Specification of Advanced Communication Primitives (ACP) Library

Version 2.1 (draft)

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Updates

From version 2.0 to 2.1

- New interfaces
  1. Added functions of the following data structures:
     Set, Map and Workspace

- Fixed bugs and problems
  1. Implementations are refined to achieve better performance.

From version 1.2 to 2.0

- New facilities
  1. Added following commands to launch multiple MPI programs with ACP:
     macprun

- New interfaces
  1. Added functions of the following data structures:
     Vector, Deque and List

- Modified interfaces
  1. Definitions of the following functions have been changed:
     acp_insert_list, acp_push_back_list.

- Fixed bugs and problems
  1. acpbl_ib.c: Solved following issues:
     - performance of acp_sync()
     - CPU utilization in the communication thread
     - memory usage

- Known issues
  1. Facility for launching multiple MPI programs with ACP is not supported on Tofu interconnect, yet.

From version 1.1 to 1.2

- New interfaces
  1. Added following functions:
     acp_clear_vector, acp_end_map

- Modified interfaces
  1. Definitions of the following functions have been changed:
     acp_insert_list, acp_push_back_list, acp_insert_map, acp_find_map.
  2. Names and definitions of some functions have been changed as follows:
     - old: acp_increment_list, new: acp_increment_list_it
     - old: acp_decrement_list, new: acp_decrement_list_it

- Fixed bugs and problems
  1. acpcl.c: Fixed bugs that had caused hangs in some cases. Also, changed the protocol for long messages from rendezvous to pipelined-eager.
  2. acpbl_ib.c: Fixed bugs that had caused incorrect behaviors in acp_init, acp_colors, acp_register_memory and acp_unregister_memory.
  3. acpdl_malloc.c: Modified algorithms for acp_malloc and acp_free to achieve better performance.

From version 1.0 to 1.1

- New interfaces
  1. Map interface

- Fixed bugs
  1. acpcc: Fixed behavior with -l option.
  2. acpcl.c: Fixed to enable thread-safety.
  3. acpcl.c, acpcl_progress.{c,h}: Fixed the way to notify the arrivals of connection

requests.

- Known issues
  2. acpbl_ib.c:
     - In some cases, arrivals of operations for remote atomic and remote-remote copy may be handled incorrectly.
     - Performance drops significantly when large number of operations are invoked.

Contents

1. Introduction

1.1 About This Document

This document introduces the specifications of the interfaces of Advanced Communication Primitives (ACP) Library. This library is designed to enable applications with sufficient inherent parallelism to achieve high scalability up to exa-scale computing systems, where the number of processes is expected to be more than a million.

1.2 Motivation

As the performance of environments for high-performance computing (HPC) is approaching from peta to exa, the number of cores in one node is increasing, while the amount of memory per node is expected to remain almost the same. Therefore, reducing memory consumption has become an important issue for achieving sustained scalability toward exa-scale computers.

Especially, communication middleware on those environments must be carefully designed to achieve high memory efficiency. There is always a trade-off between the memory consumption and the performance of communication. To avoid conflicts of resources and achieve high performance, sufficient amount of buffers should be allocated. Therefore, appropriate control of the allocation and de-allocation of buffers is a key to enable memory-efficient communications.

1.3 Approach

To minimize the requirements of memory consumption at the initialization, ACP Library provides RDMA model as the basic communication layer. On interconnect networks where RDMA is supported as a fundamental facility, this layer can be implemented with minimal memory consumption and overhead.

Since programming with RDMA needs detailed operations such as memory registrations, address exchanges and synchronizations, ACP also prepares some sets of programmer-friendly interfaces as the middle layer. To enable the library to consume just-enough amount of memory, each interface of the middle layer requires explicit allocation of the memory region before using it. This region can be explicitly de-allocated so that the memory region can be reused for other purposes.

Each of the interfaces of this middle layer is primitive and independent. For example, the channel interface in this layer only supports one-directional and in-order data transfer between a pair of processes. This helps to minimize the memory consumption

and overhead in the implementation. Also, the independent interfaces enable precise control of the allocation and de-allocation of memory regions for them. At this point, interfaces of channels, vectors, lists and memory allocation are defined in ACP. There are plans for other interfaces such as group communications, deques, maps, sets and counters.

1.4 Terminology

process	A unit of program execution by OS.
task	A unit of parallel program execution including multiple processes.
rank	A number to distinguish process in a task.
ACE project	Advanced Communication for Exa project. It develops a communication library with low memory consumption and low overhead.
ACP library	Advanced Communication Primitives library. A library that has been developed in the ACE project.
GMA	Global Memory Access. Direct access to the memory of a remote process in a task.
global memory	Memory region to which remote processes can establish GMAs.
starter memory	A region of global memory that is prepared in each rank at the initialization.
global address	64bit address space shared by all of the processes in a task.
address translation key	An identifier used for translating logical address to global address.
color	A number to distinguish the path for transferring data with GMA.
channel	Virtual path to transfer messages between a pair of processes.
vector	One-dimensional array.
list	Bi-directional list.
iterator	An index to refer to an element in a data structure.

