NVIDIA Magnum IO GPUDirect Storage

cuFile API

API Reference
Table of Contents

Chapter 1. Introduction ........................................................................................................ 1

Chapter 2. Usage................................................................................................................. 2
   2.1. Dynamic Interactions................................................................................................. 2
   2.2. Driver, File, and Buffer Management....................................................................... 3
   2.3. cuFile Compatibility Mode....................................................................................... 3

Chapter 3. cuFile API Specification.....................................................................................6
   3.1. Data Types................................................................................................................... 6
       3.1.1. Declarations and Definitions................................................................................ 6
       3.1.2. Typedefs................................................................................................................ 8
       3.1.3. Enumerations........................................................................................................... 8
   3.2. cuFile Driver APIs.......................................................................................................10
   3.3. cuFile IO APIs.............................................................................................................11
   3.4. cuFile File Handle APIs............................................................................................. 11
   3.5. cuFile Buffer APIs...................................................................................................... 12
   3.6. Future cuFile File Stream APIs.................................................................................. 12
   3.7. Future cuFile Batch APIs.......................................................................................... 12

Chapter 4. cuFile API Functional Specification................................................................... 14
   4.1. cuFileDriver API Functional Specification.............................................................. 14
       4.1.1. cuFileDriverOpen................................................................................................. 14
       4.1.2. cuFileDriverClose............................................................................................... 15
       4.1.3. cuFileDriverGetProperties.................................................................................. 15
       4.1.4. cuFileDriverSetPollMode(bool poll, size_t poll_threshold_size)...................... 17
       4.1.5. cuFileDriverSetMaxDirectIOSize(size_t max_direct_io_size).......................... 18
       4.1.6. cuFileDriverSetMaxCacheSize(size_t max_cache_size)....................................... 19
       4.1.7. cuFileDriverSetMaxPinnedMemSize(size_t max_pinned_memory_size).............. 19
       4.1.8. JSON Configuration File...................................................................................... 20
   4.2. cuFile IO API Functional Specification....................................................................... 23
       4.2.1. cuFileHandleRegister......................................................................................... 23
       4.2.2. cuFileHandleDeregister....................................................................................... 24
       4.2.3. cuFileRead............................................................................................................ 25
       4.2.4. cuFileWrite........................................................................................................... 26
   4.3. cuFile Memory Management Functional Specification........................................... 27
       4.3.1. cuFileBufRegister............................................................................................... 27
       4.3.2. cuFileBufDeregister............................................................................................. 28
   4.4. cuFile Stream API Functional Specification.......................................................... 29
Chapter 1. Introduction

NVIDIA® Magnum IO GPUDirect® Storage (GDS) is part of the GPUDirect family. GDS enables a direct data path for direct memory access (DMA) transfers between GPU memory and storage, which avoids a bounce buffer through the CPU. This direct path increases system bandwidth and decreases the latency and utilization load on the CPU.

This document provides information about the cuFile APIs that are used in applications and frameworks to leverage GDS technology and describes the intent, context, and operation of those APIs which are part of the GDS technology.

Note: The APIs and descriptions are subject to change without notice.
Chapter 2. Usage

This section describes the operation of the cuFile APIs. Because the functionality is part of the CUDA Driver C API, the APIs use the cuFile prefix and camel case motif of the CUDA Driver.

All APIs are thread-safe.

All APIs are issued from the CPU, not the GPU.

2.1. Dynamic Interactions

The following describes the dynamic interactions between the cuFile APIs.

Some of the cuFile APIs are optional. If they are not called proactively, their actions will occur reactively:

If cuFile{Open, HandleRegister, BufRegister} is called on a driver, file, or buffer, respectively that has been opened or registered by a previous cuFile* API call, this will result in an error. Calling cuFile{BufDeregister, HandleDeregister, DriverClose} on a buffer, file, or driver, respectively that has never been opened or registered by a previous cuFile* API call results in an error. For these errors, the output parameters of the APIs are left in an undefined state, and there are no other side effects.

- cuFileDriverOpen explicitly causes driver initialization.
  
  Its use is optional. If it is not used, driver initialization happens implicitly at the first use of the cuFile{HandleRegister, Read, Write, BufRegister} APIs.

- Mandatory cuFileHandleRegister turns an OS-specific file descriptor into a cuFileHandle and performs checking on the GDS supportability based on the mount point and the way that the file was opened.

- cuFileBufRegister explicitly registers a memory buffer.
  
  If this API is not called, a memory buffer is registered the first time the buffer is used, for example, in cuFile{Read, Write}.

- cuFile{BufDeregister, HandleDeregister} explicitly frees a buffer and file resources.
  
  If this API is not called, the buffer and resources are implicitly freed when the driver is closed.

- cuFileDriverClose explicitly frees driver resources.
If this API is not called, the driver resources are implicitly freed when the process is terminated.

If cuFile{Open, HandleRegister, BufRegister} is called on a driver, file, or buffer, respectively that has been opened or registered by a previous cuFile* API call, results in an error. Calling cuFile{BufDeregister, HandleDeregister, DriverClose} on a buffer, file, or driver, respectively that has never been opened or registered by a previous cuFile* API call also results in an error. For these errors, the output parameters of the APIs are left in an undefined state and there are no other side effects.

2.2. Driver, File, and Buffer Management

This section describes the overall workflow to manage the driver, the file, and buffer management:

1. Call cuFileDriverOpen() to initialize the state of the critical performance path.
2. Allocate GPU memory with cudaMalloc.
3. To register the buffer, call cuFileBufRegister to initialize the buffer state of the critical performance path.
4. Complete the following IO workflow:
   a). For Linux, open a file with POSIX open.
   b). Call cuFileHandleRegister to wrap an existing file descriptor in an OS-agnostic cuFileHandle. This step evaluates the suitability of the file state and the file mount for GDS and initializes the file state of the critical performance path.
   c). Call cuFileRead/cuFileWrite on an existing cuFile handle and existing buffer.
      ▶ If the cuFileBufRegister has not been previously called, the first time that cuFileRead/cuFileWrite is accessed, the GDS library performs a validation check on the GPU buffer and an IO is issued.
      ▶ Not using cuFileBufRegister might not be performant for small IO sizes.
      ▶ Refer to the GPUDirect Best Practices Guide for more information.
   d). Unless an error condition is returned, the IO is performed successfully.
5. Call cuFileBufDeregister to free the buffer-specific cuFile state.
6. Call cuFileHandleDeregister to free the file-specific cuFile state.
7. Call cuFileDriverClose to free up the cuFile state.

Note: Not using the Deregister and Close APIs (steps 5, 6, and 7) might unnecessarily consume resources, as shown by tools such as valgrind. The best practice is to always use these APIs.

2.3. cuFile Compatibility Mode

Use Cases
cuFile APIs can be used in different scenarios:

- Developers building GPUDirect Storage applications with cuFile APIs, but don’t have the supported hardware configurations.
- Developers building applications running on GPU cards that have CUDA compute capability > 6, but don’t have BAR space exposed.
- Deployments where nvidia-fs.ko is not loaded or cannot be loaded.
- Deployments where the Linux distribution does not support GPUDirect Storage.
- Deployments where the filesystem may be not supported with GPUDirect Storage.
- Deployments where the network links are not enabled with RDMA support.
- Deployment where the configuration is not optimal for GPUDirect Storage.

Behavior

The cuFile library provides a mechanism for cuFile reads and writes to use compatibility mode using POSIX pread and pwrite APIs respectively to system memory and copying to GPU memory. The behavior of compatibility mode with cuFile APIs is determined by the following configuration parameters.

