Computational Storage API

Version 0.9 rev 1

ABSTRACT: This SNIA Draft Standard defines the interface between an application and a Computational Storage device (CSx). For each CSx there will need to be a library that performs the mapping from the APIs in this specification and the CSx on the specific interface for that CSx.

Publication of this Working Draft for review and comment has been approved by the Computational Storage TWG. This draft represents a “best effort” attempt by the Computational Storage TWG to reach preliminary consensus, and it may be updated, replaced, or made obsolete at any time. This document should not be used as reference material or cited as other than a “work in progress.” Suggestions for revisions should be directed to http://www.snia.org/feedback/.

Working Draft

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USAGE

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1 Scope

This document describes the software application interface definitions for a Computational Storage device CSx. This is the base set of functions and additional libraries are able to be built on this set of functions.

Familiarity to storage and filesystems usage is desired. An understanding on how compute and memory may be utilized in an application and sound understanding of the Operating System environment is required. Applications of computational storage, although not typically restricted, apply to Enterprise and Datacenter usages and applications in high-performance and datacenter environments.

This document is intended for members of the SNIA workgroup and its associates.

1.1 About Computational Storage APIs

Computational Storage (CS) APIs are targeted towards providing a standardized way to access compute offload capable devices. This API specification is based on the SNIA Computational Storage Architecture and Programming Model. These may be connected direct attached or network attached or attached over some kind of fabric. This specification of CS APIs targets both types of connected devices with the aim of providing an interface that is seamless while standardized across all such current and future Computational Storage Devices.

Additionally, the CS APIs may provide an interface that is able to also work when the application is in transition and does not have a device-based offload mechanism in place. For such cases, a host CPU based mechanism may be substituted for a device-based implementation without changing the API interface.

1.2 Document layout

This document is broken down by providing a familiarity of device types, API usages, API definitions and sample code.

2 Definitions, abbreviations, and conventions

For the purposes of this document, the following definitions and abbreviations apply.

2.1 Definitions

2.1.1 Allocated Function Data Memory

Function Data Memory (FDM) that is allocated for a particular instance of an API

Note 1 to entry:

See SNIA Computational Storage Architecture and Programing Model

2.1.2 Computational Storage

architectures that provide Computational Storage Functions coupled to storage, offloading host processing or reducing data movement

Note 1 to entry:

These architectures enable improvements in application performance and/or infrastructure efficiency through the integration of compute resources (outside of the traditional compute & memory architecture) either directly with storage or between the host and the storage. The goal of these architectures is to enable parallel computation and/or to alleviate constraints on existing compute, memory, storage, and I/O.

note 2 to entry:

See SNIA Computational Storage Architecture and Programing Model

2.1.3 Computational Storage Array

collection of Computational Storage Devices, control software, and optional storage devices.

Note 1 to entry:

See SNIA Computational Storage Architecture and Programing Model

2.1.4 Computational Storage Device

Computational Storage Drive, Computational Storage Processor, or Computational Storage Array.

Note 1 to entry:

See SNIA Computational Storage Architecture and Programing Model

2.1.5 Computational Storage Drive

storage element that provides Computational Storage Functions and persistent data storage.

Note 1 to entry:

See SNIA Computational Storage Architecture and Programing Model

2.1.6 Computational Storage Engine

component that is able to execute one or more CSFs

Note 1 to entry

Examples are: CPU, FPGA.

note 2 to entry: See SNIA Computational Storage Architecture and Programing Model

2.1.7 Computational Storage Engine Environment

operating environment for a CSE

Note 1 to entry Examples are: Operating System, Container Platform, eBPF, and FPGA Bitstream.

2.1.8 Computational Storage Function

Specific operations that may be configured and executed by a CSE.

Note 1 to entry

Examples are: compression, RAID, erasure coding, regular expression, encryption.

Note 1 to entry:

See SNIA Computational Storage Architecture and Programing Model

2.1.9 Computational Storage Processor

device that provides Computational Storage Functions for an associated storage system without providing persistent data storage.

Note 1 to entry:

See SNIA Computational Storage Architecture and Programing Model

2.1.10 Computational Storage Resource

resource available for a host to provision on a CSx that enables that CSx to be programmed to perform a CSF

Note 1 to entry

A CSx contains one or more CSEs and each CSE executes one or more CSFs.

Note 2 to entry

Examples: CSE, CPU, memory, and FPGA resources

Note 3 to entry:

See SNIA Computational Storage Architecture and Programing Model

2.1.11 Container

A container does not host a VM but instead binds an application to a container library that provides a secure container-type environment to the application and host OSs. It uses fewer resources and is lightweight compared to a conventional Hypervisor/VM configuration

2.1.12 CSx name

a string that identifies a CSx. This is returned in query requests (e.g., `csQueryCSxList)` and provided to the `csOpenCSx` function

2.1.13 Filesystem

software component that imposes structure on the address space of one or more physical or virtual disks so that applications may deal more conveniently with abstract named data objects of variable size called files

2.1.14 Function Data Memory

Device memory used for storing data that is used by the Computational Storage Functions (CSFs) and is composed of allocated and unallocated Function Data Memory

Note 1 to entry:

See SNIA Computational Storage Architecture and Programing Model

2.1.15 host

computer system to which disks, disk subsystems, or file servers are attached and accessible for data storage and I/O

2.1.16 Hypervisor

host OS with elevated privileges that works with hardware mechanisms such as Intel's VT and VT-d technology and hosts VMs

2.1.17 NVMe®

NVM Express Specification

2.1.18 Peer-to-Peer

data transfer directly between two devices that does not involve a host or host memory

2.1.19 P2P

Peer-to-Peer

2.1.20 PCIe®

Peripheral Component Interconnect Express is a high-speed serial computer expansion bus standard

2.1.21 string

a C language style string

A string is a sequence of characters that are treated as a single data item. A string is terminated by the null character '\0'.

2.1.22 Virtual Machine

virtual machine or guest OS within a virtualized environment

2.2 Keywords

In the remainder of the specification, the following keywords are used to indicate text related to compliance:

2.2.1 ***mandatory***

a keyword indicating an item that is required to conform to the behavior defined in this standard

2.2.2 ***may***

a keyword that indicates flexibility of choice with no implied preference; “may” is equivalent to “may or may not”

2.2.3 ***may not***

keywords that indicate flexibility of choice with no implied preference; “may not” is equivalent to “may or may not”

2.2.4 ***need not***

keywords indicating a feature that is not required to be implemented; “need not” is equivalent to “is not required to”

2.2.5 ***optional***

a keyword that describes features that are not required to be implemented by this standard; however, if any optional feature defined in this standard is implemented, then it shall be implemented as defined in this standard

2.2.6 ***shall***

a keyword indicating a mandatory requirement; designers are required to implement all such mandatory requirements to ensure interoperability with other products that conform to this standard

2.2.7 ***should***

a keyword indicating flexibility of choice with a strongly preferred alternative

2.3 **Abbreviations**

AFDM	Allocated Function Data Memory
API	Application Programming Interface
CSA	Computational Storage Array
CSD	Computational Storage Drive

CSE	Computational Storage Engine
CSEE	Computational Storage Engine Environment
CSF	Computational Storage Function
CSP	Computational Storage Processor
CSR	Computational Storage Resource
CSx	Computational Storage devices
DMA	Direct Memory Access
FDM	Function Data Memory
FPGA	Field-Programmable Gate Array
NVM	Non-Volatile Memory
P2P	Peer-to-Peer
SSD	Solid State Disk
VM	Virtual Machine

2.4 References

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

SNIA Computational Storage Architecture and Programming Model

2.5 Conventions

Text in light blue indicates a common definition (see 6.3)

3 Computational Storage

These APIs provide definitions of functions to support the SNIA Computational Storage Architecture specification.

As defined in the SNIA Computational Storage Architecture specification, Computational storage provides Computational Storage Functions coupled to storage, offloading host processing or reducing data movement.

CSxes as defined in the SNIA Computational Storage Architecture specification includes Computational Storage Processors (CSP), Computational Storage Drives (CSD) and Computational Storage Arrays (CSA) (see Figure 1)

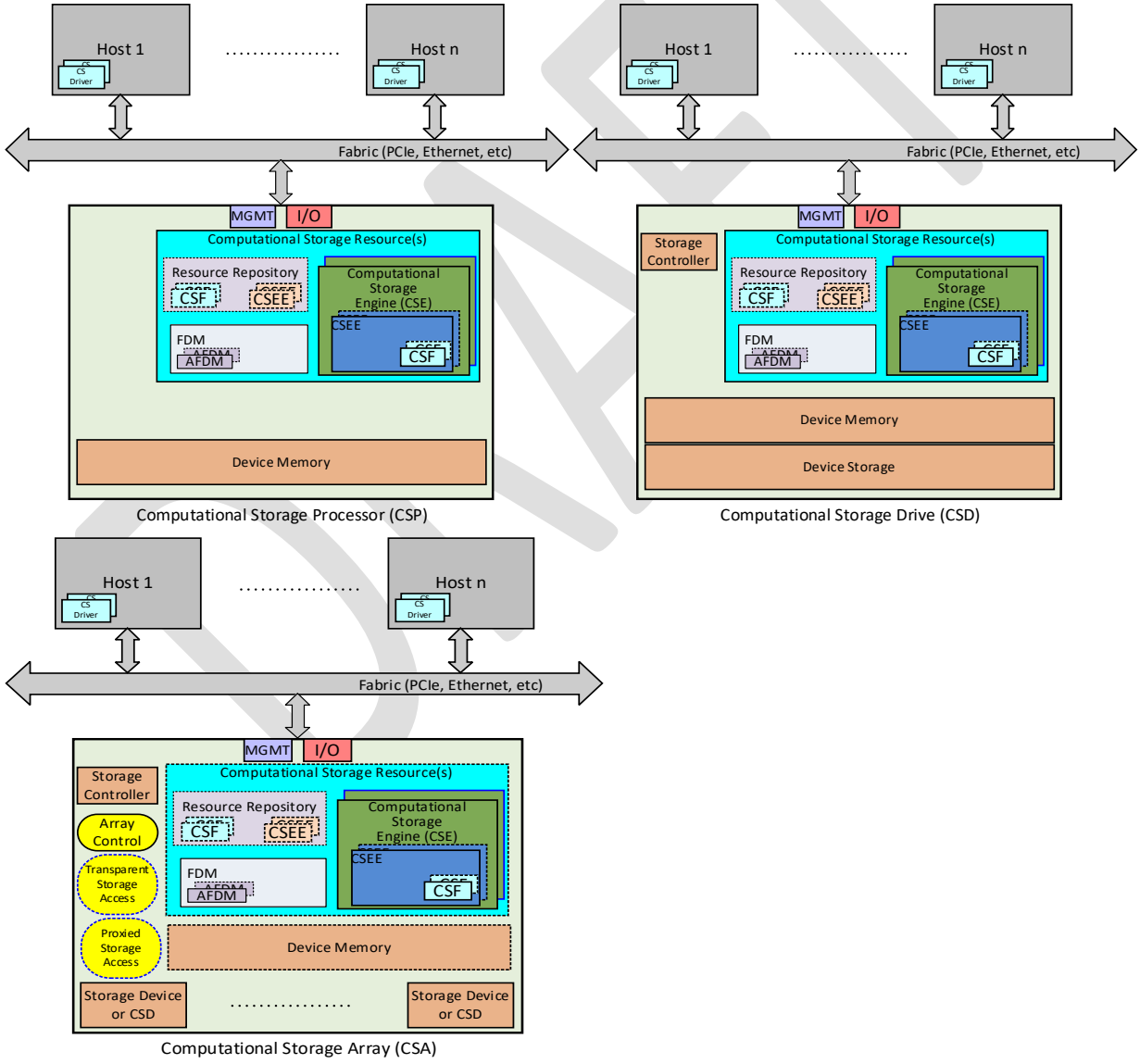


Figure 1: An Architectural view of Computational Storage

Additionally, a Computational Storage Function (CSF) is defined as a data function that performs computation on data as defined in the SNIA Computational Storage Architecture and Programming Model. The table below provides examples of computational storage functions.

Table 1: Example Computational Storage Function Types

Compression
Encryption
Database filter
Erasure coding
RAID
Hash/CRC
RegEx (pattern matching)
Scatter Gather
Pipeline
Video compression
Data Deduplication
Large Data Set

Table 2: Example Computational Storage Engine Environment Types

Operating System Image

Container Image

Berkeley packet filter (BPF)

FPGA Bitstream

The SNIA Computational Storage Architecture and Programming Model defines Host Agents that are able to communicate with the device using a device driver and an interface (e.g., PCIe, Ethernet,). Host Agents are able to perform management, discovery, configuration, monitoring, operations and security on the device. The fixed and programmable computational storage functions are programmable through a Host Agent using a well-defined interface.

This document defines the host level interfaces at the application level using software APIs.

4 APIs Overview

Computational storage is possible with CSEs that are able to execute compute tasks typically run on a host CPU. These CSEs may use FDM that is different from the host memory and memory for storing CSFs. This memory is where computation functions run when they do. A mechanism is needed to transfer data to and from AFDM. These data transfers are required for inputs and outputs to the CSE compute functions. Data transfers to AFDM may be from host memory and/or storage. There are specific APIs that target these operations and interactions with the CSE. This section targets the usage of APIs and how they are able to be used with CSEs for computational storage.

This standard defines a base set of APIs that may be implemented in an API library as shown in Figure 2. Additional libraries are able to be built on this base set of functions. This version of the standard is tailored for a host orchestrated interface. There are additional APIs required for a fully device managed interface.

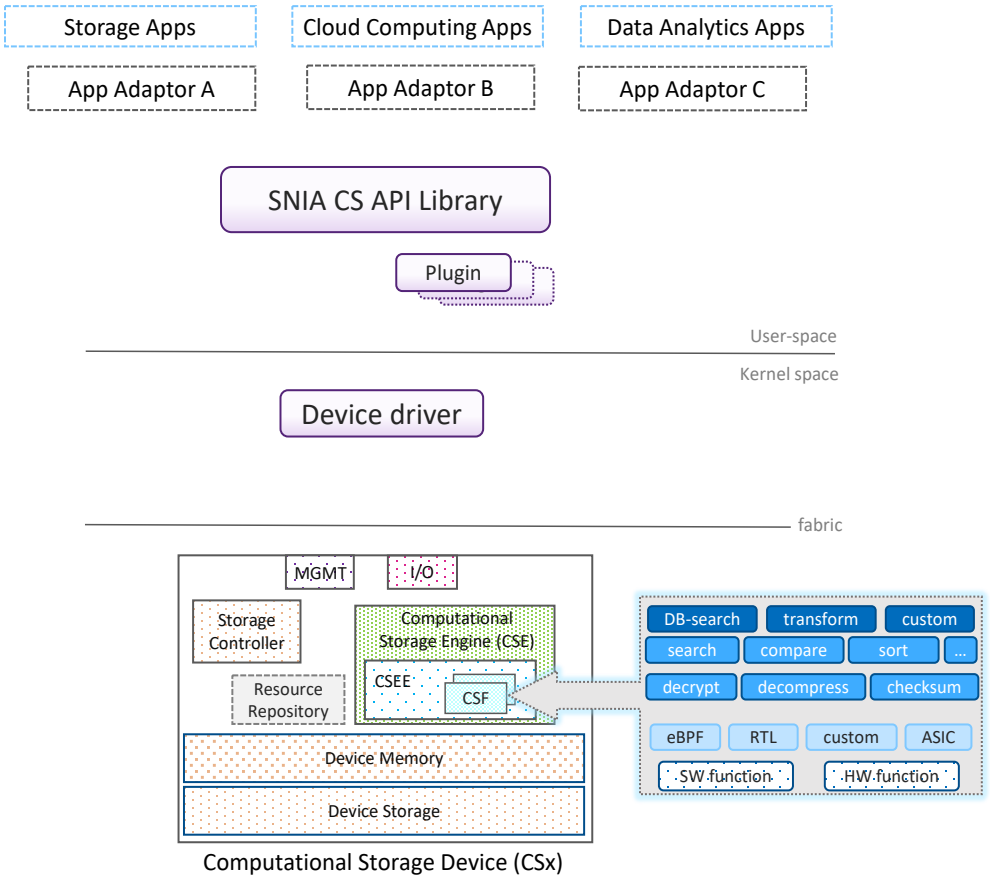


Figure 2: CS API Library

Although the APIs have been tailored for a host managed interface, they also apply to a device managed interface. In the device managed interface, the APIs are performed by

the device. Discovery, access, allocation and configuration of resources and all queued operations directly apply. Only the completion models may need host support to map them (e.g., callback vs. synchronous model).

As Computational Storage APIs provide mechanisms to allocate AFDM, there is a requirement that the case of computation overrunning the AFDM needs to be documented.

If the device that this API interfaces to does not implement a particular API, then the API may return an error or implement an emulation of that API. The default is to return an error.

The interrelation between applications, APIs, CSxes, and functions is shown in Figure 3.

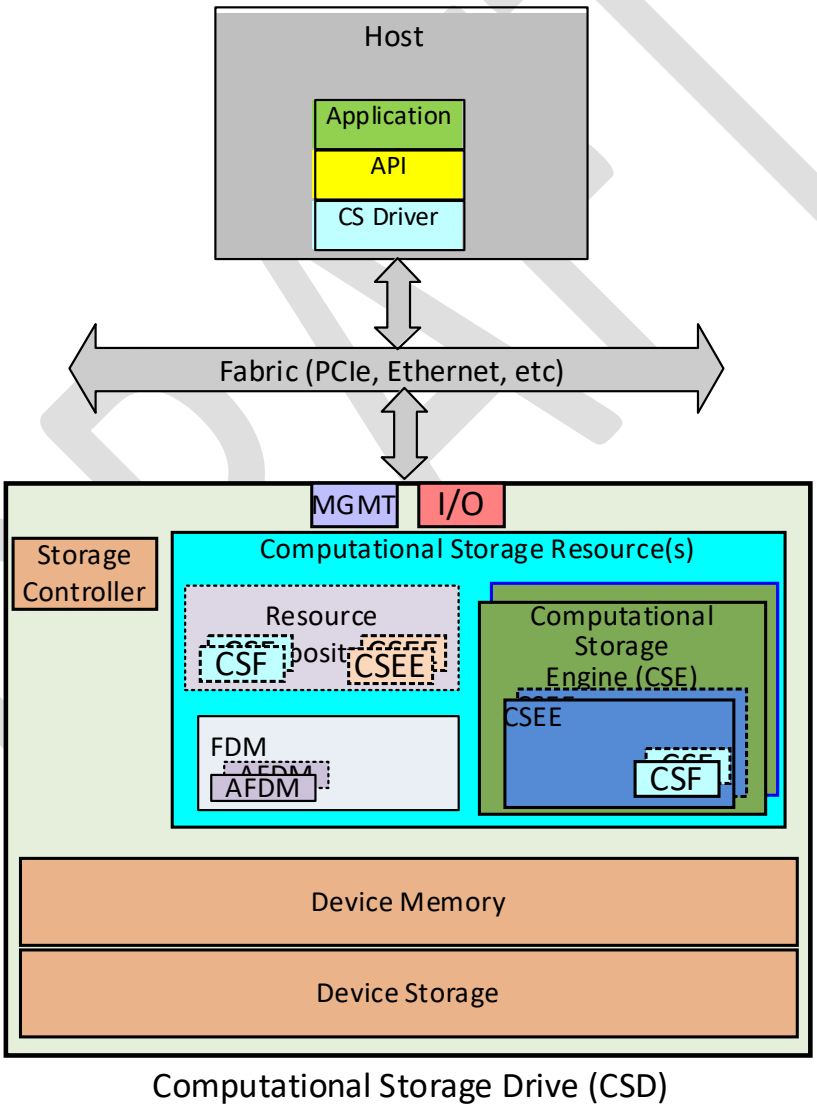


Figure 3: API interrelationships

4.1 Discovery and configuration

As shown in Figure 1, computational storage is provided by CSxes (i.e., CSDs, CSPs and CSAs). Each of these may have their own configurations, that may be specified prior to use (see 6.12.5). The CSx may be directly attached to the host or connected through a network or fabric. This document and the APIs are storage agnostic. This API provides mechanisms for discovery of functionality of CSxes but not discovery of CSxes. We use NVMe as the exemplar fabric throughout.

4.1.1 Discovery

4.1.1.1 CSx Discovery

CSxes may be discovered using the `csQueryCSxList()` API. The API returns a comma separated list of CSxes if there are more than one available. A CSx may also be discovered using the `csGetCSxFromPath()` API, where the path represents a device, directory or file.

Once a CSx is discovered, its resources may be queried with the `csQueryDeviceProperties()` API.

4.1.1.2 Discovery API

The `csQueryDeviceProperties()` API provides individual properties available at different resource levels (e.g., CSx, CSE, CSEE, FDM and CSF). The API also provides details on the repository, activation states and configuration. Figure 4 illustrates how the API may be applied at various resource levels by providing the resource identifier as the input. The engine type here is an abstracted representation of the compute hardware resource and is specific to a device as provided by the vendor. It is uniquely identified by the field `CSETypeToken`. A vendor may choose not to expose engine differences.

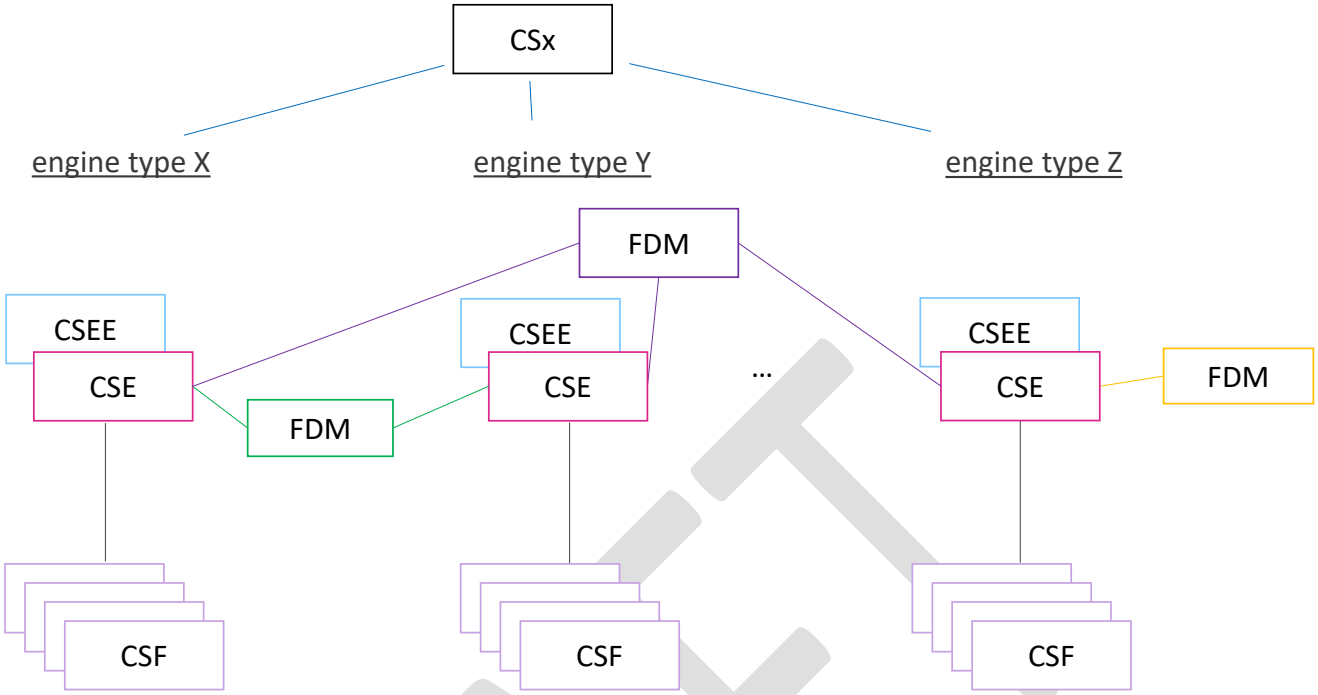


Figure 4: CSx resource overview

The `csQueryDeviceProperties()` API takes the resource type as input and provides the properties of the resource as output. The `csQueryDeviceProperties()` API called with a resource type of `CS_CSx_TYPE` returns the `CsxProperties` data structure as output which denotes hardware and software details of the CSx. Similarly, other resource types may be provided as input to get the necessary outputs, as shown in Figure 4.

Table 3: Device properties by resource type

CS_RESOURCE_TYPE Input	Properties Output
CS_CSx_TYPE	CSxProperties
CS_CSE_TYPE	CSEProperties
CS_CSEE_TYPE	CSEEProperties
CS_FDM_TYPE	FDMProperties

CS_CSF_TYPE	CSFProperties
CS_VENDOR_SPECIFIC_TYPE	CSVendorSpecific

Additional details on the properties data structures and their sub-structures are provided in 6.3.5.3.1.

Figure 5 summarizes the APIs required to discover and configure a CSx and its resources.