2. Overview

2.1 Fundamental Design

2.1.1 Execution Model

The execution model of ACP is a single program multiple data (SPMD) model. Therefore, each process in a task executes the same program. Processes are distinguished by ranks. Ranks are mapped to the processes at the initialization. ACP also supports re-mapping ranks during the execution.

2.1.2 Communication Models

As written in the previous section, the basic communication model of ACP is RDMA. However, in this model, programmers need to write codes for memory registration, address exchange and appropriate synchronization before establishing data transfer.
Therefore, ACP also supports additional two categories of interfaces as the middle layer, the communication patterns and the data structures. The communication pattern interfaces support explicit transfers of data on the local memory of each process. Currently, ACP provides one interface, channel, as this category of interfaces.
On the other hand, the data structure interface supports implicit data transfer via the operations on dynamic distributed data structures. At this point, vector and list are supported in this category. The heart of this category is an asynchronous global memory allocator that allocates a segment of global memory involving no processor at the provider-side. The design concept of this category derives from the C/C++ languages and is more straightforward than the novel design concept of the basic layer.
As mentioned previously, memory efficiency is the target property in the design of ACP. Towards this target, each interface in the middle layer is designed to support a primitive facility so that it can be implemented with minimal memory consumption and overhead.
In addition to that, to enable just-enough memory consumption, each interface of the middle layer consists of functions for allocation and de-allocation. Programs must explicitly call the allocation function of the interface before establishing data-transfer operations in it. This function allocates a region of memory to be used by a set of processes that participate in the corresponding communication pattern or the data structure. Eventually the information required for establishing communications on the interface is exchanged until the completion of the first data transfer with it. On the other hand, the de-allocation function frees the memory regions allocated for the

interface.
In a program, the same set of processes can call the allocation function of the interface multiple times. This will prepare independent memory region for each call. This policy can cause redundant allocation of memory region. However, sharing resources among multiple calls of allocation can complicates the mechanisms for handling memory regions and causes higher memory consumptions and overheads.
To establish communications that are not supported in the middle layer, the programmers can use the interfaces of the basic RDMA operations of ACP. It consists of two categories of interfaces, the global memory management (GMM) and the global memory access (GMA). In this model, any local memory regions can be mapped to the global address space shared among processes. ACP uses 64bit unsigned integer as the global address that specifies the position in the space. As GMA, the remote copy operation and some atomic operations are supported.

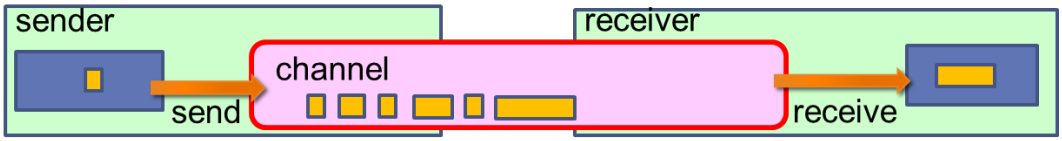
2.2 Interfaces

2.2.1 Infrastructure

Each process starts its execution as a part of an ACP program by calling the initialization function, **`acp_init`**, and ends by calling finalization function, **`acp_finalize`**. ACP also prepares a function for aborting the program, **`acp_abort`**, in case of an error.
The reset function, **`acp_reset`**, remaps ranks to the processes as specified by its argument. There are functions to query current rank of the process, **`acp_rank`**, and the total number of processes, **`acp_procs`**.
Processes are implicitly synchronized at the initialization, reset and finalization. There is also a synchronization function, **`acp_sync`**, to explicitly synchronize all of the processes. This function returns after determining arrivals of all processes.

2.2.2 Channel

This interface provides a virtual pass for message passing from one process to another. The data transfer supported by it is single direction and in-order. Therefore, the implementation of it can be simple and efficient. Before establishing data transfer with the interface, both the sender process and the receiver process must call the allocation function to establish a channel between them. If a channel has become useless, the program can free the channel by calling the de-allocation function at both sides.



The allocation function, **acp_create_ch**, of this interface allocates a region of memory according to the role of the process that invoked the function. After that, it starts exchanging the information about the region with another peer of the channel to establish the connection of the channel. Then, it returns a handle of the channel, with the data type of **acp_ch_t**, without waiting for the completion of the connection. The library implicitly progresses the establishment of the connection.

The non-blocking functions for sending and receiving messages, **acp_nbsend_ch** and **acp_nbrecv_ch**, on a channel can be invoked before the completion of its connection. Each of these functions stores the information about the invocation in the request queue of the channel, and returns a request handle with the data type of **acp_request_t**. It starts transferring messages after it has completed the connection. The wait function, **acp_wait_ch**, wait for the completion of the request.

