse_sp2m()

```
aoclsparse_status aoclsparse_sp2m(aoclsparse_operation opA, const aoclsparse_mat_descr descrA, const  
                                    aoclsparse_matrix A, aoclsparse_operation opB, const  
                                    aoclsparse_mat_descr descrB, const aoclsparse_matrix B, const  
                                    aoclsparse_request request, aoclsparse_matrix *C)
```

Sparse matrix Sparse matrix multiplication for real and complex datatypes.

aoclsparse_sp2m multiplies two sparse matrices in CSR storage format. The result is stored in a newly allocated sparse matrix in CSR format, such that

$$C = op(A) op(B),$$

with

$$op(A) = \begin{cases} A, & \text{if } opA = \text{aoclsparse_operation_none} \\ A^T, & \text{if } opA = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } opA = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

and

$$op(B) = \begin{cases} B, & \text{if } opB = \text{aoclsparse_operation_none} \\ B^T, & \text{if } opB = \text{aoclsparse_operation_transpose} \\ B^H, & \text{if } opB = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

where A is a $m \times k$ matrix , B is a $k \times n$ matrix, resulting in $m \times n$ matrix C , for opA and $opB = \text{aoclsparse_operation_none}$. A is a $k \times m$ matrix when $opA = \text{aoclsparse_operation_transpose}$ or $\text{aoclsparse_operation_conjugate_transpose}$ and B is a $n \times k$ matrix when $opB = \text{aoclsparse_operation_transpose}$ or $\text{aoclsparse_operation_conjugate_transpose}$

aoclsparse_sp2m can be run in single-stage or two-stage. The single-stage algorithm allocates and computes the entire output matrix in a single stage *aoclsparse_stage_full_computation*. Whereas, in two-stage algorithm, the first stage *aoclsparse_stage_nnz_count* allocates memory for the output matrix and computes the number of entries of the matrix. The second stage *aoclsparse_stage_finalize* computes column indices of non-zero elements and values of the output matrix. The second stage has to be invoked only after the first stage. But, it can be also be invoked multiple times consecutively when the sparsity structure of input matrices remains unchanged, with only the values getting updated.

Example - Complex space (tests/examples/sample_zsp2m.cpp)

Parameters

- **opA** – [in] matrix A operation type.
- **descrA** – [in] descriptor of the sparse CSR matrix A . Currently, only *aoclsparse_matrix_type_general* is supported.
- **A** – [in] sparse CSR matrix A .
- **opB** – [in] matrix B operation type.
- **descrB** – [in] descriptor of the sparse CSR matrix B . Currently, only *aoclsparse_matrix_type_general* is supported.
- **B** – [in] sparse CSR matrix B .

- **request** – [in] Specifies full computation or two-stage algorithm *ao-clsparse_stage_nnz_count*, Only rowIndex array of the CSR matrix is computed internally. The output sparse CSR matrix can be extracted to measure the memory required for full operation. *aoclsparse_stage_finalize*. Finalize computation of remaining output arrays (column indices and values of output matrix entries) . Has to be called only after aoclsparse_sp2m call with aoclsparse_stage_nnz_count parameter. *aoclsparse_stage_full_computation* . Perform the entire computation in a single step.
- *C – [out] Pointer to sparse CSR matrix C . Matrix C arrays will always have zero-based indexing, irrespective of matrix A or matrix B being one-based or zero-based indexing. The column indices of the output matrix in CSR format can appear unsorted.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_pointer** – descrA, descrB, A, B, C is invalid.
- **aoclsparse_status_invalid_size** – input size parameters contain an invalid value.
- **aoclsparse_status_invalid_value** – input parameters contain an invalid value.
- **aoclsparse_status_wrong_type** – A and B matrix datatypes do not match.
- **aoclsparse_status_memory_error** – Memory allocation failure.
- **aoclsparse_status_not_implemented** – *aoclsparse_matrix_type* is not *ao-clsparse_matrix_type_general* or input matrices A or B is not in CSR format

aoclsparse::sp2m()

```
template<typename T>
aoclsparse_status aoclsparse::sp2m(aoclsparse_operation opA, const aoclsparse_mat_descr descrA, const
                                    aoclsparse_matrix A, aoclsparse_operation opB, const
                                    aoclsparse_mat_descr descrB, const aoclsparse_matrix B,
                                    aoclsparse_request request, aoclsparse_matrix *C)
```

`aoclsparse::sp2m` is the C++ interface to `aoclsparse_sp2m` that multiplies two sparse matrices in CSR storage format and the result is stored in a newly allocated sparse matrix in CSR format.

Example - Complex space (tests/examples/sample_csr2m_cpp.cpp)

Template Parameters

T – Data type supported for T are double, float, std::complex<double> or std::complex<float>

aoclsparse_spmm()

```
aoclsparse_status aoclsparse_spmm(aoclsparse_operation opA, const aoclsparse_matrix A, const
                                    aoclsparse_matrix B, aoclsparse_matrix *C)
```

Sparse matrix Sparse matrix multiplication for real and complex datatypes.

`aoclsparse_?spmm` multiplies two sparse matrices in CSR storage format. The result is stored in a newly allocated sparse matrix in CSR format, such that

$$C = op(A) \cdot B, \text{ with } op(A) = \begin{cases} A, & \text{if } opA = \text{aoclsparse_operation_none} \\ A^T, & \text{if } opA = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } opA = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

where A is a $m \times k$ matrix, B is a $k \times n$ matrix, resulting in $m \times n$ matrix C , for $\text{opA} = \text{aoclsparse_operation_none}$. A is a $k \times m$ matrix when $\text{opA} = \text{aoclsparse_operation_transpose}$ or $\text{aoclsparse_operation_conjugate_transpose}$

Parameters

- **opA** – [in] matrix A operation type.
- **A** – [in] sparse CSR matrix A .
- **B** – [in] sparse CSR matrix B .
- ***C** – [out] Pointer to sparse CSR matrix C . Matrix C arrays will always have zero-based indexing, irrespective of matrix A or matrix B being one-based or zero-based indexing. The column indices of the output matrix in CSR format can appear unsorted.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_pointer** – A, B, C is invalid.
- **aoclsparse_status_invalid_size** – input size parameters contain an invalid value.
- **aoclsparse_status_invalid_value** – input parameters contain an invalid value.
- **aoclsparse_status_wrong_type** – A and B matrix data types do not match.
- **aoclsparse_status_memory_error** – Memory allocation failure.
- **aoclsparse_status_not_implemented** – Input matrices A or B is not in CSR format

aoclsparse_?csrmm()

```
aoclsparse_status aoclsparse_scsrmm(aoclsparse_operation op, const float alpha, const aoclsparse_matrix A,  
                                     const aoclsparse_mat_descr descr, aoclsparse_order order, const float *B,  
                                     aoclsparse_int n, aoclsparse_int ldb, const float beta, float *C,  
                                     aoclsparse_int ldc)
```

```
aoclsparse_status aoclsparse_dcsrmm(aoclsparse_operation op, const double alpha, const aoclsparse_matrix A,  
                                     const aoclsparse_mat_descr descr, aoclsparse_order order, const double  
                                     *B, aoclsparse_int n, aoclsparse_int ldb, const double beta, double *C,  
                                     aoclsparse_int ldc)
```

```
aoclsparse_status aoclsparse_ccsrmm(aoclsparse_operation op, const aoclsparse_float_complex alpha, const  
                                     aoclsparse_matrix A, const aoclsparse_mat_descr descr,  
                                     aoclsparse_order order, const aoclsparse_float_complex *B,  
                                     aoclsparse_int n, aoclsparse_int ldb, const aoclsparse_float_complex beta,  
                                     aoclsparse_float_complex *C, aoclsparse_int ldc)
```

```
aoclsparse_status aoclsparse_zcsrmm(aoclsparse_operation op, const aoclsparse_double_complex alpha, const  
                                     aoclsparse_matrix A, const aoclsparse_mat_descr descr,  
                                     aoclsparse_order order, const aoclsparse_double_complex *B,  
                                     aoclsparse_int n, aoclsparse_int ldb, const aoclsparse_double_complex  
                                     beta, aoclsparse_double_complex *C, aoclsparse_int ldc)
```

Sparse matrix dense matrix multiplication using CSR storage format.

`aoclsparse_?csrmm` multiplies a scalar α with a sparse $m \times k$ matrix A , defined in CSR storage format, and a dense $k \times n$ matrix B and adds the result to the dense $m \times n$ matrix C that is multiplied by a scalar β , such that

$$C = \alpha op(A) B + \beta C, \quad \text{with} \quad op(A) = \begin{cases} A, & \text{if } \text{trans_A} = \text{aoclsparse_operation_none} \\ A^T, & \text{if } \text{trans_A} = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } \text{trans_A} = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Example (tests/examples/sample_csrmm.cpp)

Parameters

- **op** – [in] Matrix A operation type.
- **alpha** – [in] Scalar α .
- **A** – [in] Sparse CSR matrix A structure.
- **descr** – [in] descriptor of the sparse CSR matrix A . Currently, supports `aoclsparse_matrix_type_general`, `aoclsparse_matrix_type_symmetric`, and `aoclsparse_matrix_type_hermitian` matrices. Both, base-zero and base-one input arrays of CSR matrix are supported.
- **order** – [in] `aoclsparse_order_row` / `aoclsparse_order_column` for dense matrix
- **B** – [in] Array of dimension $ldb \times n$ for `aoclsparse_order_column`. For `aoclsparse_order_row`, the dimension is $(\text{number of columns in } A) \times ldb$ if $op(A) = A$, or $(\text{number of rows in } A) \times ldb$ if $op(A) = A^T$.
- **n** – [in] Number of columns of the dense matrix C .
- **ldb** – [in] Leading dimension of B .
- **beta** – [in] Scalar β .
- **C** – [inout] Array of dimension $ldc \times n$ for `aoclsparse_order_column`. For `aoclsparse_order_row`, the dimension is $(\text{number of rows in } A) \times ldc$ if $op(A) = A$, or $(\text{number of columns in } A) \times ldc$ if $op(A) = A^T$.
- **ldc** – [in] Leading dimension of C .

Return values

- `aoclsparse_status_success` – The operation completed successfully.
- `aoclsparse_status_invalid_size` – The value of m , n , k , nnz , ldb or ldc is invalid.
- `aoclsparse_status_invalid_pointer` – The pointer `descr`, `A`, `B`, or `C` is invalid.
- `aoclsparse_status_invalid_value` – The values of `descr->base` and `base` specified at the creation of the matrix do not coincide.
- `aoclsparse_status_not_implemented` – `aoclsparse_matrix_type` is not one of these: `aoclsparse_matrix_type_general`, `aoclsparse_matrix_type_symmetric`, `aoclsparse_matrix_type_hermitian` or input matrix `A` is not in CSR format

aoclsparse_?csr2m()

```
aoclsparse_status aoclsparse_dcsr2m(aoclsparse_operation trans_A, const aoclsparse_mat_descr descrA, const
                                     aoclsparse_matrix csrA, aoclsparse_operation trans_B, const
                                     aoclsparse_mat_descr descrB, const aoclsparse_matrix csrB, const
                                     aoclsparse_request request, aoclsparse_matrix *csrC)
```

```
aoclsparse_status aoclsparse_scsr2m(aoclsparse_operation trans_A, const aoclsparse_mat_descr descrA, const
                                      aoclsparse_matrix csrA, aoclsparse_operation trans_B, const
                                      aoclsparse_mat_descr descrB, const aoclsparse_matrix csrB, const
                                      aoclsparse_request request, aoclsparse_matrix *csrC)
```

Sparse matrix Sparse matrix multiplication using CSR storage format for single and double precision datatypes.