<table>
<thead>
<tr>
<th>Configuration Option (default)</th>
<th>cuFile IO Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;allow_compat_mode&quot;: true</td>
<td>If true, falls back to using compatibility mode when the library detects that the buffer file descriptor opened cannot use GPUDirect Storage.</td>
</tr>
<tr>
<td>&quot;GPUDirect Storage_rdma_write_support&quot;: true</td>
<td>If false, forces compatibility mode to be used for writes even when the underlying file system is capable of performing GPUDirect Storage writes.</td>
</tr>
<tr>
<td>&quot;posix_unaligned_writes&quot; : false</td>
<td>If true, forces compatibility mode to be used for writes where the file offset and/or IO size is not aligned to Page Boundary (4KB).</td>
</tr>
</tbody>
</table>
| "lustre:posix_GPUDirect Storage_min_kb" : 0 | If greater than 0, compatibility mode is used for IO sizes between [1 - posix_GPUDirect Storage_min_kb] specified in kB.  
**Note:** This option will force posix mode even if "allow_compat_mode" is set to "false". |
| "weka:rdma_write_support" : false | If this option is false, WekaFs will use compatibility mode for all writes to the filesystem.  
**Note:** if the option is set to "false", cuFile library will use the posix path even if the allow_compat_mode option is true or false. |
| "rdma_dynamic_routing": false, "rdma_dynamic_routing_order": [ "SYS_MEM" ] | If rdma_dynamic_routing is set to true and rdma_dynamic_routing_order is set to ["SYS_MEM"], then all IO for DFS will use compatibility mode. |

In addition to the above configuration options, compatibility mode will be used as a fallback option for following use cases.
<table>
<thead>
<tr>
<th>Use Case</th>
<th>cuFile IO Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBM Spectrum Scale File System writes.</td>
<td>Note: All IBM Spectrum Scale in GPUDirect Storage 1.0.0.x release use posix path for writes even if the allow_compat_mode option is set to false.</td>
</tr>
<tr>
<td>No BAR1 memory in GPU.</td>
<td>Use compatibility mode.</td>
</tr>
<tr>
<td>For wekaFS or IBM Spectrum Scale mounts: If there are no rdma_dev_addr_list specified, or failure to register MR with ib device.</td>
<td>Use compatibility mode.</td>
</tr>
<tr>
<td>Bounce buffers cannot be allocated in GPU memory.</td>
<td>Use compatibility mode.</td>
</tr>
<tr>
<td>For WekaFS and IBM Spectrum Scale: If the kernel returns -ENOTSUP for GPUDirect Storage read/write.</td>
<td>Retry the IO operation internally using compatibility mode.</td>
</tr>
<tr>
<td>The nvidia_fs.ko driver is not loaded.</td>
<td>All IO operations will use compatibility mode.</td>
</tr>
</tbody>
</table>

**Limitations**

- Compatible mode does not work in cases where the GPUs have CUDA compute capability less than 6.
- Compatible mode is supported only on GPUDirect Storage enabled filesystems.
- There is no option to force all IO to use compatibility mode. The user can unload the nvidia_fs.ko or not expose the character devices in the docker container environment.
Chapter 3. cuFile API Specification

This section provides information about the cuFile APIs that are used from the CPU to enable applications and frameworks.

3.1. Data Types

Data types are used by the cuFile APIs, first the typedefs second, and finally, the enumerations.

3.1.1. Declarations and Definitions

Here are the relevant enums and their descriptions.

typedef struct CUfileError {
    CUfileOpError err; // cufile error
    enum CUresult cu_err; // for CUDA-specific errors
} CUfileError_t;

/**
 * error macros to inspect error status of type CUfileOpError
 */
#define IS_CUFILE_ERR(err) ((abs((err)) > CUFILEOP_BASE_ERR))
#define CUFILE_ERRSTR(err) cufileop_status_error(static_cast<CUfileOpError>(abs((err))))
#define IS_CUDA_ERR(status) ((status).err == CU_FILE_CUDA_DRIVER_ERROR)
#define CU_FILE_CUDA_ERR(status) ((status).cu_

The following enum and two structures enable broader cross-OS support:

enum CUfileFileHandleType {
    CU_FILE_HANDLE_TYPE_OPAQUE_FD = 1, /* linux based fd */
    CU_FILE_HANDLE_TYPE_OPAQUE_WIN32 = 2, /* windows based handle */
    CU_FILE_HANDLE_TYPE_USERSPACE_FS = 3, /* userspace based FS */
};

typedef struct CUfileDescr_t {
    CUfileFileHandleType type; /* type of file being registered */
    union {
        int fd; /* Linux */
        void *handle; /* Windows */
    } handle;
    const CUfileFSops_t *fs_ops; /* file system operation table */
} CUfileDescr_t;
/* cuFile handle type */
typedef void* CUfileHandle_t;

typedef struct cufileRDMAInfo {
    int version;
    int desc_len;
    const char *desc_str;
} cufileRDMAInfo_t;

typedef struct CUfileFSOps {
    /* NULL means discover using fstat */
    const char* (*fs_type) (void *handle);
    /* list of host addresses to use, NULL means no restriction */
    int (*getRDMADeviceList)(void *handle, sockaddr_t **hostaddrs);
    /* -1 no pref */
    int (*getRDMADevicePriority)(void *handle, char*, size_t,
                                loff_t, sockaddr_t* hostaddr);
    /* NULL means try VFS */
    ssize_t (*read) (void *handle, char*, size_t, loff_t, cufileRDMAInfo_t*);
    ssize_t (*write) (void *handle, const char *, size_t, loff_t,
                      cufileRDMAInfo_t*);
} CUfileFSOps_t;

enum CUfileDriverStatusFlags {
    CU_FILE_LUSTRE_SUPPORTED = 0,
    CU_FILE_WEKAFS_SUPPORTED = 1
};

enum CUfileDriverControlFlags {
    CU_FILE_USE_POLL_MODE = 0, /*!< use POLL mode. properties.use_poll_mode*/
    CU_FILE_ALLOW_COMPAT_MODE = 1 /*!< allow COMPATIBILITY mode.
                                      properties.allow_compat_mode*/
};

typedef enum CUfileFeatureFlags {
    CU_FILE_DYN_ROUTING_SUPPORTED =0,
    CU_FILE_BATCH_IO_SUPPORTED = 1,
    CU_FILE_STREAMS_SUPPORTED = 2
} CUfileFeatureFlags_t;

/* cuFileDriverGetProperties describes this structure’s members */
typedef struct CUfileDrvProps {
    struct {
        unsigned int major_version;
        unsigned int minor_version;
        size_t poll_thresh_size;
        size_t max_direct_io_size;
        unsigned int dstatusflags;
        unsigned int dcontrolflags;
    } nvfs;
    CUfileFeatureFlags_t fflags;
    unsigned int max_device_cache_size;
    unsigned int per_buffer_cache_size;
    unsigned int max_pinned_memory_size;
    unsigned int max_batch_io_timeout_msecs;
} CUfileDrvProps_t;

/* Parameter block for async cuFile IO */
/* Batch APIs use an array of these */
/* Status must be CU_FILE_WAITING when submitted, and is
   updated when enqueued and when complete, so this user-allocated
   structure is live until the operation completes */
/* Status of Batch IO operation */
enum CUfileBatchIOStatus {
    CU_FILE_WAITING,  /* required value prior to submission */
    CU_FILE_PENDING,  /* once enqueued */
    CU_FILE_INVALID,  /* request was ill-formed or could not be enqueued */
    CU_FILE_CANCELED, /* request successfully canceled */
    CU_FILE_COMPLETE, /* request successfully completed */
    CU_FILE_TIMEOUT,  /* request timed out */
    CU_FILE_FAILED    /* unable to complete */
};

struct CUfileBatchIOParams {
    CUFileHandle_t         cfh;         /* File descriptor */
    off_t                  file_offset; /* File offset in bytes */
    volatile void*         target_buf;  /* Location of buffer in memory */
    size_t                 nbytes;      /* length of the buffer */
    size_t                 nbytes_transacted; /* what was actually moved */
    CufileBatchOpcode_t    opcode;      /* op code to perform */
    CUfileStatus_t         status;      /* status of the operation */
    CUfileError_t          error;       /* operation level error */
};

3.1.2. Typedefs

cuFile typedefs:

typedef struct CUfileDescr CUfileDesr_t
typedef struct CUfileError CUfileError_t
typedef struct CUfileDrvProps CUfileDrvProps_t
typedef enum CUfileFeatureFlags CUfileFeatureFlags_t
typedef enum CUfileDriverStatusFlags_enum CUfileDriverStatusFlags_t
typedef enum CUfileDriverControlFlags_enum CUfileDriverControlFlags_t
typedef struct CUfileIOParams CUfileIOParams_t
typedef enum CUfileBatchOpcode CUfileBatchOpcode_t

3.1.3. Enumerations

cuFile enums:

- enum CUfileBatchOpcode_enum

This is the cuFile operation code for batch mode.

<table>
<thead>
<tr>
<th>OpCode</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU_FILE_READ</td>
<td>0</td>
<td>Batch Read</td>
</tr>
<tr>
<td>CU_FILE_WRITE</td>
<td>1</td>
<td>Batch Write</td>
</tr>
</tbody>
</table>

/* cuFile Batch IO operation kind */
enum CUfileOBatchpcode {
    CU_FILE_READ,
    CU_FILE_WRITE,
};

- enum CUfileStatus

The cuFile Status codes for batch mode.