The non-blocking de-allocation function, **acp_free_ch**, starts freeing memory regions of the channel specified by the handle. The behavior of the functions of send and receive on the channel that has been specified for this function is not defined.

2.2.3 Vector

The vector interface provides the data structure and algorithms of dynamic array. The type of for referencing vectors is **acp_vector_t**, and the type of the iterator of vectors is **acp_vector_it_t**. Vectors can be created via the constructor function, **acp_create_vector**. As an argument, this function accepts the rank to place the instance of the vector.

2.2.4 Deque

The deque interface provides the data structure and algorithms of double ended queue. The type of for referencing deques is **acp_deque_t**, and the type of the iterator of deques is **acp_deque_it_t**. Deques can be created via the constructor function, **acp_create_deque**. As an argument, this function accepts the rank to place the instance of the deque.

2.2.5 List

The list interface provides the data structure and algorithms of bidirectional linked list. The type for referencing lists is **`acp_list_t`**, and the type for the iterator of lists is **`acp_list_it_t`**. Lists are created via the constructor function, **`acp_create_list`**. This function prepares an empty list. As an argument, it accepts the rank to place the control structure of the list. Elements can be added to a list via functions, such as **`acp_push_back_list`** and **`acp_insert_list`**. Each of these functions also accepts the rank to allocate the instance of the element, as an argument. Therefore, the control structure and the elements of a list can be placed on different processes.

2.2.6 Map

The map interface provides the data structure and algorithms of associative arrays. The type for referencing maps is **`acp_map_t`**, the type for the iterator of maps is **`acp_map_it_t`**, and the type for returning result of finding element in a map is **`acp_map_ib_t`**. Maps are created via the constructor function, **`acp_create_map`**. This function prepares an empty map distributed among a group of processes. As an argument, it accepts the number of processes, the array of ranks of the processes in the group, the number of slots and the rank to place the control structure of the map. Elements can be added to a map via the function **`acp_insert_map`**. In addition to the map to insert, this function accepts the key and the value of the element, as an argument. Each of the key and the value are specified by a pair of the address and the size in byte. The rank to place the element to be inserted is decided according to the hash value calculated from the key. **`acp_find_map`** searches the key in a map. It returns the value true or false according to the result, and the iterator of the element with the key if it has been found.

2.2.7 Workspace

Workspace is a temporal memory space that is shared among all of processes. Creation and destruction of a workspace is done collectively via functions **`acp_create_ws`** and **`acp_destroy_ws`**. The type of the handle for referencing workspaces is **`acp_ws_t`**. Once created, each process can perform read/write accesses to the workspace via functions **`acp_read_ws`** and **`acp_write_ws`** that are similar to POSIX pread/pwrite. Size of the workspace is specified at its creation. Initial value of the workspace is undefined. Distribution of the temporal memory workspace among processes can be controlled by parameters specified via the function **`acp_setparams_ws`**.

2.2.8 Malloc

The malloc interface provides the functions for asynchronous allocation and de-allocation of global memory. It is the same as that of the asynchronous global heap that designs a memory pool to be accessible via RDMA as well as via processor instructions. This interface consists of the **acp_malloc** function that allocates a segment of global memory from specified process by a rank number. A global memory segment allocated by this function can be freed by the **acp_free** function.

2.2.9 Global Memory Management

The basic layer provides global address space shared among all of the processes. This space is addressed by 64bit unsigned integer, so that it can be directly handles by the atomic operations of CPUs and devices.

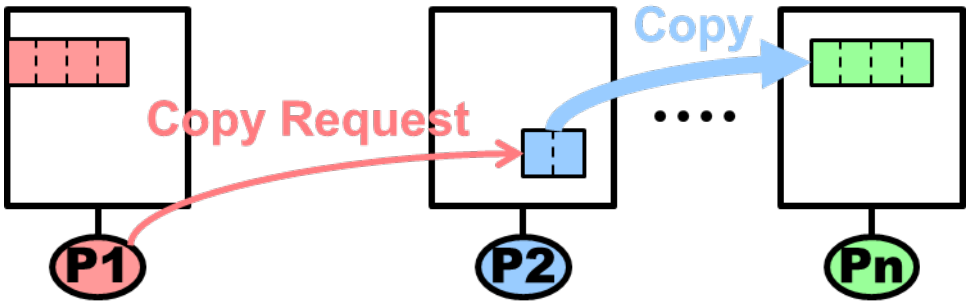
Any local memory space of any process can be mapped to this space via the registration function, **acp_register_memory**, of this layer. It returns a key with the data type of **acp_atkey_t**. There is also a de-registration function, **acp_unregister_memory**, to unregister the region of the specified key. Global address in a registered region can be retrieved by a query function, **acp_query_ga**. It returns the address with the data type of **acp_ga_t**.