`aoclsparse_?csr2m` multiplies a sparse $m \times k$ matrix A , defined in CSR storage format, and the sparse $k \times n$ matrix B , defined in CSR storage format and stores the result to the sparse $m \times n$ matrix C , such that

$$C = op(A) \cdot op(B),$$

with

$$op(A) = \begin{cases} A, & \text{if } \text{trans_A} = \text{aoclsparse_operation_none} \\ A^T, & \text{if } \text{trans_A} = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } \text{trans_A} = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

and

$$op(B) = \begin{cases} B, & \text{if } \text{trans_B} = \text{aoclsparse_operation_none} \\ B^T, & \text{if } \text{trans_B} = \text{aoclsparse_operation_transpose} \\ B^H, & \text{if } \text{trans_B} = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Example (tests/examples/sample_csr2m.cpp)

Parameters

- **trans_A** – [in] matrix A operation type.
- **descrA** – [in] descriptor of the sparse CSR matrix A . Currently, only `aoclsparse_matrix_type_general` is supported.
- **csrA** – [in] sparse CSR matrix A structure.
- **trans_B** – [in] matrix B operation type.
- **descrB** – [in] descriptor of the sparse CSR matrix B . Currently, only `aoclsparse_matrix_type_general` is supported.
- **csrB** – [in] sparse CSR matrix B structure.
- **request** – [in] Specifies full computation or two-stage algorithm `aoclsparse_stage_nnz_count`, Only rowIndex array of the CSR matrix is computed internally. The output sparse CSR matrix can be extracted to measure the memory required for full operation. `aoclsparse_stage_finalize`. Finalize computation of remaining output arrays (column indices and values of output matrix entries). Has to be called only after `aoclsparse_dcsr2m()` call with `aoclsparse_stage_nnz_count` parameter. `aoclsparse_stage_full_computation`. Perform the entire computation in a single step.
- ***csrC** – [out] Pointer to sparse CSR matrix C structure.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – input parameters contain an invalid value.
- **aoclsparse_status_invalid_pointer** – descrA, csr, descrB, csrB, csrC is invalid.
- **aoclsparse_status_not_implemented** – *aoclsparse_matrix_type* is not *aoclsparse_matrix_type_general* or input matrices A or B is not in CSR format

aoclsparse_?add()

aoclsparse_status **aoclsparse_sadd**(const *aoclsparse_operation* op, const *aoclsparse_matrix* A, const float alpha, const *aoclsparse_matrix* B, *aoclsparse_matrix* *C)

aoclsparse_status **aoclsparse_dadd**(const *aoclsparse_operation* op, const *aoclsparse_matrix* A, const double alpha, const *aoclsparse_matrix* B, *aoclsparse_matrix* *C)

aoclsparse_status **aoclsparse_cadd**(const *aoclsparse_operation* op, const *aoclsparse_matrix* A, const *aoclsparse_float_complex* alpha, const *aoclsparse_matrix* B, *aoclsparse_matrix* *C)

aoclsparse_status **aoclsparse_zadd**(const *aoclsparse_operation* op, const *aoclsparse_matrix* A, const *aoclsparse_double_complex* alpha, const *aoclsparse_matrix* B, *aoclsparse_matrix* *C)

Addition of two sparse matrices.

aoclsparse_?add adds two sparse matrices and returns a sparse matrix. Matrices can be either real or complex types but cannot be intermixed. It performs

$$C = \alpha op(A) + B \quad \text{with} \quad op(A) = \begin{cases} A, & \text{if } op = \text{aoclsparse_operation_none} \\ A^T, & \text{if } op = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } op = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

where *A* is a $m \times n$ matrix and *B* is a $m \times n$ matrix, if *op* = *aoclsparse_operation_none*. Otherwise *A* is $n \times m$ and the result matrix *C* has the same dimension as *B*.

Note: Only matrices in CSR format are supported in this release.

Parameters

- **op** – [in] matrix *A* operation type.
- **alpha** – [in] scalar with same precision as *A* and *B* matrix
- **A** – [in] source sparse matrix *A*
- **B** – [in] source sparse matrix *B*
- ***C** – [out] pointer to the sparse output matrix *C*

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – A or B or C are invalid
- **aoclsparse_status_invalid_size** – The dimensions of A and B are not compatible.

- **aoclsparse_status_internal_error** – Internal Error Occurred
- **aoclsparse_status_memory_error** – Memory allocation failure.
- **aoclsparse_status_not_implemented** – Matrices are not in CSR format.

aoclsparse_?spmmd()

aoclsparse_status aoclsparse_spmmd(const *aoclsparse_operation* op, const *aoclsparse_matrix* A, const *aoclsparse_matrix* B, const *aoclsparse_order* layout, float *C, const *aoclsparse_int* ldc)

aoclsparse_status aoclsparse_dpmmd(const *aoclsparse_operation* op, const *aoclsparse_matrix* A, const *aoclsparse_matrix* B, const *aoclsparse_order* layout, double *C, const *aoclsparse_int* ldc)

aoclsparse_status aoclsparse_cpmmd(const *aoclsparse_operation* op, const *aoclsparse_matrix* A, const *aoclsparse_matrix* B, const *aoclsparse_order* layout, *aoclsparse_float_complex* *C, const *aoclsparse_int* ldc)

aoclsparse_status aoclsparse_zpmmd(const *aoclsparse_operation* op, const *aoclsparse_matrix* A, const *aoclsparse_matrix* B, const *aoclsparse_order* layout, *aoclsparse_double_complex* *C, const *aoclsparse_int* ldc)

Matrix multiplication of two sparse matrices stored in the CSR storage format. The output matrix is stored in a dense format.

aoclsparse_?spmmd multiplies a sparse matrix *A* and a sparse matrix *B*, both stored in the CSR storage format, and saves the result in a dense matrix *C*, such that

$$C := op(A) \cdot B,$$

with

$$op(A) = \begin{cases} A, & \text{if } op = \text{aoclsparse_operation_none} \\ A^T, & \text{if } op = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } op = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Parameters

- **op** – [in] Operation to perform on matrix *A*.
- **A** – [in] Matrix structure containing sparse matrix *A* of size $m \times k$.
- **B** – [in] Matrix structure containing sparse matrix *B* of size $k \times n$ if *op* is *aoclsparse_operation_none* otherwise of size $m \times n$.
- **layout** – [in] Ordering of the dense output matrix: valid values are *aoclsparse_order_row* and *aoclsparse_order_column*.
- **C** – [inout] Dense output matrix *C* of size $m \times n$ if *op* is *aoclsparse_operation_none*, otherwise of size $k \times n$ containing the matrix-matrix product of *A* and *B*.
- **ldc** – [in] Leading dimension of *C*, e.g., for *C* stored in *aoclsparse_order_row*, *ldc* must be at least $\max(1, m)$ when *op(A) = A*, or $\max(1, k)$ if *op(A) = A^T* or *op(A) = A^H*.

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_size** – *m*, *n*, *k*, *nnz* or *ldc* is not valid.

- **aoclsparse_status_invalid_pointer** – A, B or C pointer is not valid.
- **aoclsparse_status_wrong_type** – *aoclsparse_matrix_data_type* does not match the precision type.
- **aoclsparse_status_not_implemented** – *aoclsparse_matrix_format_type* is not *aoclsparse_csr_mat*.

aoclsparse_?sp2md()

aoclsparse_status **aoclsparse_ssp2md**(const *aoclsparse_operation* opA, const *aoclsparse_mat_descr* descrA,
const *aoclsparse_matrix* A, const *aoclsparse_operation* opB, const
aoclsparse_mat_descr descrB, const *aoclsparse_matrix* B, const float
alpha, const float beta, float *C, const *aoclsparse_order* layout, const
aoclsparse_int ldc)

aoclsparse_status **aoclsparse_dsp2md**(const *aoclsparse_operation* opA, const *aoclsparse_mat_descr* descrA,
const *aoclsparse_matrix* A, const *aoclsparse_operation* opB, const
aoclsparse_mat_descr descrB, const *aoclsparse_matrix* B, const double
alpha, const double beta, double *C, const *aoclsparse_order* layout, const
aoclsparse_int ldc)

aoclsparse_status **aoclsparse_csp2md**(const *aoclsparse_operation* opA, const *aoclsparse_mat_descr* descrA,
const *aoclsparse_matrix* A, const *aoclsparse_operation* opB, const
aoclsparse_mat_descr descrB, const *aoclsparse_matrix* B,
aoclsparse_float_complex alpha, *aoclsparse_float_complex* beta,
aoclsparse_float_complex *C, const *aoclsparse_order* layout, const
aoclsparse_int ldc)

aoclsparse_status **aoclsparse_zsp2md**(const *aoclsparse_operation* opA, const *aoclsparse_mat_descr* descrA,
const *aoclsparse_matrix* A, const *aoclsparse_operation* opB, const
aoclsparse_mat_descr descrB, const *aoclsparse_matrix* B,
aoclsparse_double_complex alpha, *aoclsparse_double_complex* beta,
aoclsparse_double_complex *C, const *aoclsparse_order* layout, const
aoclsparse_int ldc)

A variant of matrix multiplication of two sparse matrices stored in the CSR storage format. The output matrix is stored in a dense format. Supports operations on both sparse matrices.

aoclsparse_?sp2md multiplies a sparse matrix *A* and a sparse matrix *B*, both stored in the CSR storage format, and saves the result in a dense matrix *C*, such that

$$C := \alpha \cdot op(A) \cdot op(B) + \beta \cdot C,$$

with

$$op(A) = \begin{cases} A, & \text{if } opA = \text{aoclsparse_operation_none} \\ A^T, & \text{if } opA = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } opA = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

and

$$op(B) = \begin{cases} B, & \text{if } opB = \text{aoclsparse_operation_none} \\ B^T, & \text{if } opB = \text{aoclsparse_operation_transpose} \\ B^H, & \text{if } opB = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

Parameters

- **opA** – [in] Operation to perform on matrix A .
- **descrA** – [in] Descriptor of A . Only `aoclsparse_matrix_type_general` is supported at present. As a consequence, all other parameters within the descriptor are ignored.
- **A** – [in] Matrix structure containing sparse matrix A of size $m \times k$.
- **opB** – [in] Operation to perform on matrix B .
- **descrB** – [in] Descriptor of B . Only `aoclsparse_matrix_type_general` is supported at present. As a consequence, all other parameters within the descriptor are ignored.
- **B** – [in] Matrix structure containing sparse matrix B of size $k \times n$ if `op` is `aoclsparse_operation_none` otherwise of size $m \times n$.
- **alpha** – [in] Value of α .
- **beta** – [in] Value of β .
- **C** – [inout] Dense output matrix C .
- **layout** – [in] Ordering of the dense output matrix: valid values are `aoclsparse_order_row` and `aoclsparse_order_column`.
- **ldc** – [in] Leading dimension of C , e.g., for C stored in `aoclsparse_order_row`, `ldc` must be at least $\max(1, m)$ ($op(A) = A$) or $\max(1, k)$ ($op(A) = A^T$ or $op(A) = A^H$).

Return values

- `aoclsparse_status_success` – The operation completed successfully.
- `aoclsparse_status_invalid_size` – m, n, k, nnz or `ldc` is not valid.
- `aoclsparse_status_invalid_pointer` – A, B or C pointer is not valid.
- `aoclsparse_status_wrong_type` – `aoclsparse_matrix_data_type` does not match the precision type.
- `aoclsparse_status_not_implemented` – `aoclsparse_matrix_format_type` is not `aoclsparse_csr_mat`.
- `aoclsparse_status_internal_error` – An internal error occurred.

`aoclsparse_syrk()`

`aoclsparse_status aoclsparse_syrk(const aoclsparse_operation opA, const aoclsparse_matrix A, aoclsparse_matrix *C)`

Multiplication of a sparse matrix and its transpose (or conjugate transpose) stored as a sparse matrix.

`aoclsparse_syrk` multiplies a sparse matrix with its transpose (or conjugate transpose) in CSR storage format. The result is stored in a newly allocated sparse matrix in CSR format, such that

$$C := A \cdot op(A)$$

if `opA` is `aoclsparse_operation_none`.

Otherwise,

$$C := op(A) \cdot A,$$

where

$$op(A) = \begin{cases} A^T, & \text{transpose of } A \text{ for real matrices} \\ A^H, & \text{conjugate transpose of } A \text{ for complex matrices} \end{cases}$$

where A is a $m \times n$ matrix, opA is one of `aoclsparse_operation_none`, `aoclsparse_operation_transpose` (for real matrices) or `aoclsparse_operation_conjugate_transpose` (for complex matrices). The output matrix C is a sparse symmetric (or Hermitian) matrix stored as an upper triangular matrix in CSR format.

Example (tests/examples/sample_dsyrk.cpp)

Note: `aoclsparse_syrk` assumes that the input CSR matrix has sorted column indices in each row. If not, call `aoclsparse_order_mat()` before calling `aoclsparse_syrk`.