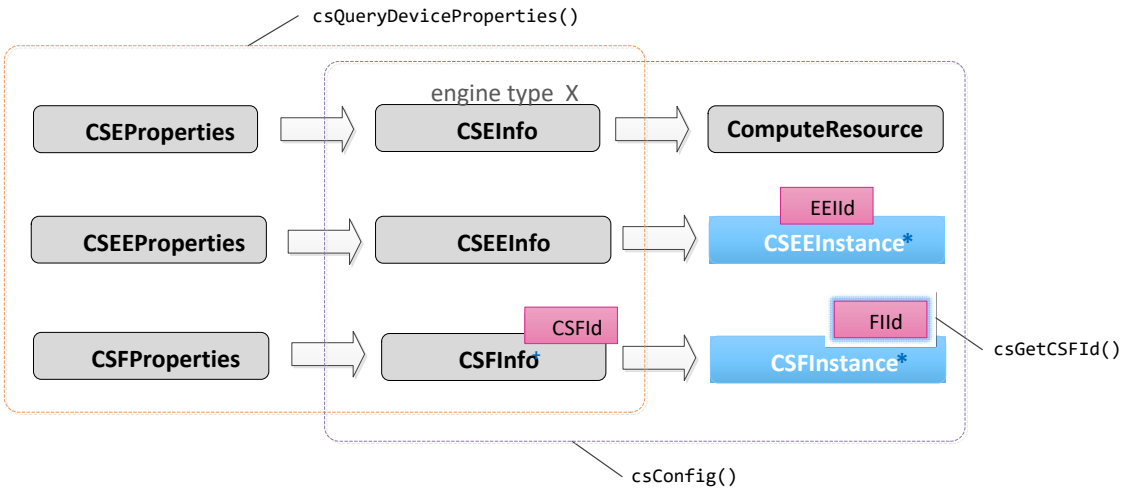


Figure 5: API mapping for discovery and configuration

4.1.1.3 CSF Discovery

CSFs are not executable before activation. Activation is done as described in 4.1.2.2. A list of available CSFs is retrieved using the `csQueryDeviceProperties()` API using the `CS_RESOURCE_TYPE` enumerator `CS_CSF_TYPE`. Activated CSFs may be discovered using the `csGetCSFId()` API and the `csQueryCSFList()` API. Only activated CSF instances denoted by their FIId's will be populated by the `csGetCSFId()` API and the `csQueryCSFList()` API.

4.1.1.4 Example discovery process

The following code example illustrates how the discovery APIs may be applied. The CSx comma separated list is first parsed for individual CSx entries and each entry is queried for each resource as shown below.

```
// query all available CSxes
```

```
status = csQueryCSxList(&len, listBuf);
token = strtok(listBuf, ",");
i = 0;
while (token != NULL) {
    status = csOpenCSx(token, NULL, &devArray[i]);
    // query for CSX properties
    status = csQueryDeviceProperties(devArray[i], CS_CSx_TYPE, &lenCSx, propCSx);
    if (status != CS_SUCCESS)
        ERROR_OUT("Query CSx properties error!\n");
    // query for CSE properties
    status = csQueryDeviceProperties(devArray[i], CS_CSE_TYPE, &lenCSE, propCSE);
    if (status != CS_SUCCESS)
        ERROR_OUT("Query CSE properties error!\n");
    // query for CSEE properties
    status = csQueryDeviceProperties(devArray[i], CS_CSEE_TYPE, &lenCSEE, propCSEE);
    if (status != CS_SUCCESS)
        ERROR_OUT("Query CSEE properties error!\n");
    // query for CSF properties
    status = csQueryDeviceProperties(devArray[i], CS_CSF_TYPE, &lenCSF, propCSF);
    if (status != CS_SUCCESS)
        ERROR_OUT("Query CSF properties error!\n");
    // loop through the whole list
    token = strtok(NULL, ",");
    i++;
}
```

4.1.2 Configuration

A CSx needs to be configured to be usable. Once it has been fully discovered, it may be configured using the `csConfig()` API. Configuration involves activation of the specific resource. This API takes the CsConfigInfo data structure as input to configure the specific resource.

Each resource is identified by an Id field in the associated data structure (e.g., the CSEInfo data structure for a CSE is identified by its unique CSEId).

4.1.2.1 Configuring a CSEE

A CSEE is required to be configured and activated before it may be used. A CSEE is activated by pairing its CSEEId in CSEEInfo data structure with a CSEId in the CSEInfo data structures. More than one engine type may be paired with a CSEE by activating the Id pairs. Figure 6 depicts a CSEE being paired with a CSE whose Ids are provided as input, and on successful activation, return EEIId, the activated CSEE instance.

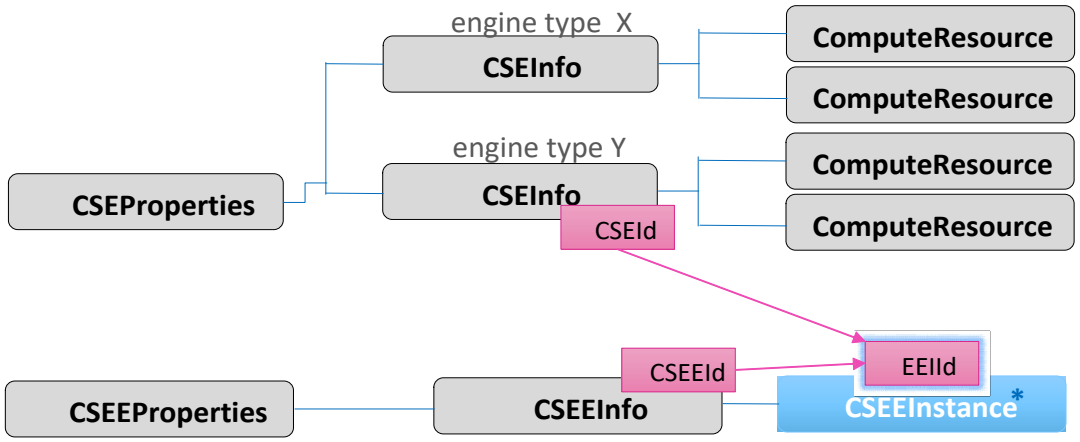


Figure 6: Activating a CSEE

An EEIId is used to configure a CSF. The CSEE activated instance informs the device that it will be utilized for computational storage activities. The device in turn will setup internal configuration options and resources to bring it to this state.

4.1.2.2 Configuring a CSF

Only activated CSFs may be used during execution. Activation of a CSF involves pairing the CSF with an active CSEE instance and one or more compute resources.

As input, a previously activated CSEE instance EEIId is paired with a CSF using its CSFId and one or more compute resources represented by ERId. Figure 7 depicts the flow with the various inputs, and on successful activation, provides FIId for the activated CSF instance as output.

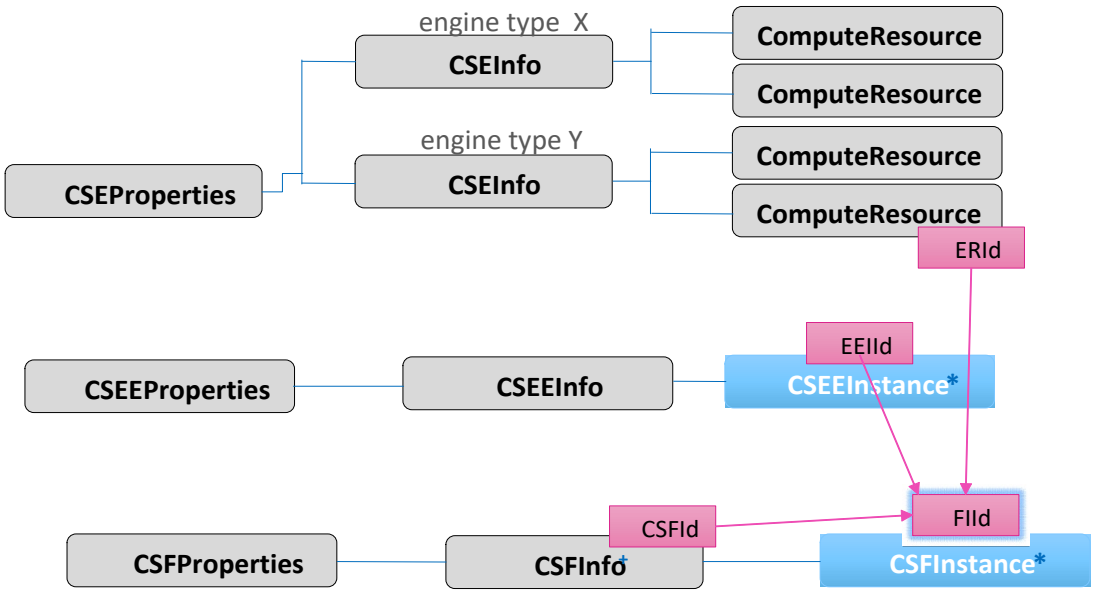


Figure 7: Activating a CSF

Activated resources will consume device resources as part of their internal configuration. CSF's and CSEE's may also be deactivated using the `csConfig()` API. A resource is deactivated when it is no longer required or to release resources for other CSFs or CSEEs(e.g., a well-known algorithm-based CSF that is downloadable may be more performant than the vendor provided CSF that is built-in and therefore the built-in CSF may be deactivated to conserve device resources).

Additional details on configuration data structures are provided in 6.3.5.3.2.

4.2 FDM allocation

FDM is memory that is closest to the CSE and is separate from host memory but may be mapped to a host memory address. FDM is the memory that a computational storage function will operate on. FDM may be exposed to the host (e.g., through a PCIe BAR) when direct attached or not exposed at all for direct or network attached usages.

There may be more than one FDM available to the device as shown in Figure 1. In a device that has more than one CSE, FDM may be configured for different accesses (i.e., one CSE may be configured to access all available FDMs while another CSE may be configured to access only one FDM). These details are discoverable through the device properties API. Since all FDM usage is based on the CSF and the CSE that can access it, an application chooses the appropriate FDM while discovering CSFs through the `csGetCSFId()` API. This API provides a list of all FDMs that the CSF has access to, along with their access details, as specified in `FDMAccess` data structure.

FDM is allocated and deallocated using the `csAllocMem()` API and the `csFreeMem()` API.

4.3 Compute types and execution

CSEs that are able to perform compute offload may be of various types (e.g., ASICs, FPGAs, and embedded CPUs). Execution of compute operations initiated by the `csQueueComputeRequest()` API or the `csQueueBatchRequest()` API are independent of the type of CSE. The type specific functionality of a CSE may be handled by a device driver whose implementation details may be abstracted at the API level.

For cases where a CSx does not exist and compute is conducted on the host CPU, the plugin framework may be utilized to provide similar functionality transparently so that the application does not have to change. Additional details on plugins are available in section 6.13.

4.4 Downloading Functions

In certain CSEEs, CSFs are able to be downloaded. The `csCSFDownload()` API provides the mechanism for downloading CSFs to CSEEs with such capabilities. Following a download, the host may initiate a discovery to determine what CSFs are available.

4.5 Extending API support

The plugin capability of this specification provides the ability to extend capabilities.

A plugin is a software entity that provides the data exchange between the abstracted CS APIs and a device's specific interface. The data exchange is accomplished by having a mapping layer between these interfaces. A Plugin may also abstract specific functionality for a device. Plugins also play a role in providing seamless access, e.g., local or remote connectivity using the same APIs, supporting new features, substituting/aiding in device feature support. Plugins may be applied at various places in a CS API software stack implementation to provide features and to help support a common set of APIs. Plugins are required to be registered first with the API library before they are able to be applied. The `csRegisterPlugin()` API and the `csDeregisterPlugin()` API are used to insert/remove plugin capability in the CS API stack.

4.6 Association of CSP and storage

Association between storage and a CSP is required for any device-to-device activity (e.g., peer-to-peer (P2P)) to function properly. With CSPs, the CSE is a free standing device where storage is separate. Without association, P2P has the possibility of failing since data may not get loaded or stored in the right device. This problem becomes evident when more than one CSP is configured on the same system. The problem becomes severe when the host user application is not able to identify the association between these devices.

For PCIe implementations, issues that arise due to incorrect association result in data corruption, IO failures in the case where the CPU prohibits access across root-complexes, and in virtualized environments where each device may get mapped in a way that has no co-relation at the PCIe bus level.

The mechanism to associate a CSP with one or more storage controllers is vendor specific and is out of scope for this document.

4.7 API usage example

The following example illustrates the usage of CS APIs for a typical flow for near data processing. In this example, the CSD provides decrypt function capability and does not expose FDM to the host. The steps below depict the individual items in Figure 8 for a CSD.

1) Host application allocates FDM input and output buffers for processing in CSx.
2) Data is next initiated to load from the storage device into input AFDM.
3) Data is loaded from the storage device into the AFDM by P2P transfer.
4) The decryption CSF is invoked to work on data in the AFDM.
5) The CSF posts the output data into the output AFDM buffer and notifies the application that the decryption is complete.
6) The output results are copied from the output AFDM to host memory.

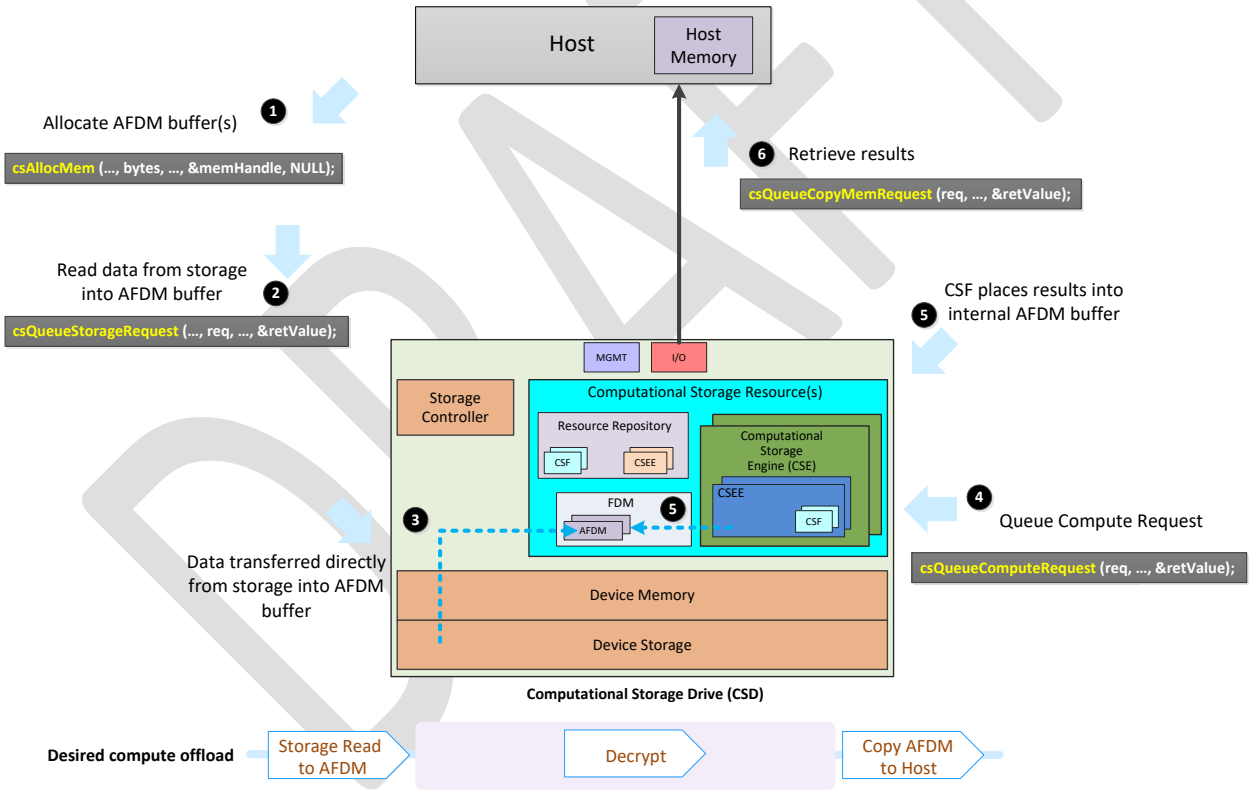


Figure 8: Example API flows

5 Details on Common Usages

5.1 FDM Usage

A CSx has FDM that is allocated for a CSF to use for inputs and outputs. This memory is pre-allocated by the host application prior to its usage.

The `csAllocMem()` API and the `csFreeMem()` API are used to allocate and free FDM. This memory is allocated out of FDM and is referred to as AFDM.

CSxes may implement FDM in different ways. The API abstractions provide a transparent view of the FDM.

5.1.1 FDM usage example for CSD

This CSD example does not expose FDM to the host and hence all data transfers, while opaque, are described using the CS APIs.

When the host allocates FDM buffers, they are referenced as AFDM. Once allocated, these AFDMs may be provided as input and output buffers for loading data from storage media, running compute functions with these data buffers, and copying data to and from host memory.

The host allocates the necessary amount of AFDM buffers with the `csAllocMem()` API.

The loading of storage media into the allocated AFDM is conducted by the `csQueueStorageRequest()` API.

Compute functions provided with these buffers are executed using the `csQueueComputeRequest()` API and the `csQueueBatchRequest()` API.

Data transfers between AFDM and host memory are conducted using the `csQueueCopyMemRequest()` API.

Key resources utilized by CSFs include compute and device memory. In this example, we use a generic CSF to describe compute and memory. For existing CSx architectures, memory usage is as follows:

a) Data transfer from host memory to FDM
    A) Data that the CSF will work on
    B) Input parameters to the CSF
b) Data transfer from FDM to host memory
    A) Data that the CSF returns to host application
    B) Miscellaneous results (e.g., status and other variables)
c) Memory (that is outside of FDM) usage for CSFs

A) Internal device memory usage for CSFs during runtime not accessible by host (e.g., stack, scratchpad, operating system memory when the CSF is hosted by one, device local RAM for device-based functions)

In this architecture, the host pre-populates the data that the CSF has to work on (item a.A above) into the FDM. This is achieved by the device having the capability to transfer data directly between storage and FDM. For a CSx that does not contain storage such as a CSP, the host reads data into host memory from a storage device (e.g., SSD or CSD) and then copies it to FDM on the CSP. These memory transactions involve DMA transfers through the fabric. This is because in this model, the CSFs have no direct DMA access to the host or peer device(s) and vice versa. Similarly, when the CSF has output data (item b.A above) stored in FDM that is required to be written to the media, the data is first DMAed to host memory and then written to the media. Each of these operations require 2 data transactions on the fabric, and in doing so, consume a part or all of the available bandwidth to the CPU. There is a high possibility of running into performance limitations when there are other similar devices populated and when network cards are also transferring data on the same fabric.

5.1.2 Allocating from FDM

FDM is allocated using the `csAllocMem()` API to provide memory for inputs and outputs of the CSF. FDM may or may not be visible in host address space depending on the CSx type. For example, Figure 8 depicts a CSD that does not expose FDM in the host's address space. The `csAllocMem()` API allocates FDM at a granularity as specified by the CSx. In addition to allocating FDM, this API also facilitates mapping it into host's system address space, if the CSx supports this mapping.

5.1.2.1 When to map AFDM to a virtual address

When AFDM is allocated, it should request host address mapping in only the following conditions:

a) AFDM will be passed to the OS filesystem/block subsystem to load data directly from the SSD utilizing the P2P protocol
b) AFDM will be passed to the OS filesystem/block subsystem to commit data directly from CSx to SSD using P2P; and
c) AFDM will be accessed directly from host application software

The allocation request for mapping however depends on the ability of the CSx to have FDM exposed in host address space.

5.1.2.2 When not to map AFDM to a virtual address

AFDM should not request a virtual address pointer when allocated for the following usages:

a) AFDM is not exposed by the device to the host;
b) AFDM is used to transfer data from host memory as input to CSF for computation;

c) AFDM is used to collect results from CSF and subsequently copied back to host memory;
d) AFDM is used in batch requests;
e) When a CSx has large memory area to expose that may run into restrictions with the host systems BIOS;
f) When there are multiple CSxes and the additional exposed memory hits system BIOS limits; and
g) When the CSx is connected remotely.

For data transfers between host memory and device memory, the `csQueueCopyMemRequest()` API provides a mechanism for data transfer. In certain configurations (e.g., a virtualized configuration with a hypervisor), direct device memory access may provide unpredictable results and the DMA request may encounter errors (i.e., even though the memory is mapped with a virtual address, it may still fail if accessed directly).

In these cases, device memory should be accessed through the device DMA engine using this API.

5.1.3 FDM to host memory mapping

FDM may be used as memory mapped to host address space or without a mapping. The device should be queried for its properties using the `csQueryDeviceProperties()` API to verify which modes it supports.

a) memory exposed to host address space with mapping; or
b) memory not exposed to host address space.

5.1.3.1 FDM not exposed to host address space

In this example, FDM allocations with the `csAllocMem()` API do not request a virtual address pointer to be returned by setting the parameter `VaAddressPtr` to NULL. The device provides translations for such allocations internally for their memory locations. For this example, the API hides such details through the abstracted interface and provides the same definitions by skipping the mapping functionality. Remotely connected CSxes also adopt this usage model as they do not expose FDM as a virtual address to the local host.

Storage I/O to this type of FDM is achieved using the `csQueueStorageRequest()` API which facilitates the transfer of data from storage directly to FDM buffers where the transfers do not leave the device. Doing so may save host CPU usage, cache and memory usage, and fabric bandwidth. These savings translate into performance, latency, and power benefits.

5.1.3.2 FDM exposed to host address space

The API definitions support devices that also expose FDM to host address space. In this usage, a virtual address pointer is requested during allocation through the parameter `VaAddressPtr`. With CSxes that map FDM to host memory address space, it is possible to transfer directly between storage and the FDM using P2P. This saves on the

additional hop to host memory, host CPU involvement and in some cases, external fabric transactions.

The `csAllocMem()` API maps the AFDM to host's address space, if the device provides such an interface. With AFDM mapped to host address space, an application is able to perform P2P data transfers between SSD and AFDM using the filesystem.

5.1.3.2.1 *Using AFDM for P2P transfers*

As shown in Figure 9, devices operate with host CPU by exposing AFDM in the host's address space (e.g., the NVMe and CSx both make their memory visible through PCIe BARs). The CPU has full visibility of FDM in this system address space. Devices are able to transfer data to any physical address in host addressable memory.

AFDM is able to be used for P2P transfers as follows:

a) Host software allocates the required amount of FDM using the `csAllocMem`() API with the option of mapping to a virtual address. Memory should be allocated in a size that is aligned to the device and favorable of host software usage (e.g., in host OS page size increments which maps it to the host page boundary), where security protections are able to be enforced;
b) The mapped virtual address is able to be passed to a filesystem or block subsystem for read/write access. Before the AFDM buffer is provided as input to the filesystem, the application is required to ensure that no buffering occurs in the I/O request. This may be achieved by disabling I/Os from being cached by the OS. For filesystems, the file should be opened with the `O_DIRECT` flag so no buffering occurs and the I/O is directly submitted to the OS block layer. If not, the results are indeterminate since data may be directly passed to the CSx and any caching layers in between may prevent this;
c) Memory passed to the SSD is required to start at the minimum offset supported by the block device. This is 4KB for all modern SSDs;
d) The SSD DMAs data to an address that resides on the CSx. P2P is complete when the I/O request is complete and signaled back to the host as part of the normal I/O operations. The DMA transfer that occurred between the SSD and the AFDM does not involve the external fabric if both devices are within the same device enclosure. This action saves fabric bandwidth and associated latencies with the I/O. For user space filesystems and block level accesses, the virtual address returned in step 2 needs to be passed directly through an `ioctl` call to the NVMe driver. Here the SSD block translations may need to be done from the appropriate filesystem to describe the I/O request at the block level;

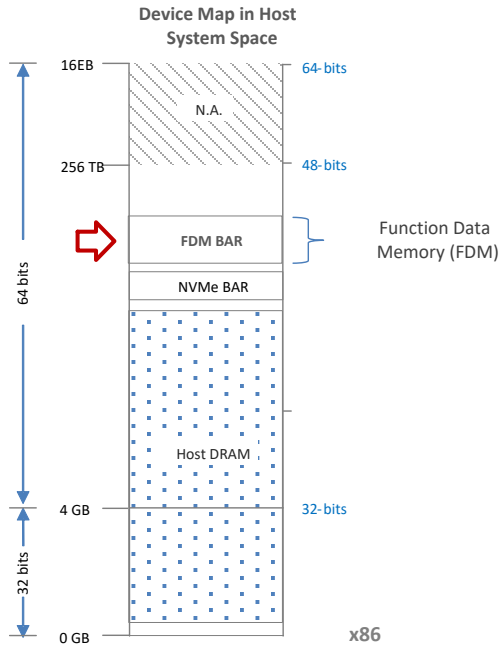


Figure 9: System Memory Map

e) The application then invokes the CSF to act on the data transferred. The CSF has local access to the data transferred since it is in AFDM; and
f) When compute is complete, the CSF passes the data back to the application memory either through the `csQueueCopyMemRequest()` API or committing it directly to SSD as in step 4.

Even though data movement is offloaded from host memory, the host CPU is still involved in the orchestration of data, as this is where the application resides.

There are three key advantages with the peering approach:

a) Reduction of PCIe bus bandwidth utilization;
b) Reduction in CPU utilization due to reduced memory copies; and
c) Reduction in host memory utilization.

5.1.4 Copy data between host memory and AFDM

Data transfers between host memory and AFDM requires only the `csQueueCopyMemRequest()` API.

This API takes data transfer direction as part of the request, as shown in Figure 10.