At the registration, in addition to the start address and the size of the local region to be mapped, the color of the global address can be specified. Color is used for specifying device in the node to be used for making remote access to the region. There is a function, **acp_colors**, to query the maximum number of colors available on the current system.

At the initialization, a special region, called starter memory, is allocated on each process. Each of the starter memories of the processes is registered to the global address space, and there is a function, **acp_query_starter_ga**, to query for the global address of the starter memory of the specified rank. This region is mainly used for exchanging global addresses before performing RDMA operations on the global address space.

2.2.10 Global Memory Access

The RDMA operations on the global memory space of the basic layer is called global memory access (GMA). ACP prepares GMA functions, such as **acp_copy**, **acp_add4**, **acp_add8**, **acp_cas4** and so on, to perform copy and atomic operations on the global memory space. Unlike other communication libraries, both of the source and the destination of copy function can be remote.



All of the GMA functions are non-blocking. Therefore, each of them returns a GMA handle with the data type of **`acp_handle_t`** to wait for the completion. Each GMA function has an argument 'order' to specify the condition for starting the operation. If a GMA handle is specified for this argument, it will wait for the completion of the GMA of the handle before starting its access. If **`ACP_HANDLE_NULL`** is specified as the order, it starts the access immediately. If **`ACP_HANDLE_ALL`** is specified, it will wait for the completions of all of the previously invoked GMAs. If **`ACP_HANDLE_CONT`** is specified as the order, and if the GMA that is invoked immediately before this one has the same source rank, target rank, source color and target color, it can start its access with the same condition of the previous one, as far as it will not overtake the order. If there is any difference in those parameters, the behavior is same as the case with **`ACP_HANDLE_ALL`**. There can be an implementation that always performs the same way as the case with **`ACP_HANDLE_ALL`**, even if **`ACP_HANDLE_CONT`** is specified.

The completion function, **`acp_complete`**, waits for the completion of the GMA specified by the handle. The completions of GMA functions are ensured in-order. This means that the completion of one GMA function ensures the completion of all of the other GMA functions that have been invoked earlier than it on the process. There is also a function, **`acp_inquire`**, which check the completions of the GMA specified by the handle and the GMAs that have been invoked before it.

3. Usage

3.1 Installation

The simplest way to install ACP library is typically a combination of running "configure" and "make". Execute the following commands to install the ACP library system from within the directory at the top of the tree:

```
shell$ ./configure --prefix=/where/to/install
 [...lots of output...]
shell$ make all install
```

If you need special access to install, then you can execute "make all" as a user with write permissions in the build tree, and a separate "make install" as a user with write permissions to the install tree.
See INSTALL for more details.

3.2 Compilation

ACP provides "wrapper" compilers that should be used for compiling ACP applications:

C:	`acpcc`, `acpgcc`
C++:	`acpc++`, `acpcxx`
Fortran:	`acpfc` (not provided yet)

For example:

```
shell$ acpcc hello_world_acp.c -o hello_world_acp -g
shell$
```

All the wrapper compilers do is add a variety of compiler and linker flags to the command line and then invoke a back-end compiler. To be specific: the wrapper compilers do not parse source code at all; they are solely command-line manipulators, and have nothing to do with the actual compilation or linking of programs. The end result is an ACP executable that is properly linked to all the relevant libraries.
Customizing the behavior of the wrapper compilers is possible (e.g., changing the compiler [not recommended] or specifying additional compiler/linker flags).

3.3 Execution

ACP library supports acprun program to launch ACP appliations. For example:

```
shell$ acprun -np 2 hello_world_acp   .
```

This launches two `hello_world_acp` applications on localhost. Option "`-np 2`" is same as long option "`--acp-nprocs=2`". Please note that "`-np nprocs`" has to be 'first' option of `acprun` command. There are no such limitations for long option.
You can specify a `--acp-nodefile=nodefile` option to indicate hostnames on which `hello_world_acp` command will be launched.

If you want launch two processes on pc01 and pc02, use following command:

```
shell$ acprun -np 2 --acp-nodefile=nodefile hello_world_acp
```

with the following nodefile:

```
---------------------------------------------------------------------------
pc01
pc01
pc02
pc02
---------------------------------------------------------------------------
```

To specify network device, for example infiniband (or udp, tofu), use `--acp-envent=ib` (or udp, tofu) option as follows:

```
shell$ acprun -np 2 --acp-nodefile=nodefile --acp-nodefile=ib
hello_world_acp
```

If you want control starter memory size of ACP basic layer library, use `--acp-startermemsize=size` (byte unit) option as follows:

```
shell$ acprun -np 2 --acp-nodefile=nodefile --acp-nodefile=ib
--acp-startermemsize=4096 hello_world_acp
```

Notice:

1. Other "`--acp-*`" options are parsed as errors in regard to invalid option, even though that option is used as user program option.
2. Tofu network device may not supported in this version.