Note: `aoclsparse_syrk` currently does not support `aoclsparse_operation_transpose` for complex A.

Parameters

- **opA** – [in] Matrix A operation type.
- **A** – [in] Sorted sparse CSR matrix A .
- ***C** – [out] Pointer to the new sparse CSR symmetric/Hermitian matrix C . Only upper triangle of the result matrix is computed. The column indices of the output matrix in CSR format might be unsorted. The matrix should be freed by `aoclsparse_destroy()` when no longer needed.

Return values

- `aoclsparse_status_success` – The operation completed successfully.
- `aoclsparse_status_invalid_pointer` – A, C is invalid.
- `aoclsparse_status_wrong_type` – A and its operation type do not match.
- `aoclsparse_status_not_implemented` – The input matrix is not in the CSR format or opA is `aoclsparse_operation_transpose` and A has complex values.
- `aoclsparse_status_invalid_value` – The value of opA is invalid.
- `aoclsparse_status_unsorted_input` – Input matrices are not sorted.
- `aoclsparse_status_memory_error` – Memory allocation failure.

`aoclsparse_?syrkd()`

```
aoclsparse_status aoclsparse_ssyrkd(const aoclsparse_operation opA, const aoclsparse_matrix A, const float alpha, const float beta, float *C, const aoclsparse_order orderC, const aoclsparse_int ldc)
```

```
aoclsparse_status aoclsparse_dsyrkd(const aoclsparse_operation opA, const aoclsparse_matrix A, const double alpha, const double beta, double *C, const aoclsparse_order orderC, const aoclsparse_int ldc)
```

```
aoclsparse_status aoclsparse_csyrkd(const aoclsparse_operation opA, const aoclsparse_matrix A, const aoclsparse_float_complex alpha, const aoclsparse_float_complex beta, aoclsparse_float_complex *C, const aoclsparse_order orderC, const aoclsparse_int ldc)
```

```
aoclsparse_status aoclsparse_zsyrkd(const aoclsparse_operation opA, const aoclsparse_matrix A, const  
                                     aoclsparse_double_complex alpha, const aoclsparse_double_complex  
                                     beta, aoclsparse_double_complex *C, const aoclsparse_order orderC,  
                                     const aoclsparse_int ldc)
```

Multiplication of a sparse matrix and its transpose (or conjugate transpose) for all data types.

`aoclsparse_syrkd` multiplies a sparse matrix with its transpose (or conjugate transpose) in CSR storage format. The result is stored in a dense format, such that

$$C := \alpha \cdot A \cdot op(A) + \beta \cdot C$$

if `opA` is `aoclsparse_operation_none`.

Otherwise,

$$C := \alpha \cdot op(A) \cdot A + \beta \cdot C$$

$$op(A) = \begin{cases} A^T, & \text{transpose of } A \text{ for real matrices} \\ A^H, & \text{conjugate transpose of } A \text{ for complex matrices} \end{cases}$$

where A is a $m \times n$ sparse matrix, `opA` is one of `aoclsparse_operation_none`, `aoclsparse_operation_transpose` (for real matrices) or `aoclsparse_operation_conjugate_transpose` (for complex matrices). The output matrix C is a dense symmetric (or Hermitian) matrix stored as an upper triangular matrix.

Example (tests/examples/sample_dsyrkd.cpp)

Note: `aoclsparse_syrkd` assumes that the input CSR matrix has sorted column indices in each row. If not, call `aoclsparse_order_mat()` before calling `aoclsparse_syrkd`.

Note: For complex type, only the real parts of α and β are taken into account to preserve Hermitian C .

Note: `aoclsparse_syrkd` currently does not support `aoclsparse_operation_transpose` for complex A .

Parameters

- **opA – [in]** Matrix A operation type.
- **A – [in]** Sorted sparse CSR matrix A .
- **alpha – [in]** Scalar α .
- **beta – [in]** Scalar β .
- **C – [inout]** Output dense matrix. Only upper triangular part of the matrix is processed during the computation, the strictly lower triangle is not modified.
- **orderC – [in]** Storage format of the output dense matrix, C . It can be `aoclsparse_order_row` or `aoclsparse_order_column`.

- **ldc** – [in] Leading dimension of C .

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_pointer** – A, C is invalid.
- **aoclsparse_status_wrong_type** – A and its operation type do not match.
- **aoclsparse_status_not_implemented** – The input matrix is not in the CSR format or opA is aoclsparse_operation_transpose and A has complex values.
- **aoclsparse_status_invalid_value** – The value of opA, orderC or ldc is invalid.
- **aoclsparse_status_unsorted_input** – Input matrix is not sorted.
- **aoclsparse_status_memory_error** – Memory allocation failure.

aoclsparse_?sypr()

```
aoclsparse_status aoclsparse_sypr(aoclsparse_operation opA, const aoclsparse_matrix A, const
                                    aoclsparse_matrix B, const aoclsparse_mat_descr descrB, aoclsparse_matrix
                                    *C, const aoclsparse_request request)
```

Symmetric product of three sparse matrices for real and complex datatypes stored as a sparse matrix.

aoclsparse_sypr multiplies three sparse matrices in CSR storage format. The result is returned in a newly allocated symmetric or Hermitian sparse matrix stored as an upper triangle in CSR format.

If opA is *aoclsparse_operation_none*,

$$C = A \cdot B \cdot A^T,$$

or

$$C = A \cdot B \cdot A^H,$$

for real or complex input matrices, respectively, where A is a $m \times n$ general matrix, B is a $n \times n$ symmetric (for real data types) or Hermitian (for complex data types) matrix, resulting in a symmetric or Hermitian $m \times m$ matrix C .

Otherwise,

$$C = op(A) \cdot B \cdot A,$$

with

$$op(A) = \begin{cases} A^T, & \text{if } opA = \text{aoclsparse_operation_transpose} \\ A^H, & \text{if } opA = \text{aoclsparse_operation_conjugate_transpose} \end{cases}$$

where A is a $m \times n$ matrix and B is a $m \times m$ symmetric (or Hermitian) matrix, resulting in a $n \times n$ symmetric (or Hermitian) matrix C .

Depending on **request**, **aoclsparse_sypr** might compute the result in a single stage (*aoclsparse_stage_full_computation*) or in two stages. Then the first stage (*aoclsparse_stage_nnz_count*) allocates memory for the new output matrix C and computes its number of non-zeros and their structure which is followed by the second stage (*aoclsparse_stage_finalize*) to compute the column indices and values of all elements. The second stage can be invoked multiple times (either after *aoclsparse_stage_full_computation* or *aoclsparse_stage_nnz_count*) to recompute the numerical values of C on assumption that the sparsity structure of the input matrices remained unchanged and only the values of the non-zero elements were modified (e.g., by a call to *aoclsparse_update_values()* and variants).

Example (tests/examples/sample_zsypr.cpp)

Note: `aoclsparse_sypr` supports only matrices in CSR format which have sorted column indices in each row. If the matrices are unsorted, you might want to call `aoclsparse_order_mat()`.

Note: Currently, `opA = aoclsparse_operation_transpose` is supported only for real data types.

Parameters

- **opA** – [in] matrix A operation type.
- **A** – [in] sorted sparse CSR matrix A .
- **B** – [in] sorted sparse CSR matrix B to be interpreted as symmetric (or Hermitian).
- **descrB** – [in] descriptor of the sparse CSR matrix B . `aoclsparse_matrix_type` must be `aoclsparse_matrix_type_symmetric` for real matrices or `aoclsparse_matrix_type_hermitian` for complex matrices. `aoclsparse_fill_mode` might be either `aoclsparse_fill_mode_upper` or `aoclsparse_fill_mode_lower` to process the upper or lower triangular matrix part, respectively.
- **request** – [in] Specifies if the computation takes place in one stage (`aoclsparse_stage_full_computation`) or in two stages (`aoclsparse_stage_nnz_count` followed by `aoclsparse_stage_finalize`).
- ***C** – [inout] Pointer to the new sparse CSR symmetric/Hermitian matrix C . Only upper triangle of the result matrix is computed. Matrix C will always have zero-based indexing, irrespective of the zero/one-based indexing of the input matrices A and B . The column indices of the output matrix in CSR format might be unsorted. If `request` is `aoclsparse_stage_finalize`, matrix C must not be modified by the user since the last call to `aoclsparse_sypr`, in the other cases is C treated as an output only. The matrix should be freed by `aoclsparse_destroy()` when no longer needed.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_invalid_pointer` – `descrB`, `A`, `B` or `C` is invalid.
- `aoclsparse_status_invalid_size` – Matrix dimensions do not match A or B is not square.
- `aoclsparse_status_invalid_value` – Input parameters are invalid, for example, `descrB` does not match B indexing or B is not symmetric/Hermitian, C has been modified between stages or `opA` or `request` is not recognized.
- `aoclsparse_status_wrong_type` – A and B matrix data types do not match.
- `aoclsparse_status_not_implemented` – Input matrix A or B is not in CSR format.
- `aoclsparse_status_unsorted_input` – Input matrices are not sorted.
- `aoclsparse_status_memory_error` – Memory allocation failure.

aoclsparse_?sypr()

```
aoclsparse_status aoclsparse_ssyprd(const aoclsparse_operation op, const aoclsparse_matrix A, const float *B,
                                     const aoclsparse_order orderB, const aoclsparse_int ldb, const float alpha,
                                     const float beta, float *C, const aoclsparse_order orderC, const
                                     aoclsparse_int ldc)
```

```
aoclsparse_status aoclsparse_dsyprd(const aoclsparse_operation op, const aoclsparse_matrix A, const double
                                     *B, const aoclsparse_order orderB, const aoclsparse_int ldb, const double
                                     alpha, const double beta, double *C, const aoclsparse_order orderC, const
                                     aoclsparse_int ldc)
```

```
aoclsparse_status aoclsparse_csyprd(const aoclsparse_operation op, const aoclsparse_matrix A, const
                                     aoclsparse_float_complex *B, const aoclsparse_order orderB, const
                                     aoclsparse_int ldb, const aoclsparse_float_complex alpha, const
                                     aoclsparse_float_complex beta, aoclsparse_float_complex *C, const
                                     aoclsparse_order orderC, const aoclsparse_int ldc)
```

```
aoclsparse_status aoclsparse_zsyprd(const aoclsparse_operation op, const aoclsparse_matrix A, const
                                     aoclsparse_double_complex *B, const aoclsparse_order orderB, const
                                     aoclsparse_int ldb, const aoclsparse_double_complex alpha, const
                                     aoclsparse_double_complex beta, aoclsparse_double_complex *C, const
                                     aoclsparse_order orderC, const aoclsparse_int ldc)
```

Performs symmetric triple product of a sparse matrix and a dense matrix and stores the output as a dense matrix.

`aoclsparse_?syprd` performs product of a scalar α , with the symmetric triple product of a sparse $m \times k$ matrix A , defined in CSR format, with a $k \times k$ symmetric dense (or Hermitian) matrix B , and a $k \times m$ $op(A)$. Adds the resulting matrix to $m \times m$ symmetric dense (or Hermitian) matrix C that is multiplied by a scalar β , such that

$$C := \alpha \cdot A \cdot B \cdot op(A) + \beta \cdot C$$

if op is `aoclsparse_operation_none`.

Otherwise,

$$C := \alpha \cdot op(A) \cdot B \cdot A + \beta \cdot C$$

$$op(A) = \begin{cases} A^T, & \text{if } op = \text{aoclsparse_operation_transpose (real matrices)} \\ A^H, & \text{if } op = \text{aoclsparse_operation_conjugate_transpose (complex matrices)} \end{cases}$$

Notes

1. This routine assumes the dense matrices (B and C) are stored in full although the computations happen on the upper triangular portion of the matrices.
2. `aoclsparse_operation_transpose` is only supported for real matrices.
3. `aoclsparse_operation_conjugate_transpose` is only supported for complex matrices.
4. Complex dense matrices are assumed to be Hermitian matrices.

Parameters

- **op** – [in] Matrix A operation type.
- **A** – [in] Sparse CSR matrix A structure.