<table>
<thead>
<tr>
<th>Status</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU_FILE_WAITING</td>
<td>0</td>
<td>The initial value.</td>
</tr>
<tr>
<td>CU_FILE_PENDING</td>
<td>1</td>
<td>Set once enqueued into the driver.</td>
</tr>
</tbody>
</table>
### Status

<table>
<thead>
<tr>
<th>Status</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU_FILE_INVALID</td>
<td>2</td>
<td>Invalid parameters.</td>
</tr>
<tr>
<td>CU_FILE_COMPLETE</td>
<td>3</td>
<td>Successfully completed.</td>
</tr>
<tr>
<td>CU_FILE_TIMEOUT</td>
<td>4</td>
<td>The operation has timed out.</td>
</tr>
<tr>
<td>CU_FILE_FAILED</td>
<td>5</td>
<td>IO has failed.</td>
</tr>
</tbody>
</table>

- enum CUfileOpError
  - The cuFile Operation error types.
  - All error code values, other than `CU_FILE_SUCCESS`, are considered failures that might leave the output and input parameter values of APIs in an undefined state.
    - These values cannot have any side effects on the file system, the application process, and the larger system.
    - We selected a base number for error codes that enables users to distinguish between POSIX errors and cuFile errors.
      ```
      #define CUFILEOP_BASE_ERR 5000
      ```

### Error Code

<table>
<thead>
<tr>
<th>Error Code</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU_FILE_SUCCESS</td>
<td>0</td>
<td>The cufile is successful.</td>
</tr>
<tr>
<td>CU_FILE_DRIVER_NOT_INITIALIZED</td>
<td>5001</td>
<td>The nvidia-fs driver is not loaded.</td>
</tr>
<tr>
<td>CU_FILE_DRIVER_INVALID_PROPS</td>
<td>5002</td>
<td>An invalid property.</td>
</tr>
<tr>
<td>CU_FILE_DRIVER_UNSUPPORTED_LIMIT</td>
<td>5003</td>
<td>A property range error.</td>
</tr>
<tr>
<td>CU_FILE_DRIVER_VERSION_MISMATCH</td>
<td>5004</td>
<td>An nvidia-fs driver version mismatch.</td>
</tr>
<tr>
<td>CU_FILE_DRIVER_VERSION_READ_ERROR</td>
<td>5005</td>
<td>An nvidia-fs driver version read error.</td>
</tr>
<tr>
<td>CU_FILE_DRIVER_CLOSING</td>
<td>5006</td>
<td>Driver shutdown in progress.</td>
</tr>
<tr>
<td>CU_FILE_PLATFORM_NOT_SUPPORTED</td>
<td>5007</td>
<td>GDS is not supported on the current platform.</td>
</tr>
<tr>
<td>CU_FILE_IO_NOT_SUPPORTED</td>
<td>5008</td>
<td>GDS is not supported on the current file.</td>
</tr>
<tr>
<td>CU_FILE_DEVICE_NOT_SUPPORTED</td>
<td>5009</td>
<td>GDS is not supported on the current GPU.</td>
</tr>
<tr>
<td>CU_FILE_NVFS_DRIVER_ERROR</td>
<td>5010</td>
<td>An nvidia-fs driver ioctl error.</td>
</tr>
<tr>
<td>CU_FILE_CUDA_DRIVER_ERROR</td>
<td>5011</td>
<td>A CUDA Driver API error. This error indicates a CUDA driver-api error. If this is set, a CUDA-specific error code is set in the cu_err field for cuFileError.</td>
</tr>
<tr>
<td>CU_FILE_CUDA_POINTER_INVALID</td>
<td>5012</td>
<td>An invalid device pointer.</td>
</tr>
<tr>
<td>CU_FILE_CUDA_MEMORY_TYPE_INVALID</td>
<td>5013</td>
<td>An invalid pointer memory type.</td>
</tr>
<tr>
<td>CU_FILE_CUDA_POINTER_RANGE_ERROR</td>
<td>5014</td>
<td>The pointer range exceeds the allocated address range.</td>
</tr>
</tbody>
</table>
cuFile API Specification

<table>
<thead>
<tr>
<th>Error Code</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU_FILE_CUDA_CONTEXT_MISMATCH</td>
<td>5015</td>
<td>A CUDA context mismatch.</td>
</tr>
<tr>
<td>CU_FILE_INVALID_MAPPING_SIZE</td>
<td>5016</td>
<td>Access beyond the maximum pinned memory size.</td>
</tr>
<tr>
<td>CU_FILE_INVALID_MAPPING_RANGE</td>
<td>5017</td>
<td>Access beyond the mapped size.</td>
</tr>
<tr>
<td>CU_FILE_INVALID_FILE_TYPE</td>
<td>5018</td>
<td>An unsupported file type.</td>
</tr>
<tr>
<td>CU_FILE_INVALID_FILE_OPEN_FLAG</td>
<td>5019</td>
<td>Unsupported file open flags.</td>
</tr>
<tr>
<td>CU_FILE_DIO_NOT_SET</td>
<td>5020</td>
<td>The fd direct IO is not set.</td>
</tr>
<tr>
<td>CU_FILE_INVALID_VALUE</td>
<td>5022</td>
<td>Invalid API arguments.</td>
</tr>
<tr>
<td>CU_FILE_MEMORY_ALREADY_REGISTERED</td>
<td>5023</td>
<td>Device pointer is already registered.</td>
</tr>
<tr>
<td>CU_FILE_MEMORY_NOT_REGISTERED</td>
<td>5024</td>
<td>A device pointer lookup failure has occurred.</td>
</tr>
<tr>
<td>CU_FILE_PERMISSION_DENIED</td>
<td>5025</td>
<td>A driver or file access error.</td>
</tr>
<tr>
<td>CU_FILE_DRIVER_ALREADY_OPEN</td>
<td>5026</td>
<td>The driver is already open.</td>
</tr>
<tr>
<td>CU_FILE_HANDLE_NOT_REGISTERED</td>
<td>5027</td>
<td>The file descriptor is not registered.</td>
</tr>
<tr>
<td>CU_FILE_HANDLE_ALREADY_REGISTERED</td>
<td>5028</td>
<td>The file descriptor is already registered.</td>
</tr>
<tr>
<td>CU_FILE_DEVICE_NOT_FOUND</td>
<td>5029</td>
<td>The GPU device cannot be not found.</td>
</tr>
<tr>
<td>CU_FILE_INTERNAL_ERROR</td>
<td>5030</td>
<td>An internal error has occurred.</td>
</tr>
<tr>
<td>CU_FILE_NEWFD_FAILED</td>
<td>5031</td>
<td>Failed to obtain new file descriptor.</td>
</tr>
<tr>
<td>CU_FILE_NVFS_SETUP_ERROR</td>
<td>5033</td>
<td>An NVFS driver initialization error has occurred.</td>
</tr>
<tr>
<td>CU_FILE_IO_DISABLED</td>
<td>5034</td>
<td>GDS is disabled by config on the current file.</td>
</tr>
</tbody>
</table>

Note: Data path errors are captured via standard error codes by using errno. The long-term expectation is that these error codes will be folded into CUresult, and CUFileOpError will go away.

3.2. cuFile Driver APIs

The following cuFile APIs that are used to initialize, finalize, query, and tune settings for the cuFile system.

/* Initialize the cuFile infrastructure */
CUfileError_t cuFileDriverOpen();

/* Finalize the cuFile system */
CUfileError_t cuFileDriverClose();

/* Query capabilities based on current versions, installed functionality */
CUfileError_t cuFileGetDriverProperties(CUfileDrvProps_t *props);
3.3. cuFile IO APIs

The core of the cuFile IO APIs are the read and write functions.

```c
ssize_t cuFileRead(CUFileHandle_t fh, void *devPtr_base, size_t size, off_t file_offset, off_t devPtr_offset);
ssize_t cuFileWrite(CUFileHandle_t fh, const void *devPtr_base, size_t size, off_t file_offset, off_t devPtr_offset);
```

The buffer on the device has both a base (`devPtr_base`) and offset (`devPtr_offset`). This offset is distinct from the offset in the file.

Note that by default for all paths where GDS is not supported, the cuFile IO API will be attempting IO using file system supported posix mode APIs when `properties.allow_compat_mode` is set to true. In order to disable cuFile APIs falling back to posix APIs for unsupported GDS paths, `properties.allow_compat_mode` in the `/etc/cufile.json` file should be set to false.

3.4. cuFile File Handle APIs

Here is some information about the cuFile Handle APIs.

The `cuFileHandleRegister` API makes a file descriptor or handle that is known to the cuFile subsystem by using an OS-agnostic interface. The API returns an opaque handle that is owned by the cuFile subsystem.

To conserve memory, the `cuFileHandleDeregister` API is used to release cuFile-related memory objects. Using only the POSIX close will not clean up resources that were used by cuFile. Additionally, the clean up of cuFile objects associated with the files that were operated on in the cuFile context will occur at `cuFileDriverClose`.

```c
CUfileError_t cuFileHandleRegister(CUFileHandle_t *fh, CUFileDescr_t *descr);
void cuFileHandleDeregister(CUFileHandle_t fh);
```
3.5. cuFile Buffer APIs

The cuFileBufRegister API incurs a significant performance cost, so registration costs should be amortized where possible. Developers must ensure that buffers are registered up front and off the critical path.