4. API

4.1 Infrastructure

The infrastructure interface provides fundamental functions that are commonly used among communication models of ACP.

4.1.1 acp_init

`int acp_init (int * argc, char *** argv)`

ACP initialization.
Initializes the ACP library. Must be invoked before other functions of ACP. argc and argv are the pointers for the arguments of the main function. It returns after all of the processes complete initialization. In this function, the initialization functions of the modules of the middle layer are invoked.

Parameters:

argc A pointer for the number of arguments of the main function.

argv A pointer for the array of arguments of the main function.

Return values:

0 Success

-1 Fail

4.1.2 acp_finalize

`int acp_finalize (void)`

ACP finalization.
Finalizes the ACP library. All of the resources allocated in the library before this function are freed. It returns after all of the processes complete finalization. In this function, the finalization functions of the modules of the middle layer are invoked.

Return values:

0 Success

-1 Fail

4.1.3 acp_abort

void acp_abort (const char * *str*)

ACP abort.
Aborts the ACP library. It prints out the error message specified as the argument and the system message according to the error number ACP_ERRNO. ACP_ERRNO holds a number that shows the reason of the fail of the functions of ACP basic layer.

Parameters::

str Additional error message.

4.1.4 acp_procs

int acp_procs (void)

Query for the number of processes.
Returns the number of the processes.

Return values:

>=1 Number of processes.

-1 Fail

4.1.5 acp_rank

int acp_rank (void)

Query for the process rank.
Returns the rank number of the process that called this function.

Return values:

>=0 Rank number of the process.

-1 Fail

4.1.6 acp_sync

`int acp_sync (void)`

ACP Syncronization.
Synchronizes among all of the processes. Returns after all of the processes call this function.

Return values:

- ***`0`*** Success
- ***`-1`*** Fail

4.1.7 acp_reset

`int acp_reset (int rank)`

ACP Re-initialization.
Re-initializes the ACP library. As rank, the new rank number of this process after this function is specified. All of the resources allocated in the library before this function are freed. The starter memory of each process is cleared to be zero. This function returns after all of the processes complete re-initialization. In this function, the functions for the initialization and the finalization of the modules of the middle layer are invoked.

Parameters:

- ***`rank`*** New rank number of this process after re-initialization.

Return values:

- ***`0`*** Success
- ***`-1`*** Fail

4.2 Channel

The channel interface provides functions for transferring messages via channels that are established between specific pairs of processes.

4.2.1 Data types and macros

Data types:

`acp_ch_t`

`acp_request_t`

Macros:

`ACP_CH_NULL` Represents no channel.

`ACP_REQUEST_NULL` Represents fail of the non-blocking operation.

4.2.2 acp_create_ch

`acp_ch_t acp_create_ch (int sender, int receiver)`

Creates an endpoint of a channel to transfer messages from sender to receiver.

Creates an endpoint of a channel to transfer messages from sender to receiver, and returns a handle of it. It returns error if sender and receiver is same, or the caller process is neither the sender nor the receiver. This function does not wait for the completion of the connection between sender and receiver. The connection will be completed by the completion of the communication through this channel. There can be more than one channels for the same sender-receiver pair.

Parameters:

`sender` Rank of the sender process of the channel.

`receiver` Rank of the receiver process of the channel.

Return values:

`ACP_CH_NULL` Fail

otherwise A handle of the endpoint of the channel.

4.2.3 acp_free_ch

`int acp_free_ch (acp_ch_t ch)`

Frees the endpoint of the channel specified by the handle.
Frees the endpoint of the channel specified by the handle. It waits for the completion of negotiation with the counter peer of the channel for disconnection. It returns error if the caller process is neither the sender nor the receiver. Behavior of the communication with the handle of the channel endpoint that has already been freed is undefined.

Parameters:

ch Handle of the channel endpoint to be freed.

Return values:

0 Success

-1 Fail

4.2.4 acp_nbfree_ch

`acp_request_t acp_nbfree_ch (acp_ch_t ch)`

Starts a non-blocking free of the endpoint of the channel specified by the handle.
It returns error if the caller process is neither the sender nor the receiver. Otherwise, it returns a handle of the request for waiting the completion of the free operation. Communication with the handle of the channel endpoint that has been started to be freed causes an error.

Parameters:

ch Handle of the channel endpoint to be freed.

Return values:

ACP_REQUEST_NULL Fail

otherwise A handle of the request for waiting the completion of this operation.

4.2.5 acp_nbsend_ch

acp_request_t acp_nbsend_ch (acp_ch_t *ch*, void * *buf*, size_t *size*)

Non-Blocking send via channels.
Starts a non-blocking send of a message through the channel specified by the handle. It returns error if the sender of the channel endpoint specified by the handle is not the caller process. Otherwise, it returns a handle of the request for waiting the completion of the non-blocking send.