- **B** – [in] Array of dimension $ldb \times ldb$. Only the upper triangular matrix is used for computation.
- **orderB** – [in] *aoclsparse_order_row* or *aoclsparse_order_column* for dense matrix B.
- **ldb** – [in] Leading dimension of B, must be at least $\max(1, k)$ ($op(A) = A$) or $\max(1, m)$ ($op(A) = A^T$ or $op(A) = A^H$).
- **alpha** – [in] Scalar α .
- **beta** – [in] Scalar β .
- **C** – [inout] Array of dimension $ldc \times ldc$. Only upper triangular part of the matrix is processed.
- **orderC** – [in] *aoclsparse_order_row* or *aoclsparse_order_column* for dense matrix C.
- **ldc** – [in] Leading dimension of C, must be at least $\max(1, m)$ ($op(A) = A$) or $\max(1, k)$ ($op(A) = A^T$ or $op(A) = A^H$).

Return values

- **aoclsparse_status_success** – The operation completed successfully.
- **aoclsparse_status_invalid_operation** – The operation is invalid if the matrix B and C has a different layout ordering.
- **aoclsparse_status_wrong_type** – The data type of the matrices are not matching or invalid.
- **aoclsparse_status_invalid_size** – The value of m , k , nnz , ldb or ldc is invalid.
- **aoclsparse_status_invalid_pointer** – The pointer A, B, or C is invalid.
- **aoclsparse_status_not_implemented** – The values of **orderB** and **orderC** are different.

2.5 Iterative Linear System Solvers

2.5.1 Introduction of Iterative Solver Suite (itsol)

AOCL-Sparse Iterative Solver Suite (itsol) is an iterative framework for solving large-scale sparse linear systems of equations of the form

$$Ax = b,$$

where A is a sparse full-rank square matrix of size n by n , b is a dense n -vector, and x is the vector of unknowns also of size n . The framework solves the previous problem using either the Conjugate Gradient method or GMRES. It supports a variety of preconditioners (*accelerators*) such as Symmetric Gauss-Seidel or Incomplete LU factorization, ILU(0).

Iterative solvers at each step (iteration) find a better approximation to the solution of the linear system of equations in the sense that it reduces an error metric. In contrast, direct solvers only provide a solution once the full algorithm has been executed. A great advantage of iterative solvers is that they can be interrupted once an approximate solution is deemed acceptable.

Forward and Reverse Communication Interfaces

The suite presents two separate interfaces to all the iterative solvers, a direct one, `aoclsparse_itsol_d_solve()`, (`aoclsparse_itsol_s_solve()`, `aoclsparse_itsol_c_solve()`, `aoclsparse_itsol_z_solve()`) and a reverse communication (RCI) one `aoclsparse_itsol_d_rci_solve()` (`aoclsparse_itsol_s_rci_solve()` `aoclsparse_itsol_c_rci_solve()`, `aoclsparse_itsol_z_rci_solve()`) While the underlying algorithms are exactly the same, the difference lies in how data is communicated to the solvers.

The direct communication interface expects to have explicit access to the coefficient matrix A . On the other hand, the reverse communication interface makes no assumption on the matrix storage. Thus when the solver requires some matrix operation such as a matrix-vector product, it returns control to the user and asks the user perform the operation and provide the results by calling again the RCI solver.

Recommended Workflow

For solving a linear system of equations, the following workflow is recommended:

- Call `aoclsparse_itsol_s_init()` or `aoclsparse_itsol_d_init()` or `aoclsparse_itsol_c_init()` or `aoclsparse_itsol_z_init()` to initialize `aoclsparse_itsol_handle`.
- Choose the solver and adjust its behaviour by setting optional parameters with `aoclsparse_itsol_option_set()`, see there all options available.
- If the reverse communication interface is desired, define the system's input with `aoclsparse_itsol_s_rci_input()` (or `aoclsparse_itsol_d_rci_input()` or `aoclsparse_itsol_c_rci_input()` or `aoclsparse_itsol_z_rci_input()`).
- Solve the system with either using direct interface `aoclsparse_itsol_s_solve()` (or `aoclsparse_itsol_d_solve()` or `aoclsparse_itsol_c_solve()` or `aoclsparse_itsol_z_solve()`) or reverse communication interface `aoclsparse_itsol_s_rci_solve()` (or `aoclsparse_itsol_d_rci_solve()` or `aoclsparse_itsol_c_rci_solve()` or `aoclsparse_itsol_z_rci_solve()`)
- Free the memory with `aoclsparse_itsol_destroy()`.

Information Array

The array `rinfo[100]` is used by the solvers (e.g. `aoclsparse_itsol_s_solve()` or `aoclsparse_itsol_d_rci_solve()` or `aoclsparse_itsol_c_rci_solve()` or `aoclsparse_itsol_z_rci_solve()`) to report back useful convergence metrics and other solver statistics. The user callback `monit` is also equipped with this array and can be used to view or monitor the state of the solver. The solver will populate the following entries with the most recent iteration data

Index	Description
0	Absolute residual norm, $r_{\text{abs}} = \ Ax - b\ _2$.
1	Norm of the right-hand side vector b , $\ b\ _2$.
2-29	Reserved for future use.
30	Iteration counter.
31-99	Reserved for future use.

References

- Collaborative. Acceleration methods. *Encyclopedia of Mathematics*, 2023 (retrieved in). https://encyclopediaofmath.org/index.php?title=Acceleration_methods&oldid=52131.
- Collaborative. Conjugate gradients, method of. *Encyclopedia of Mathematics*, 2023 (retrieved in). https://encyclopediaofmath.org/index.php?title=Conjugate_gradients,_method_of&oldid=46470.
- Yousef Saad. *Iterative Methods for Sparse Linear Systems*. 2nd edition, 2003.

2.5.2 API documentation

`aoclsparse_itsol_rci_job`

enum `aoclsparse_itsol_rci_job`

Values of `ircmm` used by the iterative solver reverse communication interface (RCI) `aoclsparse_itsol_d_rci_solve` and `aoclsparse_itsol_s_rci_solve` to communicate back to the user which operation is required.

Values:

enumerator `aoclsparse_rci_interrupt`

if set by the user, signals the solver to terminate. This is never set by the solver. Terminate.

enumerator `aoclsparse_rci_stop`

found a solution within specified tolerance (see options “cg rel tolerance”, “cg abs tolerance”, “gmres rel tolerance”, and “gmres abs tolerance” in [Options](#)). Terminate, vector `x` contains the solution.

enumerator `aoclsparse_rci_start`

initial value of the `ircmm` flag, no action required. Call solver.

enumerator `aoclsparse_rci_mv`

perform the matrix-vector product $v = Au$. Return control to solver.

enumerator `aoclsparse_rci_precond`

perform a preconditioning step on the vector u and store in v . If the preconditioner M has explicit matrix form, then applying the preconditioner would result in the operations $v = Mu$ or $v = M^{-1}u$. The latter would be performed by solving the linear system of equations $Mv = u$. Return control to solver.

enumerator `aoclsparse_rci_stopping_criterion`

perform a monitoring step and check for custom stopping criteria. If using a positive tolerance value for the convergence options (see [aoclsparse_rci_stop](#)), then this step can be ignored and control can be returned to solver.

aoclsparse_itsol_?_init()

```
aoclsparse_status aoclsparse_itsol_s_init(aoclsparse_itsol_handle *handle)
aoclsparse_status aoclsparse_itsol_d_init(aoclsparse_itsol_handle *handle)
aoclsparse_status aoclsparse_itsol_c_init(aoclsparse_itsol_handle *handle)
aoclsparse_status aoclsparse_itsol_z_init(aoclsparse_itsol_handle *handle)
```

Initialize a problem handle (`aoclsparse_itsol_handle`) for the iterative solvers suite of the library.

The init apis initialize a data structure referred to as problem handle. This handle is used by iterative solvers (itsol) suite to setup options, define which solver to use, etc.

Note: Once the handle is no longer needed, it can be destroyed and the memory released by calling `aoclsparse_itsol_destroy`.

Parameters

handle – [inout] the pointer to the problem handle data structure.

Return values

- `aoclsparse_status_success` – the operation completed successfully.
- `aoclsparse_status_memory_error` – internal memory allocation error.
- `aoclsparse_status_invalid_pointer` – the pointer to the problem handle is invalid.
- `aoclsparse_status_internal_error` – an unexpected error occurred.

aoclsparse_itsol_destroy()

```
void aoclsparse_itsol_destroy(aoclsparse_itsol_handle *handle)
```

Free the memory reserved in a problem handle previously initialized by `aoclsparse_itsol_s_init` or `aoclsparse_itsol_d_init`.

Once the problem handle is no longer needed, calling this function to deallocate the memory is advisable to avoid memory leaks.

Note: Passing a handle that has not been initialized by `aoclsparse_itsol_s_init` or `aoclsparse_itsol_d_init` may have unpredictable results.

Parameters

handle – [inout] pointer to a problem handle.

aoclsparse_itsol_?_solve()

```
aoclsparse_status aoclsparse_itsol_s_solve(aoclsparse_itsol_handle handle, aoclsparse_int n,
                                            aoclsparse_matrix mat, const aoclsparse_mat_descr descr, const
                                            float *b, float *x, float rinfo[100], aoclsparse_int
                                            precond(aoclsparse_int flag, aoclsparse_int n, const float *u, float
                                            *v, void *udata), aoclsparse_int monit(aoclsparse_int n, const
                                            float *x, const float *r, float rinfo[100], void *udata), void *udata)

aoclsparse_status aoclsparse_itsol_d_solve(aoclsparse_itsol_handle handle, aoclsparse_int n,
                                            aoclsparse_matrix mat, const aoclsparse_mat_descr descr, const
                                            double *b, double *x, double rinfo[100], aoclsparse_int
                                            precond(aoclsparse_int flag, aoclsparse_int n, const double *u,
                                            double *v, void *udata), aoclsparse_int monit(aoclsparse_int n,
                                            const double *x, const double *r, double rinfo[100], void *udata),
                                            void *udata)

aoclsparse_status aoclsparse_itsol_c_solve(aoclsparse_itsol_handle handle, aoclsparse_int n,
                                            aoclsparse_matrix mat, const aoclsparse_mat_descr descr, const
                                            aoclsparse_float_complex *b, aoclsparse_float_complex *x, float
                                            rinfo[100], aoclsparse_int precond(aoclsparse_int flag,
                                            aoclsparse_int n, const aoclsparse_float_complex *u,
                                            aoclsparse_float_complex *v, void *udata), aoclsparse_int
                                            monit(aoclsparse_int n, const aoclsparse_float_complex *x, const
                                            aoclsparse_float_complex *r, float rinfo[100], void *udata), void
                                            *udata)

aoclsparse_status aoclsparse_itsol_z_solve(aoclsparse_itsol_handle handle, aoclsparse_int n,
                                            aoclsparse_matrix mat, const aoclsparse_mat_descr descr, const
                                            aoclsparse_double_complex *b, aoclsparse_double_complex *x,
                                            double rinfo[100], aoclsparse_int precond(aoclsparse_int flag,
                                            aoclsparse_int n, const aoclsparse_double_complex *u,
                                            aoclsparse_double_complex *v, void *udata), aoclsparse_int
                                            monit(aoclsparse_int n, const aoclsparse_double_complex *x,
                                            const aoclsparse_double_complex *r, double rinfo[100], void
                                            *udata), void *udata)
```

Forward communication interface to the iterative solvers suite of the library.

This function solves the linear system of equations

$$Ax = b,$$

where the matrix of coefficients A is defined by `mat`. The right hand-side is the dense vector `b` and the vector of unknowns is `x`. If A is symmetric and positive definite then set the option “iterative method” to “cg” to solve the problem using the [Conjugate Gradient method](#), alternatively set the option to “gmres” to solve using [GMRes](#). See the [Options](#) for a list of available options to modify the behaviour of each solver.

The expected workflow is as follows:

- a. Call `aoclsparse_itsol_s_init` or `aoclsparse_itsol_d_init` to initialize the problem `handle` (`aoclsparse_itsol_handle`).
- b. Choose the solver and adjust its behaviour by setting optional parameters with `aoclsparse_itsol_option_set`, see also [Options](#).
- c. Solve the system by calling `aoclsparse_itsol_s_solve` or `aoclsparse_itsol_d_solve` or `aoclsparse_itsol_c_solve` or `aoclsparse_itsol_z_solve`.