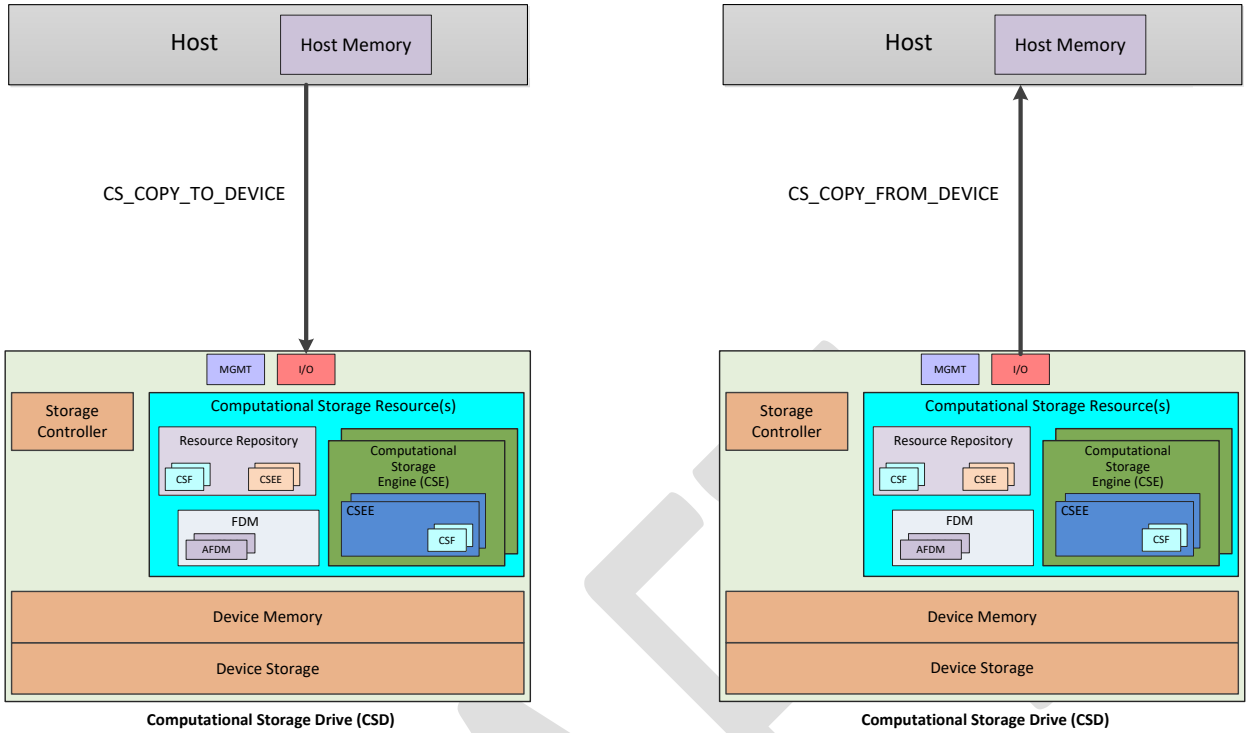


Figure 10: Example data transfers between AFDM in a CSx and host memory

5.2 Scheduling Compute Offload Jobs

Scheduling compute offload is done using the `csQueueComputeRequest()` API. This request API takes as input the CSF to which a job should be queued along with its arguments. The number of arguments and their values should match the definition of the CSF as the API library will not enforce these and the behavior may be undefined.

An advanced method of queuing jobs is batching multiple requests together using the `csQueueBatchRequest()` API. This APIallows multiple jobs to be batched together as one request.

Compute offload jobs require input and produce output. Each of these entities require a job request.

Table 4 summarizes job processing for input, compute and output.

Table 4: Job request processing

Job	Details

Input

Provides input to a compute job. Input to a compute job may be provided in two ways:

Input method	Related function
Storage	a) Use file system calls with device memory mapped to host; and b) Use the csQueueStorageRequest() API with type option CS_STORAGE_LOAD_TYPE
Host memory	Use the csQueueCopyMemRequest() API or the csQueueBatchRequest() API with option CS_COPY_TO_DEVICE

Compute

The actual compute job may be scheduled to run in the following ways:

method	Related function
Single or batch request	Use the csQueueComputeRequest() API for a single request or the csQueueBatchRequest() API for batch request.

Output

Provides output from a compute job. Output from a compute job may be received in two ways:

Input method	Related function
Storage	a) Use file system calls with device memory mapped to host; and b) Use the csQueueStorageRequest() API with type option CS_STORAGE_STORE_TYPE
Host memory	Use the csQueueCopyMemRequest() API or the csQueueBatchRequest() API

with option
CS_COPY_FROM_DEVICE

5.2.1 Batching requests

The `csQueueBatchRequest()` API is an advanced queuing mechanism that minimizes the interactions between host software and the device by optimizing the input(s) and output(s). It is useful in cases where the work required to be performed by the CSx is required to be done in a particular order with a set of operations. These could be serialized jobs, parallelized jobs, or a combination of jobs that may be queued to a CSx. Jobs may be combined into a single batch request and submitted by the application at one time and get notified of a completion response only after all of the batched requests are done.

Batching requests using this API helps the application to pipeline multiple requests by their dependencies, reduce host CPU usage, reduce latencies by having less host context switches, and providing a more optimized execution path. Most computation jobs tend to have a combination of more than one queued job to complete the required task in a combination of input, compute, and output jobs. Batching requests may or may not be supported in hardware. For cases where it is not supported in hardware, the underlying software implementation of the APIs supports this usage and APIs and provide similar functionality. Batch request functionality is able to be discovered using the `csQueryDeviceProperties()` API.

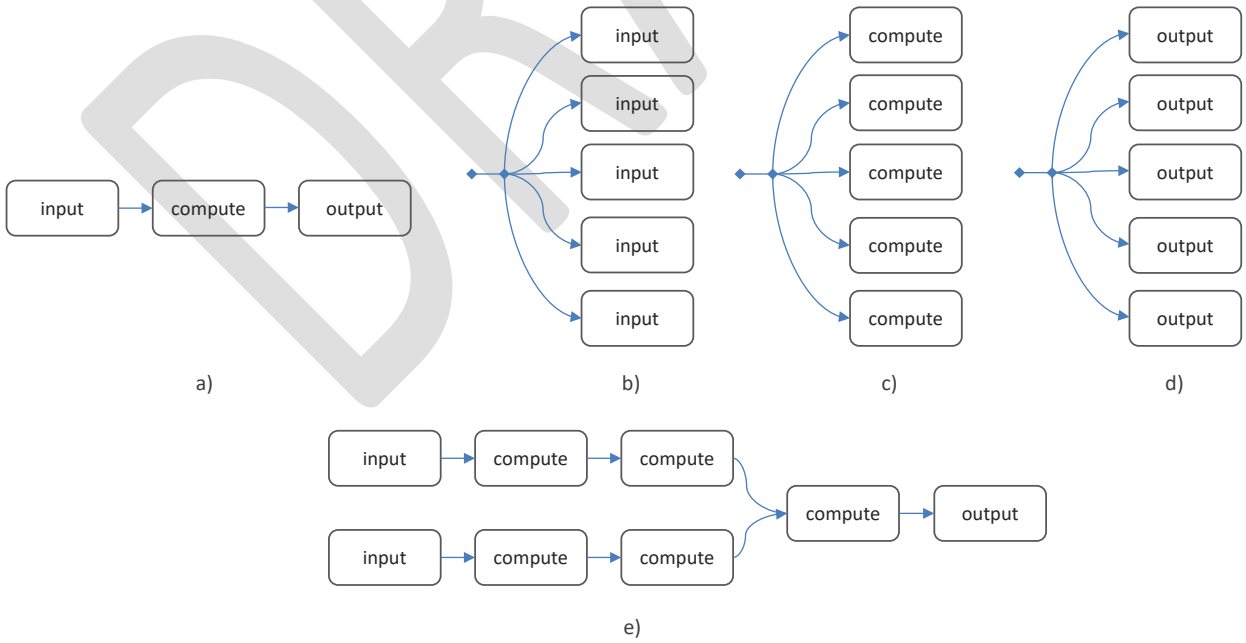


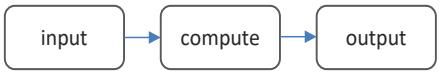
Figure 11: Batch requests

Figure 11 illustrates different types of batch requests. In option a, a serialized notation of job requests using the batching option is shown. In this option, input is the first job and on completion, provides data to the compute job. On completion of the compute job, the results are provided to the output job, which satisifies the serialization and dependency requirements. Options b, c and d illustrate parallel operations of job processing for input, compute and output respectively. Option e represents a more complex batch request where there are more inputs and more compute requests in one batch request. This option also exhibits parallelism and dependencies from the previous job, as applicable. The usage of each job type is defined in Table 4.

Here are a few illustrative examples on how multiple job requests may be scheduled with one request.

5.2.1.1 Serialized operations example

Serialized operations involve dependencies, where the output of the previous job is the input to the next job. Instead of submitting each of these jobs individually, the user is able to create a batch request and post them at one time and get the results after the last job has completed. On the CSx, the requests will be processed serially and will not interrupt the user on completion of each job in the batch.



Applying it with API calls, there are many combinations of these jobs. A serial batch request presents jobs as an array with the order required. Serial batch request implies dependency between the previous and next job and does not require additional dependency details as a hybrid operation does (see 5.2.1.3).

In this example, data is first copied from host memory to device and compute offload work is scheduled after the copy is done. The next operation does not start before the previous operation is completed.

The next example is the same as the previous with the addition of copying the results back to host memory. This example demonstrates an input job, a compute job and an output job.

The following example is a typical flow that manipulates stored data and provides the output back to host.

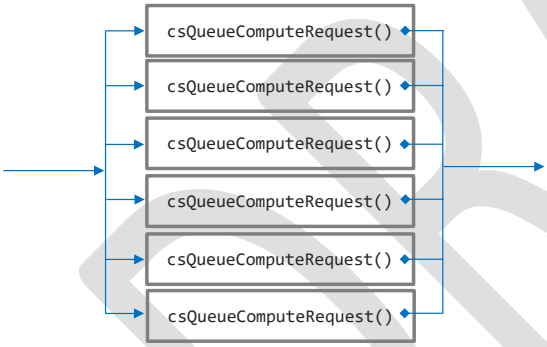
In the following example, the output of a compute request becomes the input to the next compute request.

For additional details, see sample code in section A.3.

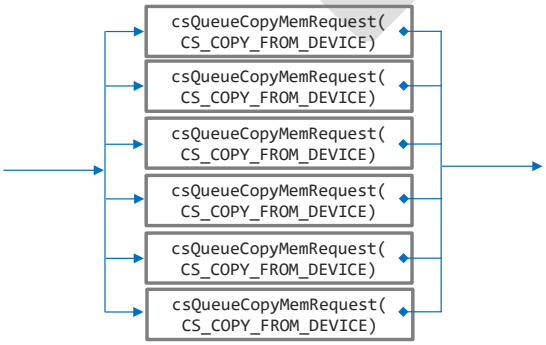
5.2.1.2 Parallelized operations examples

Parallelized operations apply to jobs that are required to be done by multiple CSEs at the same time in a distributed manner. The ability to do so is required to be supported by the CSE.

In this example, 6 compute jobs are initiated at the same time and their completion results are conveyed back after all of them are completed. This type of scheduling and completion greatly simplifies the application orchestration tasks on the host side.



In another example usage, data results may have been completed in AFDM by many CSFs or the results may be fragmented and ready for the host. The batch request helps in collating the results back to the host in a manner similar to scatter gather lists.



With some CSx implementations, DMA copy operations may be more efficient if multiple requests are collapsed together with a single request for best performance.

The parallelized operations apply very well with distributed compute usages not only for single CSEs but also for multiple CSEs and may be more optimal from the execution point of view. As shown in the above two examples, the same operations may be queued to two different CSEs with a single API request. This may provide interesting and powerful application outcomes.

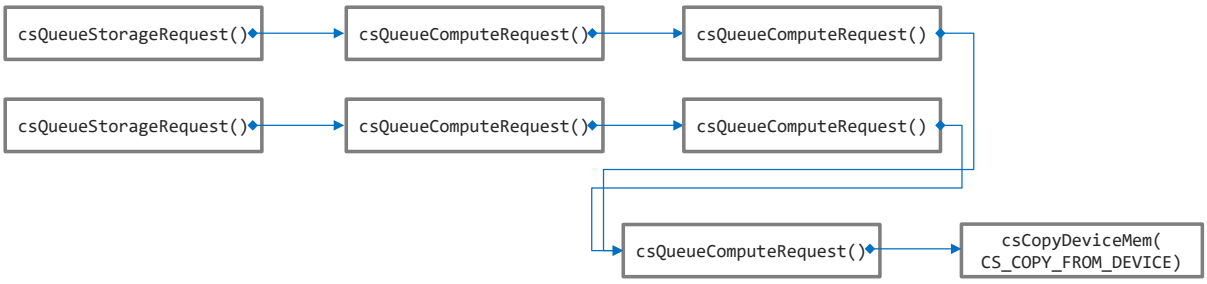
For additional details, see sample code in section A.3.

5.2.1.3 Hybrid operations examples

Hybrid scheduling operations are able to be employed when the current job's input depends on the previous job's output to complete. These may be in any order and nested too. Here are some examples of the combinations.

a) A previous serial/parallel job's output is the input to the next serial/parallel job;
b) A previous storage job's output is the input to the next serial/parallel job; and
c) A previous data copy job's output is the input to the next serial/parallel job.

Each of these use cases has a serialization step between the completion of one operation and execution of the next operation. A dependency exists that one operation has to complete to provide the data required by the subsequent operation. The use case where a serial job depends on a previous serial job is not covered above since it may be handled by serialized operations as listed in section 5.2.1.1. There may also be paths where data dependency does not exist. This may be the case which has multiple inputs at the start of the batch request and where each request may take a different path. The example shown below shows such a case. This is also depicted in Figure 11 option e.



Since a data dependency exists, and the data resides in device space, it is able to be provided as an input to enable hybrid mode using the `csQueueBatchRequest()` API.Batch requests in hybrid mode may take dependencies into account as part of execution. Serial and parallel requests by design are assumed to follow a specific flow and no additional information on dependency may be followed in the execution path.

Scheduling hybrid batch operations is possible using the `csQueueBatchRequest()` API with additional parameters. The additional batch functions define the dependencies

by resource type and provides details on what the current request depends on to complete before it is able to start. Using these dependencies, complex operations as listed in the combinations above are able to be performed by queuing them in advance and allowing the subsystem to take care of the executions and order. This may also be handled directly in the device or by the software framework without application intervention.

In this example, each request represents a node in the batch of requests with `Mode` specifying the operation for that node.

Table 5 summarizes batch operations.

Table 5: Batch requests

Batch mode	Details
serial	A batch request that has more than one request that is executed in pipeline mode, where, the next job will not start until the current job is complete. Since dependency is explicit, only the request details are necessary to execute the batch request. Batch requests are listed serially using the helper functions. Individual APIs that are able to be batched serially are the `csQueueStorageRequest()` API, the `csQueueComputeRequest()` API and the `csQueueCopyMemRequest()` API.
parallel	In this mode of execution, the intended purpose is to breakdown a larger request into smaller jobs and execute them independently. There is no dependency on any of these parallel jobs within the request and they may all start together at the same time. The `csQueueStorageRequest()` API, the `csQueueComputeRequest()` API, or the `csQueueCopyMemRequest()` API are able to be batched in a single request to execute in parallel. These APIs may also be mixed together and also run in parallel. The supporting hardware is required to support the required parallelism for this batch operation to execute as intended.

hybrid	In this mode, complex and nested operations are able to be performed with the batch request. The `csQueueStorageRequest()` API, the `csQueueComputeRequest()` API, and the `csQueueCopyMemRequest()` API are able to be batched in a single request to execute in batch mode. The sequence of requests may be included as single requests or as a series of nested graph operations.

For additional details, see sample code in section A.3.

5.2.2 Optimal Scheduling

Batch based scheduling requests provide optimal IO flows to and from CSFs. The scheduling of compute and data movement internally utilize the most efficient path available through the compute offload device. No separate calls are necessary to prepare for it.

Some attention has to be placed on the CSE if more than one CSF is queued for execution at the same time. If multiple CSFs are queued on a CSE, then function grouping is required to be used to provide hints during scheduling. Grouping is achieved by the `csGroupComputeByIds()` API.

When compute has to be aligned to utilize a CSF without idle time in-between executions, the scheduler, by design, should manage the transitions between different execution times most efficiently.

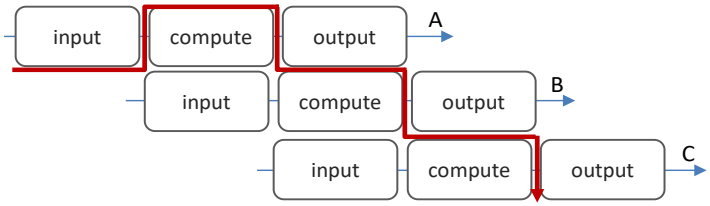


Figure 12: Optimal CSF Scheduling

Figure 12 depicts compute being utilized very efficiently with minimal idle time. A, B and C are separate batch request executions that use a single CSF. For this example, start of execution also depends on when the previous input request completes.

5.3 Working with CSFs

CSF functionality depends on its CSE implementation. Since CSEs types may be built differently from one another, a CSF for one type of CSE may not have similar characteristics to a CSF for another type of CSE. A CSF for one CSE type may not work with another CSE type. Some CSFs may be able to execute multiple instances from one image while others may require their own image instance to run.

A CSx may be preloaded with zero or more CSFs by the manufacturer. CSFs may also be downloaded. These two sources for CSFs and the available count are dependent on the implementation of the CSx, CSEE and CSE resources. CSFs may be downloaded using the `csCSFDownload()` API.

A CSF may be represented by a name such as compress, checksum etc. Since a name string may not be able to uniquely represent a CSFs implementation, a global unique identifier is also supported. This identifier may provide a standardized representation of the CSF's algorithmic implementation.

A CSF by default resides in the resource repository. CSFs are required to be configured and activated before they can be executed. This involves pairing the CSF with the correct CSE and CSEE environment. Configuration and activation is achieved using the `csConfig()` API. They are discovered for this step using the `csQueryDeviceProperties()` API. Both of these APIs are privileged operations and are used to setup a CSx.

Activated CSFs are discoverable by non-privileged users using the `csGetCSFId()` API which returns details on one or more CSFs in the `CSFIdInfo` data structure. These details include a `CSFId` that may be used to execute the CSF, relative performance and power details, which may be used to choose a CSF from the list, and a count of the instances available for execution.

Executing a CSF is done using the `csQueueComputeRequest()` API. An advanced version of execution may also be achieved using the `csQueueBatchRequest()` API, which facilitates batching a sequence of operations.

To save reqources, a CSF instance, if not utilized, may be deactivated using the `csConfig()` API. A CSF that was previously downloaded may be unloaded using the `csCSFDownload()` API.

5.4 Completion Models

Storage, Memory Copy and Compute requests use a queued IO model, where the request may be queued. These requests have three different options to complete the

request as shown in Table 6. The requests may be queued for synchronous or asynchronous completions.

With the synchronous completion model, the request does not return before it is completed from the API library.

With an Asynchronous completion model, the request may be queued with a callback API or with an event. The callback API will be notified asynchronously in an arbitrary thread context when request completes. With events, the user may poll using the `csPollEvent()` API in the callers context and when ready to process the completion. The IO for both asynchronous completion types get a completion back only when the request at the device is complete.

Table 6: Completion Models

Completion Model	Inputs	Description

Synchronous	`Context = NULL`
	
	`CallbackFn = NULL`
	
	`EventHandle = NULL`
		This is a blocking model, where the submitted request will not return to caller until complete.

Asynchronous Callback	`Context = <User Context>`
	
	`CallbackFn = <User Callback API>`
	
	`EventHandle = NULL`
		This is a non-blocking model, where the user callback API is notified when the requested IO is complete.

Asynchronous Event	`Context = <User Context>`
	
	`CallbackFn = NULL`
	
	`EventHandle = <User Event handle>`
		This is a non-blocking model, where the user event is signaled when the requested IO is complete. The user is able to poll the event handle for completion status to change from `CS_QUEUED`.

6 CS API Interface Definitions

CS APIs enable interfacing with one or more CSEs and provide near storage processing access methods. Definitions will be provided in the following file

#include "cs.h"

This header file defined for a C programming language contains structures, data types and interface definitions. The associated interface definitions for the APIs will be provided as a user space library. The details of the library are out of scope for this document.

6.1 API Access and flow conventions

The API definitions listed in this section use the following convention for handles. Handles have very specific usage. Only one handle is accepted per task as the main input and additional handles will be referenced either as arguments or internally based on reference.

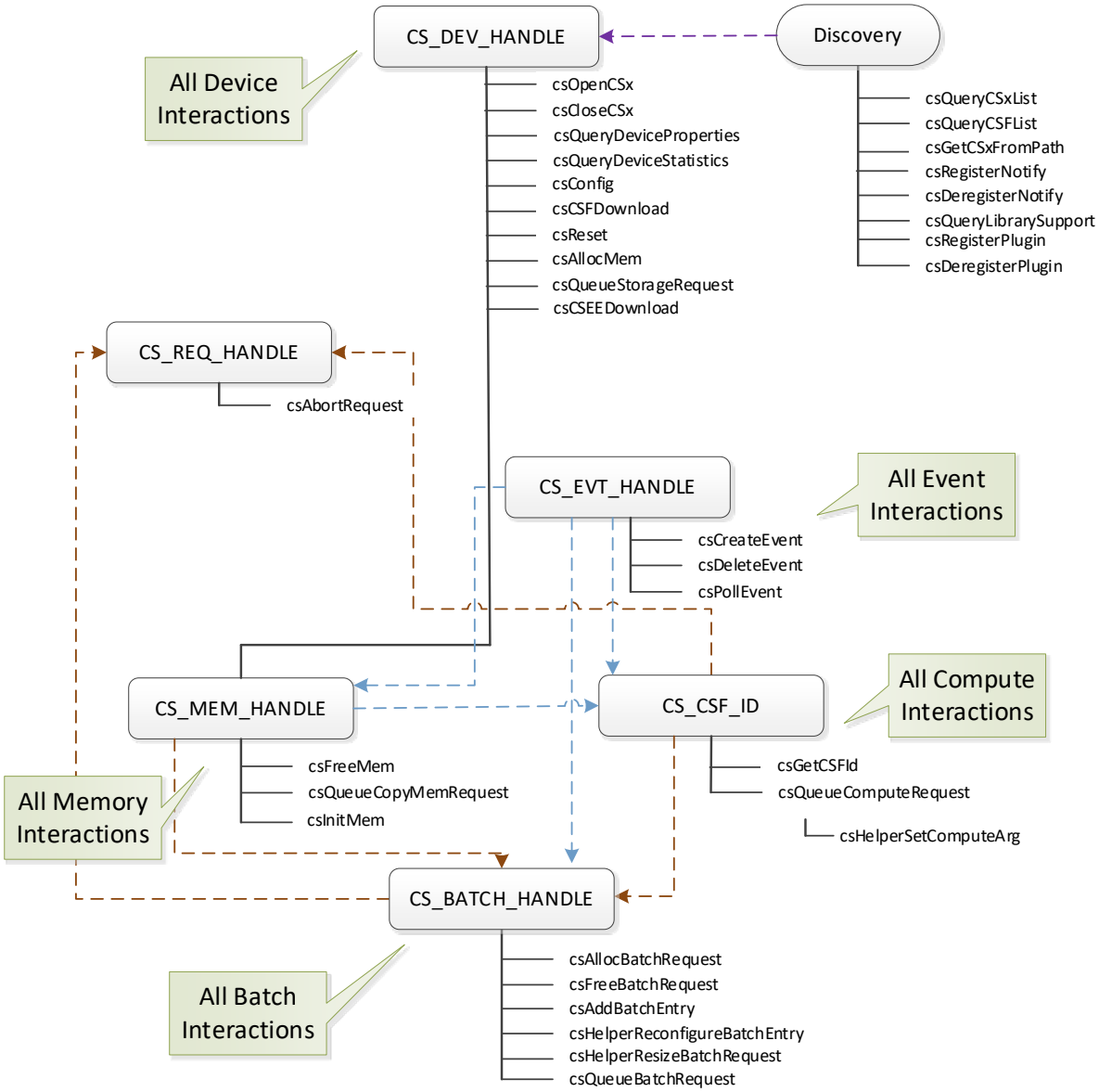


Figure 13: API access flows

6.2 Usage Overview

The CS API interface to applications is able to be broken down by functionality into the sections as defined in

Table 7.

Table 7: CS API matrix

Functionality	APIs
Device Discovery - Identify CSxes - Identify CSFs - Identify CSx associated with Storage device	csQueryCSxList() csQueryCSFList() csGetCSxFromPath()
Device Access - Open/Close CSx device for access	csOpenCSx() csCloseCSx()
FDM management - Allocate/Deallocate FDM	csAllocMem() csFreeMem() csInitMem()
Storage IOs - Issue read/write IOs from/to Storage	Use filesystem with FDM and initiate P2P csQueueStorageRequest()
CSx Data movement - Transfer data between device memory and host memory	csQueueCopyMemRequest()
CSF access and scheduling - Schedule CSF on device	csGetCSFId() csAbortRequest() csQueueComputeRequest() csHelperSetComputeArg() csQueueBatchRequest() csAllocBatchRequest()

	csFreeBatchRequest() csAddBatchEntry() csHelperReconfigureBatchEntry() csHelperResizeBatchRequest()
Device Management - Query device properties and capabilities - Manage device functionality	csQueryDeviceProperties() csQueryDeviceStatistics() csGroupComputeByIds() csUngroupComputeFromGroupId() csCSFDownload() csCSEEDownload() csConfig() csReset() csRegisterNotify() csDeregisterNotify()
Event Management - Create/delete events for completion processing	csCreateEvent() csDeleteEvent() csPollEvent()
Library Management - Query API library support - Manage library interfaces to support APIs	csQueryLibrarySupport() csRegisterPlugin() csDeregisterPlugin()

6.3 Common Definitions

6.3.1 Character Arrays

All strings are null terminated. Since a string is null terminated, the maximum number of non-null characters in the character array is one less than the size of the character array.