The cuFileBufRegister API is optional. If this is not used, instead of pinning the user’s memory, cuFile-managed and internally pinned buffers are used.

The cuFileBufDeregister API is used to optimally clean up cuFile-related memory objects, but CUDA currently has no analog to cuFileBufDeregister. The cleaning up of objects associated with the buffers operated on in the cuFile context occurs at cuFileDriverClose. If explicit APIs are used, the incurred errors are reported immediately, but if the operations of these explicit APIs are performed implicitly, error reporting and handling are less clear.

```
CUfileError_t cuFileBufRegister(const void *devPtr_base, size_t size, int flags);
CUfileError_t cuFileBufDeregister(const void *devPtr_base);
```

3.6. Future cuFile File Stream APIs

Operations that are enqueued with cuFile Stream APIs are FIFO ordered with respect to other work on the stream and must be completed before continuing with the next action in the stream. cuFile Stream APIs require special enabling with the NVreg_EnableStreamMemOPs=1 modprobe.

**Note:** Support for these APIs might be staged over time.

There are two flavors of these two APIs, for runtime APIs and types (cudaStream_t) and those for the driver (CUstream). We anticipate that the runtime APIs will be integrated into cuda.h, and the driver APIs will be integrated into cuda_runtime.h.

```
CUfileError_t cuFileReadAsync(CUFileHandle_t fh, void *devPtr_base, size_t *size, off_t *file_offset, off_t *devPtr_offset, ssize_t *bytes_read, CUStream stream);
CUfileError_t cuFileWriteAsync(CUFileHandle_t fh, void *devPtr_base, size_t *size, off_t *file_offset, off_t *devPtr_offset, ssize_t *bytes_written, CUstream stream);
```

3.7. Future cuFile Batch APIs

cuFile Batch APIs enable an arbitrary mix of read and write transactions, multiple files, and multiple locations in a file in one dispatch. Operations enqueued with cuFile Batch APIs are FIFO ordered with respect to other work on the stream, and must be completed before continuing to the next action in the stream.

Individual operations in each batch might be reordered with respect to each other.

**Note:** The batch APIs are considered experimental and might take a different form later or be absorbed into other approaches such as CUDA Graphs.
Support for these APIs might be staged over time. There are two flavors of these two APIs: runtime APIs and types (`cudaStream_t`) and APIs for the driver (CUstream). We anticipate that the runtime APIs will be integrated into `cuda.h`, while the driver APIs will be integrated into `cuda_runtime.h`.

```c
CUfileError_t
    cudaFileBatchIOSubmit(int *batch_idp, int nr, CUfileIOParams_t *iocbp,
                       unsigned int flags, cudaStream_t stream);
CUfileError_t
    cuFileBatchIOSubmit(int *batch_idp, int nr, CUfileIOParams_t *iocbp,
                       unsigned int flags, CUstream stream);
CUfileError_t
    cuFileBatchIOGetStatus(int batch_idp, int *nr, CUfileIOParams_t *iocbp);
CUfileError_t cuFileBatchIOCancel(int batch_idp);
void cuFileBatchIODestroy(int batch_idp);
```
Chapter 4. cuFile API Functional Specification

This section provides information about the cuFile API functional specification. See the GPUDirect Storage Overview Guide for a high-level analysis of the set of functions and their relation to each other. We anticipate adding additional return codes for some of these functions.

All cuFile APIs are called from the CPU.

4.1. cuFileDriver API Functional Specification

This section provides information about the cuFileDriver API functional specification.

4.1.1. cuFileDriverOpen

CUfileError_t cuFileDriverOpen();

Opens the Driver session to support GDS IO operations.

Parameters

- None

Returns

- **CU_FILE_SUCCESS** on a successful open, or if the driver is already open.
- **CU_FILE_DRIVER_NOT_INITIALIZED** on a failure to open the driver.
- **CU_FILE_PERMISSION_DENIED** on a failure to open. This can happen when the character device (/dev/nvidia_fs[0-15]) is restricted to certain users by an administrator, for example, admin, where /dev is not exposed with read permissions in the container.
- **CU_FILE_DRIVER_VERSION_MISMATCH**, when there is a mismatch between the cuFile library and its kernel driver.
- **CU_FILE_CUDA_DRIVER_ERROR** if the CUDA driver failed to initialize.
- **CU_FILE_PLATFORM_NOT_SUPPORTED** if the current platform is not supported by GDS.
CU_FILE_NVFS_SETUP_ERROR for a cuFile-specific internal error.

Refer to the cufile.log file for more information.

**Description**

- This API opens the session with the NVFS kernel driver to communicate from userspace to kernel space and calls the GDS driver to set up the resources required to support GDS IO operations.
- The API checks whether the current platform supports GDS and initializes the cuFile library.
- This API loads the cuFile settings from a JSON configuration file in /etc/cufile.JSON. If the JSON configuration file does not exist, the API loads the default library settings. To modify this default config file, administrative privileges are needed. The administrator can modify it to grant cuFile access to the specified devices and mount paths and also tune IO parameters (in KB, 4K aligned) that are based on the type of workload. Refer to the default config file (/etc/cufile.json) for more information.

4.1.2. **cuFileDriverClose**

```cpp
cuFileDriverClose API
CUfileError_t cuFileDriverClose();
```

- Closes the driver session and frees any associated resources for GDS.
- This happens implicitly upon process exit.
- The driver can be reopened once it is closed.

**Parameters**

- None

**Returns**

- CU_FILE_SUCCESS on a successful close.
- CU_FILE_DRIVER_NOT_INITIALIZED on failure.

**Description**

- Close the GDS session and any associated memory resources. If there are buffers registered by using cuFileBufRegister, which are not unregistered, a driver close implicitly unregisters those buffers. Any in-flight IO when cuFileDriverClose is in-progress will receive an error.

4.1.3. **cuFileDriverGetProperties**

```cpp
cuFileDriverGetProperties API.
CUfileError_t cuFileDriverGetProperties(cuFileDrvProps_t *props);
```

The cuFileDrvProps_t structure can be queried with cuFileDriverGetProperties and selectively modified with cuFileDriverSetProperties. The structure is self-describing, and its fields are consistent with the major and minor API version parameters.
Gets the Driver session properties for GDS functionality.

**Parameters**

*props*

- Pointer to the cuFile Driver properties.

**Returns**

- CU_FILE_SUCCESS on a successful completion.
- CU_FILE_DRIVER_NOT_INITIALIZED on failure.
- CU_FILE_DRIVER_VERSION_MISMATCH on a driver version mismatch.
- CU_FILE_INVALID_VALUE if input is invalid.

**Description**

This API is used to get current GDS properties and nvidia-fs driver properties and functionality, such as support for SCSI, NVMe, and NVMe-OF.

This API is used to get the current nvidia-fs drivers-specific properties such as the following:

- **major_version**: the cuFile major version
- **minor_version**: the cuFile minor version
- **props.nvfs.dstatusflags**, which are bit flags that indicate support for the following driver features:
  - CU_FILE_EXASCALER_SUPPORTED, a bit to check whether the DDN EXAScaler parallel filesystem solutions (based on the Lustre filesystem) client supports GDS.
  - CU_FILE_WEKAFS_SUPPORTED, a bit to check whether WekaFS supports GDS.
- **Props.nvfs.dcontrolflags**, which are bit flags that indicate the current activation for driver features:
  - CU_FILE_USE_POLL_MODE, when bit is set, IO uses polling mode.
  - CU_FILE_ALLOW_COMPAT_MODE, if the value is 1 compatible mode is set. Otherwise, the compatible mode is disabled.
- **Props.fflags**, which are bit flags that indicate whether the following library features are supported:
  - CU_FILE_STREAMS_SUPPORTED, an attribute that checks whether CUDA-streams are supported.
  - CU_FILE_DYN_ROUTING_SUPPORTED, an attribute that checks whether dynamic routing feature is supported.
- **Props.nvfs.poll_thresh_size**, a maximum IO size, in KB and must be 4K-aligned, that is used for the POLLING mode.
- **Props.nvfs.max_direct_io_size**, a maximum GDS IO size, in KB and must be 4K-aligned, that is requested by the nvidia-fs driver to the underlying filesystem.
- Props.max_device_cache_size, a maximum GPU buffer space per device, in KB and must be 4K-aligned. Used internally, for example, to handle unaligned IO and optimal IO path routing. This value might be rounded down to the nearest GPU page size.
- Props.max_device_pinned_mem_size, a maximum buffer space, in KB and must be 4K-aligned, that is pinned and mapped to the GPU BAR space. This might be rounded down to the nearest GPU page size.
- Props.per_buffer_cache_size, a GPU bounce buffer size, in KB, used for internal pools.