- d. If there is another linear system of equations to solve with the same matrix but a different right-hand side b , then repeat from step 3.
- e. If solver terminated successfully then vector \mathbf{x} contains the solution.
- f. Free the memory with `aoclsparse_itsol_destroy`.

This interface requires to explicitly provide the matrix A and its descriptor `descr`, this kind of interface is also known as `_forward communication_` which contrasts with `*reverse communication*` in which case the matrix A and its descriptor `descr` need not be explicitly available. For more details on the latter, see `aoclsparse_itsol_d_rci_solve` or `aoclsparse_itsol_s_rci_solve`.

Example - CG / floating point double precision (tests/examples/sample_itsol_d_cg.cpp)

Example - GMRES / floating point double precision (tests/examples/sample_itsol_d_gmres.cpp)

Example - CG / floating point single precision (tests/examples/sample_itsol_s_cg.cpp)

Example - GMRES / floating point single precision (tests/examples/sample_itsol_s_gmres.cpp)

Parameters

- **handle** – `[inout]` a valid problem handle, previously initialized by calling `aoclsparse_itsol_s_init` or `aoclsparse_itsol_d_init`.
- **n** – `[in]` the size of the square matrix `mat`.
- **mat** – `[inout]` coefficient matrix A .
- **descr** – `[inout]` matrix descriptor for `mat`.
- **b** – `[in]` right-hand side dense vector b .
- **x** – `[inout]` dense vector of unknowns. On input, it should contain the initial guess from which to start the iterative process. If there is no good initial estimate guess then any arbitrary but finite values can be used. On output, it contains an estimate to the solution of the linear system of equations up to the requested tolerance, e.g. see “cg rel tolerance” or “cg abs tolerance” in *Options*.
- **rinfo** – `[out]` vector containing information and stats related to the iterative solve, see Information Array.
- **precond** – `[in]` (optional, can be `nullptr`) function pointer to a user routine that applies the preconditioning step

$$v = Mu \text{ or } v = M^{-1}u,$$

where v is the resulting vector of applying a preconditioning step on the vector u and M refers to the user specified preconditioner in matrix form and need not be explicitly available. The void pointer `udata`, is a convenience pointer that can be used by the user to point to user data and is not used by the `itsol` framework. If the user requests to use a predefined preconditioner already available in the suite (refer to e.g. “cg preconditioner” or “gmres preconditioner” in *Options*), then this parameter need not be provided.

- **monit** – `[in]` (optional, can be `nullptr`) function pointer to a user monitoring routine. If provided, then at each iteration, the routine is called and can be used to define a custom stopping criteria or to oversee the convergence process. In general, this function need not be provided. If provided then the solver provides `n` the problem size, `x` the current iterate, `r` the current residual vector ($r = Ax - b$), `rinfo` the current solver’s stats, see Information

Array, and `udata` a convenience pointer that can be used by the user to point to arbitrary user data and is not used by the itsol framework.

- **udata** – [**[inout]**] (optional, can be `nullptr`) user convenience pointer, it can be used by the user to pass a pointer to user data. It is not modified by the solver.

`aoclsparse_itsol_option_set()`

`aoclsparse_status aoclsparse_itsol_option_set(aoclsparse_itsol_handle handle, const char *option, const char *value)`

Option Setter.

This function sets the value to a given option inside the provided problem handle. Handle options can be printed using `aoclsparse_itsol_handle_prn_options`. Available options are listed in [Options](#).

Options

The iterative solver framework has the following options.

Option name	Type	Default	Description	Constraints
cg iteration limit	integer	$i = 500$	Set CG iteration limit	$1 \leq i$.
gmres iteration limit	integer	$i = 150$	Set GMRES iteration limit	$1 \leq i$.
gmres restart iterations	integer	$i = 20$	Set GMRES restart iterations	$1 \leq i$.
cg rel tolerance	real	$r = 1.08735e - 06$	Set relative convergence tolerance for cg method	$0 \leq r$.
cg abs tolerance	real	$r = 0$	Set absolute convergence tolerance for cg method	$0 \leq r$.
gmres rel tolerance	real	$r = 1.08735e - 06$	Set relative convergence tolerance for gmres method	$0 \leq r$.
gmres abs tolerance	real	$r = 1e - 06$	Set absolute convergence tolerance for gmres method	$0 \leq r$.
iterative method	string	$s = cg$	Choose solver to use	$s = cg, gmres, or pcg$.
cg preconditioner	string	$s = none$	Choose preconditioner to use with cg method	$s = gs, none, sgs, symgs, or user$.
gmres preconditioner	string	$s = none$	Choose preconditioner to use with gmres method	$s = ilu0, none, or user$.

Note: It is worth noting that only some options apply to each specific solver, e.g. name of options that begin with “cg” affect the behaviour of the CG solver.

Parameters

- **handle** – [inout] pointer to the iterative solvers' data structure.
- **option** – [in] string specifying the name of the option to set.
- **value** – [in] string providing the value to set the option to.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_value** – either the option name was not found or the provided option value is out of the valid range.
- **aoclsparse_status_invalid_pointer** – the pointer to the problem handle is invalid.
- **aoclsparse_status_internal_error** – an unexpected error occurred.

aoclsparse_itsol_handle_prn_options()

```
void aoclsparse_itsol_handle_prn_options(aoclsparse_itsol_handle handle)
```

Print options stored in a problem handle.

This function prints to the standard output a list of available options stored in a problem handle and their current value. For available options, see Options in [aoclsparse_itsol_option_set](#).

Parameters

- handle** – [in] pointer to the iterative solvers' data structure.

aoclsparse_itsol_?_rci_input()

```
aoclsparse_status aoclsparse_itsol_s_rci_input(aoclsparse_itsol_handle handle, aoclsparse_int n, const
float *b)
```

```
aoclsparse_status aoclsparse_itsol_d_rci_input(aoclsparse_itsol_handle handle, aoclsparse_int n, const
double *b)
```

```
aoclsparse_status aoclsparse_itsol_c_rci_input(aoclsparse_itsol_handle handle, aoclsparse_int n, const
aoclsparse_float_complex *b)
```

```
aoclsparse_status aoclsparse_itsol_z_rci_input(aoclsparse_itsol_handle handle, aoclsparse_int n, const
aoclsparse_double_complex *b)
```

Store partial data of the linear system of equations into the problem handle.

This function needs to be called before the reverse communication interface iterative solver is called. It registers the linear system's dimension **n**, and stores the right-hand side vector **b**.

Note: This function does not need to be called if the forward communication interface is used.

Parameters

- **handle** – [inout] problem handle. Needs to be initialized by calling [aoclsparse_itsol_s_init](#) or [aoclsparse_itsol_d_init](#).
- **n** – [in] the number of columns of the (square) linear system matrix.
- **b** – [in] the right hand side of the linear system. Must be a vector of size **n**.

Return values

- **aoclsparse_status_success** – initialization completed successfully.
- **aoclsparse_status_invalid_pointer** – one or more of the pointers handle, and b are invalid.
- **aoclsparse_status_wrong_type** – handle was initialized with a different floating point precision than requested here, e.g. *aoclsparse_itsol_d_init* (double precision) was used to initialize handle but *aoclsparse_itsol_s_rci_input* (single precision) is being called instead of the correct double precision one, *aoclsparse_itsol_d_rci_input*.
- **aoclsparse_status_invalid_value** – n was set to a negative value.
- **aoclsparse_status_memory_error** – internal memory allocation error.

aoclsparse_itsol_?_rci_solve()

```
aoclsparse_status aoclsparse_itsol_s_rci_solve(aoclsparse_itsol_handle handle, aoclsparse_itsol_rci_job  
*ircomm, float **u, float **v, float *x, float rinfo[100])
```

```
aoclsparse_status aoclsparse_itsol_d_rci_solve(aoclsparse_itsol_handle handle, aoclsparse_itsol_rci_job  
*ircomm, double **u, double **v, double *x, double  
rinfo[100])
```

```
aoclsparse_status aoclsparse_itsol_c_rci_solve(aoclsparse_itsol_handle handle, aoclsparse_itsol_rci_job  
*ircomm, aoclsparse_float_complex **u,  
aoclsparse_float_complex **v, aoclsparse_float_complex  
*x, float rinfo[100])
```

```
aoclsparse_status aoclsparse_itsol_z_rci_solve(aoclsparse_itsol_handle handle, aoclsparse_itsol_rci_job  
*ircomm, aoclsparse_double_complex **u,  
aoclsparse_double_complex **v,  
aoclsparse_double_complex *x, double rinfo[100])
```

Reverse Communication Interface (RCI) to the iterative solvers (itsol) suite.

This function solves the linear system of equations

$$Ax = b,$$

where the matrix of coefficients A is not required to be provided explicitly. The right hand-side is the dense vector b and the vector of unknowns is x . If A is symmetric and positive definite then set the option “iterative method” to “cg” to solve the problem using the [Conjugate Gradient method](#), alternatively set the option to “gmres” to solve using [GMRes](#). See the [Options](#) for a list of available options to modify the behaviour of each solver.

The reverse communication interface (RCI), also known as `_matrix-free_` interface does not require the user to explicitly provide the matrix A . During the solve process whenever the algorithm requires a matrix operation (matrix-vector or transposed matrix-vector products), it returns control to the user with a flag `ircomm` indicating what operation is requested. Once the user performs the requested task it must call this function again to resume the solve.

The expected workflow is as follows:

- Call *aoclsparse_itsol_s_init* or *aoclsparse_itsol_d_init* or *aoclsparse_itsol_c_init* or *aoclsparse_itsol_z_init* to initialize the problem handle (*aoclsparse_itsol_handle*)
- Choose the solver and adjust its behaviour by setting optional parameters with *aoclsparse_itsol_option_set*, see also [Options](#).
- Define the problem size and right-hand side vector b with *aoclsparse_itsol_d_rci_input*.

- d. Solve the system with either `aoclsparse_itsol_s_rci_solve` or `aoclsparse_itsol_d_rci_solve` or `aoclsparse_itsol_c_rci_solve` or `aoclsparse_itsol_z_rci_solve`.
- e. If there is another linear system of equations to solve with the same matrix but a different right-hand side b , then repeat from step 3.
- f. If solver terminated successfully then vector x contains the solution.
- g. Free the memory with `aoclsparse_itsol_destroy`.

These reverse communication interfaces complement the `_forward communication_` interfaces `aoclsparse_itsol_d_rci_solve`, `aoclsparse_itsol_s_rci_solve`, `aoclsparse_itsol_c_rci_solve` and `aoclsparse_itsol_z_rci_solve`.

Example - CG / floating point double precision (tests/examples/sample_itsol_d_cg_rci.cpp)

Example - GMRES / floating point double precision (tests/examples/sample_itsol_d_gmres.cpp)

Example - CG floating point single precision (tests/examples/sample_itsol_s_cg_rci.cpp)

Example - GMRES / floating point single precision (tests/examples/sample_itsol_s_gmres.cpp)

Note: This function returns control back to the user under certain circumstances. The table in `aoclsparse_itsol_rci_job` indicates what actions are required to be performed by the user.