Parameters:

ch Handle of the channel endpoint to send a message.

buf Initial address of the send buffer.

size Size in byte of the message.

Return values:

ACP_REQUEST_NULL Fail.

otherwise A handle of the request for waiting the completion of this operation.

4.2.6 acp_nbrecv_ch

acp_request_t acp_nbrecv_ch (acp_ch_t *ch*, void * *buf*, size_t *size*)

Non-Blocking receive via channels.
Starts a non-blocking receive of a message through the channel specified by the handle. It returns error if the receiver of the channel endpoint specified by the handle is not the caller process. Otherwise, it returns a handle of the request for waiting the completion of the non-blocking receive. If the message is smaller than the size of the receive buffer, only the region of the message size, starting from the initial address of the receive buffer is modified. If the message is larger than the size of the receive buffer, the exceeded part of the message is discarded.

Parameters:

ch Handle of the channel endpoint to receive a message.

buf Initial address of the receive buffer.

size Size in byte of the receive buffer.

Return values:

ACP_REQUEST_NULL Fail.

otherwise A handle of the request for waiting the completion of this operation.

4.2.7 acp_wait_ch

size_t acp_wait_ch (acp_request_t *request*)

Waits for the completion of the non-blocking operation.
Waits for the completion of the non-blocking operation specified by the request handle. If the operation is a non-blocking receive, it returns the size of the received data.

Parameters:

request Handle of the request of a non-blocking operation.

Return values:

>=0 Success. if the operation is a non-blocking receive, the size of the received data.

-1 Fail.

4.3 Vector

The vector interface provides functions to manipulate dynamic array. Each element of a vector can be manipulated by an iterator. An iterator is valid only at the process that retrieved it. Iterators will be invalid after modification of the vector by: **acp_assign_vector**, **acp_assign_range_vector**, **acp_clear_vector**, **acp_destroy_vector**, **acp_erase_vector**, **acp_erase_range_vector**, **acp_insert_vector**, **acp_insert_range_vector** and **acp_swap_vector**.

4.3.1 Data types and macros

Data types:

```
typedef struct {
        acp_ga_t ga;
} acp_vector_t
typedef struct {
        acp_vector_t vector;
        int index;
} acp_vector_it_t
```

4.3.2 acp_assign_vector

```
void acp_assign_vector(acp_vector_t vector1,acp_vector_t vector2);
```

Copy data from ***vector2*** to ***vector1***. Old data in ***vector1*** is overwritten.

Parameters:

vector1 Destination vector.

vector2 Source vector.

4.3.3 acp_assign_range_vector

```
void acp_assign_range_vector(acp_vector_t vector,
acp_vector_it_t start, acp_vector_it_t end);
```

Copy a range of data in a ***vector*** to another ***vector***. The iterators of the ***start*** and the ***end*** of the range must be in the same ***vector***. Old data in the destination ***vector*** is overwritten.

Parameters:

vector	Destination vector.
start	Iterator that specifies the start of the range of the vector to be copied.
end	Iterator that specifies the end of the range of the vector to be copied.

4.3.4 acp_at_vector

```
acp_ga_t acp_at_vector(acp_vector_t vector, int offset);
```

Query for the global address of the specified position in a ***vector.***

Parameters:

vector	Vector.
offset	Offset from the beginning of the vector.

Return values;

ACP_GA_NULL	Fail
otherwise	Global address of the specified position.

4.3.5 acp_begin_vector

```
acp_vector_it_t acp_begin_vector(acp_vector_t vector);
```

Query for the head iterator of a ***vector.***

Parameters:

vector	Vector.

Return values;

The head iterator of the vector.

4.3.6 acp_capacity_vector

```
size_t acp_capacity_vector(acp_vector_t vector);
```

Query for the capacity of the ***vector*** without extending area.

Parameters:

vector Vector.

Return values

The capacity of the vector without extending area.

4.3.7 acp_clear_vector

```
void acp_clear_vector(acp_vector_t vector);
```

Set the size of ***vector*** to be zero.

Parameters:

vector Vector.

4.3.8 acp_create_vector

```
acp_vector_t acp_create_vector(size_t size, int rank);
```

Creates a vector on the specified process.

Parameters:

size Size of the vector

rank Rank of the process on which the vector is located

Return values;

ga == ACP_GA_NULL Fail

otherwise **Created vector**

4.3.9 acp_destroy_vector

`void acp_destroy_vector (acp_vector_t vector);`

Destroy ***`vector`***.

Parameters:

`vector` Vector.

4.3.10 acp_empty_vector

`int acp_empty_vector(acp_vector_t vector);`

Query for the emptiness of ***`vector`***.

Parameters:

`vector` Vector.