Additional Information
Support for NVMe, NVMe-OF, and SCSI are experimental.

See the following for more information:
- cuFileDriverSetPollMode(bool poll, size_t poll_threshold_size)
- cuFileDriverSetMaxDirectIOSize(size_t max_direct_io_size)
- cuFileDriverSetMaxCacheSize(size_t max_cache_size)
- cuFileDriverSetMaxPinnedMemSize(size_t max_pinned_memory_size)

4.1.4. cuFileDriverSetPollMode(bool poll, size_t poll_threshold_size)

Sets whether the Read/Write APIs use polling to complete IO operations. If poll mode is enabled, an IO size less than or equal to the threshold value is used for polling.
- The poll_threshold_size must be 4K aligned.

Parameters
- poll
  - Boolean to indicate whether to use the poll mode.
- poll_threshold_size
  - IO size to use for POLLING mode in KB.
  - The default value is 4KB.

Returns
- CU_FILE_SUCCESS on a successful completion.
- CU_FILE_DRIVER_NOT_INITIALIZED on failure to load the driver.
- CU_FILE_DRIVER_UNSUPPORTED_LIMIT on failure to set with valid threshold size

Description
This API is used in conjunction with cuFileGetDriverProperties. This API is used to set whether the library should use polling and the maximum IO threshold size less than or equal to which it will poll.

This API overrides the default value that may be set through the JSON configuration file using the config keys properties.poll_mode and properties.poll_max_size_kb for the current process.

See the following for more information:
  ▶ cuFileDriverGetProperties

### 4.1.5. cuFileDriverSetMaxDirectIOSize(size_t max_direct_io_size)

The following is information about the cuFileDriverSetMaxDirectIOSize(size_t max_direct_io_size) API.

```
CUfileError_t cuFileDriverSetMaxDirectIOSize(size_t max_direct_io_size);
```

- Sets the max IO size, in KB.
  - This parameter is used by the nvidia-fs driver as the maximum IO chunk size in which IO is issued to the underlying filesystem. In compatible mode, this is the maximum IO chunk size that the library uses to issue POSIX read/writes.
  - The max direct IO size must be 4K aligned.

**Parameters**

- **max_direct_io_size**
  - The maximum allowed direct IO size in KB.
  - The default value is 16384KB. This is because typically parallel-file systems perform better with bulk read/writes.

**Returns**

- **CU_FILE_SUCCESS** on successful completion.
- **CU_FILE_DRIVER_NOT_INITIALIZED** on failure to load the driver.
- **CU_FILE_DRIVER_UNSUPPORTED_LIMIT** on failure to set with valid size.

**Description**

This API is used with cuFileGetDriverProperties and is used to set the maximum direct IO size used by the library to specify the nvidia-fs kernel driver the maximum chunk size in which the latter can issue IO to the underlying filesystem. In compatible mode, this is the maximum IO chunk size which the library uses for issuing POSIX read/writes. This parameter is dependent on the underlying GPU hardware and system memory.

This API overrides the default value that might be set through the JSON configuration file by using the properties.max_direct_io_size_kb config key for the current process.

Refer to the following for more information:
4.1.6. cuFileDriverSetMaxCacheSize(size_t max_cache_size)

The following is information about the cuFileDriverSetMaxCacheSize(size_t max_cache_size) API.

CUfileError_t cuFileDriverSetMaxCacheSize(size_t max_cache_size);

Sets the maximum GPU buffer space, in KB, per device and is used for internal use, for example, to handle unaligned IO and optimal IO path routing. This value might be rounded down to the nearest GPU page size.

The max cache size must be 4K aligned.

This API overrides the default value that might be set through the JSON configuration file using the properties.max_device_cache_size_kb config key for the current process.

Parameters

max_cache_size

The maximum GPU buffer space, in KB, per device used for internal use, for example, to handle unaligned IO and optimal IO path routing. This value might be rounded down to the nearest GPU page size.

The default value is 131072KB.

Returns

- CU_FILE_SUCCESS on successful completion.
- CU_FILE_DRIVER_NOT_INITIALIZED on failure to load the driver.
- CU_FILE_DRIVER_UNSUPPORTED_LIMIT on failure to set with valid IO size

Description

This API is used with cuFileGetDriverProperties and is used to set the upper limit on the cache size per device for internal use by the library.

See cuFileDriverGetProperties for more information.

4.1.7. cuFileDriverSetMaxPinnedMemSize(size_t max_pinned_memory_size)

Here is some information about the cuFileDriverSetMaxPinnedMemSize(size_t max_pinned_memory_size) API.

CUfileError_t cuFileDriverSetMaxPinnedMemSize(size_t max_pinned_mem_size);

Sets the maximum GPU buffer space, in KB, that is pinned and mapped. This value might be rounded down to the nearest GPU page size.

The max pinned size must be 4K aligned.

The default value corresponds to the maximum PinnedMemory or the physical memory size of the device.
This API overrides the default value that may be set by the properties.max_device_pinned_mem_size_kb JSON config key for the current process.

Parameters

max_pinned_memory_size

- The maximum buffer space, in KB, that is pinned and mapped to the GPU BAR space.
- This value might be rounded down to the nearest GPU page size.
- The maximum limit may be set to UINT64_MAX, which is equivalent to no enforced limit. It may be set to something smaller than the size of the GPU’s physical memory.

Returns

- CU_FILE_SUCCESS on successful completion.
- CU_FILE_DRIVER_NOT_INITIALIZED on failure to load driver.
- CU_FILE_DRIVER_UNSUPPORTED_LIMIT on failure to set with valid size.

Description

This API is used with cuFileGetDriverProperties and is used to set an upper limit on the maximum size of GPU memory that can be pinned and mapped and is dependent on the underlying GPU hardware and system memory. This API is related to cuFileBufRegister, which is used to register GPU device memory. See cuFileDriverGetProperties for more information.

4.1.8. JSON Configuration File

This section provides the schema for the cufile.json configuration file. The values for each parameter are default values, if the parameters are not listed in the file. APIs are available that correspond to a subset of these parameters. When they are invoked, they override the cufile.json parameter values for the process from which they are called.

The following table lists the usage of different configuration parameters:

<table>
<thead>
<tr>
<th>Configuration Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>logging:dir</td>
<td>The log directory for the cufile.log file. If the log directory has not been enabled, the log file is created under the current working directory. The default value is currently the working directory.</td>
</tr>
<tr>
<td>logging:level</td>
<td>The level indicates the type of messages that will be logged.</td>
</tr>
<tr>
<td></td>
<td>- ERROR indicates log critical errors only.</td>
</tr>
<tr>
<td></td>
<td>- DEBUG indicates the log information that includes error, informational, and debugging the library. The default value is set to ERROR.</td>
</tr>
</tbody>
</table>