Parameters

- **handle** – [inout] problem handle. Needs to be previously initialized by `aoclsparse_itsol_s_init` or `aoclsparse_itsol_d_init` or `aoclsparse_itsol_c_init` or `aoclsparse_itsol_z_init` and then populated using either `aoclsparse_itsol_s_rci_input` or `aoclsparse_itsol_d_rci_input`, or `aoclsparse_itsol_c_rci_input` or `aoclsparse_itsol_z_rci_input` as appropriate.
- **ircomm** – [inout] pointer to the reverse communication instruction flag and defined in `aoclsparse_itsol_rci_job`.
- **u** – [inout] pointer to a generic vector of data. The solver will point to the data on which the operation defined by `ircomm` needs to be applied.
- **v** – [inout] pointer to a generic vector of data. The solver will ask that the result of the operation defined by `ircomm` be stored in `v`.
- **x** – [inout] dense vector of unknowns. On input, it should contain the initial guess from which to start the iterative process. If there is no good initial estimate guess then any arbitrary but finite values can be used. On output, it contains an estimate to the solution of the linear system of equations up to the requested tolerance, e.g. see “cg rel tolerance” or “cg abs tolerance” in *Options*.
- **rinfo** – [out] vector containing information and stats related to the iterative solve, see Information Array. This parameter can be used to monitor progress and define a custom stopping criterion when the solver returns control to user with `ircomm = aoclsparse_rci_stopping_criterion`.

aoclsparse_?symgs()

```
aoclsparse_status aoclsparse_ssymgs(aoclsparse_operation trans, aoclsparse_matrix A, const
                                     aoclsparse_mat_descr descr, const float alpha, const float *b, float *x)
```

```
aoclsparse_status aoclsparse_dsymgs(aoclsparse_operation trans, aoclsparse_matrix A, const
                                     aoclsparse_mat_descr descr, const double alpha, const double *b, double
                                     *x)
```

```
aoclsparse_status aoclsparse_csymgs(aoclsparse_operation trans, aoclsparse_matrix A, const
                                     aoclsparse_mat_descr descr, const aoclsparse_float_complex alpha, const
                                     aoclsparse_float_complex *b, aoclsparse_float_complex *x)
```

```
aoclsparse_status aoclsparse_zsymgs(aoclsparse_operation trans, aoclsparse_matrix A, const
                                     aoclsparse_mat_descr descr, const aoclsparse_double_complex alpha,
                                     const aoclsparse_double_complex *b, aoclsparse_double_complex *x)
```

Symmetric Gauss Seidel(SYMGs) Preconditioner for real/complex single and double data precisions.

aoclsparse_?symgs performs an iteration of Gauss Seidel preconditioning. Krylov methods such as CG (Conjugate Gradient) and GMRES (Generalized Minimal Residual) are used to solve large sparse linear systems of the form

$$op(A) x = \alpha b,$$

where A is a sparse matrix of size m , $op()$ is a linear operator, b is a dense right-hand side vector and x is the unknown dense vector, while α is a scalar. This Gauss Seidel(GS) relaxation is typically used either as a preconditioner for a Krylov solver directly, or as a smoother in a V –cycle of a multigrid preconditioner to accelerate the convergence rate. The Symmetric Gauss Seidel algorithm performs a forward sweep followed by a backward sweep to maintain symmetry of the matrix operation.

To solve a linear system $Ax = b$, Gauss Seidel(GS) iteration is based on the matrix splitting

$$A = L + D + U = -E + D - F$$

where $-E$ or L is strictly lower triangle, D is diagonal and $-F$ or D is strictly upper triangle. Gauss-Seidel is best derived as element-wise (refer Yousef Saad's book Iterative Methods for Sparse Linear Systems, Second Edition, Chapter 4.1, p. 125 onwards):

$$x_i = \frac{1}{a_{ii}} \left(b_i - \sum_{j=1}^{i-1} a_{ij} x_j - \sum_{j=i+1}^n a_{ij} x_j \right)$$

where the first sum is lower triangle i.e., $-Ex$ and the second sum is upper triangle i.e., $-Fx$. If we iterate through the rows $i=1$ to n and keep overwriting/reusing the new x_i , we get forward GS, expressed in matrix form as,

$$(D - E) x_{k+1} = F x_k + b$$

Iterating through the rows in reverse order from $i=n$ to 1, the upper triangle keeps using the new x_{k+1} elements and we get backward GS, expressed in matrix form as,

$$(D - F) x_{k+1} = E x_k + b$$

The above two equations can be expressed in terms of L, D and U as follows,

$$(L + D) x_1 = b - U x_0$$

$$(U + D) x = b - L x_1$$

So, Symmetric Gauss Seidel (SYMGS) can be computed using two `aoclsparse_?mv` and two `aoclsparse_?trsv` operations.

The sparse matrix A can be either a symmetric or a Hermitian matrix, whose fill is indicated by `fill_mode` from the matrix descriptor `descr` where either upper or lower triangular portion of the matrix is used. Matrix A must be of full rank, that is, the matrix must be invertible. The linear operator `op()` can define the transposition or conjugate transposition operations. By default, no transposition is performed. The right-hand-side vector b and the solution vector x are dense and must be of the correct size, that is m . If used as fixed point iterative method, the convergence is guaranteed for strictly diagonally dominant and symmetric positive definite matrices from any starting point, $\mathbf{x}0$. However, the API can be applied to wider types of input or as a preconditioning step. Refer Yousef Saad's Iterative Methods for Sparse Linear Systems 2nd Edition, Theorem 4.9 and related literature for mathematical theory.

1. If the matrix descriptor `descr` specifies that the matrix A is to be regarded as having a unitary diagonal, then the main diagonal entries of matrix A are not accessed and are considered to all be ones.
2. If the matrix A is described as upper triangular, then only the upper triangular portion of the matrix is referenced. Conversely, if the matrix A is described lower triangular, then only the lower triangular portion of the matrix is used.
3. This set of APIs allocates couple of work array buffers of size m for to store intermediate results
4. If the input matrix is of triangular type, the SGS is computed using a single `aoclsparse_?trsv` operation and a quick return is made without going through the 3-step reference(described above)

Example - Real space (tests/examples/sample_dsymgs.cpp)

Example - Complex space (tests/examples/sample_zsymgs.cpp)

Note:

Parameters

- **trans** – [in] matrix operation to perform on A . Possible values are `aoclsparse_operation_none`, `aoclsparse_operation_transpose`, and `aoclsparse_operation_conjugate_transpose`.
- **A** – [in] sparse matrix A of size m .
- **descr** – [in] descriptor of the sparse matrix A .
- **alpha** – [in] scalar α .
- **b** – [in] dense vector, of size m .
- **x** – [out] solution vector x , dense vector of size m .

Return values

- **aoclsparse_status_success** – indicates that the operation completed successfully.
- **aoclsparse_status_invalid_size** – informs that either m , n or nnz is invalid. The error code also informs if the given sparse matrix A is not square.

- **aoclsparse_status_invalid_value** – informs that either base, trans, matrix type descr->type or fill mode descr->fill_mode is invalid. If the sparse matrix A is not of full rank, the error code is returned to indicate that the linear system cannot be solved.
- **aoclsparse_status_invalid_pointer** – informs that either descr, A, b, or x pointer is invalid.
- **aoclsparse_status_not_implemented** – this error occurs when the provided matrix's *aoclsparse_fill_mode* is *aoclsparse_diag_type_unit* or the input format is not *aoclsparse_csr_mat*, or when *aoclsparse_matrix_type* is *aoclsparse_matrix_type_general* and *trans* is *aoclsparse_operation_conjugate_transpose*.

```
aoclsparse_status aoclsparse_ssymgs_mv(aoclsparse_operation trans, aoclsparse_matrix A, const  
                                         aoclsparse_mat_descr descr, const float alpha, const float *b, float *x,  
                                         float *y)
```

```
aoclsparse_status aoclsparse_dsymgs_mv(aoclsparse_operation trans, aoclsparse_matrix A, const  
                                         aoclsparse_mat_descr descr, const double alpha, const double *b,  
                                         double *x, double *y)
```

```
aoclsparse_status aoclsparse_csymgs_mv(aoclsparse_operation trans, aoclsparse_matrix A, const  
                                         aoclsparse_mat_descr descr, const aoclsparse_float_complex alpha,  
                                         const aoclsparse_float_complex *b, aoclsparse_float_complex *x,  
                                         aoclsparse_float_complex *y)
```

```
aoclsparse_status aoclsparse_zsymgs_mv(aoclsparse_operation trans, aoclsparse_matrix A, const  
                                         aoclsparse_mat_descr descr, const aoclsparse_double_complex alpha,  
                                         const aoclsparse_double_complex *b, aoclsparse_double_complex *x,  
                                         aoclsparse_double_complex *y)
```

Symmetric Gauss Seidel Preconditioner followed by SPMV for single and double precision datatypes.

For full details refer to [aoclsparse_?symgs\(\)](#).

This variation of SYMGS, namely with a suffix of _mv, performs matrix-vector multiplication between the sparse matrix A and the Gauss Seidel solution vector x .

Example - Real space (tests/examples/sample_dsymgs_mv.cpp)

Example - Complex space (tests/examples/sample_zsymgs_mv.cpp)

Parameters

- **trans** – [in] matrix operation to perform on A . Possible values are *aoclsparse_operation_none*, *aoclsparse_operation_transpose*, and *aoclsparse_operation_conjugate_transpose*.
- **A** – [in] sparse matrix A of size m .
- **descr** – [in] descriptor of the sparse matrix A .
- **alpha** – [in] scalar α .
- **b** – [in] dense vector, of size m .
- **x** – [out] solution vector x , dense vector of size m .

- **y** – [out] sparse-product vector y , dense vector of size m .

Return values

- **aoclsparse_status_success** – indicates that the operation completed successfully.
- **aoclsparse_status_invalid_size** – informs that either m , n or nnz is invalid. The error code also informs if the given sparse matrix A is not square.
- **aoclsparse_status_invalid_value** – informs that either **base**, **trans**, matrix type **descr->type** or fill mode **descr->fill_mode** is invalid. If the sparse matrix A is not of full rank, the error code is returned to indicate that the linear system cannot be solved.
- **aoclsparse_status_invalid_pointer** – informs that either **descr**, **A**, **b**, **x** or **y** pointer is invalid.
- **aoclsparse_status_not_implemented** – this error occurs when the provided matrix's **aoclsparse_fill_mode** is **aoclsparse_diag_type_unit** or the input format is not **aoclsparse_csr_mat**, or when **aoclsparse_matrix_type** is **aoclsparse_matrix_type_general** and **trans** is **aoclsparse_operation_conjugate_transpose**.

aoclsparse_?sorv()

aoclsparse_status **aoclsparse_ssorv**(*aoclsparse_sor_type* *sor_type*, const *aoclsparse_mat_descr* *descr*, const *aoclsparse_matrix* *A*, float *omega*, float *alpha*, float **x*, const float **b*)

aoclsparse_status **aoclsparse.dsorv**(*aoclsparse_sor_type* *sor_type*, const *aoclsparse_mat_descr* *descr*, const *aoclsparse_matrix* *A*, double *omega*, double *alpha*, double **x*, const double **b*)

Performs successive over-relaxation preconditioner operation for single and double precision datatypes to solve a linear system of equations $Ax = b$.

aoclsparse_?sorv performs successive over-relaxation preconditioner on a linear system of equations represented using a sparse matrix A in CSR storage format. This is an iterative technique that solves the left hand side of this expression for x , using an initial guess for x

$$(D + \omega L) x^1 = \omega b - (\omega U + (\omega - 1) D) x^0$$

where $A = L + D + U$, x^0 is an input vector x and x^1 is an output stored in vector x .

Initially

$$x^0 = \begin{cases} alpha * x^0, & \text{if } alpha \neq 0 \\ 0, & \text{if } alpha = 0 \end{cases}$$

The convergence is guaranteed for strictly diagonally dominant and positive definite matrices from any starting point, x^0 . API returns the vector x after single iteration. Caller can invoke this function in a loop until their desired convergence is reached.

NOTE:

1. Input CSR matrix should have non-zero full diagonals with each diagonal occurring only once in a row.
2. API supports forward sweep on general matrix for single and double precision datatypes.

Example (tests/examples/sample_dsorv.cpp)

Parameters

- **sor_type** – [in] Selects the type of operation performed by the preconditioner. Only `ao-clsparse_sor_forward` is supported at present.
- **descr** – [in] Descriptor of A. Only `aoclsparse_matrix_type_general` is supported at present. As a consequence, all other parameters within the descriptor are ignored.
- **A** – [in] Matrix structure containing a square sparse matrix A of size $m \times m$.
- **omega** – [in] Relaxation factor. For better convergence, $0 < \omega < 2$. If $\omega = 1$, the preconditioner is equivalent to the Gauss-Seidel method.
- **alpha** – [in] Scalar value used to normalize or set to zero the vector x that holds an initial guess.
- **x** – [inout] A vector of m elements that holds an initial guess as well as the solution vector.
- **b** – [in] A vector of m elements that holds the right-hand side of the equation being solved.

Return values

- `aoclsparse_status_success` – Completed successfully.
- `aoclsparse_status_invalid_pointer` – One or more of the pointers A, descr, x or b are invalid.
- `aoclsparse_status_wrong_type` – Data type of A does not match the function.
- `aoclsparse_status_not_implemented` – Expecting general matrix in CSR format for single or double precision datatypes with `aoclsparse_sor_forward`.
- `aoclsparse_status_invalid_size` – Matrix is not square.
- `aoclsparse_status_invalid_value` – M or N is set to a negative value; or A, descr or sor_type has invalid value; or presence of zero-valued or repeated diagonal elements.