The null termination character is not included in the string length.

6.3.2 Data Types

Name	Description
s8	Signed 8-bit data; used as input to functions and arguments
u8	Unsigned 8-bit data; used in arguments scheduling a CSF
f8	Float 8-bit data; used in arguments scheduling a CSF
s16	Signed 16-bit data; used as input to functions and arguments
u16	Unsigned 16-bit data; used in arguments scheduling a CSF
f16	Float 16-bit data; used in arguments scheduling a CSF
s32	Signed 32-bit data; used as input to functions and arguments
u32	Unsigned 32-bit data; used in arguments scheduling a CSF
f32	Float 32-bit data; used in arguments scheduling a CSF
s64	Signed 64-bit data; used as input to functions and arguments

u64	Unsigned 64-bit data; used in arguments scheduling a CSF
f64	Float 64-bit data; used in arguments scheduling a CSF
u128	Unsigned 128-bit data; used in arguments scheduling a CSF

6.3.3 Status Values

One or more of the values in Table 8 are returned by the interface APIs and are classified under `CS_STATUS`.

Table 8: Status Value Definitions

Status Value Definition	Description
CS_SUCCESS	The action was completed with success
CS_COULD_NOT_MAP_MEMORY	The requested memory allocated could not be mapped
CS_DEVICE_ERROR	The device is in error and is not able to make progress
CS_DEVICE_NOT_AVAILABLE	The CSx is unavailable
CS_DEVICE_NOT_READY	The device is not ready for any transactions
CS_DEVICE_NOT_PRESENT	The requested device is not present
CS_INVALID_DEVICE_NAME	The device name specified does not exist
CS_INVALID_PATH	No such device, file or directory exists
CS_ENTITY_NOT_ON_DEVICE	The entity does not exist on requested device

CS_NO_MATCHING_DEVICE	No Storage or CSx was available
CS_ERROR_IN_EXECUTION	There was an error that occurred in the execution path
CS_FATAL_ERROR	There was a fatal error that occurred
CS_HANDLE_IN_USE	The requested handle is already in use
CS_INVALID_HANDLE	An invalid handle was passed
CS_INVALID_ARG	One or more invalid arguments were provided
CS_INVALID_ID	The specified input ID was invalid and does not exist
CS_INVALID_LENGTH	The specified buffer is not of sufficient length
CS_INVALID_OPTION	An invalid option was specified
CS_INVALID_CSF_ID	The CSF identifier specified was invalid
CS_INVALID_CSF_NAME	The CSF name specified does not exist or is invalid
CS_INVALID_FDM_ID	The FDM identifier specified was invalid
CS_INVALID_GLOBAL_ID	The Global Identified specified is not valid
CS_IO_TIMEOUT	An IO submitted has timed out
CS_LOAD_ERROR	The specified download could not be initialized
CS_MEMORY_IN_USE	The requested memory is still in use
CS_NO_PERMISSIONS	There were insufficient permissions to proceed with request

CS_NOT_DONE	The request is not done
CS_NOT_ENOUGH_MEMORY	There is not enough memory to satisfy the request
CS_OUT_OF_RESOURCES	The system is out of resources to satisfy the request
CS_QUEUED	The request was successfully queued
CS_NOTHING_QUEUED	No queued requests to poll
CS_COULD_NOT_UNMAP_MEMORY	Memory previously mapped could not be unmapped for AFDM
CS_UNKNOWN_MEMORY	The memory referenced was unknown
CS_UNSUPPORTED	The request is not supported
CS_UNSUPPORTED_TYPE	The specified download type is not supported
CS_UNSUPPORTED_INDEX	The specified hardware index is not supported for this download

6.3.4 Notification Options

The following definitions specify the fixed defined values that can be specified as notification options as an input to the `csRegisterNotify()` API. The same values will be provided to the notification callback, if invoked.

Table 9: Notification Value Definitions

Status Value Definition	Description
CS_NOTIFY_SYSTEM_ERROR	A system error has occurred
CS_NOTIFY_CSE_UNRESPONSIVE	The specified CSE is not responding normally and may be unusable

CS_NOTIFY_CSEE_UNRESPONSIVE	The specified CSEE is not responding normally and may be unusable
CS_NOTIFY_CSF_UNRESPONSIVE	The specified CSF is not responding normally and may be unusable
CS_NOTIFY_CSE_RESET	A CSE resource was reset
CS_NOTIFY_CSEE_RESET	A CSEE resource was reset
CS_NOTIFY_CSx_RESET	The CSx was reset
CS_NOTIFY_CSx_ADDED	A new CSx is available
CS_NOTIFY_CSx_REMOVED	A CSx is not available
CS_NOTIFY_CSF_ADDED	A new CSF was loaded
CS_NOTIFY_CSF_REMOVED	A CSF was unloaded
CS_NOTIFY_RESOURCE_WARNING	The CSx is running out of resources
CS_NOTIFY_DOWNLOAD_INFO	Additional information is available for downloaded CSF
CS_NOTIFY_CONFIG_INFO	Additional information is available for downloaded configuration

6.3.5 Data Structures

6.3.5.1 Definitions

6.3.5.2 Enumerations

The enumerations in this section are used in API parameters and data structures.

6.3.5.2.1 *CS_RESOURCE_TYPE*

```
typedef enum {
```

```
    CS_CSx_TYPE              = 1,
    CS_CSE_TYPE              = 2,
    CS_CSEE_TYPE             = 3,
    CS_FDM_TYPE              = 4,
    CS_CSF_TYPE              = 5,
    CS_VENDOR_SPECIFIC_TYPE  = 6
} CS_RESOURCE_TYPE;
```

6.3.5.2.2 *CS_CSEE_RESOURCE_TYPE*

```
typedef enum {
    CS_CSEE_UNDEFINED          = 0,
    CS_CSEE_FPGA               = 1,
    CS_CSEE_BPF                = 2,
    CS_CSEE_CONTAINER          = 3,
    CS_CSEE_OPERATING_SYSTEM   = 4,
    CS_CSEE_VENDOR_SPECIFIC    = 65535
} CS_CSEE_RESOURCE_TYPE;
```

6.3.5.2.3 *CS_CSF_RESOURCE_TYPE*

```
typedef enum {
    CS_CSF_UNDEFINED               = 0,
    CS_CSF_FPGA_BITSTREAM          = 1,
    CS_CSF_BPF_PROGRAM             = 2,
    CS_CSF_CONTAINER_IMAGE         = 3,
    CS_CSF_OPERATING_SYSTEM_IMAGE  = 4,
    CS_CSF_VENDOR_SPECIFIC         = 65535
} CS_CSF_RESOURCE_TYPE;
```

6.3.5.2.4 *CS_RESOURCE_SUBTYPE*

The following enum defines CSEE and CSF resource subtypes that may be used with `the csCSEEDownload() API` and `the csCSFDownload() API.`

```
typedef enum {
    CS_SUBTYPE_UNDEFINED              = 0,
    CS_SUBTYPE_FPGA_AMD               = 1,
    CS_SUBTYPE_FPGA_INTEL             = 2,
    CS_SUBTYPE_CONTAINER_DOCKER       = 3,
    CS_SUBTYPE_CONTAINER_KUBERNETES   = 4,
    CS_SUBTYPE_OS_LINUX               = 5,
    CS_SUBTYPE_OS_VMWARE              = 6,
    CS_SUBTYPE_VENDOR_SPECIFIC        = 65535
} CS_RESOURCE_SUBTYPE;
```

6.3.5.2.5 *CS_STATE*

```
typedef enum {
    CS_INACTIVE_STATE            = 0,
    CS_ACTIVE_STATE              = 1,
} CS_STATE;
```

6.3.5.2.6 *CS_CONFIG_TYPE*

```
typedef enum {
    CS_CSEE_ACTIVATE             = 1,
    CS_CSF_ACTIVATE              = 2,
    CS_FDM_ACTIVATE              = 3,
    CS_VENDOR_SPECIFIC           = 4
} CS_CONFIG_TYPE;
```

6.3.5.2.7 *CS_FDM_FLAG_TYPE*

CS_FDM_FLAG_TYPE specifies options to csMemFlags parameter for the `csAllocMem()` API and the `csFreeMem()` API.

```
typedef enum {
CS_FDM_CLEAR        = 1,         // clears AFDM to all zeroes
CS_FDM_FILL         = 2          // fill AFDM with specified value
} CS_FDM_FLAG_TYPE;
```

6.3.5.2.8 *CS_MEM_COPY_TYPE*

```
typedef enum {
    CS_COPY_TO_DEVICE      = 1,
    CS_COPY_FROM_DEVICE    = 2,
    CS_COPY_WITHIN_DEVICE  = 3
} CS_MEM_COPY_TYPE;
```

6.3.5.2.9 *CS_STORAGE_REQ_MODE*

```
typedef enum {
     CS_STORAGE_BLOCK_IO   = 1,
     CS_STORAGE_FILE_IO    = 2
} CS_STORAGE_REQ_MODE;
```

6.3.5.2.10 *CS_STORAGE_IO_TYPE*

```
typedef enum {
     CS_STORAGE_LOAD_TYPE        = 1,
     CS_STORAGE_STORE_TYPE       = 2
} CS_STORAGE_IO_TYPE;
```

6.3.5.2.11 *CS_COMPUTE_ARG_TYPE*

This `enum` defines the CSF argument types.

```
typedef enum {
CS_AFDM_TYPE               = 1,
CS_8BIT_VALUE_TYPE         = 2,
CS_16BIT_VALUE_TYPE        = 3,
CS_32BIT_VALUE_TYPE        = 4,
CS_64BIT_VALUE_TYPE        = 5,
CS_128BIT_VALUE_TYPE       = 6,
CS_DESCRIPTOR_TYPE         = 7
} CS_COMPUTE_ARG_TYPE;
```

6.3.5.2.12 *CS_BATCH_MODE*

This `enum` enumerated the possible batch modes as follows:

```
typedef enum {
     CS_BATCH_SERIAL      = 1,
     CS_BATCH_PARALLEL    = 2,
     CS_BATCH_HYBRID      = 3
} CS_BATCH_MODE;
```

6.3.5.2.13 *CS_BATCH_REQ_TYPE*

```
typedef enum {
     CS_COPY_AFDM         = 1,
     CS_STORAGE_IO        = 2,
     CS_QUEUE_COMPUTE     = 3
} CS_BATCH_REQ_TYPE;
```

6.3.5.2.14 *CS_STAT_TYPE*

This data type defines various statistics that are able to be queried from a CSx.

```
typedef enum {
     CS_STAT_CSE_USAGE           = 1,   // query to provide CSE runtime statistics
     CS_STAT_CSx_MEM_USAGE       = 2,   // query CSx memory usage
     CS_STAT_CSF                 = 3    // query statistics on a specific function
} CS_STAT_TYPE;
```

6.3.5.2.15 *CS_LIBRARY_SUPPORT*

```
typedef enum {
     CS_FILE_SYSTEMS_SUPPORTED   = 1,
     CS_RESERVED                 = 2
} CS_LIBRARY_SUPPORT;
```

6.3.5.2.16 *CS_PLUGIN_TYPE*

```
typedef enum {
     CS_PLUGIN_COMPUTE           = 1,
     CS_PLUGIN_NVME              = 2,
     CS_PLUGIN_FILE_SYSTEM       = 4,
     CS_PLUGIN_CUSTOM            = 8
} CS_PLUGIN_TYPE;
```

A plugin may be more than one type; therefore, this is a defined as a bitmask.

6.3.5.3 Structures

The structures in this section are used in API parameters and within other data structures.

6.3.5.3.1 *Properties Data Structures*

The following data structures are used for discovery of all resources for a CSx. The data structure `CSProperties` is queried using the `csQueryDeviceProperties()` API and provides the properties for all compute resources of a CSx. The structure contains sub-structures that are required to be queried individually using the `CS_RESOURCE_TYPE` enumerator. The discoverable sub-structures include `CSxProperties`, `CSEProperties`, `CSEEProperties`, `FDMProperties`, and `CSFProperties`.

The sub-structure `CSxProperties` provides information pertaining to the CSx. The `BatchRequestsSupported` field specifies if this CSx supports batch requests in hardware.

The sub-structure `CSEProperties` provides information on all CSEs, where each one is described by the sub-structure `CSEInfo`. The field `CSETypeToken` is a device specified entry that uniquely distinguishes between different CSE types. The `MaxRequestsPerBatch` field denotes the maximum number of requests that may be batched together in a batch request through `csQueueBatchRequest` API. The `MaxCSFParametersAllowed` field denotes the maximum parameters supported for a given CSF by the CSE. A function cannot exceed this number and will be rejected if it

does by the queueing API. Each CSE is further identified by the sub-structure `ComputeResource` that provides individual details on the CSE.

The sub-structure `CSEEProperties` provides details on the execution environment and is associated to the CSE by the `CSETypeToken` field. Each CSEE represented by `CSEEInfo` sub-structure may describe any CSFs that are built-in or preloaded in the CSx by the field `NumBuiltinCSFs`. The `NumActivatedCSFs` field denotes the total number of CSFs available for execution.

The sub-structure `FDMProperties` describes all FDMs available on the CSx. Each FDM is described by sub-structure `FDMInfo`. The `DeviceManaged` field when set to 1 identifies that the CSx manages FDM for allocations and deallocations and determines how the memory is managed. If this field is set to zero, it means that the host manages this resource. The `HostVisible` field when set to 1 denotes that FDM is available as a physical resource in the system's address space and may be mapped into a host's virtual address. If set to zero, FDM is not visible and needs specific APIs to operate on it. The `ClearContentsSupported` and `InvalidateContentsSupported` fields when set to 1 specify if the FDM supports this feature in hardware. The `ConfigSupported` field specifies if the FDM may be configured. The `NumCSEs` field denotes the CSEs that have access to the FDM while `CSEList` field is a pointer that provides the details on the individual CSEs described in `CSEAccess` data structure.

The sub-structure `CSFProperties` describes all the CSFs that are available on the CSx. Each CSF is described by the sub-structure `CSFInfo` that describes its association to a CSE by the `CSETypeToken` field. Additional fields such as `CSFId` uniquely identify the CSF and `BuiltIn` verify if it is built-in/preloaded by the vendor. A CSF are required to be activated to be able to run on a CSE and its activation state and associations is further described by the sub-structure `CSFInstance`. A CSF may be executed on more than one CSE if that engine type allows it.

6.3.5.3.1.1 CsProperties

```
typedef union {
     CSxProperties CSxDetails;          // details on CSx
     CSEProperties CSEDetails[1];       // details on all CSEs
     CSEEProperties CSEEDetails[1];     // details on all CSEEs
     FDMProperties FDMDetails[1];       // details on all FDMs
     CSFProperties CSFDetails[1];       // details on all CSFs
     CSVendorSpecific VSDetails;        // vendor specific
} CsProperties;
```

6.3.5.3.1.2 CSxProperties

```
typedef struct {
     u16 HwVersion;              // specifies the hardware version of this CSx
     u16 SwVersion;              // specifies the software version that runs on this
     CSx
     u32 VendorId;               // specifies the vendor id of this CSx
     u32 DeviceId;               // specifies the device id of this CSx
     char FriendlyName[32];      // an identifiable string for this CSx
     struct {
             u64 BatchRequestsSupported : 1;// CSx supports batch requests in hardware
             u64 Reserved : 63;
     } Flags;
} CSxProperties;
```

6.3.5.3.1.3 ComputeResource

```
typedef struct {
     u16 HwVersion;
     u16 SwVersion;
     char Name[32];              // an identifiable string for this CR
     u32 ERId;                   // Engine Resource Identifier for this
     ComputeResource
     CRProperties *Features;     // additional features like perf, security etc [TBD]
} ComputeResource;
```

6.3.5.3.1.4 CSEInfo

```
typedef struct {
     u16 CSETypeToken;           // device provided token to differentiate between its
                                 // CSE types
     u8 RelativePerformance;     // values [1-10]; higher is better; 0 is not defined
     u8 RelativePower;           // values [1-10]; lower is better; 0 is not defined
     u32 MaxRequestsPerBatch;    // maximum number of requests supported per
                                 // batch request
     u32 MaxCSFParametersAllowed;// maximum number of parameters supported
     u32 CSEId;                  // CSE Id unique to this CSx
     u16 MaxCSEEs;               // maximum number of CSEEs for this CSE
     u16 NumActivatedCSEEs;      // number of activated CSEEs
     u16 NumAvailableCRs;        // number of CRs not allocated
     u16 NumCRs;                 // total CRs in list
     ComputeResource *CRs;       // a pointer to a list of CRs for this CSE Type
} CSEInfo;
```

6.3.5.3.1.5 CSEProperties

```
typedef struct {
     u16 NumCSEs;                // number of CSEs in array
     CSEInfo CSE[1];             // a array of CSEs
} CSEProperties;
```

6.3.5.3.1.6 CSEEInstance

```
typedef struct {
     CS_STATE State;              // current activation state
     u32 CSEId;                   // CSE Id unique to this CSx
     u32 EEIId;                   // Execution Environment Instance Identifier
} CSEEInstance;
```

6.3.5.3.1.7 CSEEInfo

```
typedef struct {
     CS_CSEE_RESOURCE_TYPE Type;        // the type of CSEE
     u16 SwVersion;
     char Name[32];                     // an identifiable string for this CSEE
     u16 CSETypeToken;                  // device provided token to differentiate
     between
                                        // its CSE types
     u16 NumBuiltinCSFs;                // number of available vendor preloaded CSFs
     u32 CSEEId;                        // unique CSEE Id
     u16 MaxCSFs;                       // maximum number of CSFs for this CSEE
     u16 NumActivatedCSFs;              // number of activated CSFs
     u16 NumEEIs;                       // number of activated CSEE instances
     CSEEInstance *EEInstances;         // a pointer to a list of activated CSEE
     instances
} CSEEInfo;
```

6.3.5.3.1.8 CSEEProperties

```
typedef struct {
     u16 NumCSEEs;              // number of CSEEs in array
     CSEEInfo CSEE[1];          // an array of CSEEs
} CSEEProperties;
```

6.3.5.3.1.9 FDMFlags

```
typedef struct {
       u64 DeviceManaged: 1;            // FDM allocations managed by device
       u64 HostVisible: 1;              // FDM may be mapped to host address space
       u64 ClearContentsSupported: 1;   // supports clearing FDM with zeros
       u64 InvalidateContentsSupported: 1;// supports invalidating FDM with non-zeros
       u64 ConfigSupported: 1;          // supports configuration
       u64 Reserved: 59;
} FDMFlags;
```

6.3.5.3.1.10 CSEAccess

```
typedef struct {
     u32 CSEId;                   // CSE Id unique to this CSx
     u8 RelativePerformance;      // values [1-10]; higher is better; 0 is not defined
     u8 RelativePower;            // values [1-10]; lower is better; 0 is not defined
} CSEAccess;
```

6.3.5.3.1.11 FDMInfo

```
typedef struct {
     u32 FDMId;                  // unique FDM Id
     u64 FDMSize;                // size of FDM in bytes
     FDMFlags Flags;             // FDM Settings
     u16 NumCSEs;                // total CSEs in list
     CSEAccess *CSEList;         // a pointer to a list of CSEs having access
} FDMInfo;
```

6.3.5.3.1.12 FDMProperties

```
typedef struct {
     u16 NumFDMs;                // number of FDMs in array
     FDMInfo FDM[1];             // an array of FDMs (as applicable)
} FDMProperties;
```

6.3.5.3.1.13 CSFInstance

```
typedef struct {
     CS_STATE State;             // current activation state
     u32 EEIId;                  // paired CSEE instance Id
     u32 FIId;                   // unique CSF Instance Id
     u16 NumCRs;                 // number of CRs in CRList
     u32 *ERList;                // pointer to a list of CR identifiers on which a CSF
                                 // instance is activated
} CSFInstance;
```

6.3.5.3.1.14 CSFInfo

```
typedef struct {
     u64 GlobalId;               // global unique identifier assigned to the CSF
     char UniqueName[32];        // an identifiable string for this CSF, if available
     u16 CSETypeToken;           // device provided token to differentiate between its
                                 // CSE types
     u32 CSFId;                  // unique CSF Id
     u8 Builtin: 1;              // preloaded by vendor
     u8 Reserved: 7;
     u16 NumFIs;                 // number of associated instances for this CSF
     CSFInstance *FInstances;    // pointer to list of CSF instances with CSEE & CR
     details
} CSFInfo;
```

6.3.5.3.1.15 CSFProperties

```
typedef struct {
     u16 NumCSFs;                // number of CSFs in CSFInfo array
     CSFInfo CSF[1];             // an array of CSFs
} CSFProperties;
```

6.3.5.3.1.16 CSVendorSpecific

```
typedef struct {
     void *VSData;
} CSVendorSpecific;
```

6.3.5.3.2 *Configuration Data Structures*

The data structure `csConfigInfo` is provided as input to configure a CSx using the `csConfig()` API. On success, the data structure `CsConfigData` provides the results of the requested configuration. Configurations are selected using the `CS_CONFIG_TYPE` enumerator.

The CSEE resource may be configured with a CSE resource that matches its resource type by the `CSETypeToken` field in their respective data structures. Configuring these resources together is described using the `CSEEConfig` data structure. On successful configuration, the a unique Execution Environment Instance Identifier (EEIId) along with the activation state set is returned as a result in sub-data structure `CsActivationInfo`. The EEIId identifier is primarily used for activating a CSF.

Similarly, the CSF resource may be configured with a valid EEIId and one or more compute resource (CR). The configuration request is valid for the same `CSETypeToken` types i.e., an activation may only be performed on the same `CSETypeToken` types. On successful configuration, the sub-data structure `CsActivationInfo` is populated with the unique Functional Instance Identifier (FIId) and the resultant activated state. The FIId is a unique instance of a CSF. There can be multiple activated FIIds for a single CSF. The maximum number of CSFs that may be activated is dependent on the CSE. Only activated CSFs are visible when queried using the `csGetCSFId()` API and the `csQueryCSFList()` API. Only activated CSF instances are used in execution using the `csQueueComputeRequest()` API or the `csQueueBatchRequest()` API.

The FDM resource may be configured using the `FDMConfig` sub-structure. The specified `FDMId` may be configured to the specified `State` field only if the FDM supports it as specified in `FDMInfo`. If successful, the applied state is reflected in the `State` field of `CsActivationInfo`.

6.3.5.3.2.1 CsConfigInfo

The data structure `CsConfigInfo` is defined as follows:

```
typedef struct {
     CS_CONFIG_TYPE Type;
     union {
             CSEEConfig CSEEActivateInfo;      // configuration details for CSEE
             CSFConfig CSFActivateInfo;        // configuration details for CSF
```

```
            FDMConfig FDMActivateInfo;       // configuration details for FDM
            CSVendorConfig VSInfo;           // vendor specific
     } u;
} CsConfigInfo;
```

6.3.5.3.2.2 CsConfigData

```
typedef union {
     CsActivationInfo Data;
     void *VSData;
} CsConfigData;
```

6.3.5.3.2.3 CSEEConfig

```
typedef struct {
     CS_STATE State;             // requested activation state
     u32 CSEEId;                 // unique CSEE Identifier
     u32 CSEId;                  // CSE Id unique to CSx
} CSEEConfig;
```

6.3.5.3.2.4 CSFConfig

```
typedef struct {
     CS_STATE State;             // requested activation state
     u32 CSFId;                  // unique CSF Id
     u32 EEIId;                  // Execution Environment Instance Identifier
     U16 NumCRs;                 // number of CRs in array
     u32 CRArray[1];             // an array of one or more Compute Resources
                                 // (ERIds see 6.3.5.3.1.3)
} CSFConfig;
```

6.3.5.3.2.5 FDMConfig

```
typedef struct {
     CS_STATE State;             // requested configuration state
     u32 FDMId;                  // requested FDM configuration by Id
} FDMConfig;
```

6.3.5.3.2.6 CSVendorConfig

```
typedef struct {
     void *VSData;
} CSVendorConfig;
```

6.3.5.3.2.7 CsActivationInfo

```
typedef struct {
```

```
     CS_STATE State;             // current activation state
     u32 Id;                     // resource specific unique Identifier
} CsActivationInfo;
```

6.3.5.3.3 *Memory Data Structures*

The memory data structures provide the definitions on how memory is organized and for its access usage with the necessary APIs. Memory is represented by its memory handle and is required to be allocated using the `csAllocMem()` API prior to usage.

6.3.5.3.3.1 CsMemFlags

The data structure `CsMemFlags` provides inputs to the `csAllocMem()` API specifying:

- the FDM (i.e., in the FDMId field) from which to allocate memory; and
- flags that specify how the memory is to be initialized.