The default value is currently the working directory.
<table>
<thead>
<tr>
<th>Configuration Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>properties:max_direct_io_size_kb</td>
<td>This parameter indicates the maximum unit of IO size that is exchanged between the cufile library and the storage system. The default value is set to 16MB.</td>
</tr>
<tr>
<td>properties:max_device_cache_size_kb</td>
<td>This parameter indicates the maximum per GPU memory-size in KB that can be reserved for internal bounce buffers. The default value is set to 128MB.</td>
</tr>
<tr>
<td>properties:max_device_pinned_mem_size_kb</td>
<td>This parameter indicates the maximum per GPU memory-size in KB that can be pinned including the memory for internal bounce buffers. The default value is set to 32GB.</td>
</tr>
<tr>
<td>properties:use_poll_mode</td>
<td>Boolean that indicates whether the cufile library uses polling or synchronous wait for the storage to complete IO. Polling might be useful for small IO transactions. The default value is false.</td>
</tr>
<tr>
<td>properties:poll_mode_max_size_kb</td>
<td>The maximum IO size in KB used as the threshold if polling mode is set to true.</td>
</tr>
<tr>
<td>properties:allow_compat_mode</td>
<td>If this option is set to true, cuFile APIs work functionally with the nvidia-fs driver. The purpose is to test newer file systems for environments where GDS applications do not have the kernel driver installed, or for comparison tests.</td>
</tr>
<tr>
<td>properties:rdma_dev_addr_list</td>
<td>This parameter list provides the list of IPv4 addresses for all the interfaces that can be used for RDMA.</td>
</tr>
<tr>
<td>fs:generic:posix_unaligned_writes</td>
<td>If this option is set to true, the GDS path is disabled for unaligned writes and will go through the POSIX compatibility mode.</td>
</tr>
<tr>
<td>fs:lustre:posix_gds_min_kb</td>
<td>This option is applicable only for the EXAScaler filesystem. It provides an option to fallback to the POSIX compatible mode for IO sizes that are smaller than or equal to the set value. This is applicable for reads and writes.</td>
</tr>
<tr>
<td>denylist:drivers</td>
<td>An administrative setting to disable specific supported storage drivers on the node.</td>
</tr>
<tr>
<td>denylist:devices</td>
<td>An administrative setting to disable specific supported block devices on the node. Not applicable for DFS.</td>
</tr>
<tr>
<td>denylist:mounts</td>
<td>An administrative setting to disable specific mounts in the supported GDS enabled file systems on the node.</td>
</tr>
</tbody>
</table>
The following is the JSON schema:

```json
# /etc/cufile.json
{
    "logging": {
        // log directory, if not enabled will create log file
        // under current working directory
        // "dir": "/home/<xxxxx>",
        // ERROR|WARN|INFO|DEBUG|TRACE (in decreasing order of priority)
        "level": "ERROR"
    },

    "profile": {
        // nvtx profiling on/off
        "nvtx": false,
        // cufile stats level (0-3)
        "cufile_stats": 0
    },

    "properties": {
        // max IO size (4K aligned) issued by cuFile to nvidia-fs driver (in KB)
        "max_direct_io_size_kb": 16384,
        // device memory size (4K aligned) for reserving bounce buffers
        // for the entire GPU (in KB)
        "max_device_cache_size_kb": 131072,
        // limit on maximum memory (4K aligned) that can be pinned
        // for a given process (in KB)
        "max_device_pinned_mem_size_kb": 33554432,
        // true or false (true will enable asynchronous io submission to nvidia-fs driver)
        "use_poll_mode": false,
        // maximum IO request size (4K aligned) within or equal
        // to which library will poll (in KB)
        "poll_mode_max_size_kb": 4,
        // allow compat mode, this will enable use of cufile posix read/writes
        "allow_compat_mode": false,
        // client-side rdma addr list for user-space file-systems
        // (e.g ["10.0.1.0", "10.0.2.0"])
        "rdma_dev_addr_list": [ ]
    },

    "fs": {
        "generic": {
            // for unaligned writes, setting it to true
            // will use posix write instead of cuFileWrite
            "posix_unaligned_writes": false
        },

        "lustre": {
            // IO threshold for read/write (4K aligned) equal to or below
            // which cufile will use posix reads (KB)
        }
    }
}
```
4.2. cuFile IO API Functional Specification

This section provides information about the cuFile IO API function specification.

The device pointer addresses referred to in these APIs pertain to the current context for the caller.

Unlike the non-async version of cuMemcpy, the cuFileHandleRegister, cuFileHandleDeregister, cuFileRead, and cuFileWrite APIs do not have the semantic of being ordered with respect to other work in the null stream.

4.2.1. cuFileHandleRegister

The following is information about the cuFileHandleRegister API.

```c
CUfileError_t cuFileHandleRegister(CUFileHandle_t *fh, CUfileDescr_t *descr);
```

- Register an open file.
- cuFileHandleRegister is required and performs extra checking that is memoized to provide increased performance on later cuFile operations.
- This API is OS agnostic.

**Parameters**

- `fh`
  Valid pointer to the OS-neutral cuFile handle structure supplied by the user but populated and maintained by the cuFile runtime.

- `desc`
  Valid pointer to the OS-neutral file descriptor supplied by the user carrying details regarding the file to be opened such as fd for Linux-based files.

**Returns**

- `CU_FILE_SUCCESS` on successful completion.
CU_FILE DRIVER NOT_INITIALIZED on failure to load the driver.
CU_FILE_IO_NOT_SUPPORTED, if the filesystem is not supported.
CU_FILE_INVALID_VALUE if there are null or bad API arguments.
CU_FILE INVALID_FILE_OPEN_FLAG, if the file is opened with unsupported modes like no O DIRECT, without compat mode enabled, O_APPEND, O_NOCTTY, O_NONBLOCK, O_DIRECTORY, O_NOFOLLOW, O_NOATIME, and O_TMPFILE.
CU_FILE INVALID_FILE_TYPE, if the file path is not valid, not a regular file, not a symbolic link, or not a device file.
CU_FILE HANDLE_ALREADY_REGISTERED if the file is already registered using the same file-descriptor.

Description

Given a file-descriptor will populate and return the cuFileHandle needed for issuing IO with cuFile APIs.
A return value of anything other than CU_FILE_SUCCESS leaves fh in an undefined state but has no other side effects.
By default this API expects the file descriptor to be opened with O_DIRECT mode. But if compatibility mode is enabled, then this requirement is relaxed.
It is recognized that in order to be fully compatible, cuFileHandleRegister should not limit the set of flags that are supported, relative to a POSIX pread or pwrite. But those conditions are not fully tested. Currently checks for O_DIRECT and GDS supported file system-specific checks are relaxed. We anticipate additional relaxation on restrictions over time.

Refer to the following for more information:

- cuFileRead
- cuFileWrite
- cuFileReadAsync
- cuFileWriteAsync
- cuFileHandleDeregister

4.2.2. cuFileHandleDeregister

Here is some information about the cuFileHandleDeregister API.

```c
CUfileError_t cuFileHandleDeregister(CUFileHandle_t *fh);
```

Parameters

- `fh`
  - The file handle obtained from cuFileHandleRegister.

Returns
Note: This API only logs an ERROR level message in the cufile.log file for valid inputs.

Description

- The API is used to release resources that are claimed by cuFileHandleRegister.
  This API should be invoked only after the application ensures there are no outstanding IO operations with the handle. If cuFileHandleDeregister is called while IO on the file is in progress might result in undefined behavior.
- The user is still expected to close the file descriptor outside the cuFile subsystem after calling this API using close system call.
  Closing a file handle without calling cuFileHandleDeregister does not release the resources that are held in the cuFile library. If this API is not called, the cuFile subsystem releases the resources lazily or when the application exits.

See the following for more information:

- cuFileRead
- cuFileWrite
- cuFileHandleDeregister

4.2.3. cuFileRead

The following is information about the cuFileRead API.

```
ssize_t cuFileRead(CUFileHandle fh, void *devPtr_base, size_t size, off_t file_offset, off_t devPtr_offset);
```

- Reads specified bytes from the file descriptor into the device memory.

Parameters

- `fh`
  File descriptor for the file.
- `devPtr_base`
  Base address of buffer in device memory. For registered buffers, devPtr_base must remain set to the base address used in the cuFileBufRegister call.
- `size`
  Size in bytes to read.
- `file_offset`
  Offset in the file to read from.
- `devPtr_offset`
  Offset relative to the devPtr_base pointer to read into. This parameter should be used only with registered buffers.

Returns
- Size of bytes that were successfully read.
- -1 on an error, so errno is set to indicate filesystem errors.
- All other errors return a negative integer value of the CUfileOpError enum value.

**Description**

This API reads the data from a specified file handle at a specified offset and size bytes into the GPU memory by using GDS functionality. The API works correctly for unaligned offsets and any data size, although the performance might not match the performance of aligned reads. This is a synchronous call and blocks until the IO is complete.

**Note:** For the devPtr_offset, if data will be read starting exactly from the devPtr_base that is registered with cuFileBufRegister, devPtr_offset should be set to 0. To read starting from an offset in the registered buffer range, the relative offset should be specified in the devPtr_offset, and the devPtr_base must remain set to the base address that was used in the cuFileBufRegister call.

See the following for more information:

- cuFileWrite
- cuFileReadAsync
- cuFileWriteAsync

### 4.2.4. cuFileWrite

The following is information about the cuFileWrite API.

```c
ssize_t cuFileWrite(CUFileHandle fh, const void *devPtr_base, size_t size, off_t file_offset, off_t devPtr_offset);  
```

- Writes specified bytes from the device memory into the file descriptor using GDS.

**Parameters**

- **fh**
  - File descriptor for the file
- **devPtr_base**
  - Base address of buffer in device memory. For registered buffers, devPtr_base must remain set to the base address used in the cuFileBufRegister call.
- **size**
  - Size in bytes to which to write.
- **file_offset**
  - Offset in the file to which to write.
- **devPtr_offset**
  - Offset relative to the devPtr_base pointer from which to write. This parameter should be used only with registered buffers.

**Returns**
Description

This API writes the data from the GPU memory to a file specified by the file handle at a specified offset and size bytes by using GDS functionality. The API works correctly for unaligned offset and data sizes, although the performance is not on-par with aligned writes. This is a synchronous call and will block until the IO is complete.

Note: GDS functionality modified the standard file system metadata in SysMem. However, GDS functionality does not take any special responsibility for writing that metadata back to permanent storage. The data is not guaranteed to be present after a system crash unless the application uses an explicit fsync(2) call. If the file is opened with an O_SYNC flag, the metadata will be written to the disk before the call is complete.