`aoclsparse_ilu_?smoother()`

```
aoclsparse_status aoclsparse_silu_smoothen(aoclsparse_operation op, aoclsparse_matrix A, const
                                             aoclsparse_mat_descr descr, float **precond_csr_val, const float
                                             *approx_inv_diag, float *x, const float *b)

aoclsparse_status aoclsparse_dilu_smoothen(aoclsparse_operation op, aoclsparse_matrix A, const
                                             aoclsparse_mat_descr descr, double **precond_csr_val, const
                                             double *approx_inv_diag, double *x, const double *b)

aoclsparse_status aoclsparse_cilu_smoothen(aoclsparse_operation op, aoclsparse_matrix A, const
                                             aoclsparse_mat_descr descr, aoclsparse_float_complex
                                             **precond_csr_val, const aoclsparse_float_complex
                                             *approx_inv_diag, aoclsparse_float_complex *x, const
                                             aoclsparse_float_complex *b)

aoclsparse_status aoclsparse_zilu_smoothen(aoclsparse_operation op, aoclsparse_matrix A, const
                                             aoclsparse_mat_descr descr, aoclsparse_double_complex
                                             **precond_csr_val, const aoclsparse_double_complex
                                             *approx_inv_diag, aoclsparse_double_complex *x, const
                                             aoclsparse_double_complex *b)
```

Incomplete LU factorization with zero fill-in, ILU(0).

Performs incomplete LU factorization with zero fill-in on square sparse matrix A of size $n \times n$. It also performs a solve for x in

$$LUx = b, \quad \text{where} \quad LU \approx A.$$

Matrix A should be numerically of full rank. The first call will perform both the factorization and the solve, whereas any subsequent calls will only solve the system with the existing factors.

Example (tests/examples/sample_itsol_d_gmres.cpp)

Parameters

- **op** – [in] matrix A operation type. Transpose or conjugate transpose are not supported in this release.
- **A** – [in] sparse matrix handle. Currently only CSR matrix format is supported. The matrix needs to be square with all diagonal elements and fully or partially sorted in rows. The partial sorting means that all strictly lower triangular elements are followed by the diagonal and strictly upper triangular elements in each row, however, the non-diagonal elements don't need to follow any particular order within their group. If the matrix is unsorted, you might want to call [aoclsparse_order_mat\(\)](#).
- **descr** – [in] descriptor of the sparse matrix handle A . Currently, only [ao-clsparse_matrix_type_general](#) is supported.
- **precond_csr_val** – [out] pointer to the internal array of L and U values, it must not be changed by the user. It gets deallocated when the matrix handle A is destroyed. It contains L and U factors after the ILU factorization stored as one matrix with the same number of nonzeros and sparsity pattern as A . Strictly lower triangular elements define L (together with the implicit unit diagonal), the upper triangular elements represent U .
- **approx_inv_diag** – [in] Reserved for future use. This is not used and hence not validated.
- **x** – [out] array of n elements containing an approximate solution of $Ax = b$.
- **b** – [in] Right-hand-side of the linear system of equations $Ax = b$.

Return values

- **aoclsparse_status_success** – the operation completed successfully.
- **aoclsparse_status_invalid_size** – wrong matrix size (e.g., not square).
- **aoclsparse_status_invalid_value** – input parameters contain an invalid value (e.g., wrong base).
- **aoclsparse_status_invalid_pointer** – descr, A, precond_csr_val, x or b is invalid.
- **aoclsparse_status_wrong_type** – matrix handle A does not match the floating point data type.
- **aoclsparse_status_unsorted_input** – input matrix is not sorted.
- **aoclsparse_status_numerical_error** – encountered a diagonal pivot too close to zero or a diagonal element is missing.

- **aoclsparse_status_not_implemented** – matrix format, type or operation is not supported.
- **aoclsparse_status_memory_error** – memory allocation failure.
- **aoclsparse_status_internal_error** – an internal error occurred.

2.6 AOCL-Sparse Types

2.6.1 Numerical types

`typedef int32_t aoclsparse_int`

Specifies the size in bits of integer type to be used.

Typedef used to define the integer type this can be either 32-bit or 64-bit interger type.

This is determined at compile-time and can be specified using the CMake option `-DBUILD_ILP64=On|Off`
Setting to **On** will use use 64-bit integer data type.

`struct aoclsparse_float_complex`

Default complex float type.

User can redefine to accommodate custom complex float type definition.

Note: The library expects that complex numbers real and imaginary parts are contiguous in memory.

Public Members

`float real`

Real part.

`float imag`

Imaginary part.

`struct aoclsparse_double_complex`

Default complex double type.

User can redefine to accommodate custom complex double type definition.

Note: The library expects that complex numbers real and imaginary parts are contiguous in memory.

Public Members

`double real`

Real part.

`double imag`

Imaginary part.

2.6.2 Matrix object and descriptor

`typedef struct _aoclsparse_matrix *aoclsparse_matrix`

Matrix object.

This structure holds the matrix data. It is initialized using e.g. `aoclsparse_create_scsr` (or other variants, see table bellow). The returned matrix object needs be passed to all subsequent library calls that involve the matrix. It should be destroyed at the end using `aoclsparse_destroy`.

Table 2: Initialization of matrix objects.

Storage	<i>Precision</i> P	Initialization function
<i>Compressed Sparse Rows (CSR)</i>	s, d, c, z	<code>aoclsparse_create_Pcsr</code>
<i>Compressed Sparse Columns (CSC)</i>	s, d, c, z	<code>aoclsparse_create_Pcsc</code>
<i>Coordinate storage (COO)</i>	s, d, c, z	<code>aoclsparse_create_Pcoo</code>
<i>Triangular Compressed Sparse Rows (TCSR)</i>	s, d, c, z	<code>aoclsparse_create_Ptcsr</code>

`typedef struct _aoclsparse_mat_descr *aoclsparse_mat_descr`

Matrix object descriptor.

This structure holds properties describing a matrix and how to access its data. It must be initialized using `aoclsparse_create_mat_descr` and the returned descriptor object is passed to all subsequent library calls that involve the matrix. It is destroyed by using `aoclsparse_destroy_mat_descr`.

2.6.3 Enums

Function return status

`enum aoclsparse_status`

Values returned by the library API to indicate success or failure.

This table provides a brief explanation on the reason why a function call failed. It is **strongly** encouraged during the development cycle of applications or services to check the exit status of any call.

Values:

enumerator `aoclsparse_status_success`

success.

enumerator **aoclsparse_status_not_implemented**

functionality is not implemented.

enumerator **aoclsparse_status_invalid_pointer**

invalid pointer parameter.

enumerator **aoclsparse_status_invalid_size**

invalid size parameter.

enumerator **aoclsparse_status_internal_error**

internal library failure.

enumerator **aoclsparse_status_invalid_value**

invalid parameter value.

enumerator **aoclsparse_status_invalid_index_value**

invalid index value.

enumerator **aoclsparse_status_maxit**

function stopped after reaching number of iteration limit.

enumerator **aoclsparse_status_user_stop**

user requested termination.

enumerator **aoclsparse_status_wrong_type**

function called on the wrong type (double/float).

enumerator **aoclsparse_status_memory_error**

memory allocation failure.

enumerator **aoclsparse_status_numerical_error**

numerical error, e.g., matrix is not positive definite, divide-by-zero error

enumerator **aoclsparse_status_invalid_operation**

cannot proceed with the request at this point.

enumerator **aoclsparse_status_unsorted_input**

the input matrices are not sorted

enumerator **aoclsparse_status_invalid_kid**

user requested kernel id was not available.

Associated with `aoclsparse_matrix`

`enum aoclsparse_matrix_data_type`

Specify the matrix *data type*.

Values:

enumerator **`aoclsparse_dmat`**

double precision data.

enumerator **`aoclsparse_smat`**

single precision data.

enumerator **`aoclsparse_cmat`**

single precision complex data.

enumerator **`aoclsparse_zmat`**

double precision complex data.

See also:

- `aoclsparse_index_base`

Associated with matrix descriptor (`aoclsparse_mat_descr`)

`enum aoclsparse_matrix_type`

Specify the matrix type.

Specifies the type of a matrix. A matrix object descriptor describes how to interpret the type of the matrix. The data in the matrix object need not match the type in the matrix object descriptor. It can be set using `aoclsparse_set_mat_type` and retrieved using `aoclsparse_get_mat_type`.

Values:

enumerator **`aoclsparse_matrix_type_general`**

general matrix, no special pattern.

enumerator **`aoclsparse_matrix_type_symmetric`**

symmetric matrix, $A = A^T$. It stores only a single triangle specified using `aoclsparse_fill_mode`.

enumerator **`aoclsparse_matrix_type_hermitian`**

hermitian matrix, $A = A^H$. Same storage comment as for the symmetric case.

enumerator **`aoclsparse_matrix_type_triangular`**

triangular matrix, $A = \text{tril}(A)$ or $A = \text{triu}(A)$. Here too, `aoclsparse_fill_mode` specifies which triangle is available.

enum `aoclsparse_index_base`

Specify the matrix index base.

Indicate the base used on the matrix indices, either 0-base (C, C++) or 1-base (Fortran). The base is set using `aoclsparse_set_mat_index_base`. The current of a matrix object can be obtained by calling `aoclsparse_get_mat_index_base`.

Note: The base-indexing information is stored in two distinct locations: the matrix object `aoclsparse_matrix` and the matrix object descriptor `aoclsparse_mat_descr`, these **must** coincide, either be both zero or both one. Any function accepting both objects will fail if these do not match.

Values:

enumerator `aoclsparse_index_base_zero`

zero based indexing, C/C++ indexing.

enumerator `aoclsparse_index_base_one`

one based indexing, Fortran indexing.

enum `aoclsparse_diag_type`

Indicates how to interpret the diagonal entries of a matrix.

Used to indicate how to use the diagonal elements of a matrix. The purpose of this is to optimize certain operations inside the kernels. If the diagonal elements are not stored but should be interpreted as being all ones, then this can accelerate the operation by avoiding unnecessary memory accesses. For a given `aoclsparse_mat_descr`, the diagonal type can be set using `aoclsparse_set_mat_diag_type` and can be retrieved by calling `aoclsparse_get_mat_diag_type`.

Values:

enumerator `aoclsparse_diag_type_non_unit`

diagonal entries are present and arbitrary.

enumerator `aoclsparse_diag_type_unit`

diagonal entries are to be considered all ones. Kernels will not access the diagonal elements in the matrix data.

enumerator `aoclsparse_diag_type_zero`

ignore diagonal entries: for specifying strict lower or upper triangular matrices.

enum `aoclsparse_fill_mode`

Specify the matrix fill mode.

Indicates if the lower or the upper part of a triangular or symmetric matrix is stored. The fill mode can be set using `aoclsparse_set_mat_fill_mode`, and can be retrieved by calling `aoclsparse_get_mat_fill_mode`.

Values:

enumerator `aoclsparse_fill_mode_lower`

lower triangular part is stored.

enumerator **aoclsparse_fill_mode_upper**

upper triangular part is stored.

enum **aoclsparse_order**

Specify the memory layout (order) used to store a dense matrix.

Values:

enumerator **aoclsparse_order_row**

Row major, (C/C++ storage).

enumerator **aoclsparse_order_column**

Column major, (Fortran storage).

Miscellaneous

enum **aoclsparse_operation**

Indicate the operation type performed on a matrix.

Values:

enumerator **aoclsparse_operation_none**

No operation is performed on the matrix.

enumerator **aoclsparse_operation_transpose**

Operate with transpose.

enumerator **aoclsparse_operation_conjugate_transpose**

Operate with conjugate transpose.

typedef struct _aoclsparse_itsol_handle ***aoclsparse_itsol_handle**

Optimization handle.

This type of handle is a container box for storing problem data and optional parameter values. it must be initialized using [aoclsparse_itsol_s_init](#), and should be destroyed after using it with [aoclsparse_itsol_destroy](#). For double precision data types use [aoclsparse_itsol_d_init](#).

For more details, refer to Solver chapter introduction Iterative Solver Suite (itsol).

enum **aoclsparse_ilu_type**

Specify the type of Incomplete LU (ILU) factorization.