The value for `FDMId` is queried by CSF using the the `csGetCSFId()` API.

```
typedef struct {
     u32 FDMId;                          // refer to the csGetCSFId() API for details
     CS_FDM_FLAG_TYPE Flags;             // see 6.3.5.2.7
     u32 FillValue;                      // only valid when fill flag is specified
} CsMemFlags;
```

6.3.5.3.3.2 CsDevAFDM

The data structure `CsDevAFDM` defines how memory may be used and defines a previously allocated memory handle and an offset denoted by `ByteOffset` to reference within that memory.

```
typedef struct {
     CS_MEM_HANDLE MemHandle;            // an opaque memory handle for AFDM
     unsigned long ByteOffset;           // denotes the offset with AFDM
} CsDevAFDM;
```

6.3.5.3.3.3 CsCopyMemRequest

The structure `CsCopyMemRequest` describes the memory copy request between the host memory and the AFDM. A `CsCopyMemRequest` is able to describe a copy from host memory to the AFDM or from the AFDM to host memory based on the `Type` field.

```
typedef struct {
     CS_MEM_COPY_TYPE Type;              // see 6.3.5.2.8
      union {
         void *HostVAddress;             // defines host memory if specified in Type
         CsDevAFDM SrcDevMem;            // defines the source device memory for copy
                                         // between device memories
```

```
      } u;
     CsDevAFDM DevMem;                  // see 6.3.5.3.3.1
     unsigned int Bytes;
} CsCopyMemRequest;
```

6.3.5.3.4 *Storage Data Structures*

The structure `CsStorageRequest` describes the storage IO request between the storage device and the CSF. Storage IO is able to be described as a block or file request and utilizes the `Mode` field to select it. The `Type` field describes the direction of data flow from storage device.

Block requests describe details such as the namespace to operate on, the LBA and number of blocks to transfer. Multiple LBA block ranges may be specified in the same request. They also describe the AFDM that the transfer occurs to/from. The `StorageIndex` field specifies the drive to target the request to in a CSA and is reserved for other CSx types. See `CsDevAFDM` data structure for details on the `DevMem` field as specified in section 6.3.5.3.3.1.

For file requests, the `CsFileIo` structure describes the file request to perform with details on the file handle, offset within the file, bytes to read/write, and device memory buffer details. File based requests will be satisfied for the default file system(s) for that OS. A specific file system support should be first queried before making a file-based request. The handle is required to refer to a valid open file with the required set of access rights to satisfy the intent of the request. File offset and bytes requested are required to adhere to the storage drives block requirements. For file write based requests, the API will synchronize on writing to that portion of the file with the filesystem and reserve space in advance, if needed. File based requests get translated internally to a storage IO request. See section 6.13.1 for more information on file system support.

6.3.5.3.4.1 CsStorageRequest

The data structure `CsStorageRequest` is defined as follows:

```
typedef struct {
     CS_STORAGE_REQ_MODE Mode;          // see 6.3.5.2.9
     CS_DEV_HANDLE DevHandle;           // the CSx handle
     union {
      CsBlockIo BlockIo;                // see 6.3.5.3.4.1
      CsFileIo FileIo;                  // see 6.3.5.3.4.4
     } u;
} CsStorageRequest;
```

6.3.5.3.4.2 CSBlockRange

The data structure `CsBlockRange` is defined as follows:

```
typedef struct {
     u32 NamespaceId;                  // represents a LUN or namespace
     u64 StartLba;                     // the starting LBA for this range
     u32 NumBlocks;                    // total number of blocks for this range
} CsBlockRange;
```

6.3.5.3.4.3 CsBlockIo

The data structure `CsBlockIo` is defined as follows:

```
typedef struct {
     CS_STORAGE_IO_TYPE Type;          // see 6.3.5.2.10
     u32 StorageIndex;                 // denotes the index in a CSA, zero otherwise
     CsDevAFDM DevMem;                 // see 6.3.5.3.3.1
     int NumRanges;                    // number of LBA block ranges
     CsBlockRange Range[1];            // An array of LBA block ranges
} CsBlockIo;
```

6.3.5.3.4.4 CsFileIo

The data structure `CsFileIo` is defined as follows:

```
typedef struct {
     CS_STORAGE_IO_TYPE Type;          // see 6.3.5.2.10
     void *FileHandle;
     u64 Offset;
     u32 Bytes;
     CsDevAFDM DevMem;                 // see 6.3.5.3.3.1
} CsFileIo;
```

6.3.5.3.5 ***Compute Data Structures***

Compute requests are described using the `CsComputeRequest` data-structure. The `CSFId` data field holds the identifier of the CSF that has to be executed. The `NumArgs` field describes the total number of arguments passed down to the CSF while `Args` describes the first argument. `Args` may be described in an array where, the total count in the array is described by `NumArgs` field.

The `Args` field is described by the `CsComputeArg` data-structure. The `Type` field denotes the argument type while the details are one of the types in the union.

6.3.5.3.5.1 CsComputeRequest

The structure `CsComputeRequest` is an input to schedule and run a CSF. The arguments are function dependent.

```
typedef struct {
     CS_CSF_ID CSFId;            // A unique identifier for a Computational Storage
                                 // Function within a CSx see 6.3.7
     int NumArgs;                // set to total arguments to CSF
     CsComputeArg Args[1];       // see 6.3.5.3.5
                                 // allocate enough space past this for multiple
```

```
} CsComputeRequest;              // arguments
```

6.3.5.3.5.2 CsComputeArg

The structure `CsComputeArg` describes an individual argument to a CSF. A handle references AFDM while the values refer to scalar inputs to the CSF.

```
typedef struct {
     CS_COMPUTE_ARG_TYPE Type;
     union {
       CsDevAFDM DevMem;          // see 6.3.5.3.3.1
       u64 Value64;
       u32 Value32;
       u16 Value16;
       u8 Value8;
     } u;
} CsComputeArg;
```

6.3.5.3.6 *Batch Data Structures*

Batch requests help optimize the total number of API requests by combining multiple requests into one batch. Batch requests also help execute repeatable tasks. Batch request setup is defined in detail under section 5.2.

Each request in a batch is described by the `CsBatchRequest` data structure. The `ReqType` data field describes the type of batch request.

6.3.5.3.6.1 CsBatchRequest

The data structure `CsBatchRequest` is defined as follows:

```
typedef struct {
     CS_BATCH_REQ_TYPE ReqType;          // see 6.3.5.2.13
     union {
       CsCopyMemRequest CopyMem;         // see 6.3.5.3.3.3
       CsStorageRequest StorageIo;       // see Error! Reference source not found.
       CsComputeRequest Compute;         // see Error! Reference source not found.
     } u;
} CsBatchRequest;
```

6.3.5.3.7 *Statistics Data Structures*

CSx statistics for specific resources may be queried using the `csQueryDeviceStatistics()` API.

The `Stats` parameter defined as `CsStatsInfo` structure is used to query a specific statistic type as provided by the `Type` input parameter. The optional `Identifier` parameter may be provided if `Type` requires it. For example, the `CSFId` may be provided as the `Identifier` parameter to query the particular CSF's usage statistics as defined in `CSFUsage` data structure.

6.3.5.3.7.1 CsStatsInfo

The data structure `CsStatsInfo` is defined as follows:

```
typedef union {
     CSEUsage CSEDetails;
     CSxMemory MemoryDetails;     // see 6.3.5.3.7.3
     CSFUsage CSFDetails;         // see 6.3.5.3.7.4
} CsStatsInfo;
```

6.3.5.3.7.2 CSEUsage

`CSEUsage` provides the following details when queried for a particular CSE. The counters reflect numbers since the device was last reset.

```
typedef struct {
     u32 PowerOnMins;
     u32 IdleTimeMins;
     u64 TotalFunctionExecutions;// total number of executions performed by CSE
} CSEUsage;
```

6.3.5.3.7.3 CSxMemory

CSxMemory defines device memory usage.

All counters are represented in bytes if not specified.

```
typedef struct {
     u64 TotalAllocatedFDM;             // total FDM in bytes that have been allocated
     u64 LargestBlockAvailableFDM;      // largest amount of FDM that may be allocated
     u64 AverageAllocatedSizeFDM;       // average size of FDM allocations in bytes
     u64 TotalFreeFDM;                  // total FDM memory that is not in use
     u64 TotalAllocationsFDM;           // count of total number of FDM allocations
     u64 TotalDeAllocationsFDM;         // count of total number of FDM deallocations
     u64 TotalFDMtoHostinMB;            // total FDM transferred to host memory in
                                        // megabytes
     u64 TotalHosttoFDMinMB;            // total host memory transferred to FDM in
     megabytes
     u64 TotalFDMtoStorageinMB;  // total FDM transferred to storage in megabytes
     u64 TotalStoragetoFDMinMB;  // total storage transferred to FDM in megabytes
} CSxMemory;
```

6.3.5.3.7.4 CSFUsage

CSFUsage defines per function statistics since the function was loaded. The counters get cleared when it gets unloaded. The specific function is chosen as input with the `Identifier` parameter.

```
typedef struct {
     u64 TotalUptimeSeconds;      // total utilized time by CSF in seconds
     u64 TotalExecutions;         // number of executions performed
     u64 ShortestTimeUsecs;       // the shortest time the CSF ran in microseconds
     u64 LongestTimeUsecs;        // the longest time the CSF ran in microseconds
     u64 AverageTimeUsecs;        // the average runtime in microseconds
} CSFUsage;
```

6.3.5.3.8 *FDMAccess*

The data structure `FDMAccess` specifies the FDM access by `FDMId` for a given CSF and is defined as follows:

```
typedef struct {
     u32 FDMId;                  // Unique FDM identifier that is used to allocate FDM
     u8 RelativePerformance;     // values [1-10]; higher is better; 0 is not defined
     u8 RelativePower;           // values [1-10]; lower is better; 0 is not defined
     FDMFlags Flags;             // FDM settings
} FDMAccess;
```

6.3.5.3.9 *CSFUniqueId*

```
typedef struct {
     char UniqueName[32];        // an identifiable string for CSF if available,
                                 // NULL otherwise
     u64 GlobalId;               // global unique identifier for CSF if available,
                                 // zeroes otherwise
} CSFUniqueId;
```

6.3.5.3.10 *CSFIdInfo*

The data structure `CSFIdInfo` is returned on a successful query from the `csGetCSFId()` API and is defined as follows:

```
typedef struct {
     CS_CSF_ID CSFId;            // unique CSF Identifier used to schedule compute
                                 // work
     u8 RelativePerformance;     // values [1-10]; higher is better; 0 is not defined
     u8 RelativePower;           // values [1-10]; lower is better; 0 is not defined
     u8 Count;                   // number of instances of this CSF available
     u8 NumFDMs;                 // number of FDMs accessible by the CSF
     FDMAccess *FDMList;         // list of accessible FDMs
} CSFIdInfo;
```

6.3.5.3.11 *CsCommonDownloadInfo*

This is a sub-structure of `CsCSFDownloadInfo` and `CsCSEEDownloadInfo` data structures. The `UniqueName` field is an identifiable string for the resource being downloaded, if available. The `Unload` field is only set if a previously downloaded resource at `Index` in the main data structure is to be unloaded. This field is set to zero otherwise. The `Length` and `DataBuffer` fields denote the length and contents of the resource being downloaded.

```
typedef struct {
     char UniqueName[32];        // an identifiable string for resource, if available
     int Unload;                 // unload previously loaded entity, zero otherwise
     int Length;                 // length in bytes of data in DataBuffer
```

```
    void *DataBuffer;           // download data for CS resource
} CsCommonDownloadInfo;
```

6.3.5.3.12 *CsCSEEDownloadInfo*

The data structure `CsCSEEDownloadInfo` contains download information for a CSEE resource based on the enumerated `Type` field. The `Type` field is required to be set to one of CS_CSEE_RESOURCE_TYPE definitions (see 6.3.5.2.2). The `SubType` field provides additional information on the download for the chosen resource (see 6.3.5.2.4. The `CSEId` field refers to a CSE identifier the CSEE is being downloaded to while the `Index` field is a hardware specific index for the CSE chosen.

If `Unload` field in `common` is set, then only the `CSEId` and `Index` fields are valid.

```
typedef struct {
    CS_CSEE_RESOURCE_TYPE Type;
    CS_RESOURCE_SUBTYPE SubType;        // value dependent on resource type
    u32 CSEId;                          // CSE Id to download the resource to
    u32 Index;                          // A hardware-based index where the download
                                        // resides
    CsCommonDownloadInfo common;        // common fields (refer to 6.3.5.3.11)
} CsCSEEDownloadInfo;
```

6.3.5.3.13 *CsCSFDownloadInfo*

The data structure `CsCSFDownloadInfo` contains download information for a CSF resource based on the enumerated `Type` field. The `Type` field is required to be set to one of CS_CSF_RESOURCE_TYPE definitions (see 6.3.5.2.3). The `SubType` field provides additional information on the download for the chosen resource (see 6.3.5.2.4). The `GlobalId` field, if non-zero, refers to a global unique identifier for the CSF being downloaded. The `CSEEId` field refers to a CSEE identifier the CSF is being downloaded to while the `Index` field is a hardware specific index for the CSEE chosen.

If `Unload` field in `common` is set, then only the `CSEEId` and `Index` fields are valid.

```
typedef struct {
    CS_CSF_RESOURCE_TYPE Type;
    CS_RESOURCE_SUBTYPE SubType;        // value dependent on resource type
    u64 GlobalId;                       // global unique identifier assigned to
                                        // the CSF, if available
    u32 CSEEId;                         // CSEE Id to download the resource to
    u32 Index;                          // A hardware-based index where the
                                        // download resides
    CsCommonDownloadInfo common;        // common fields (refer to 6.3.5.3.11)
} CsCSFDownloadInfo;
```

6.3.5.3.14 *CsPluginRequest*

The data structure `CsPluginRequest` is defined as follows:

```
typedef struct {
      enum CS_PLUGIN_TYPE Type;                    // see 6.3.5.2.16
      char PluginPath[4096];                       // full path to plugin
} CsPluginRequest;
```

6.3.6 Resources

Table 10: Table of resources

Resource	Details
CS_DEV_HANDLE	The global device handle received back from `csOpenCSx`
CS_MEM_HANDLE	Denotes a device memory handle and represents memory allocated on device
CS_CSF_ID	Denotes a computational storage function for all compute offload purposes
CS_EVT_HANDLE	Denotes an event handle for asynchronous IO
CS_BATCH_HANDLE	Denotes a batch request handle
CS_REQ_HANDLE	A handle to the outstanding request

6.3.7 Resource Dependency

Table 10 describes the resource dependency for each resource.

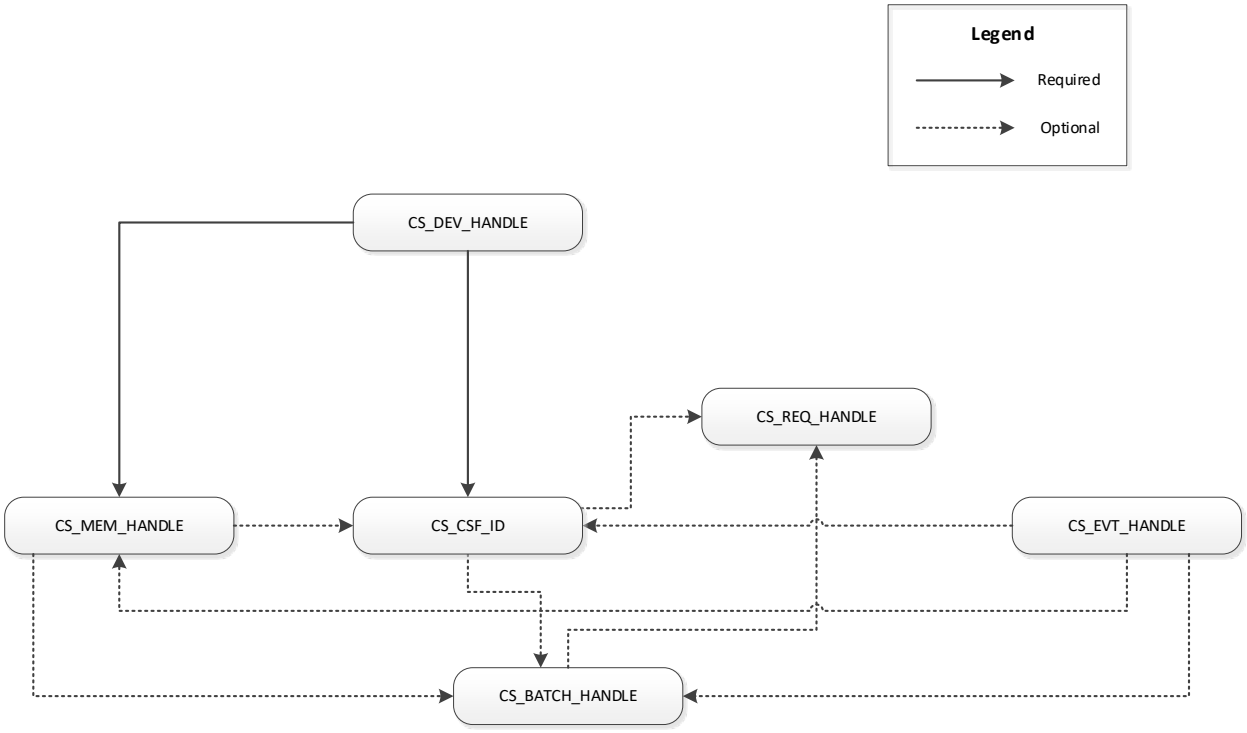


Figure 14: Resource dependency chart

Each resource created with the device is represented by a handle of type `CS_XXX_HANDLE` or `CS_CSF_ID` where `XXX` denotes the resource handle type. Some paths are required for the resource to be created and used while other paths may be optional.

For example, scheduling of compute offload jobs uses the `CS_CSF_ID` and may be done using synchronous or asynchronous notification mechanisms for completion. Here, `CS_EVT_HANDLE` is a notification option available that is not mandatory since an asynchronous mechanism may also be utilized with the callback option. Similarly, `CS_MEM_HANDLE` may be used by itself for device memory transfer operations.

The resource `CS_EVT_HANDLE` is a global resource while the others are allocated from the device. In a multi-device usage scenario, device specific resource handles play a key role in uniquely identifying resource by device type. The underlying implementation infrastructure will guarantee that there is no overlap between the resources and they areable to be kept unique when scaled.

6.3.8 Notification Callbacks

Common callback API definition to receive notifications on various CS based events. The callback is registered through the `csRegisterNotify()` API.

```
typedef void(*csDevNotificationFn)(u32 Notification,
```

```
    void *Context, CS_STATUS Status, int Length, void *Buffer);
```

This callback is invoked with specific notification information for which the context will correspond to. If the notification is for the CSx, the context will correspond to the context specified when the CSx was opened. If the notification corresponds to a CSE, then the context will correspond the CSE at the time it was opened.

Common callback API definition while queuing IO to the CSx

```
typedef void(*csQueueCallbackFn)(void *QueueContext,
    CS_STATUS Status, u64 CompValue);
```

6.4 Discovery

6.4.1 csQueryCSxList()

This API returns all of the CSxes available in the system.

6.4.1.1 Synopsis

```
CS_STATUS csQueryCSxList(int *Length, char *Buffer);
```

6.4.1.2 Parameters

IN OUT Length	Length in bytes of buffer passed for output
OUT Buffer	Returns a list of CSx names

6.4.1.3 Description

The `csQueryCSxList()` API fills `Buffer` with a comma separated list of all known CSxes identified by CSx names, if the length specified in `Length` is sufficient. This API may return zero or more CSxes as a list in `Buffer` when there are multiple CSxes devices in the system. If the length specified in `Length` is not sufficient to hold the contents returned in `Buffer`, then `Length` will be populated with the required size and an error status will be returned.

If a valid `Buffer` pointer is specified where the length specified in `Length` is sufficient, then it is updated with the list of CSx names available and `Length` updated to the actual length of the string returned. If the length specified in `Length` is not sufficient to hold the contents returned in `Buffer`, then `Length` will be populated with the required size and an error status will be returned. An invalid input will return an error status.

If a `NULL` pointer is specified for `Buffer` and a valid pointer is provided for `Length`, then the required buffer size is returned back in `Length`. The user will have to allocate a buffer of the returned size and reissue the request. The user is able to also provide a large enough buffer and satisfy the request.

All input and output parameters are required for this API.

6.4.1.4 Return Value

This API returns `CS_SUCCESS` if there is no error and zero or more CSxes were available for the list.

Otherwise, this API returns a status of CS_DEVICE_NOT_PRESENT, CS_INVALID_ARG, or CS_INVALID_LENGTH as defined in 6.3.3.

6.4.1.5 Notes

There may be one to multiple CSxes available in the system. The caller should always check the value of `Length` in bytes for a non-zero value, which represents valid entries. A null terminated string is returned in `Buffer` if `Length` is non-zero. If the list contains more than one CSx entry, then each entry will be comma separated. This API may still return with success when `Length` is zero.

The returned comma separated list of CSx names is able to be parsed and an entry is able to be selected and provided to the `csOpenCSx()` API to interface with the CSx.

An example source fragment implementation to return all known CSxes is:

```
length = 0;
status = csQueryCSxList(&length, NULL);
if (status != CS_INVALID_LENGTH)
    ERROR_OUT("unknown error!\n);

csx_array = malloc(length);
status = csGetCSxList(&length, &csx_array[0]);
if (status != CS_SUCCESS)
    ERROR_OUT("csGetCSxList() failed with status %d \n", status);
// process comma separated CSx list
```

6.4.2 csQueryCSFList()

This API returns zero or more CSFs available based on the query criteria.

6.4.2.1 Synopsis

```
CS_STATUS csQueryCSFList(const char *Path, int *Length, int *Count,
        CSFUniqueId *Buffer);
```

6.4.2.2 Parameters

IN Path	A string that denotes a path to a file, directory that resides on a device, a device path, or a CSx. The file/directory may indirectly refer to a namespace and partition.
IN OUT Length	Length of buffer passed for output
OUT Count	The total count of `CSFUniqueId` data structures returned
OUT Buffer	A pointer to hold an array of `CSFUniqueId` data structures for one or more activated CSFs if successful

6.4.2.3 Description

The `csQueryCSFList()` API fills `Buffer` with an array of `CSFUniqueId` data structures for one or more activated CSFs for the query based on `Path` if the length specified in `Length` is sufficient. This API may return one or more `CSFUniqueId` data structures in `Buffer` that match the `Path` criteria. A `Path` set to NULL is an invalid option and an error will be returned.

If a valid `Buffer` pointer is specified where the length specified in `Length` is sufficient, then the buffer is updated with the array of `CSFUniqueId` data structures available and `Length` is updated to the actual length of all `CSFUnqiueId` data structures returned for all functions that match `Path`. If the length specified in `Length` is not sufficient to hold the contents returned in `Buffer`, then `Length` will be populated with the required buffer size and an error status will be returned. An invalid input will return an error status.

If a `NULL` pointer is specified for `Buffer` and a valid pointer is provided for `Length`, then the required buffer size is returned back in `Length`. The user will have to allocate a buffer of the returned size and reissue the request. The user is able to also provide a large enough buffer and satisfy the request.

The `Count` value returned specifies the total number of `CSFUniqueId` data structures populated in `Buffer`.

All input and output parameters are required for this API.

6.4.2.4 Return Value

This API returns `CS_SUCCESS` if there is no error and one or more functions were available for the list.

Otherwise, this API returns a status of CS_INVALID_ARG, CS_INVALID_LENGTH, CS_UNSUPPORTED, CS_OUT_OF_RESOURCES, CS_DEVICE_NOT_PRESENT, CS_ENTITY_NOT_ON_DEVICE, CS_INVALID_DEVICE_NAME, CS_INVALID_PATH or CS_NO_MATCHING_DEVICE as defined in 6.3.3.

6.4.2.5 Notes

If the `Path` input specified a device path or a CSx, then the `CSFUniqueId` data structures returned, if any, are those available in that path. If the `Path` input specified a file or a directory, the query will reference the device path they reside on to satisfy the query.

There may be one to multiple CSFs available on any given CSx. The caller should always check the value of `Length` and `Count` for non-zero values which represents valid entries. If the `Buffer` contains more than one `CSFUniqueId` data structures, then

`Count` will specify the total number of data structures. This API may still return with success when `Length` is zero.

The returned list of `CSFUniqueId` data structures may be parsed and a required entry may be selected for further discovery or utilized to interface with a specific CSx.

6.4.3 csGetCSxFromPath()

This API returns the CSx associated with the specified file or directory path.

6.4.3.1 Synopsis

```
CS_STATUS csGetCSxFromPath(const char *Path, unsigned int *Length,
        char *DevName);
```

6.4.3.2 Parameters

IN Path	A string that denotes a path to a file, directory that resides on a device or a device path. The file/directory may indirectly refer to a namespace and partition.
IN OUT Length	Length of buffer passed for output
OUT DevName	Returns the qualified name to the CSx

6.4.3.3 Description

The `csGetCSxFromPath()` API queries the device, file, or directory path provided by `Path` to return the CSx associated with the specified path. If a `NULL` pointer is specified in `Path`, then all known CSxes are returned. If multiple CSxes are returned, then they will be comma separated.

If a valid `DevName` buffer pointer is specified where the length specified in `Length` is sufficient, then it is updated with the qualified name of the CSx for access. If the length specified in `Length` is not sufficient to hold the contents returned in `Buffer`, then `Length` will be populated with the required size and an error status will be returned. An invalid input returns an error status.

If a `NULL` pointer is specified for `DevName` and a valid pointer is provided for `Length`, then the requested buffer size is returned back in `Length`. The user may allocate a buffer of the returned length and reissue the request. The user may also provide a large enough buffer and satisfy the request.

All input and output parameters are required for this API.

6.4.3.4 Return Value

This API returns `CS_SUCCESS` if there is no error and a CSx was found to be associated with the path specified.

Otherwise, this API returns a status of CS_INVALID_ARG, CS_INVALID_PATH, CS_ENTITY_NOT_ON_DEVICE, CS_NO_MATCHING_DEVICE, CS_UNSUPPORTED, CS_OUT_OF_RESOURCES, CS_DEVICE_NOT_PRESENT, or CS_INVALID_LENGTH as defined in 6.3.3.