Refer to the note in cuFileRead for more information about devPtr_offset:

Refer to the following for more information:

- cuFileWrite
- cuFileReadAsync
- cuFileWriteAsync

4.3. cuFile Memory Management Functional Specification

The device pointer addresses that are mentioned in the APIs in this section pertain to the current context for the caller. cuFile relies on users to complete their own allocation before using the cuFileBufRegister API and free after using the cuFileBufDeregister API.

4.3.1. cuFileBufRegister

The following is information about the cuFileBufRegister API.

```
CUfileError_t cuFileBufRegister(const void *devPtr_base,
                                size_t size, int flags);
```

- Registers existing cuMemAlloc’d (pinned) memory for GDS IO operations.

Parameters

- devPtr_base
  Address of device pointer. cuFileRead and cuFileWrite must use this devPtr_base as the base address.

- size
  Size in bytes from the start of memory to map.
- **flags**
  
  Reserved for future use, must be 0.

### Returns

- **CU_FILE_SUCCESS** on a successful registration.
- **CU_FILE_NVFS_DRIVER_ERROR** if the nvidia-fs driver cannot handle the request.
- **CU_FILE_INVALID_VALUE** on a failure.
- **CU_FILE_CUDA_DRIVER_ERROR** on CUDA-specific errors. CUresult code can be obtained using `CU_FILE_CUDA_ERR(err)`.
- **CU_FILE_MEMORY_ALREADY_REGISTERED**, if memory is already registered.
- **CU_FILE_INTERNAL_ERROR**, an internal library-specific error.
- **CU_FILE_CUDA_MEMORY_TYPE_INVALID**, for device memory that is not allocated via `cudaMalloc` or `cuMemAlloc`.
- **CU_FILE_CUDA_POINTER_RANGE_ERROR**, if the size exceeds the bounds of the allocated memory.
- **CU_FILE_INVALID_MAPPING_SIZE**, if the size exceeds the GPU resource limits.

### Description

This API registers the specified GPU address and size for use with the `cuFileRead` and `cuFileWrite` operations. The user must call `cuFileBufDeregister` to release the pinned memory mappings.

See the following for more information:

- **cuFileBufDeregister**

4.3.2. **cuFileBufDeregister**

The following is information about the `cuFileBufDeregister` API.

```c
CUfileError_t cuFileBufDeregister(const void *devPtr_base);
```

- Deregisters CUDA memory registered using the `cuFileBufRegister` API.

### Parameters

- **devPtr_base**
  
  Address of device pointer to release the mappings that were provided to `cuFileBufRegister`

### Returns

- **CU_FILE_SUCCESS** on a successful deregistration.
- **CU_FILE_MEMORY_NOT_REGISTERED**, if `devPtr_base` was not registered.
- **CU_FILE_ERROR_INVALID_VALUE** on failure to find the registration for the specified device memory.
- **CU_FILE_INTERNAL_ERROR**, an internal library-specific error.
Description

This API deregisters memory mappings that were registered by cuFileBufRegister. Refer to cuFileBufRegister for more information.

4.4. cuFile Stream API Functional Specification

This section provides information about the cuFile stream API functional specification. The stream APIs are similar to Read and Write, but they take a stream parameter to support asynchronous operations and execute in the CUDA stream order.

4.4.1. cuFileReadAsync

The following is information about the cuFileReadAsync API.

```c
CUfileError_t cudaFileReadAsync(CUFileHandle_t fh, void *devPtr_base,
                                size_t *size, off_t file_offset,
                                off_t devPtr_offset,
                                int *bytes_read, cudaStream_t stream);
CUfileError_t cuFileReadAsync(CUFileHandle_t fh, void *devPtr_base,
                              size_t *size, off_t file_offset,
                              off_t devPtr_offset,
                              int *bytes_read, CUstream stream);
```

- Enqueues a read operation for the specified bytes from the cuFile handle into the device memory by using GDS functionality.
- If non-NULL, the action is ordered in the stream.
- The current context of the caller is assumed.

Parameters

- `fh`
  The cuFile handle for the file.
- `devPtr_base`
  - The base address of the buffer in the device memory into which to read.
  - For registered buffers, `devPtr_base` must remain set to the base address used in cuFileBufRegister call.
- `size`
  Size in bytes to read.
- `file_offset`
  Offset in the file from which to read.
- `devPtr_offset`
  The offset relative to the `devPtr_base` pointer from which to write.
- `bytes_read`
  - The number of bytes successfully read.
-1 on IO errors.
All other errors return a negative integer value of the CUfileOpError enum value.

- stream
  CUDA stream in which to enqueue the operation.
  If NULL, make this operation synchronous.

Returns
- CU_FILE_SUCCESS on a successful submission.
- CU_FILE_DRIVER_ERROR, if the nvidia-fs driver cannot handle the request.
- CU_FILE_ERROR_INVALID_VALUE on a failure.
- CU_FILE_CUDA_ERROR on CUDA-specific errors.
CUresult code can be obtained by using CU_FILE_CUDA_ERR(err).

Description
- This API reads the data from the specified file handle at the specified offset and size bytes into the GPU memory using GDS functionality.
  This is an asynchronous call and enqueues the operation into the specified CUDA stream and will not block the host thread for IO completion. The operation can be waited upon using cuStreamSynchronize(stream).
- The bytes_read memory should be allocated with cuMemHostAlloc or registered with cuMemHostRegister.
  The pointer to access that memory from the device can be obtained by using cuMemHostGetDevicePointer.
- Operations that are enqueued with cuFile Stream APIs are FIFO ordered with respect to other work on the stream and must be completed before continuing to the next action in the stream.

Refer to the following for more information:
- cuFileRead
- cuFileWrite
- cuFileWriteAsync

4.4.2. cuFileWriteAsync

The following is information about the cuFileWriteAsync API.

```c
CUfileError_t cudaFileWriteAsync(CUFileHandle_t fh, void *devPtr_base,
                                 size_t *size, off_t file_offset,
                                 off_t devPtr_offset,
                                 int *bytes_written, cudaStream_t stream);
CUfileError_t cuFileWriteAsync(CUFileHandle_t fh, void *devPtr_base,
                               size_t *size, off_t file_offset,
                               off_t devPtr_offset,
                               int *bytes_written, CUstream_t stream);
```
Queues Write operation for the specified bytes from the device memory into the cuFile handle by using GDS.

Parameters

- `fh`
  The cuFile handle for the file.

- `devPtr_base`
  The base address of the buffer in the device memory from which to write. For registered buffers, `devPtr_base` must remain set to the base address used in the `cuFileBufRegister` call.

- `size`
  Size in bytes to write.

- `file_offset`
  Offset in the file from which to write.

- `devPtr_offset`
  Offset relative to the `devPtr_base` pointer from which to write.

- `bytes_written`
  - The number of bytes successfully written.
  - `-1` on IO errors.
  - All other errors will return a negative integer value of the `CUfileOpError` enum value.

- `stream`
  The CUDA stream to enqueue the operation.

Returns

- `CU_FILE_SUCCESS` on a successful submission.
- `CU_FILE_DRIVER_ERROR`, if the nvidia-fs driver cannot handle the request.
- `CU_FILE_ERROR_INVALID_VALUE` on a failure.
- `CU_FILE_CUDA_ERROR` on CUDA-specific errors.

The CUresult code can be obtained by using `CU_FILE_CUDA_ERR(err)`.

Description

- This API writes the data from the GPU memory to a file specified by the file handle at a specified offset and size bytes by using GDS functionality. This is an asynchronous call and enqueues the operation into the specified CUDA stream and will not block the host thread for IO completion. The operation can be waited upon by using `cuStreamSynchronize(stream)`.

- The `bytes_written` pointer should be allocated with `cuMemHostAlloc` or registered with `cuMemHostRegister`, and the pointer to access that memory from the device can be obtained by using `cuMemHostGetDevicePointer`.
Operations that are enqueued with cuFile Stream APIs are FIFO ordered with respect to other work on the stream and must be completed before continuing to the next action in the stream.

See the following for more information:

- **cuFileRead**
- **cuFileWrite**
- **cuFileReadAsync**

## 4.5. cuFile Batch API Functional Specification

This section provides information about the cuFile batch API functional specification.

Batch APIs can perform a set of IO operations, and these operations can be completed on different files, different locations in the same file, or a mix. The parameter with the array of `CUfileIOParams_t` describes the IO action, status, errors, and bytes transacted for each instance. The bytes transacted field is valid only when the status indicates a completion. The completion description includes a stream and a NULL value that indicates that the batch should occur without stream ordering.

### 4.5.1. cuFileBatchIOSubmit

Here is some information about the `cuFileBatchIOSubmit` API.

```c
CUfileError_t cudaFileBatchIOSubmit(int *batch_idp, int nr, 
    CUfileIOParams_t *iocbp, 
    unsigned int flags, 
    cudaStream_t stream)
```

```c
CUfileError_t cuFileBatchIOSubmit(int *batch_idp, int nr, 
    CUfileIOParams_t *iocbp, 
    unsigned int flags, 
    CUstream stream)
```

**Parameters**

- **batch_idp**
  The address of the output parameter for the newly created batch ID, which is a -1 on an error.