Return values;

`1` Empty.

`0` Not empty.

4.3.11 acp_end_vector

`acp_vector_it_t acp_end_vector(acp_vector_t vector);`

Query for the iterator just after the tail element of ***`vector`***.

Parameters:

`vector` Vector.

Return values;

The iterator just after the tail element of the vector.

4.3.12 acp_erase_vector

acp_vector_it_t acp_erase_vector(acp_vector_it_t *it*, size_t *size*);

Erase data from a vector.

Parameters:

it Iterator that points to the beginning of the range to be erased.

size Size of the data to be erased.

Return values;

The iterator of the data immediately after the erased data.

4.3.13 acp_erase_range_vector

acp_vector_it_t acp_erase_range_vector(acp_vector_it_t *start*,
acp_vector_it_t *end*);

Erase a range of data from a vector.

Parameters:

start Iterator that points to the beginning of the range to be erased.

end Iterator that points to the end of the range to be erased

Return values;

The iterator of the data immediately after the erased data

4.3.14 acp_insert_vector

acp_vector_it_t acp_insert_vector(acp_vector_it_t *it*,
const acp_ga_t *ga*, size_t *size*)

Inserts data into the specified position of the vector.

Parameters:

it Iterator of a vector that specifies the position to insert data.

ga Global address of the data to be inserted.

size Size of the data to be inserted.

Return values;

The iterator that points to the inserted data.

4.3.15 acp_insert_range_vector

acp_vector_it_t acp_insert_range_vector(acp_vector_it_t *it*,
acp_vector_it_t *start*, acp_vector_it_t *end*)

Insert range of data from a vector to another vector.

Parameters:

it Iterator of a vector that specifies the position to insert data.

start Iterator of a vector that specifies the beginning position of the data to be inserted.

end Iterator of a vector that specifies the ending position of the data to be inserted.

Return values;

The iterator that points to the inserted data.

4.3.16 acp_pop_back_vector

void acp_pop_back_vector(acp_vector_t *vector*, size_t *size*)

Erase specified size of data from the tail of ***vector***.

Parameters:

vector Vector.

size Size of the data to erase.

4.3.17 acp_push_back_vector

void acp_push_back_vector(acp_vector_t vector,
const acp_ga_t ga, size_t size);

Add specified size of data to the tail of ***vector***.

Parameters:

vector Vector.

ga Global address of the data to be added.

size Size of the data to be added.

4.3.18 acp_reserve_vector

void acp_reserve_vector(acp_vector_t *vector*, size_t *size*)

Change the size of ***vector*** so that it can store the specified number of elements.

Parameters:

vector Vector.

size New number of elements of the vector.

4.3.19 acp_size_vector

`size_t acp_size_vector(acp_vector_t vector)`

Query for the size of the data stored in ***vector***.

Parameters:

vector Vector.

Return values;

The size of the data stored in the vector.

4.3.20 acp_swap_vector

`void acp_swap_vector(acp_vector_t vector1, acp_vector_t vector2)`

Swap data between ***vector1*** and ***vector2***.

Parameters:

vector1 Vector.

vector2 Another vector.

4.3.21 acp_advance_vector

`acp_vector_it_t acp_advance_vector_it(acp_vector_it_t it,`
`int n)`

Make advance of an iterator of a vector.

Parameters:

it Iterator of a vector.

n The number of advance to make. Minus number is also valid.

Return values;

The iterator that points to the result of the advance.

4.3.22 acp_dereference_vector

acp_ga_t acp_dereference_vector_it(acp_vector_it_t *it*)

Query for the global address of an iterator of a vector.

Parameters:

it Iterator of a vector.

Return values;

Global address of the specified iterator of the vector.

4.3.23 acp_distance_vector

int acp_distance_vector_it(acp_vector_it_t *first*,
acp_vector_it_t *last*)

Query for the distance between two iterators of a ***vector.***

Parameters;

first Iterator of a vector.

last Another iterator of the vector.

Return values;

Distance between two vectors.

4.4 Deque

The deque interface provides functions for establishing the data structure and functions of double-ended queues. Each element of a deque can be manipulated by an iterator. An iterator is valid only at the process that retrieved it. Iterators will be invalid after modification of the deque by: **acp_assign_deque, acp_assign_range_deque, acp_clear_deque, acp_destroy_deque, acp_erase_deque, acp_erase_range_deque, acp_insert_deque, acp_insert_range_deque and acp_swap_deque.**

4.4.1 Data types

Datatypes:

```
typedef struct {
    acp_ga_t ga;
} acp_deque_t;

typedef struct {
    acp_deque_t deque;
    int index;
} acp_deque_it_t;
```

4.4.2 acp_assign_deque

void acp_assign_deque(acp_deque_t *deque1*, acp_deque_t *deque2*)

Copy elements from ***deque2*** to ***deque1.***
Old elements of ***deque1*** are overwritten.