6.4.3.5 Notes

The `Path` parameter denotes the path to a device, filename or directory on a Linux filesystem. If the path specified is partial, then it will be resolved to its full path internally before mapping the device pair. This API works with most typical Linux file systems (e.g., ext3, ext4 and xfs) that are mounted on an underlying device without any raid indirections. This API will return CS_NO_MATCHING_DEVICE for such inputs.

The returned `DevName` is qualified to be used with the the `csOpenCSx()` API to interface with the CSE.

An example source fragment implementation would be:

```
status = csGetCSxFromPath(my_file_path, &length, &csx_array[0]);
if (status != CS_SUCCESS) {
    ERROR_OUT("The specified path %s returned an error %d\n", my_file_path, status);}
// open device, initialize CSF and pre-allocate buffers
status = csOpenCSx(csx_array[0], &dev_context, &dev);
…
```

6.5 Access

These set of functions are used to access a CSE. The user is able to utilize the discovery functions to find the CSE through the Storage/filesystem pair.

6.5.1 csOpenCSx()

Return a handle to the CSx associated with the specified device name.

6.5.1.1 Synopsis

```
CS_STATUS csOpenCSx(const char *DevName, void *DevContext,
        CS_DEV_HANDLE *DevHandle);
```

6.5.1.2 Parameters

IN DevName	A string that denotes the full name of the device
IN DevContext	A user specified context to associate with the device for future notifications
OUT DevHandle	Returns the handle to the CSE device

6.5.1.3 Description

The `csOpenCSx()` API opens the CSx and provides a handle for future usages to the user.

If a valid `DevName` is specified and available, a handle to the CSx is returned if all other parameters are valid. Any invalid parameter returns an error status.

All input and output parameters are required for this API.

6.5.1.4 Return Value

This API returns `CS_SUCCESS` if there is no error and the specified CSx was found.

Otherwise, this API returns a status of CS_INVALID_ARG, CS_ENTITY_NOT_ON_DEVICE or CS_DEVICE_NOT_PRESENT as defined in 6.3.3.

6.5.2 csCloseCSx()

Close a CSx previously opened and associated with the specified handle.

6.5.2.1 Synopsis

```
CS_STATUS csCloseCSx(CS_DEV_HANDLE DevHandle);
```

6.5.2.2 Parameters

IN DevHandle	Handle to CSx

6.5.2.3 Description

A valid `DevHandle` is required to be provided for this API. If the CSx is open, then it is closed and all outstanding requests are terminated.

All input and output parameters are required for this API.

6.5.2.4 Return Value

This API returns `CS_SUCCESS` if there is no error and the CSx was found as specified.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, as defined in 6.3.3.

6.5.3 csRegisterNotify()

Register a callback API to be notified based on various computational storage events across all CSxes.

This is an optional API.

6.5.3.1 Synopsis

```
CS_STATUS csRegisterNotify(const char *DevName, u32 NotifyOptions,
        csDevNotificationFn NotifyFn);
```

6.5.3.2 Parameters

IN DevName	A string that denotes a specific CSE or CSx to provide notifications for. If NULL, all CSEs and CSxes will be registered
IN NotifyOptions	Denotes the notification types to registered to
IN NotifyFn	A user specified callback notification function

6.5.3.3 Description

The `csRegisterNotify()` API registers the provided callback for notifications based on options selected in `NotifyOptions` by the user.

If a valid `DevName` is specified, the notifications will only be registered for the specified CSE or CSx. If NULL is specified, then the callback will be registered across all CSxes and CSEs. An invalid input returns an error status.

All input parameters are required for this API.

6.5.3.4 Return Value

This API returns `CS_SUCCESS` if there are no errors.

Otherwise, this API returns a status of CS_INVALID_ARG, CS_INVALID_OPTION, CS_DEVICE_NOT_PRESENT, CS_DEVICE_NOT_AVAILABLE, CS_OUT_OF_RESOURCES or CS_DEVICE_NOT_READY as defined in 6.3.3.

6.5.3.5 Notes

The callback is invoked by the API subsystem to provide notifications asynchronously based on notification options provided at registration time. Callbacks may be invoked for different types of notifications and errors, some of which may be fatal (i.e., the device is not able to recover from its error state). The caller acts upon these notifications with appropriate actions.

6.5.4 csDeregisterNotify()

Deregister a previously registered callback API for notifications on computational storage events. A callback API may have been previously registered using the `csRegisterNotify()` API.

This is an optional API.

6.5.4.1 Synopsis

CS_STATUS csDeregisterNotify(const char *DevName, csDevNotificationFn NotifyFn);

6.5.4.2 Parameters

IN DevName	A string that denotes a specific CSE or CSx to deregister notifications from. If NULL, all CSEs and CSxes will be deregistered
IN NotifyFn	The callback notification function previously registered

6.5.4.3 Description

The `csDeregisterNotify()` API removes a previously provided callback for notifications from one or more CSEs or CSxes.

If a valid `DevName` is specified, the notifications will only be deregistered for the specified CSE or CSx. If NULL, the callback will be deregistered across all CSxes and CSEs. An invalid input returns an error status.

All input parameters are required for this API.

6.5.4.4 Return Value

This API returns `CS_SUCCESS` if there are no errors.

Otherwise, this API returns a status of CS_INVALID_ARG, CS_DEVICE_NOT_PRESENT, or CS_OUT_OF_RESOURCES as defined in 6.3.3.

6.6 AFDM management

6.6.1 csAllocMem()

Allocates memory from the FDM for the requested size in bytes.

6.6.1.1 Synopsis

```
CS_STATUS csAllocMem(CS_DEV_HANDLE DevHandle, int Bytes,
        const CsMemFlags *MemFlags, CS_MEM_HANDLE *MemHandle,
        CS_MEM_PTR *VAddressPtr);
```

6.6.1.2 Parameters

IN DevHandle	Handle to CSx
IN Bytes	Length in bytes of FDM to allocate
IN MemFlags	Options for allocating FDM (see 6.3.5.3.3.1)
OUT MemHandle	Pointer to hold the memory handle once allocated
OUT VAddressPtr	Pointer to hold the virtual address of device memory allocated in host system address space. This is optional and may be NULL if memory is not required to be mapped

6.6.1.3 Description

The `csAllocMem()` API allocates requested memory from FDM.

If a valid `MemHandle` pointer is specified, it is updated with the handle to the AFDM. An invalid input returns an error status. If a valid `VAddressPtr` pointer is specified, the AFDM is mapped into the user's virtual address space in host memory. Only CSxes with

FDM host visible capability may use the `VAddressPtr` parameter. See section 6.3.5.3.1.9 for the capability details.

The values set in the `MemFlags` data structure describe how FDM is allocated. The `csAllocMem()` API allocates memory specified by the `FDMId` and only uses CS_FDM_CLEAR and CS_FDM_FILL, as defined in section 6.3.5.2.7. If CS_FDM_CLEAR is selected, then the contents of AFDM is cleared. If CS_FDM_FILL is specified, then the contents of AFDM is populated with the value in `FillValue`. The `FillValue` field is only valid is CS_FDM_CLEAR is specified and ignored otherwise. A value of zero in the `Flags` field specifies that no option was selected for `MemFlags` and AFDM is not modified on allocation.

All input parameters are required for this API.

6.6.1.4 Return Value

This API returns `CS_SUCCESS` if there were no errors and device memory was successfully allocated.

Otherwise, this API returns an error status of CS_DEVICE_NOT_AVAILABLE, CS_INVALID_HANDLE, CS_INVALID_ARG, CS_INVALID_OPTION, CS_INVALID_FDM_ID, CS_OUT_OF_RESOURCES, CS_NOT_ENOUGH_MEMORY, or CS_COULD_NOT_MAP_MEMORY as defined in 6.3.3.

6.6.1.5 Notes

AFDM is allocated using this API. AFDM is allocated on a host page size granularity and is rounded off for other values that are not in multiples of this size. It will be guaranteed that the virtual address pointer, if requested, will also be host page aligned.

The optional parameter `VAddressPtr` should only be used when the host application needs to transfer data between storage and AFDM. For all other cases this field should be set to NULL and the `MemHandle` returned from this API call should be used instead. These details are summarized below

a) If the host application wants to use the direct p2p capability between storage and AFDM, then it provides `VAddressPtr` as the buffer to filesystem read/write requests. Care should be taken that no buffering is enabled executing through a filesystem path by specifying the O_DIRECT flag when a file is opened. For those filesystems that do not provide such an interface, an appropriate mechanism should be used to keep data coherent. See section 6.7 for additional details.

b) For usages where the host applications need to transfer data between host memory and device memory, this parameter is not required and should be set to NULL. See usage of `csQueueCopyMemRequest()` in section 6.8.1.

6.6.2 csFreeMem()

Frees AFDM for the memory handle specified.

6.6.2.1 Synopsis

```
CS_STATUS csFreeMem(CS_MEM_HANDLE MemHandle,
        const CsMemFlags *MemFlags);
```

6.6.2.2 Parameters

IN MemHandle	Handle to AFDM
IN MemFlags	Options to specify while freeing FDM (see 6.3.5.3.3.1)

6.6.2.3 Description

The `csFreeMem()` API frees previously requested AFDM.

If a valid `MemHandle` value is specified, the memory represented by it is freed and returned back to the FDM. Any memory mappings created by the allocate call are also released and freed.

The values set in `MemFlags` describe how to handle AFDM when it is freed. The `csFreeMem()` API only uses CS_FDM_CLEAR and CS_FDM_FILL as defined in section **Error! Reference source not found.**. If CS_FDM_CLEAR is selected, then the contents of AFDM represented by `MemHandle` is cleared. If CS_FDM_FILL is specified, then the contents of AFDM represented by `MemHandle` is populated with the value in `FillValue`. The `FillValue` field is only valid if CS_FDM_FILL is specified and ignored otherwise. A value of zero in the `Flags` field specifies that no option is selected for `MemFlags` and AFDM is not modified when it is freed..

The `FDMId` field in `MemFlags` is ignored for this API as it does not apply.

All input parameters are required for this API.

6.6.2.4 Return Value

This API returns `CS_SUCCESS` if there is no error.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, CS_UNKNOWN_MEMORY, CS_MEMORY_IN_USE, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.6.2.5 Notes

The caller should ensure that no outstanding transactions are present on the memory handle being freed. If there outstanding transactions, then the request returns CS_MEMORY_IN_USE.

6.6.3 csInitMem()

Initialize AFDM contents for the memory handle specified.

6.6.3.1 Synopsis

```
CS_STATUS csInitMem(CS_MEM_HANDLE MemHandle, unsigned long ByteOffset,
      unsigned int Bytes, const CsMemFlags *MemFlags);
```

6.6.3.2 Parameters

IN MemHandle	Handle to AFDM
IN ByteOffset	Offset at which to start initialization
IN Bytes	Number of bytes to initialize
IN MemFlags	Options to initialize AFDM (see 6.3.5.3.3.1)

6.6.3.3 Description

The `csInitMem()` APIinitializes the contents of a previously requested AFDM with the specified details.

If a valid `MemHandle` value is specified, the contents of the memory represented by the handle is initialized. The option specified in the `MemFlags` parameter is applied to the specified AFDM for number of bytes specified by `Bytes` starting at `ByteOffset`.

The `ByteOffset` and `Bytes` parameters is required to specify valid values for the AFDM being initialized. This API returns an error if the offset plus the number of bytes specified is greater than the size of the AFDM.

The `MemFlags` parameter for the `csInitMem()` API only supports CS_FDM_CLEAR and CS_FDM_FILL for the `Flags` field as defined in section **Error! Reference source not found.**. If CS_FDM_CLEAR is selected, then the AFDM referenced by `MemHandle` is cleared. If CS_FDM_FILL is specified, then the value in the `FillValue` field is used to populate the AFDM referenced by `MemHandle`. The `FillValue` field is only valid if CS_FDM_FILL is specified and ignored otherwise. A value of zero in the `Flags` field specifies that the contents of AFDM represented by `MemHandle` not be initialized. The `FDMId` field in `MemFlags` is ignored for this API.

All input parameters are required for this API.

6.6.3.4 Return Value

This API returns `CS_SUCCESS` if there is no error.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, CS_UNKNOWN_MEMORY, CS_COULD_NOT_UNMAP_MEMORY, CS_INVALID_ARG, CS_INVALID_LENGTH, CS_INVALID_OPTION, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.6.3.5 Notes

The caller should ensure that the memory initialization requested at AFDM's offset and bytes has no outstanding transactions in progress. Doing so may incur unknown results.

6.7 Storage IOs

IO requests to and from storage devices are typically orchestrated through existing filesystems and block subsystem interfaces. P2P transfers between storage and CSxes may be achieved through filesystem read/write calls or through `csQueueStorageRequest()` API. For filesystem usage, the AFDM is allocated with virtual address mapping, and this address pointer is then passed along to the filesystem/block subsystem. This allows the data to be loaded directly into AFDM from storage and vice versa.. Only CSxes with FDM host visible capability may use the filesystem access path.

For more advanced usages, P2P access alone may not be able to satisfy a user request. The following are examples where P2P with a filesystem may not work:

- the CSx does not support host visible FDM; and
- the user requires remote CSx access.

6.7.1 csQueueStorageRequest()

Queues a storage IO request to the device.

6.7.1.1 Synopsis

```
CS_STATUS csQueueStorageRequest(const CsStorageRequest *Req, void *Context,
        csQueueCallbackFn CallbackFn, CS_EVT_HANDLE EventHandle,
        CS_REQ_HANDLE *ReqHandle, u64 *CompValue);
```

6.7.1.2 Parameters

IN Req	Structure to the storage request
IN Context	A user specified context for the storage request when asynchronous. The parameter is required only if `CallbackFn` or `EventHandle` is specified.
IN CallbackFn	A callback function if the request needs to be asynchronous.
IN EventHandle	A handle to an event previously created using the `csCreateEvent()` API. This value may be NULL if `CallbackFn` parameter is specified to be a valid value or if the request is synchronous.
OUT ReqHandle	A pointer to receive the request handle if successful. The received handle is able to be used to abort this request

	using the `csAbortRequest()` API. This is an optional parameter and depends on the implementation.
OUT CompValue	Additional completion value provided as part of completion. This may be optional depending on the implementation.

6.7.1.3 Description

The `csQueueStorageRequest()` API queues a storage request to the device.

A valid `Req` structure (see **Error! Reference source not found.**) is required to initiate the storage IO operation. All fields in `Req` structure are required and describe the source and destination details. The request may be performed synchronously or asynchronously. To be performed synchronously, the parameters `CallbackFn` and `EventHandle` should be set to NULL and `Context` is ignored. To be performed asynchronously, either a callback is required to be specified in `CallbackFn` or an event handle is required to be specified in `EventHandle`. It is an error to specify both of these parameters. If `Context` is specified, it is returned in the asynchronous completion path.

An optional pointer may be specified to receive a `ReqHandle` for the request. The `ReqHandle` allows the request to subsequently be aborted. For asynchronous operation, if a valid pointer is specified, it is updated with a handle to the submitted request. A synchronous operation ignores this parameter.

For `EventHandle`, see the `csCreateEvent()` API for usage.

6.7.1.4 Return Value

If there are no errors, then for:

a) a synchronous data transfer operation a status of CS_SUCCESS is returned; and
b) an asynchronous data transfer operation a status of CS_QUEUED is returned.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, CS_INVALID_ARG, CS_INVALID_OPTION, CS_UNKNOWN_MEMORY, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

This API may provide additional completion value returned in `CompValue`.

6.8 CSx data movement

The application is able to copy data from host memory to AFDM or from AFDM to host memory using this API call.

6.8.1 csQueueCopyMemRequest()

Copies data between host memory and AFDM in the direction requested.

6.8.1.1 Synopsis

```
CS_STATUS csQueueCopyMemRequest(const CsCopyMemRequest *CopyReq,
        void *Context, csQueueCallbackFn CallbackFn,
        CS_EVT_HANDLE EventHandle, CS_REQ_HANDLE *ReqHandle,
        u64 *CompValue);
```

6.8.1.2 Parameters

IN CopyReq	A request structure that describes the source and destination details of the copy request
IN Context	A user specified context for the copy request when asynchronous. The parameter is required only if `CallbackFn` or `EventHandle` is specified.
IN CallbackFn	A callback function if the copy request needs to be asynchronous.
IN EventHandle	A handle to an event previously created using the `csCreateEvent()` API. This value may be NULL if `CallbackFn` parameter is specified to be valid value or if also set to NULL when the request needs to be synchronous.
OUT ReqHandle	A pointer to receive the request handle if successful. The received handle is able to be used to abort this request using the `csAbortRequest()` API.This is an optional parameter and depends on the implementation.
OUT CompValue	Additional completion value provided as part of completion. This may be optional depending on the implementation.

6.8.1.3 Description

The `csQueueCopyMemRequest()` API copies data between device memory and host memory in the specified direction.

A valid `CopyReq` structure (see 6.3.5.3.3.3) is required to initiate the copy operation. All fields in the `CopyReq` structure are required and describe the source and destination details. To perform the request synchronously, the parameters `CallbackFn` and `EventHandle` should be set to NULL and `Context` is ignored. To perform the request asynchronously, either a callback is required to be specified in `CallbackFn` or an event handle is required to be specified in `EventHandle`. It is an error to specify both of these parameters. If `Context` is specified, it is returned in the asynchronous completion path. See notes for details.

An optional pointer may be specified to receive a `ReqHandle` for the request. The `ReqHandle` allows the request to subsequently be aborted. For asynchronous operation, if a valid pointer is specified, it is updated with a handle to the submitted request. A synchronous operation ignores this parameter.

6.8.1.4 Return Value

If there are no errors, then for:

a) a synchronous data transfer operation a status of CS_SUCCESS is returned; and
b) an asynchronous data transfer operation a status of CS_QUEUED is returned.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, CS_INVALID_ARG, CS_INVALID_OPTION, CS_UNKNOWN_MEMORY, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

This API may provide additional completion value returned in `CompValue`.

6.8.1.5 Notes

The `CsCopyMemRequest` structure describes the copy request with the host memory and device memory details and the size in the `Bytes` field that needs to be copied. The `Type` field describes the direction for the memory copy.

The `ByteOffset` field in `CsDevAFDM` may be set to zero for normal users. For advanced users, this field may be used in specifying one large device buffer with specific offsets for each request. One usage would be in a scatter gather list.

The copy operation may be requested to be synchronous or asynchronous. If synchronous, then all other inputs other than `CopyReq` should be set to NULL. If asynchronous, then either the `CallbackFn` or the `EventHandle` is required to be set to a valid value. It is an error for both the `CallbackFn` and the `EventHandle` to be set.

An example source fragment implementation to copy from host memory to device memory is:

```
// copy 4kb from host buffer to offset 0 of device memory handle synchronously
copyReq.Type = CS_COPY_TO_DEVICE;
copyReq.u.HostVAddress = &buffer;
copyReq.DevMem.MemHandle = devMem[0];
copyReq.DevMem.ByteOffset = 0;
copyReq.Bytes = 4096;
// block till copy is complete
status = csQueueCopyMemRequest(&copyReq, NULL, NULL, NULL, Null, NULL);
if (status != CS_SUCCESS)
    ERROR_OUT("csQueueCopyMemRequest() failed with status %d!\n", status);
…
```

6.9 CSF scheduling

CSxes provide one or more CSFs to which compute work may be scheduled. These functions require a mechanism to invoke them and collect their results.

The following APIs provide the functionality to invoke one or more CSFs.

6.9.1 csGetCSFId()

Fetches the CSF details specified by name for scheduling compute offload tasks.

6.9.1.1 Synopsis

CS_STATUS csGetCSFId(CS_DEV_HANDLE DevHandle, const char *CSFName,
    u64 GlobalId, int *Length, int *Count, CSFIdinfo *Buffer);

6.9.1.2 Parameters

IN DevHandle	Handle to CSx
IN CSFName	A pre-specified function name, if GlobalId is not specified
IN GlobalId	Global Identifier, if CSFName is not specified
IN OUT Length	The length of Buffer to hold `CSFIdInfo` details
OUT Count	Count of CSFIdInfo structures returned
OUT Buffer	A pointer to hold an array of `CSFIdInfo` data-structures for one or more CSFs if successful that contains `FDMId`, performance, and power details

6.9.1.3 Description

The `csGetCSFId()` API returns one or more `CSFIdInfo` data-structures in `Buffer` when the length specified in `Length` is sufficient to satisfy the request. The `CSFName` or `GlobalId` should be a valid value that is available in the CSx specified by `DevHandle`.

This API returns an error if:

a) the specified `CSFName` or `GlobalId` is not found; or
b) both `CSFName` and `GlobalId` are specified.

CSFs may be queried by either `CSFName` or `GlobalId`. If `CSFName` is specified by a valid NULL terminated string, then `GlobalId` should be set to zero. If `GlobalId` is specified, then `CSFName` should be set to NULL.

If a valid Buffer pointer is specified where the length specified in Length is sufficient, then it is updated with an array of available CSFIdInfo data-structures and Length is updated to the actual length of data returned in Buffer. If the length specified in Length is not sufficient to hold the contents returned in Buffer, then Length is populated with the required length and an error status is returned. An invalid input returns an error status.

If a NULL pointer is specified for Buffer and a valid pointer is provided for Length, then the required buffer length is returned in Length. The user should allocate a buffer of the returned length and reissue the request.

The Count value returned specifies the total number of CSFIdInfo data structures populated in Buffer.

All input and output parameters are required for this API.

6.9.1.4 Return Value

CS_SUCCESS is returned if there are no errors in initializing this API.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_OPTION, CS_INVALID_HANDLE, CS_INVALID_CSF_NAME, CS_INVALID_GLOBAL_ID, CS_DEVICE_NOT_AVAILABLE, or CS_INVALID_LENGTH as defined in 6.3.3.

6.9.1.5 Notes

Any compute work that needs to be run on a CSx first requires the associated CSFs to be configured. A list of configured CSFs may be queried through the csQueryCSFList() API.

This API should be called prior to any compute work being scheduled. The data returned in Buffer may contain an array of CSFIdInfo data-structures. The CSFId data field returned uniquely identifies the CSF and is used for scheduling work. The RelativePerformance data field and RelativePower data field help differentiate between multiple CSF instances, if received back from this API. The Count data field denotes the number of instances for this CSF and determines the parallelism available.

The NumFDMs data field provides the details of the FDMs that are accessible by the CSF in CSFIdInfo data structure and FDMList is a pointer to the list of FDMs. Each FDM entry contains the FDMId that may be used to allocate FDM using the csAllocMem() API while the RelativePerformance and RelativePower data fields help differentiate between FDMs.

6.9.2 csAbortRequest()

Aborts the queued request that is specified by the request handle.

6.9.2.1 Synopsis

CS_STATUS csAbortRequest(CS_REQ_HANDLE ReqHandle);

6.9.2.2 Parameters

IN ReqHandle	Handle to the outstanding request to abort.

6.9.2.3 Description

The `csAbortRequest()` API aborts the specified request. The input `ReqHandle` represents a request submitted using one of the `csQueueStorageRequest()` API, the `csQueueCopyMemRequest()` API, the `csQueueComputeRequest()` API, or the `csQueueBatchRequest()` API. If successful, the outstanding request is canceled from the queue and completed in error.

6.9.2.4 Return Value

A status value of `CS_SUCCESS` is returned if no errors were encountered in aborting the CSF.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, CS_FATAL_ERROR, CS_DEVICE_NOT_AVAILABLE, or CS_UNSUPPORTED as defined in 6.3.3.

6.9.2.5 Notes

Use this API to abort a queued task that may no longer be valid or is misbehaving.

6.9.3 csQueueComputeRequest()

Queues a compute offload request to the device to be executed synchronously or asynchronously in the device.

6.9.3.1 Synopsis

```
CS_STATUS csQueueComputeRequest(const CsComputeRequest *Req,
        void *Context, csQueueCallbackFn CallbackFn,
        CS_EVT_HANDLE EventHandle, CS_REQ_HANDLE *ReqHandle,
        u64 *CompValue);
```

6.9.3.2 Parameters

IN Req	A request structure that describes the CSE function and its arguments to queue.

IN Context	A user specified context for the queue request when asynchronous. The parameter is required only if `CallbackFn` or `EventHandle` is specified.
IN CallbackFn	A callback function if the queue request needs to be asynchronous.
IN EventHandle	A handle to an event previously created using `csCreateEvent`. This value may be NULL if `CallbackFn` parameter is specified to be valid value or if also set to NULL when the request needs to be synchronous.
OUT ReqHandle	A pointer to receive the request handle if successful. The received handle is able to be used to abort this request using the `csAbortRequest()` API.This is an optional parameter and depends on the implementation.
OUT CompValue	Additional completion value provided as part of completion. This may be optional depending on the implementation.

6.9.3.3 Description

The `csQueueComputeRequest()` API queues a CSF request to the CSx. The inputs and outputs for the CSF are specified in the `Req` data structure. The request may be performed synchronously or asynchronously. To perform the request synchronously, the parameters `CallbackFn` and `EventHandle` should be set to NULL and `Context` is ignored. To perform the request asynchronously, either a callback is required to be specified in `CallbackFn` or an event handle is required to be specified in `EventHandle`. It is an error to specify both of these parameters. If `Context` is specified, it is returned in the asynchronous completion path.

An optional pointer may be specified to receive a `ReqHandle` for the request to allow the request to be aborted. For asynchronous operation, if a valid pointer is specified, it is updated with a handle for the submitted request. A synchronous operation ignores this parameter.

For more information on callback usage, see 6.3.8.

For more information on using events for polling see 6.11.3.