- **nr**
  The number of requests in the params array.

- **iocbp**
  The pointer to contain the `CUfileIOParams_t` array structures of the `len nr` array.

- **flags**
  Reserved as 0.

- **stream**
  Reserved as 0.
The CUDA stream to enqueue the operation.
Both CUDA runtime and CUDA driver variations are offered.

Returns

- CU_FILE_SUCCESS on success.
  *batch_idp will be a value greater than 0.
- CU_FILE_MEM_ALLOC_FAILED on memory allocation failures.
- CU_FILE_DRIVER_ERROR if the nvidia-fs driver cannot handle the request.
- CU_FILE_ERROR_INVALID_VALUE on a failure to correctly set the arguments. Individual status can be checked to determine whether arguments are invalid for one or more IO operation elements.

Description

- This is a batch API to submit a read/write operation on an array of GPU data pointers from their respective file handle, offset, and size bytes. The data is transferred into the GPU memory by using GDS.
  - This is an asynchronous call and will enqueue the operation and provide a batch_id. The operation can be monitored when using this batch_id through cuFileBatchIOGetStatus.
  - The operation might be canceled by calling cuFileBatchIOCancel or cuFileBatchIODestroy.
- The entries in the CUfileIOParams_t array describe the IO action and report the status, errors, and bytes that were transacted for that operation. The bytes transacted field is valid only when the status indicates a completion.
- Operations that are enqueued with cuFile Batch APIs are FIFO ordered with respect to other work on the stream and must be completed before continuing to the next action in the stream. Operations in each batch might be reordered with respect to each another.
- The status field of individual IO operations via CUfileIOParams_t entries will have undefined values before the entire batch is complete. This definition is subject to change.

See the following for more information:

- cuFileRead
- cuFileWrite
- cuFileReadAsync
- cuFileWriteAsync
- cuFileBatchIOGetStatus
- cuFileBatchIOCancel
- cuFileBatchIODestroy
4.5.2. cuFileBatchIOGetStatus

The following is information about the cuFileBatchIOGetStatus API.

```c
CUfileError_t cuFileBatchIOGetStatus(int batch_idp,
                                      int *nrp,
                                      const CUfileIOParams_t *iocbp)
```

**Parameters**

- **batch_idp**
  The address of the output parameter for the newly created batch ID, which is a -1 on an error.

- **nrp**
  The pointer to the number of events that were returned in the batch_id. This will match the `nr` field in cuFileIOSubmit.

- **iocbp**
  The `const` pointer that points to an array of CUfileIOParams_t with nrp-sized array of events. This pointer should not be freed and the `status` field in CUfileIOParams_t will be updated to reflect the current status of each IO in the batch operation. To get the current status, refer to the description of the `status` field in cuFileStatus. The error field will contain the errors encountered during the batch operations for that IO operation in the batch.

**Returns**

- **CU_FILE_SUCCESS** on success.
  The success here refers to the completion of the API. Individual IO status and error can be obtained by examining the returned status and error in the array iocbp.

- **CU_FILE_ERROR_INVALID_VALUE** for an invalid batch ID.

**Description**

- This is a batch API to monitor the status of batch IO operations by using the `batch_id` that was returned by cuFileBatchIOSubmit. The operation will be canceled automatically if cuFileBatchIOCancel is called and the status will reflect CU_FILE_CANCELED for all canceled IO operations.

- The status of each member of the batch is queried, which would not be possible with one CUEvent. The status field of individual IO operations via CUfileIOParams_t entries will have undefined values before the entire batch is completed. This definition is subject to change.

See the following for more information:

- [cuFileBatchIOSubmit](#)
- [cuFileBatchIODestroy](#)
4.5.3. cuFileBatchIOCancel

The following is information about the cuFileBatchIOCancel API.

**CUfileError_t cuFileBatchIOCancel(int batch_idp)**

**Parameters**

- **batch_idp**
  The batch ID to cancel.

**Returns**

- **CU_FILE_SUCCESS** on success.
- **CU_FILE_ERROR_INVALID_VALUE** for an invalid batch ID.

**Description**

- This is a batch API to cancel an ongoing IO batch operation by using the batch_id that was returned by cuFileBatchIOSubmit. This API tries to cancel an individual IO operation in the batch if possible and provides no guarantee about canceling an ongoing operation. The operation will wait for a specific time based on the props.max_batch_io_timeout_msecs value to cancel any ongoing operation or will set the status to **CU_FILE_TIMEOUT**. The operation will be canceled automatically if cuFileBatchIODestroy is called.

Refer to the following for more information:

- cuFileBatchIOGetStatus
- cuFileBatchIOSubmit
- cuFileBatchIODestroy

4.5.4. cuFileBatchIODestroy

The following is information about the cuFileBatchIODestroy API.

**void cuFileBatchIODestroy(int batch_idp)**

**Parameters**

- **batch_idp**
  The address of the output parameter for the newly created batch id, -1 on error.

**Returns**

- **void**

**Description**

This is a batch API that cancels and destroys a batch context and the resources that are allocated with cuFileBatchIOSubmit.

Refer to the following for more information:

- cuFileBatchIOGetStatus
- cuFileBatchIOSubmit
cuFileApiBatchIOCancel
Chapter 5. Sample Program with cuFile APIs

The following sample program uses the cuFile APIs:

```c
#include <fcntl.h>
#include <errno.h>
#include <unistd.h>
#include <cstdlib>
#include <cstring>
#include <iostream>
#include <cuda_runtime.h>
#include "cufile.h"
#include "cufile_sample_utils.h"
using namespace std;

#define TESTFILE "/mnt/gds/gds_test"

int main(void) {
    int fd;
    ssize_t ret;
    void *devPtr_base;
    off_t file_offset = 0x2000;
    off_t devPtr_offset = 0x1000;
    ssize_t IO_size = 1UL << 24;
    size_t buff_size = IO_size + 0x1000;
    CUfileError_t status;
    // CUResult cuda_result;
    int cuda_result;
    CUfileDescr_t cf_descr;
    CUfileHandle_t cf_handle;

    fd = open(TESTFILE, O_CREAT|O_WRONLY|O_DIRECT, 0644);
    if(fd < 0) {
        std::cerr << "file open " << TESTFILE << "errno " << errno << std::endl;
        return -1;
    }

    status = cuFileDriverOpen();
    if (status.err != CU_FILE_SUCCESS) {
        std::cerr << " cuFile driver failed to open " << std::endl;
        close(fd);
        return -1;
    }

    memset((void *)&cf_descr, 0, sizeof(CUfileDescr_t));
    cf_descr_handle.fd = fd;
    cf_descr.type = CU_FILE_HANDLE_TYPE_OPAQUE_FD;
```
status = cuFileHandleRegister(&cf_handle, &cf_descr);
    if (status.err != CU_FILE_SUCCESS) {
        std::cerr << "cuFileHandleRegister fd " << fd << " status " <<
            status.err << std::endl;
        close(fd);
        return -1;
    }
    cuda_result = cudaMalloc(&devPtr_base, buff_size);
    if (cuda_result != CUDA_SUCCESS) {
        std::cerr << "buffer allocation failed " << cuda_result << std::endl;
        cuFileHandleDeregister(cf_handle);
        close(fd);
        return -1;
    }
    status = cuFileBufRegister(devPtr_base, buff_size, 0);
    if (status.err != CU_FILE_SUCCESS) {
        std::cerr << "buffer registration failed " << status.err << std::endl;
        cuFileHandleDeregister(cf_handle);
        close(fd);
        cudaFree(devPtr_base);
        return -1;
    }
    // fill a pattern
    cudaMemcpy((void *) devPtr_base, 0xab, buff_size);
    // perform write operation directly from GPU mem to file
    ret = cuFileWrite(cf_handle, devPtr_base, IO_size, file_offset,
        devPtr_offset);
    if (ret < 0 || ret != IO_size) {
        std::cerr << "cuFileWrite failed " << ret << std::endl;
    }
    // release the GPU memory pinning
    status = cuFileBufDeregister(devPtr_base);
    if (status.err != CU_FILE_SUCCESS) {
        std::cerr << "buffer deregister failed" << std::endl;
        cudaFree(devPtr_base);
        cuFileHandleDeregister(cf_handle);
        close(fd);
        return -1;
    }
    cudaFree(devPtr_base);
    // deregister the handle from cuFile
    (void) cuFileHandleDeregister(cf_handle);
    close(fd);
    // release all cuFile resources
    (void) cuFileDriverClose();
    return 0;
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