Indicates the type of factorization to perform.

Values:

enumerator **aoclsparse_ilu0**

Incomplete LU with zero fill-in, ILU(0).

enumerator `aoclsparse_ilup`

Incomplete LU with thresholding, ILU(p). Not implemented in this release.

enum `aoclsparse_request`

Request stages for API that perform sparse matrix products.

This list describes the possible request types used by matrix product kernels such as `aoclsparse_csr2m`.

Values:

enumerator `aoclsparse_stage_nnz_count`

Perform only first stage of analysis and computation. No result is returned but it is useful when optimizing for multiple calls.

enumerator `aoclsparse_stage_finalize`

Perform computation. After this stage the product result is returned. Needs to follow after a call with `aoclsparse_stage_nnz_count` request.

enumerator `aoclsparse_stage_full_computation`

Indicates to perform the entire computation in a single call.

enum `aoclsparse_sor_type`

List of successive over-relaxation types.

This is a list of supported SOR types that are supported by `aoclsparse_dsorv` (or other variants function).

Values:

enumerator `aoclsparse_sor_forward`

Forward sweep.

enumerator `aoclsparse_sor_backward`

Backward sweep.

enumerator `aoclsparse_sor_symmetric`

Symmetric preconditioner.

enum `aoclsparse_memory_usage`

List of memory utilization policy.

This is a list of supported `aoclsparse_memory_usage()` types that are used by optimization routine.

Values:

enumerator `aoclsparse_memory_usage_minimal`

Allocate memory only for auxiliary structures.

enumerator `aoclsparse_memory_usage_unrestricted`

Allocate memory upto matrix size for appropriate sparse format conversion. Default value.

2.7 Storage Schemes

This section describes the storage schemes that are supported in AOCL-Sparse with illustrative examples.

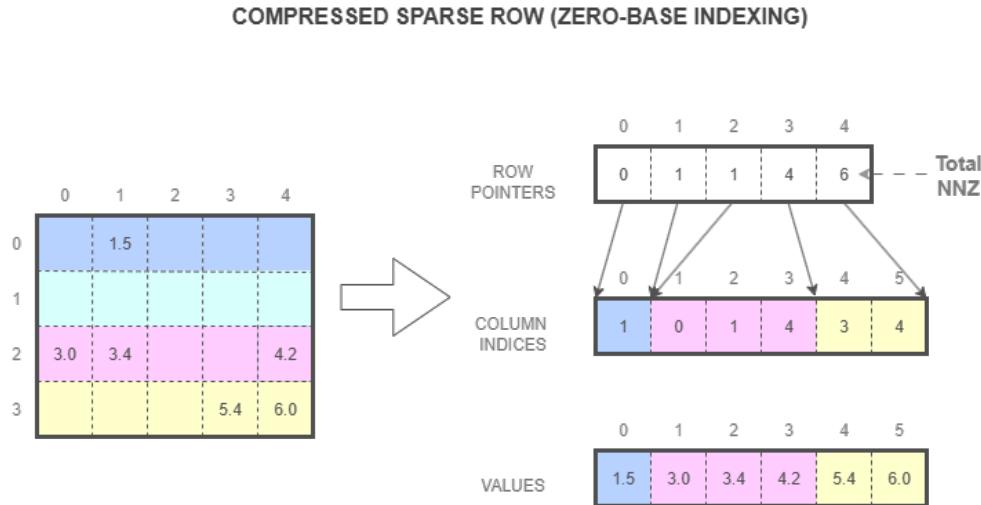
2.7.1 Compressed Sparse Row (CSR) Format

CSR (Compressed Sparse Row) is a common storage format for sparse matrices that stores all the nonzero elements in the row-wise order, i.e., all nonzeros of the first row are followed by all nonzeros in the second row, etc. The elements within the row can be stored in any order but it is often beneficial to have them sorted in the increasing order of their column indices.

The CSR format of a $M \times N$ sparse matrix with NNZ elements uses three arrays as follows:

- **row_ptr**: Array of size $M+1$ that contains pointers to the start of each row in the **col_idx** and **val** arrays. The last element points to the total number of nonzero elements. The number of nonzeros in row i can be computed as $\text{row_ptr}[i+1] - \text{row_ptr}[i]$.
- **col_idx, val**: Arrays of size NNZ containing the column indices and the corresponding values of each nonzero element, respectively.

CSR format can either use 0-based indexing (C, C++) where row and column indices start from 0 or 1-based (Fortran) where indices start from 1.



The above diagram shows a 4×5 matrix in CSR storage format with zero-based indexing.

- $M = 4$, $N = 5$, $NNZ = 6$
- $\text{row_ptr}[M+1] = \{0, 1, 1, 4, 6\}$
- $\text{col_idx}[NNZ] = \{1, 0, 1, 4, 3, 4\}$
- $\text{val}[NNZ] = \{1.5, 3.0, 3.4, 4.2, 5.4, 6.0\}$

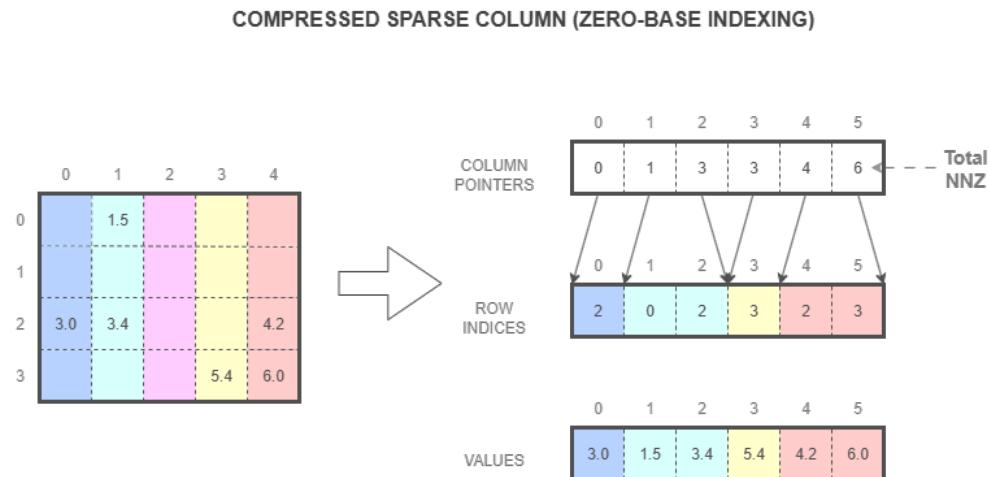
2.7.2 Compressed Sparse Column (CSC) Format

CSC (Compressed Sparse Column) is a storage format for sparse matrices that stores all the nonzero elements in the column-wise order, i.e., all nonzeros of the first column are followed by all nonzeros in the second column, etc. The elements within the column can be stored in any order but it is often beneficial to have them sorted in the increasing order of their row indices.

The CSC format of a $M \times N$ sparse matrix with NNZ elements uses three arrays as follows:

- **col_ptr**: Array of size $N+1$ that contains pointers to the start of each column in the **row_idx** and **val** arrays. The last element points to the total number of non-zero elements.
- **row_idx, val**: Arrays of size NNZ containing the row indices and the corresponding values of each nonzero element, respectively.

CSC format can either use 0-based indexing (C, C++) where row and column indices start from 0 or 1-based (Fortran) where indices start from 1.



The above diagram shows a 4×5 matrix in CSC storage format with zero-based indexing.

- $M = 4, N = 5, NNZ = 6$
- $\text{col_ptr}[N+1] = \{0, 1, 3, 3, 4, 6\}$
- $\text{row_idx}[NNZ] = \{2, 0, 2, 3, 2, 3\}$
- $\text{val}[NNZ] = \{3.0, 1.5, 3.4, 5.4, 4.2, 6.0\}$

2.7.3 Block Compressed Sparse Row (BSR) Format

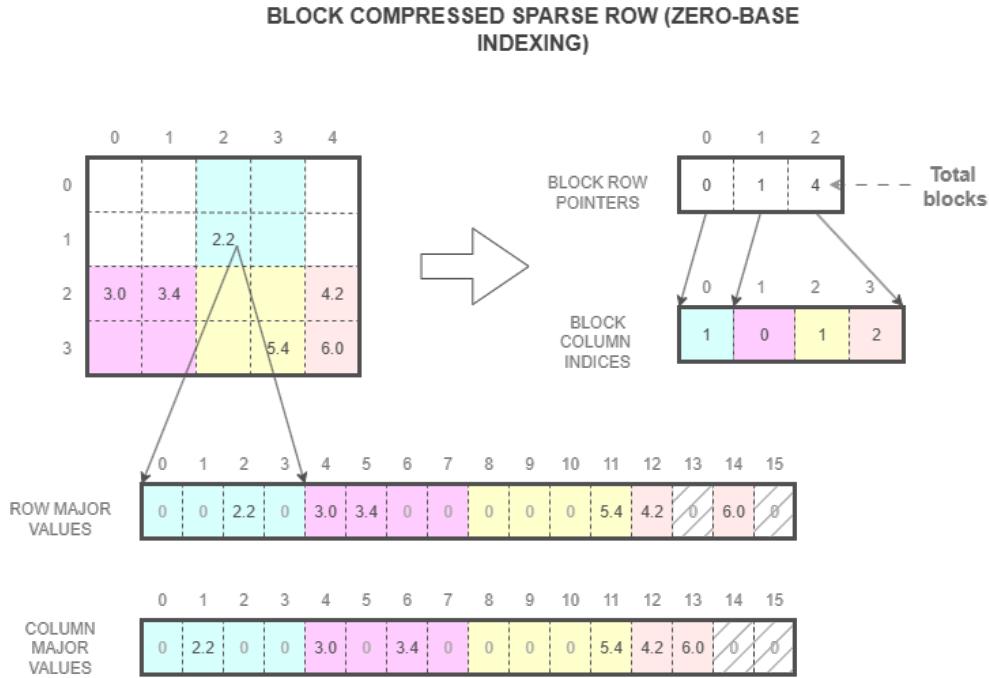
BSR (Block Compressed Sparse Row) is a sparse matrix storage format that groups nonzeros into fixed-size dense blocks (with zero padding if needed) and stores those blocks in a CSR-like structure. At present AOCL-Sparse only supports square blocks. Each block is of size **block_dim**, having **bM** block rows and **bN** block columns. The elements inside all nonzero blocks are either stored in row-major or column-major order.

The BSR format of a $bM \times bN$ block sparse matrix will have $bNNZ$ number of blocks. It uses three arrays as follows:

- **row_ptr**: Array of size $bM+1$ that contains pointers to the start of each block row in the **col_idx** and (in strides of $\text{block_dim} * \text{block_dim}$) **val** arrays. The last element points to the total number of nonzero blocks.
- **col_idx**: Array of size $bNNZ$ containing the block column indices of each nonzero blocks.

- **val:** Array of size $\text{block_dim} * \text{block_dim} * \text{bNNZ}$ containing all the nonzero elements of the matrix stored block by block, padded with zeros to fill the incomplete blocks.

BSR format can either use 0-based indexing or 1-based indexing similar to CSR and CSC formats.



The above diagram shows a BSR matrix of block size 2×3 with $\text{block_dim} = 2$ in 0-based indexing.

- $bM = 2$, $bN = 3$, $bNNZ = 4$
- $\text{row_ptr}[bM + 1] = \{0, 1, 4\}$
- $\text{col_idx}[bNNZ] = \{1, 0, 1, 2\}$

Row Major:

- $\text{val}[\text{block_dim} * \text{block_dim} * \text{bNNZ}] = \{0, 0, 2.2, 0, 3.0, 3.4, 0, 0, 0, 0, 5.4, 4.2, 0, 6.0, 0\}$

Column Major:

- $\text{val}[\text{block_dim} * \text{block_dim} * \text{bNNZ}] = \{0, 2.2, 0, 0, 3.0, 0, 3.4, 0, 0, 0, 0, 5.4, 4.2, 6.0, 0, 0\}$

Note: In BSR representation, the actual dimensions of the matrix will have $bM * \text{block_dim}$ number of rows and $bN * \text{block_dim}$ number of columns.

2.7.4 Triangular Compressed Sparse Row (TCSR) Format

2.7.5 Coordinate (COO) storage format

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