6.9.3.4 Return Value

if there are no errors, then for:

a) a synchronous queue operation CS_SUCCESS is returned; and
b) an asynchronous queue operation CS_QUEUED is returned.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_OPTION, CS_INVALID_HANDLE, CS_INVALID_CSF_ID, CS_ERROR_IN_EXECUTION, CS_UNKNOWN_MEMORY, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

This API may provide additional completion value returned in `CompValue`.

6.9.3.5 Notes

The CSF needs to be loaded first and its handle populated in the `Req` structure.

This is a generic queueing API for any type of CSF. It is the responsibility of the caller to ensure that the number of arguments and their individual values map correctly to the CSF.

The data structure `CsComputeRequest` (see **Error! Reference source not found.**) provides inputs on the function the request should be issued to and its input arguments. The field `NumArgs` defines the number of arguments that need to be issued to the function. The user should ensure that these match actual function inputs.

See the `csQueueCopyMemRequest()` API (see 6.8.1) for `DevMem` field details and requirements on the `CallbackFn` and `EventHandle` inputs. An `EventHandle` is utilized only by user space applications. Kernel space applications such as drivers and filesystems use the `CallbackFn`.

For `EventHandle`, see the `csCreateEvent()` API for usage.

6.9.4 csHelperSetComputeArg()

Helper function that is able to optionally be used to set an argument for a compute request.

6.9.4.1 Synopsis

```
void csHelperSetComputeArg(CsComputeArg *ArgPtr,
        CS_COMPUTE_ARG_TYPE Type, …);
```

Parameters

IN ArgPtr	A pointer to the argument in `CsComputeRequest` to be set.

IN Type	The argument type to set. This value may be one of the enumerated type values.
IN <…>	One or more variables that make up the argument by type.

6.9.4.2 Description

The `csHelperSetComputeArg()` API is a helper function that sets an argument for a compute request. A compute request may have one or more arguments. Each argument may have one or more inputs that describe it. This API sets up the argument with minimal code.

This API does not validate inputs.

6.9.4.3 Return Value

No status is returned from this API since it does not change any values.

6.9.4.4 Notes

The helper function may optionally be used to setup individual arguments to a compute request as shown in the following example code snippet. It helps replace the commented code when applied.

```
// setup compute request with 3 arguments
req->CSFId = functId;
req->NumArgs = 3;
argPtr = &req->Args[0];
csHelperSetComputeArg(&argPtr[0], CS_AFDM_TYPE, inMemHandle, inMemOffset);
csHelperSetComputeArg(&argPtr[1], CS_32BIT_VALUE_TYPE, 16384);
csHelperSetComputeArg(&argPtr[2], CS_AFDM_TYPE, outMemHandle, 0);
/* code it replaces
argPtr[0].Type = CS_AFDM_TYPE;                // input data buffer
argPtr[0].u.DevMem.MemHandle = inMemHandle;
argPtr[0].u.DevMem.ByteOffset = inMemOffset;
argPtr[1].Type = CS_32BIT_VALUE_TYPE;         // size
argPtr[1].u.Value32 = 16384;
argPtr[2].Type = CS_AFDM_TYPE;                // output data buffer
argPtr[2].u.DevMem.MemHandle = outMemHandle;
argPtr[2].u.DevMem.ByteOffset = 0;
*/
```

6.10 Batch scheduling

For offload work that involves more than one step with functions, batch scheduling aids in queuing such requests. Batching may involve serializing multiple requests pipelined to execute one after another or parallelizing them to execute together, provided the required hardware resources are available.

The process of scheduling batched requests helps in the following ways:

a) Minimize on host orchestration sub-tasks and associated latency costs;
b) Minimize on host CPU context switches;
c) Simplify the number of steps involved in processing user data; and
d) Reduce overall latency of the intended compute work.

Batch request processing may be conducted with the `csAllocBatchRequest()` API(see 6.10.1), the `csFreeBatchRequest()` API (see 6.10.2), the `csAddBatchEntry()` API (see 6.10.3), the `csHelperReconfigureBatchEntry()` API (see 6.10.4), the `csHelperResizeBatchRequest()` API (see 6.10.5), and the `csQueueBatchRequest()` API (see 6.10.6). A batch operation is setup by first creating a batch request and then populating it with the list of requests. Once setup, the operation is able to be queued using the `csQueueBatchRequest()` API. Batch operations are identified by the batch handle and are able to be reused once a queued request is complete. Optionally, entries added to the batch request are able to be reconfigured as needed for successive IOs.

6.10.1 csAllocBatchRequest()

Allocates a batch handle that may be used to submit batch requests. The handle resource may be set up with the individual requests that need to be batch processed. The allocation may be requested for serial, parallel, or hybrid batched request flows that support storage, compute, and data copy requests all in one function.

6.10.1.1 Synopsis

```
CS_STATUS csAllocBatchRequest(CS_BATCH_MODE Mode, int MaxReqs,
        CS_BATCH_HANDLE *BatchHandle);
```

6.10.1.2 Parameters

IN Mode	The requested batch mode namely, serial, parallel or hybrid.

IN MaxReqs	The maximum number of requests the caller perceives added to this batch resource. This parameter provides a hint to the sub-system for resource management.
OUT BatchHandle	The created handle for batch request processing if successful.

6.10.1.3 Description

The `csAllocBatchRequest()` API creates a batch request handle resource that may be used to queue more than one request later.

6.10.1.4 Return Value

If there are no errors in the allocation of the resource, then the status `CS_SUCCESS` is returned.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, CS_INVALID_ARG, CS_INVALID_OPTION, CS_OUT_OF_RESOURCES, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.10.2 csFreeBatchRequest()

Frees a batch handle previously allocated with a call to the `csAllocBatchRequest()` API.

6.10.2.1 Synopsis

CS_STATUS csFreeBatchRequest(CS_BATCH_HANDLE BatchHandle);

6.10.2.2 Parameters

IN BatchHandle	The handle previously allocated for batch requests.

6.10.2.3 Description

The `csFreeBatchRequest()` API frees all resources allocated for the requested batch handle.

6.10.2.4 Return Value

`CS_SUCCESS` is returned if there are no errors in freeing the batch resources.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, or CS_NOT_DONE as defined in 6.3.3.

6.10.3 csAddBatchEntry()

Add a request to the batch request resource represented by the input handle. The request type is: storage, compute, or copy memory. Additionally, the batch index parameters places the request at the required point in the list of requests.

6.10.3.1 Synopsis

```
CS_STATUS csAddBatchEntry(const CS_BATCH_HANDLE BatchHandle
        CsBatchRequest *Req, CS_BATCH_INDEX Before,
        CS_BATCH_INDEX After, CS_BATCH_INDEX *Curr);
```

6.10.3.2 Parameters

IN BatchHandle	The batch request handle that describes the CSx batch to which the items specified in CsBatchRequest are to be added.
IN Req	The request to add to the batch request represented by `BatchHandle` parameter. Denotes a compound request structure that describes the CSx batch items. The CSx batch items contain the CSx based work items that may include storage request, compute requests or memory copy requests.
IN Before	A batch entry index that denotes the position of an existing request entry that the current request will be inserted in front of. A zero value denotes the current request is required to be the first request. Any other non-zero value is required to represent a valid entry returned back from a previous call to this API.
IN After	A batch entry index that denotes the position of an existing request entry that the current request will be inserted in after of. A zero value denotes the current request is required to be the first request. Any other non-zero value is required to represent a valid entry returned back from a previous call to this API.
OUT Curr	A pointer to hold the output of the batch entry index for the current request index of a successful call to this API.

6.10.3.3 Description

The `csAddBatchEntry()` API adds a request to a batch of requests represented by the `BatchHandle` parameter.

6.10.3.4 Return Value

`CS_SUCCESS` is returned if there are no errors in processing the entry addition.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_OPTION, CS_INVALID_HANDLE, CS_INVALID_CSF_ID, CS_UNKNOWN_MEMORY, CS_HANDLE_IN_USE, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

Notes

The parameter `Req` defines:

a) the individual requests themselves;
b) the type of batch request (i.e., `CS_COPY_DEV_MEM`, `CS_STORAGE_IO`, or `CS_QUEUE_COMPUTE`); and
c) the work item which may be one of `CsCopyMemRequest`, `CsStorageRequest` or `CsComputeRequest` data structures.

See details in the `csQueueCopyMemRequest()` API, the `csQueueStorageRequest()` API, and the `csQueueComputeRequest()` API.

6.10.4 csHelperReconfigureBatchEntry()

Helps reconfigure an existing batch request entry with new request information.

6.10.4.1 Synopsis

```
CS_STATUS csHelperReconfigureBatchEntry(CS_BATCH_HANDLE BatchHandle,
    CS_BATCH_INDEX Entry, const CsBatchRequest *Req);
```

6.10.4.2 Parameters

IN BatchHandle	The handle previously allocated for batch requests.
IN Entry	The request's batch entry index that is reconfigured.
IN Req	The new batch request entry details.

6.10.4.3 Description

The `csHelperReconfigureBatchEntry()` API reconfigures an existing batch request entry located at the specified index denoted by `Entry` parameter.

6.10.4.4 Return Value

`CS_SUCCESS` is returned if there are no errors in reconfiguring the batch request entry.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, CS_INVALID_ARG, CS_INVALID_OPTION, CS_INVALID_HANDLE, or CS_UNKNOWN_MEMORY as defined in 6.3.3.

6.10.5 csHelperResizeBatchRequest()

Resizes an existing batch request for the maximum number of requests that it is able to accommodate.

6.10.5.1 Synopsis

```
CS_STATUS csHelperResizeBatchRequest(CS_BATCH_HANDLE BatchHandle,
    int MaxReqs);
```

6.10.5.2 Parameters

IN BatchHandle	The handle previously allocated for batch requests that is resized.
IN MaxReqs	The maximum number of requests the caller perceives that this batch resource is resized to. The parameter may not exceed the maximum supported by the CSE.

6.10.5.3 Description

The `csHelperResizeBatchRequest()` API resizes an existing batch request to the maximum request size specified.

6.10.5.4 Return Value

`CS_SUCCESS` is returned if there are no errors in the resizing of the resource.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_OPTION, CS_OUT_OF_RESOURCES, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.10.6 csQueueBatchRequest()

Queues a data graph request to the device to be executed synchronously or asynchronously in the device. The request is able to support serial, parallel or a mixed variety of batched jobs defined by their data flow and support storage, compute and

data copy requests all in one function. The handle is required to already have been populated with the list of batched requests.

6.10.6.1 Synopsis

```
CS_STATUS csQueueBatchRequest(CS_BATCH_HANDLE BatchHandle,
    void *Context, csQueueCallbackFn CallbackFn,
    CS_EVT_HANDLE EventHandle, CS_REQ_HANDLE *ReqHandle,
    u64 *CompValue);
```

6.10.6.2 Parameters

IN BatchHandle	The handle previously allocated for batch requests.
IN Context	A user specified context for the queue request when asynchronous. The parameter is required only if `CallbackFn` or `EventHandle` is specified.
IN CallbackFn	A callback function if the queue request needs to be asynchronous.
IN EventHandle	A handle to an event previously created using the `csCreateEvent()` API. This value may be `NULL` if `CallbackFn` parameter is specified to be valid value or if also set to `NULL` when the request needs to be synchronous.
OUT ReqHandle	A pointer to receive the request handle if successful. The received handle may be used to abort this request using the `csAbortRequest()` API.This is an optional parameter and depends on the implementation.
OUT CompValue	Additional completion value provided as part of completion. This may be optional depending on the implementation.

6.10.6.3 Description

The `csQueueBatchRequest()` API queues a batch of requests that may include flows for storage, compute, and device memory copies with the CSE.

The inputs and outputs for the request are specified in the `Req` data structure which contains entries for storage, compute and device memory copy. The details of `Req` are populated using the helper functions detailed in 6.10. The request may be performed synchronously or asynchronously. To perform the request synchronously, the parameters `CallbackFn` and `EventHandle` should be set to NULL and `Context` is

ignored. To perform the request asynchronously, either a callback is required to be specified in `CallbackFn` or an event handle is required to be specified in `EventHandle`. It is an error to specify both of these parameters. If `Context` is specified, it is returned in the asynchronous completion path. See notes for details.

An optional pointer may be specified to receive a `ReqHandle` for the request to allow the request to be aborted. For asynchronous operation, if a valid pointer is specified, it is updated with a handle to the submitted request. A synchronous operation ignores this parameter.

For more information on callback usage, see 6.3.8.

For more information on using events for polling see 6.11.3.

6.10.6.4 Return Value

`CS_SUCCESS` is returned if there are no errors in synchronous queue operation.

`CS_QUEUED` is returned if there are no errors in asynchronous queue operation.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_HANDLE, CS_UNKNOWN_MEMORY, CS_ERROR_IN_EXECUTION, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

This API may provide additional completion value returned in `CompValue`.

6.10.6.5 Notes

Queueing work items in batches simplifies how a more complex operation should be done in one request. A batch of requests is able to take many forms as noted below:

a) A mixture of storage operations, compute memory copy operations and device-based CSF executions. E.g. Copy data from host memory to compute memory and run a CSF. Additionally may copy the results back to host memory;
b) Divide a large compute work item into smaller work items and run each of them on similar functions in parallel;
c) Copy multiple copies of data from device memory to host memory that may describe something similar to a scatter gather list in storage;
d) Load data from storage directly in device memory, run a CSF and copy the results back to host memory. This may be the most common type of usage;
e) Queue the output of the first CSF to a second CSF and so forth;
f) Load storage data and metadata in parallel and run separate computational storage functions on them in parallel, collate the results to a secondary CSF and copy the results back to host memory.

This is a generic queueing function to batch different operations of CSFs and device memory copy operations. It is the responsibility of the caller to ensure the number of arguments and their individual values map correctly to the CSF.

The batching operation requires that a batch handle be allocated using the `csAllocBatchRequest()` API and then individual requests be added using the `csAddBatchEntry()` API.

Batching requests require the `Mode` field input, which may be `CS_BATCH_SERIAL`, `CS_BATCH_PARALLEL`, and `CS_BATCH_HYBRID`. This input instructs the API library on how to handle this request. Serialized requests are those that depend on the previous requests output as their input. Parallelized requests are breaking down multiple requests into smaller requests that execute all at the same time. Requests may be sent in parallel to the same function on the same device or different devices to be executed at the same time. For additional details on batching requests see section 5.2.1.

If the data input to a CSF has dependencies on a previous operation to complete, then the `CS_BATCH_INDEX` parameters are required to be utilized correctly to place the new request entry in the batch of requests. Each new request may be inserted anywhere in the batch and the indices help guide the queue placement. For example, a previous request may have an AFDM copy from host or a storage IO request that needs to populate the input data to this batch request. In a serialized request using `CS_BATCH_SERIAL` mode, the storage request is placed first followed by the CSF request. The dependencies of individual requests are guided by the placement of each request in the batch list. The batch request preprocessor will look up dependencies of memory resources in the list. Optimizations on queuing requests may be applied based on this information presented by the batch details. With `CS_BATCH_HYBRID` mode, complex flow graphs are able to be processed where multiple serial and parallel flows are able to be accommodated. Additional details on this usage is provided under hybrid operations in section 5.2.1.3.

The requirements on the `CallbackFn` and `EventHandle` apply the same way as in the `csQueueCopyMemRequest()` API.An `EventHandle` will be utilized only by user space applications while function space users (e.g., drivers and filesystems) will use the `CallbackFn`.

For `EventHandle`, see the `csCreateEvent()` API for usage.

The following example shows batch request processing to analyze a 1GB data file and provide the output back to the host. It demonstrates reuse and reconfigurability.

```
// preprocess: discover & configure CSF(s), Storage
//     open file in O_DIRECT mode and locate data section
//     preallocate AFDM for inputs/outputs
// Allocate a batch request for serial mode processing
status = csAllocBatchRequest(CS_BATCH_SERIAL, 3, &BatchHandle);
if (status != CS_SUCCESS)
    ERROR_OUT("csAllocBatchRequest failed\n");
// allocate storage, compute and DMA requests and set them up..
status = csAddBatchEntry(BatchHandle, &storReq, 0, 0, &storEntry);
if (status != CS_SUCCESS)
    ERROR_OUT("csAllocBatchEntry failed for storEntry\n");
```

```
status = csAddBatchEntry(BatchHandle, &compReq, 0, storEntry, &compEntry);
if (status != CS_SUCCESS)
    ERROR_OUT("csAllocBatchEntry failed for compEntry\n");
status = csAddBatchEntry(BatchHandle, &copyReq, 0, compEntry, &copyEntry);
if (status != CS_SUCCESS)
    ERROR_OUT("csAllocBatchEntry failed for copyEntry\n");
// process through entire data file of 1GB
while (fileSize) {
    status = csQueueBatchRequest(BatchHandle, NULL, NULL, NULL, NULL, NULL);
    if (status != CS_SUCCESS)
        ERROR_OUT("csQueueBatchRequest failed\n");
    fileSize -= dataSize;
    // advance file pointer to next 1MB (only updates storage batch details)
    storReq.u.StorageIo.u.FileIo.Offset += dataSize;
    status = csHelperReconfigureBatchEntry(BatchHandle, storEntry, &storReq);
    if (status != CS_SUCCESS)
        ERROR_OUT("csHelperReconfigureBatchEntry failed\n");
}
status = csFreeBatchRequest(BatchHandle);
if (status != CS_SUCCESS)
    ERROR_OUT("csFreeBatchRequest failed\n");
```

6.11 Event Management

The following functions aid in the usage of OS abstracted events.

6.11.1 csCreateEvent()

Allocates an event resource and returns a handle when successful.

6.11.1.1 Synopsis

CS_STATUS csCreateEvent(CS_EVT_HANDLE *EventHandle);

6.11.1.2 Parameters

OUT EventHandle	Pointer to hold the event handle once allocated

6.11.1.3 Description

The `csCreateEvent()` API allocates and initializes a system event resource.

If a valid `EventHandle` pointer is specified, it is updated with the handle to the allocated event resource. An invalid input will return an error status.

All input parameters are required for this API.

6.11.1.4 Return Value

`CS_SUCCESS` is returned if there were no errors and an event resource was successfully allocated.

Otherwise, this API returns an error status of CS_INVALID_ARG or CS_NOT_ENOUGH_MEMORY as defined in 6.3.3.

6.11.1.5 Notes

Event resource is allocated at the system level not at the device level. It is able to be used with any CSx. Once used, it will be referenced by that device and should not be used simultaneously by more than once device.

6.11.2 csDeleteEvent()

Frees a previously allocated event resource.

6.11.2.1 Synopsis

CS_STATUS csDeleteEvent(CS_EVT_HANDLE EventHandle);

6.11.2.2 Parameters

IN EventHandle	The event handle that needs to be freed

6.11.2.3 Description

The `csDeleteEvent()` API deletes an event resource previously allocated using the `csCreateEvent()` API.

If a valid `EventHandle` is specified, it is freed and returned back to the system. An invalid input will return an error status.

All input parameters are required for this API.

6.11.2.4 Return Value

`CS_SUCCESS` is returned if there were no errors and an event resource was successfully freed.

Otherwise, this API returns an error status of CS_INVALID_HANDLE or CS_HANDLE_IN_USE as defined in 6.3.3.

6.11.3 csPollEvent()

Polls the event specified for any pending events.

6.11.3.1 Synopsis

```
CS_STATUS csPollEvent(CS_EVT_HANDLE EventHandle, void **Context,
        u64 *CompValue);
```

6.11.3.2 Parameters

IN EventHandle	The event handle that needs to be polled
OUT Context	The context to the event that completed
OUT CompValue	Additional completion value provided as part of completion. This may be optional depending on the implementation.

6.11.3.3 Description

The `csPollEvent()` API queries an event resource previously allocated using the `csCreateEvent()` API when used with CSFs. The `Context` parameter returned will refer to the original context provided when the request was made.

If a valid `EventHandle` is specified, it is queried for any pending events. An invalid input will return an error status.

All input parameters are required for this API.

6.11.3.4 Return Value

`CS_NOT_DONE` is returned if there no pending events.

`CS_SUCCESS` is returned if the pending work item completed successfully without errors.

Otherwise, this API returns an error status of CS_INVALID_HANDLE, CS_DEVICE_NOT_AVAILABLE, CS_DEVICE_ERROR, CS_FATAL_ERROR, CS_IO_TIMEOUT, CS_NOTHING_QUEUED, or CS_ERROR_IN_EXECUTION as defined in 6.3.3 that maps to the work item it was included in.

This API may provide additional completion value returned in `CompValue`.

6.11.3.5 Notes

An event resource is submitted to the `csQueueCopyMemRequest()` API, the `csQueueComputeRequest()` API, or the `csQueueBatchRequest()` API for polling. It is the responsibility of the user to ensure that the correct event handle is used to poll and that the handle was not freed use the `csDeleteEvent()` API.

6.12 Management

Device management provides functions that are used to query and manage the device properties and resources.

6.12.1 csQueryDeviceProperties()

Queries the CSx for its properties.

This is a privileged API.

6.12.1.1 Synopsis

```
CS_STATUS csQueryDeviceProperties(CS_DEV_HANDLE DevHandle,
        CS_RESOURCE_TYPE Type, int *Length, CsProperties *Buffer);
```

6.12.1.2 Parameters

IN DevHandle	Handle to CSx
IN Type	The type of CSx resource to query
IN OUT Length	Length in bytes of buffer passed for output
OUT Buffer	A pointer to a buffer that is able to hold the device properties

6.12.1.3 Description

The `csQueryDeviceProperties()` API fills `Buffer` with the device properties for the CSx as requested by the `Type` field, if the length specified in `Length` is sufficient. This API, if successful, may return one or more sub-structures in `Buffer`.

If a valid `Buffer` pointer is provided, where the length specified in `Length` is sufficient, then it is updated with the requested CSx resource type properties and `Length` is updated with the total data returned in bytes in `Buffer`. If the length specified in `Length` is not sufficient to hold the contents returned in `Buffer`, then `Length` will be populated with the required size and an error status will be returned.

If a `NULL` pointer is specified for `Buffer` and a valid pointer is provided for `Length`, then the required buffer size is returned back in `Length` for that resource type. The user will have to allocate a buffer of the returned size and reissue the request.

If a valid pointer is specified for `Buffer` and a valid pointer is provided for `Length` and the value in `Length` is not sufficient for the device properties, then the required buffer size is returned back in `Length`.

All input parameters are required for this API.

6.12.1.4 Return Value

`CS_SUCCESS` is returned if there are no errors.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_HANDLE, CS_INVALID_ID, CS_INVALID_LENGTH, CS_NO_PERMISSIONS, CS_NOT_ENOUGH_MEMORY, CS_DEVICE_ERROR, CS_DEVICE_NOT_READY, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.12.1.5 Notes

The properties returned provide information on versions in use and are able to be used by the caller when multiple devices are in use.

A user utilizes this API early on in device setup to verify that the properties are as expected prior to configuring the CSx.

6.12.2 csQueryDeviceStatistics()

Queries the CSx for specific runtime statistics. These could vary depending on the requested type inputs. Details on CSFs and the CSx may be queried.

This is a privileged API.

6.12.2.1 Synopsis

```
CS_STATUS csQueryDeviceStatistics(CS_DEV_HANDLE DevHandle,
        CS_STAT_TYPE Type, void *Identifier, CsStatsInfo *Stats);
```

6.12.2.2 Parameters

IN DevHandle	Handle to CSx
IN Type	Statistics type to query
IN Identifier	Additional options based on Type
OUT Stats	A pointer to a buffer that will hold the requested statistics

6.12.2.3 Description

The `csQueryDeviceStatistics()` API returns the device statistics based on `Type` requested. The `Stats` field is a union of structures and is populated with the desired output based on the input provided by `Type` and `Identifier` fields.

The `identifier` is optional and is required only for certain statistics types. The `Identifier` is used with structures `CSEDetails` and `CSFDetails`. When used for `CSEDetails`, the Identifier field refers to the `CSEId` field in `CSEProperties`. When used for `CSFDetails`, the `Identifier` refers to the `CSFId` statistics to be queried.

For a specific CSE's statistics, the `Identifier` should be set to its unique `CSEId` available in the `csQueryDeviceProperties()` API.Similarly, for specific CSF statistics, the Identifier is required to be set to its unique `CSFId` also available using the `csQueryDeviceProperties()` API. An error is returned if the `Identifier` is set to NULL while `Type` requires it.

All input parameters are required for this API.

6.12.2.4 Return Value

`CS_SUCCESS` is returned if there are no errors.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_HANDLE, CS_NO_PERMISSIONS, CS_NOT_ENOUGH_MEMORY, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.12.2.5 Notes

The Statistics returned provide information on CSx usage (e.g., utilization and health). Some of the statistics reflected will be preserved since the power on state. The counters will not be reset on a query.

6.12.3 csCSEEDownload()

Downloads a specified CSEE resource. It is implementation specific as to how the downloaded resource is secured.

This is a privileged API.

6.12.3.1 Synopsis

```
CS_STATUS csCSEEDownload(CS_DEV_HANDLE DevHandle,
        CsCSEEDownloadInfo *Info, u32 *CSEEId);
```

6.12.3.2 Parameters

IN DevHandle	Handle to CSx
IN Info	A pointer to a buffer that holds the CSEE resource details to download

OUT CSEEId	A pointer to hold the identifier to the downloaded CSEE resource

6.12.3.3 Description

The `csCSEEDownload()` API downloads a CSEE using the details in `Info`. The `Info` parameter provides the details of download contents (e.g., the CS_CSEE_RESOURCE_TYPE and CS_RESOURCE_SUBTYPE. Additional details on these fields are provided in section (see 6.3.5.2.2 and 6.3.5.2.4). On a successful download, a `CSEEId` for the downloaded CSEE is returned. This value may be used to configure the downloaded resource using the `csConfig()` API.

All parameters are required for this API.

6.12.3.4 Return Value

`CS_SUCCESS` is returned if there are no errors.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_UNSUPPORTED, CS_UNSUPPORTED_ TYPE, CS_UNSUPPORTED_INDEX CS_INVALID_HANDLE, CS_NO_PERMISSIONS, CS_INVALID_OPTION, CS_LOAD_ERROR, CS_NOT_ENOUGH_MEMORY or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.12.3.5 Notes

CSxes that contain a CSE that is not capable of accepting a downloaded CSEE fail this API (e.g., CSx devices that only have fixed functionality).

6.12.4 csCSFDownload()

Downloads a specified CSF resource. It is implementation specific as to how the downloaded code is secured.

This is a privileged API.

6.12.4.1 Synopsis

```
CS_STATUS csCSFDownload(CS_DEV_HANDLE DevHandle,
        CsCSFDownloadInfo *Info, u32 *CSFId);
```

6.12.4.2 Parameters

IN DevHandle	Handle to CSx
IN Info	A pointer to a buffer that holds the CSF resource details to download

OUT CSFId	A pointer to hold the identifier to the downloaded CSF resource

6.12.4.3 Description

The `csCSFDownload()` API downloads a CSF using the details in `Info`. The `Info` parameter provides the details of download contents such as the CS_CSF_RESOURCE_TYPE. Additional details on these fields are provided in section 6.3.5.3.13 and 6.3.5.2.4. On a successful download, a `CSFId` for the downloaded CSF is returned. This value may be used to configure the downloaded resource using the `csConfig()` API.

All parameters are required for this API.

6.12.4.4 Return Value

`CS_SUCCESS` is returned if there are no errors.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_UNSUPPORTED, CS_UNSUPPORTED_ TYPE, CS_UNSUPPORTED_INDEX CS_INVALID_HANDLE, CS_NO_PERMISSIONS, CS_INVALID_OPTION, CS_LOAD_ERROR, CS_NOT_ENOUGH_MEMORY, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.12.4.5 Notes

CSxes that contain a CSEE that is not capable of accepting a downloaded CSF fail this API (e.g., CSx devices that only have fixed functionality).

6.12.5 csConfig()

Configures the activation state or vendor specific configuration of the specified CSx. The CSEE and CSF are the resources that may be activated or configured with this API. Prior to usage, these resources are required to be activated.

This is a privileged API.

6.12.5.1 Synopsis

```
CS_STATUS csConfig(CS_Dev_HANDLE DevHandle, int *Length,
        const CsConfigInfo *Info, CsConfigData *Data);
```

6.12.5.2 Parameters

IN DevHandle	Handle to CSx
IN Length	Length of Info when vendor configuration is specified

IN Info	A pointer to the data structure with the requested configuration
OUT Data	Configuration results

6.12.5.3 Description

The `csConfig()` API configures the specified CSx resource. The requested configuration is specified in `Info` and the results of the configuration are provided as output in `Data`. The `Length` parameter is specified when implementation specific details are described in the `VSInfo` field in the `Info` parameter.

The `Length` parameter is optional based on the presence of `VSInfo`. All other parameters are required for this API.

6.12.5.4 Return Value

`CS_SUCCESS` is returned if there are no errors.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_LENGTH, CS_INVALID_OPTION, CS_INVALID_ID, CS_UNSUPPORTED, CS_INVALID_HANDLE, CS_NO_PERMISSIONS, CS_LOAD_ERROR, CS_DEVICE_ERROR, CS_NOT_ENOUGH_MEMORY or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.12.5.5 Notes

Only CSxes that contain a CSE that is capable of processing configuration input accept this API.

6.12.6 csReset()

Resets the CSx resource specified.

This is a privileged API.

6.12.6.1 Synopsis

```
CS_STATUS csReset(CS_DEV_HANDLE DevHandle,
        CS_RESOURCE_TYPE ResourceType, u32 ResourceId);
```

6.12.6.2 Parameters

IN DevHandle	Handle to CSx
IN ResourceType	Type of resource to reset
IN ResourceId	The Identifier of the resource to reset

6.12.6.3 Description

The `csReset()` API resets the specified CSx resource . As part of the operation, outstanding transactions to one or more of the CSEs are aborted and IOs are de-queued and completed in error.

All input parameters are required for this API.

6.12.6.4 Return Value

`CS_SUCCESS` is returned if there are no errors.

Otherwise, this API returns an error status of CS_UNSUPPORTED, CS_INVALID_HANDLE, CS_NO_PERMISSIONS, CS_DEVICE_ERROR, CS_DEVICE_NOT_READY, CS_DEVICE_NOT_PRESENT, CS_FATAL_ERROR, CS_NOT_ENOUGH_MEMORY, or CS_DEVICE_NOT_AVAILABLE as defined in 6.3.3.

6.12.6.5 Notes

The call is only able to be done by a privileged user.

6.13 Library Management

Library management involves functions that are used to query and manage the API library interfaces and resources for compute offload devices. These library functions may be used to add additional functionality not available in the API library, achieve compatibility, or to enable vendor specific requirements.

6.13.1 csQueryLibrarySupport()

Queries the API library for supported functionality. Any application that uses the library is able to use this query.

6.13.1.1 Synopsis

```
CS_STATUS csQueryLibrarySupport(CS_LIBRARY_SUPPORT Type,
        int *Length, char *Buffer);
```

6.13.1.2 Parameters

IN Type	Library support type query
IN OUT Length	Length of buffer passed for output
OUT Buffer	Returns a list of queried items

6.13.1.3 Description

The `csQueryLibrarySupport()` API fills `Buffer` with a list of all items for query based on `Type`, if the length specified in `Length` is sufficient. The output copied to Buffer will be a set of strings separated by commas.

If a valid `Buffer` pointer is specified where the length specified in `Length` is sufficient, then the buffer is updated with the list of all items that match support for `Type` to actual length of string. If the length specified in `Length` is not sufficient to hold the contents returned in `Buffer`, then `Length` will be populated with the required size and an error status will be returned. An invalid input will return an error status.

If a `NULL` pointer is specified for `Buffer` and a valid pointer is provided for `Length`, then the required buffer size is returned back in Length. The user should allocate a buffer of the returned size and reissue the request. The user may also provide a large enough buffer and satisfy the request.

All input and output parameters are required for this API.

6.13.1.4 Return Value

`CS_SUCCESS` if there is no error and the query for `Type` was met.

Otherwise, this API returns an error status of CS_INVALID_ARG or CS_INVALID_LENGTH as defined in 6.3.3.

6.13.1.5 Notes

The caller should always check the value of `Length` for a non-zero value, which represents valid entries in `Buffer` for the specified query. A null terminated string is

returned in `Buffer` when `Length` is non-zero. This API may still return success when `Length` is zero.

The returned queried list is able to be parsed and verified as the user intended.

A typical source fragment implementation to return file system support would be

```
length = 0;
status = csQueryLibrarySupport(CS_FILE_SYSTEMS_SUPPORTED, &length, NULL);
if (status != CS_INVALID_LENGTH)
    ERROR_OUT("csQueryLibrarySupport returned unknown error\n");

fs_list = malloc(length);
status = csQueryLibrarySupport(CS_FILE_SYSTEMS_SUPPORTED, &length, &fs_list[0]);
if (status != CS_SUCCESS)
    ERROR_OUT("csQueryLibrarySupport returned error\n);
// verify if XFS filesystem is supported
…
```

6.13.2 csRegisterPlugin()

Registers a specified plugin with the API library.

This is a privileged API.

6.13.2.1 Synopsis

CS_STATUS csRegisterPlugin(const CsPluginRequest *Req);

6.13.2.2 Parameters

IN Req	Request structure to register a plugin

6.13.2.3 Description

The `csRegisterPlugin()` API registers the specified plugin.

All input parameters are required for this API.

6.13.2.4 Return Value

`CS_SUCCESS` is returned if there are no errors.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_OPTION, CS_NO_PERMISSIONS, or CS_NOT_ENOUGH_MEMORY as defined in 6.3.3.

6.13.2.5 Notes

This functionality is used by a privileged process to register a plugin in the system. Computational storage device providers and vendors who provide their own plugin support would use this API.

6.13.3 csDeregisterPlugin()

Deregisters a specified plugin from the API library.

This is a privileged API.

6.13.3.1 Synopsis

CS_STATUS csDeregisterPlugin(const CsPluginRequest *Req);

6.13.3.2 Parameters

IN Req	Request structure to deregister a plugin

6.13.3.3 Description

The `csDeregisterPlugin()` API deregisters the specified plugin.

All input parameters are required for this API.

6.13.3.4 Return Value

`CS_SUCCESS` is returned if there are no errors.

Otherwise, this API returns an error status of CS_INVALID_ARG, CS_INVALID_OPTION, CS_NO_PERMISSIONS, or CS_NOT_ENOUGH_MEMORY as defined in 6.3.3.

6.13.3.5 Notes

This functionality is used by a privileged process to deregister a plugin in the system. Computational storage device providers and vendors who provide their own plugin support would use this API.

A Sample Code

A.1 Initialization and queuing a synchronous request

A synchronous (blocking) request where the user waits for the IO to complete is illustrated in the following decryption example which exercises the following steps

a) Discover the CSx and access it;

b) Discover the CSF to run decryption;

c) Allocate device memory;

d) Transfer encrypted data from host memory to device; and

e) Execute the CSF.

Initialization may occur in the following way:

```
// discover my device
length = sizeof(csxBuffer);
status = csGetCSxFromPath("myFileToAccelerate", &length, &csxBuffer);
if (status != CS_SUCCESS)
    ERROR_OUT("No CSx device found!\n");
// open device, init function and prealloc buffers
status = csOpenCSx(csxBuffer, &MyDevContext, &dev);
if (status != CS_SUCCESS)
    ERROR_OUT("Could not access device\n");

// query run details of decrypt CSF
status = csGetCSFId(dev, "decrypt", &infoLength, &count, &csfInfo);
if (status != CS_SUCCESS)
    ERROR_OUT("CSX does not contain any decrypt CSFs \n");
// pick highest performant CSF from returned list
CSFIdInfo *p = csfInfo;
CSFIdInfo *myCSF = NULL;
for (i=0; i< count; i++, p++) {
    if ((myCSF == NULL) ||
        ((myCSF != NULL) && (p->RelativePerformance > myCSF->RelativePerformance))) {
        myCSF = p;
    }
}
decryptId = myCSF->CSFId ;


// Next, pick the most performant FDM for chosen CSF
FDMAccess *p = myCSF->FDMList;
FDMAccess *myFDM = NULL;
for (i = 0; i < myCSF->NumFDMs; i++, p++) {
    if ((myFDM == NULL) ||
        ((myFDM != NULL) && (p->RelativePerformance > myFDM->RelativePerformance))) {
        myFDM = p;
    }
}
```

```
// allocate device memory
CsMemFlags f;
f.s->FDMId = myFDM->FDMId;
f.s->Flags = 0;   // may also be CS_FDM_CLEAR
for (i = 0; i < 2; i++) {
    status = csAllocMem(dev, CHUNK_SIZE, &f, 0, &AFDMArray[i] , NULL);
    if (status != CS_SUCCESS)
        ERROR_OUT("AFDM alloc error\n");
}
```

Source data may be fetched in the following way:

```
// next, copy encrypted data from host memory into AFDM
// allocate copy request and issue it
CsCopyMemRequest copyReq = malloc(sizeof(CsCopyMemRequest));
if (!copyReq)
    ERROR_OUT("request alloc error\n");
// setup copy request
copyReq->Type = CS_COPY_TO_DEVICE;
copyReq->u.HostVAddress = encrypt_buf;
copyReq->DevMem.MemHandle = AFDMArray[0];
copyReq->DevMem.ByteOffset = 0;
copyReq->Bytes = CHUNK_SIZE;
// issue a synchronous copy request
status = csQueueCopyMemRequest(copyReq, copyReq, NULL, NULL, NULL, NULL);
if (status != CS_SUCCESS)
    ERROR_OUT("Copy to AFDM error\n");
```

Compute execution may be performed in the following way.

```
// allocate compute request for 3 args
CsComputeRequest compReq = malloc(sizeof(CsComputeRequest) + \
    (sizeof(CsComputeArg) * 3));
if (!compReq)
    ERROR_OUT("request alloc error\n");
// setup work request
compReq->CSFId = decryptId;
compReq->NumArgs = 3;
argPtr = &compReq->Args[0];
csHelperSetComputeArg(&argPtr[0], CS_AFDM_TYPE, AFDMArray[0], 0);
csHelperSetComputeArg(&argPtr[1], CS_32BIT_VALUE_TYPE, CHUNK_SIZE);
csHelperSetComputeArg(&argPtr[2], CS_AFDM_TYPE, AFDMArray[1], 0);
// issue a synchronous compute request
status = csQueueComputeRequest(compReq, compReq, NULL, NULL, NULL, NULL);
if (status != CS_SUCCESS)
    ERROR_OUT("Compute exec error\n");
```

A.2 Queuing an asynchronous request

The above example is able to be modified to be an asynchronous non-blocking request for compute offload. There are 2 asynchronous mechanisms: event based and callback based.

The following code snippet demonstrates the changes to compute execution while applying an event based mechanism.

```
// allocate event for async processing
status = csCreateEvent(&evtHandle);
if (status != CS_SUCCESS)
      ERROR_OUT("Could not create event\n");
```

```
// allocate compute request for 3 args
CsComputeRequest compReq = malloc(sizeof(CsComputeRequest) + (sizeof(CsComputeArg) *
3));
if (!compReq)
    ERROR_OUT("request alloc error\n");
// setup work request
compReq->CSFId = decryptId;
compReq->NumArgs = 3;
argPtr = &compReq->Args[0];
csHelperSetComputeArg(&argPtr[0], CS_AFDM_TYPE, AFDMArray[0], 0);
csHelperSetComputeArg(&argPtr[1], CS_32BIT_VALUE_TYPE, CHUNK_SIZE);
csHelperSetComputeArg(&argPtr[2], CS_AFDM_TYPE, AFDMArray[1], 0);
// issue an event based asynchronous compute request
status = csQueueComputeRequest(compReq, compReq, NULL, evtHandle, NULL, NULL);
if (status != CS_SUCCESS)
       ERROR_OUT("Compute exec error\n");
while ((status = csPollEvent(evtHandle, &context, NULL)) != CS_SUCCESS) {
       // IO not done; do other work
}
```

If the event usage is swapped with a callback based model, the sample code will change as follows. No event creation is required.

```
// issue a callback based asynchronous compute request
status = csQueueComputeRequest(compReq, compReq, MyAsyncCbFn, NULL, NULL, NULL);
if (status != CS_SUCCESS)
       ERROR_OUT("Compute exec error\n");
// do other work till callback MyAsyncCbFn is invoked in separate thread context
```

A.3 Using Batch processing

Batch processing aids inprocessing more than one request optimally as one `csQueueBatchRequest()` API is able to take multiple requests as process them as a single request (see section 6.10). The following example illustrates a sequence of serialized batch processing requests. Data is first read from the storage device and populated in the first AFDM buffer. In the second request, the CSF is executed on the data read to decompress its contents into a second AFDM buffer. In the third request, the contents of the second buffer are copied into host memory. The batch of requests are set to execute serially and are dependent on the serialization for the final output which is handled by this batch type. The request is set to execute asynchronously in non-blocking mode.

```
// batch execute storage IO + compute offload + DMA results to host
//
// allocate a batch request handle
status = csAllocBatchRequest(CS_BATCH_SERIAL, 3,  &batchHandle);
if (status != CS_SUCCESS)
       ERROR_OUT("batch request allocation error\n");
// setup storage IO. Batch only for LBA based IO
//  for others use normal file IO not with batch
storReq = malloc(sizeof(CsBatchRequest));
if (!storReq)
       ERROR_OUT("memory alloc error\n");
storReq->reqType = CS_STORAGE_IO;
storReq->u.StorageIo.Mode = CS_STORAGE_BLOCK_IO;
storReq->u.StorageIo.StorageIndex = 0;
storReq->u.StorageIo.DevHandle = devHandle;
storReq->u.StorageIo.u.BlockIo.Type = CS_STORAGE_LOAD_TYPE;
```

```
storReq->u.StorageIo.u.BlockIo.DevMem.MemHandle = inMemHandle;
storReq->u.StorageIo.u.BlockIo.DevMem.ByteOffset = 0;
storReq->u.StorageIo.u.BlockIo.NumRanges = 1;
storReq->u.StorageIo.u.BlockIo.Range[0].NamespaceId = NSId;
storReq->u.StorageIo.u.BlockIo.Range[0].StartLba = LBAs[0];
storReq->u.StorageIo.u.BlockIo. Range[0].NumBlocks = 1;
status = csAddBatchEntry(batchHandle, storReq, 0, 0, &storEntry);
if (status != CS_SUCCESS)
      ERROR_OUT("batch request error\n");
// next, setup compute IO with 3 CSF arguments
compReq = malloc(sizeof(CsBatchRequest) + (sizeof(CsComputeArg) * 3));
if (!compReq)
      ERROR_OUT("memory alloc error\n");
compReq->reqType = CS_QUEUE_COMPUTE;
compReq->u.Compute. CSFId = funcId;
compReq->u.Compute.NumArgs = 3;
argPtr = &compReq->u.Compute.Args[0];
csHelperSetComputeArg(&argPtr[0], CS_AFDM_TYPE, inMemHandle, 0);
csHelperSetComputeArg(&argPtr[1], CS_32BIT_VALUE_TYPE, 4096 * 3);
csHelperSetComputeArg(&argPtr[2], CS_AFDM_TYPE, outMemHandle, 0);
status = csAddBatchEntry(batchHandle, compReq, 0, storEntry, &compEntry);
if (status != CS_SUCCESS)
      ERROR_OUT("batch request error\n");
// lastly, setup DMA results to host
copyReq = malloc(sizeof(CsBatchRequest));
if (!copyReq)
      ERROR_OUT("memory alloc error\n");
copyReq->reqType = CS_COPY_DEV_MEM;
copyReq->u.CopyMem.Type = CS_COPY_FROM_DEVICE;
copyReq->u.CopyMem.u.HostVAddress = resBuffer;
copyReq->u.CopyMem.DevMem.MemHandle = outMemHandle;
copyReq->u.CopyMem.DevMem.ByteOffset = 0;
copyReq->u.CopyMem.Bytes = 4096 * 3;
status = csAddBatchEntry(batchHandle, copyReq, 0, compEntry, &copyEntry);
if (status != CS_SUCCESS)
      ERROR_OUT("batch request error\n");
// now queue batch request
status = csQueueBatchRequest(batchHandle, NULL, NULL, evtHandle, NULL, NULL);
if (status != CS_SUCCESS)
      ERROR_OUT("Batch exec error\n");
while ((status = csPollEvent(evtHandle, &context, NULL)) != CS_SUCCESS) {
      // IO not done; do other work
}
```

A.4 Applying Hybrid Batch Processing Feature

The following example demonstrates how to use dependency in batch requests to create a hybrid processing model, where an input completion is required prior to starting the next request. The example reads data from storage, runs parallel compute offload operation on it, and once complete, copies the results scattered in device memory back to host memory buffer. The example is able to be representative of analytical data that is read and computed on, and whose results are collated and provided back to host. In this example, 128KB of data is read and 32KB of results are collected.

```
// hybrid batch setup execution
//  large storage IO + 8 parallel compute requests + 8 parallel copy results to host
//
// allocate enough resources for batch request handle
status = csAllocBatchRequest(CS_BATCH_HYBRID, 1 + 8 + 8, &batchHandle);
if (status != CS_SUCCESS)
```

```
	ERROR_OUT("batch request allocation error\n");
// setup storage IO. Batch only LBA based IO
//  for others use normal file IO not with batch
storReq = malloc(sizeof(CsBatchRequest));
if (!storReq)
	ERROR_OUT("memory alloc error\n");
// read 128kb data from Storage into device memory
storReq->reqType = CS_STORAGE_IO;
storReq->u.StorageIo.Mode = CS_STORAGE_BLOCK_IO;
storReq->u.StorageIo.DevHandle = devHandle;
storReq->u.StorageIo.u.BlockIo.Type = CS_STORAGE_LOAD_TYPE;
storReq->u.StorageIo.u.BlockIo.StorageIndex = 0;
storReq->u.StorageIo.u.BlockIo.DevMem.MemHandle = inMemHandle;
storReq->u.StorageIo.u.BlockIo.DevMem.ByteOffset = 0;
storReq->u.StorageIo.u.BlockIo.NumRanges = 1;
storReq->u.StorageIo.u.BlockIo.Range[0].NamespaceId = NSId;
storReq->u.StorageIo.u.BlockIo.Range[0].StartLba = LBAs[0];
storReq->u.StorageIo.u.BlockIo.Range[0].NumBlocks = 32;
status = csAddBatchEntry(batchHandle, storReq, 0, 0, &storEntry);
if (status != CS_SUCCESS)
	ERROR_OUT("batch request error\n");
// allocate memory for parallel compute batch requests and reuse req
compReq = malloc(sizeof(CsBatchRequest) + (sizeof(CsComputeArg) * 3));
if (!compReq)
	ERROR_OUT("memory alloc error\n");
inMemOffset = 0;
for (i = 0; i < 8; i++) {
	// next, setup compute IO with 3 arguments each
	compReq->reqType = CS_QUEUE_COMPUTE;
	compReq->u.Compute.CSFId = csfId;
	compReq->u.Compute.NumArgs = 3;
	argPtr = &compReq->u.Compute.Args[0];
csHelperSetComputeArg(&argPtr[0], CS_AFDM_TYPE, inMemHandle, inMemOffset);
csHelperSetComputeArg(&argPtr[1], CS_32BIT_VALUE_TYPE, 16384);
csHelperSetComputeArg(&argPtr[2], CS_AFDM_TYPE, outMemArray[i], 0);
	status = csAddBatchEntry(batchHandle, compReq, 0, storEntry,
&computeEntryArray[i]);
	if (status != CS_SUCCESS)
		ERROR_OUT("batch request error\n");
	// distribute source buffer sequentially
	inMemOffset += 16384;
}
// now allocate memory for parallel DMA batch requests and reuse req
copyReq = malloc(sizeof(CsBatchRequest));
if (!copyReq)
	ERROR_OUT("memory alloc error\n");
outMemOffset = 0;
for (j = 0; j < 8; j++) {
	// lastly setup DMA results to host at 4kb offsets
	copyReq->reqType = CS_COPY_DEV_MEM;
	copyReq->u.CopyMem.Type = CS_COPY_FROM_DEVICE;
	copyReq->u.CopyMem.u.HostVAddress = &resBuffer[outMemOffset];
	copyReq->u.CopyMem.DevMem.MemHandle = outMemArray[j];
	copyReq->u.CopyMem.DevMem.ByteOffset = 0;
	copyReq->u.CopyMem.Bytes = 4096;
	status = csAddBatchEntry(batchHandle, copyReq, 0, computeEntryArray[j],
 &copyEntryArray[j]);
	if (status != CS_SUCCESS)
		ERROR_OUT("batch request error\n");
	// increment destination host buffer sequentially for one final output
	outMemOffset += 4096;
}
// all done, queue the batch request
```

```
status = csQueueBatchRequest(batchHandle, NULL, NULL, evtHandle, NULL, NULL);
if (status != CS_SUCCESS)
      ERROR_OUT("batch request error\n");
// wait on the final results
while ((status = csPollEvent(evtHandle, &context, NULL)) != CS_SUCCESS) {
      // IO not done; do other work
      // poll for previous IOs too and mark them done
}
```

A.5 Using files for storage IO

Using the filesystem managed files for reading and writing data is a powerful interface that the `csQueueStorageRequest()` API provides. The following example demonstrates using a file to read data at a particular offset and provide those contents to a CSF.

Files used by the CS API are required to be opened using the `O_DIRECT` flag. The file handle returned by the operating system is able to then be utilized by the API as shown below. 128K bytes are read from storage using the file handle and loaded in AFDM. Data read or written by this method are required to follow block granularity and alignment guidelines for the `Offset` and `Bytes` fields or the call may fail.

```
// query capabilities for file IO in API library
status = csQueryLibrarySupport(CS_FILE_SYSTEMS_SUPPORTED, &buflen, &buf);
if (status != CS_SUCCESS)
      ERROR_OUT("Could not query device properties\n");
// verify if filesystem is supported

// allocate storage IO request for file usage
storReq = malloc(sizeof(CsStorageRequest));
if (!storReq)
      ERROR_OUT("memory alloc error\n");

// setup request to read 128kb from the start of the file
storReq->Mode = CS_STORAGE_FILE_IO;
storeReq->DevHandle = devHandle;
storReq->u.CsFileIo.Type = CS_STORAGE_LOAD_TYPE;
storReq->u.CsFileIo.FileHandle = fd;
storReq->u.CsFileIo.Offset = 0;
storReq->u.CsFileIo.Bytes = 128 * 1024;
storReq->u.CsFileIo.DevMem.MemHandle = inMemHandle;
storReq->u.CsFileIo.DevMem.ByteOffset = 0;
status = csQueueStorageRequest(storReq, storReq, NULL, evtHandle, NULL, NULL);
if (status != CS_SUCCESS)
      ERROR_OUT("Storage request error\n");

// wait on the request to complete or do some other work
while ((status = csPollEvent(evtHandle, &context)) != CS_SUCCESS) {
      // IO not done; do other work
}
```