Parameters;

deque1 Destination deque

deque2 Source deque

4.4.3 acp_assign_range_deque

void acp_assign_range_deque(acp_deque_t *deque*, acp_deque_it_t *start*, acp_deque_it_t end)

Copy a range of elements in a ***deque,*** specified by ***start*** and ***end***, to ***deque***.
start and ***end*** must be in the same ***deque.*** Old data in ***deque*** is overwritten.

Parameters;

deque	Destination deque
start	Iterator that specifies the start of the range of the deque to be copied
end	Iterator that specifies the end of the range of the deque to be copied

4.4.4 acp_at_deque

acp_ga_t acp_at_deque(acp_deque_t *deque*, int *offset*)

Query for the global address of the position specified by ***offset*** in ***deque.***

Parameters;

deque	Deque
offset	Offset from the beginning of **deque**

Return values;

ACP_GA_NULL	Fail
otherwise	Global address of the specified position

4.4.5 acp_back_deque

acp_deque_it_t acp_back_deque(acp_deque_t *deque*)

Query for the tail element of ***deque.***

Parameters;

deque	Deque

Return values;

Iterator of the tail of **deque**

4.4.6 acp_begin_deque

`acp_deque_it_t acp_begin_deque(acp_deque_t *deque*)`

Query for the head element of ***deque***.

Parameters;

deque Deque

Return values;

Iterator of the head of **deque**

4.4.7 acp_capacity_deque

`size_t acp_capacity_deque(acp_deque_t *deque*)`

Query for the capacity of ***deque*** without extending area.

Parameters;

deque Deque

Return values;

Capacity of ***deque*** without extending area

4.4.8 acp_clear_deque

`void acp_clear_deque(acp_deque_t *deque*)`

Set the size of ***deque*** to be zero.

Parameters;

deque Deque

4.4.9 acp_create_deque

`acp_deque_t acp_create_deque(size_t size, int rank)`

Creates a deque on the specified process.

Parameters;

`size` Number of elements of the deque

`rank` Rank of the process on which the deque is located

Return values;

`ga == ACP_GA_NULL`	Fail
otherwise	Created deque

4.4.10 acp_ destroy_deque

`void acp_destroy_deque(acp_deque_t deque)`

Destroys ***`deque`***.

Parameters;

`deque` Deque

4.4.11 acp_empty_deque

`int acp_empty_deque(acp_deque_t deque)`

Query for the emptiness of ***`deque`***.

Parameters;

`deque` Deque

Return values;

`1` Empty

`0` Not empty

4.4.12 acp_end_deque

acp_deque_it_t acp_end_deque(acp_deque_t *deque*)

Query for the iterator just after the tail element of ***deque***.

Parameters;

deque Deque

Return values;

Iterator just after the tail element of deque.

4.4.13 acp_erase_deque

acp_deque_it_t acp_erase_deque(acp_deque_it_t *it*,
size_t *size*)

Erase range of elements from a deque.

Parameters;

it Iterator that points to the beginning of the range of the deque to be erased

size Size of the range to be erased

Return values;

Iterator of the element of the deque immediately after the erased range

4.4.14 acp_erase_range_deque

acp_deque_it_t acp_erase_range_deque(acp_deque_it_t *start*, acp_deque_it_t *end*)

Erase a range of elements from a deque.

Parameters;

start Iterator that points to the beginning of the range of the deque to be erased

end Iterator that points to the end of the range of the deque to be erased

Return values;

Iterator of the element of the deque immediately after the erased range

4.4.15 acp_front_deque

acp_deque_it_t acp_front_deque(acp_deque_t *deque*)

Query for the iterator just before the head element of ***deque*.**

Parameters;

deque Deque

Return values;

Iterator just before the head element of the ***deque***

4.4.16 acp_insert_deque

acp_deque_it_t acp_insert_deque(acp_deque_it_t *it*,
const acp_ga_t *ga*, size_t *size*)

Insert elements into the specified position of another deque.

Parameters;

it Iterator of a deque that specifies the position to insert elements

ga Global address of the first element to be inserted

size Number of elements to be inserted

Return values;

Iterator that points to the beginning of the inserted elements

4.4.17 acp_insert_range_deque

acp_deque_it_t acp_insert_range_deque(acp_deque_it_t *it*,
acp_deque_it_t *start*, acp_deque_it_t *end*)

Insert a range of elements in a deque to another deque.

Parameters;

it Iterator of a deque that specifies the position to insert elements

start Iterator of a deque that specifies the beginning position of the range of elements to be inserted

end Iterator of a deque that specifies the ending position of the range of elements to be inserted

Return values;

Iterator that points to the beginning of the inserted elements

4.4.18 acp_pop_back_deque

void acp_pop_back_deque(acp_deque_t *deque*, size_t *size*)

Erase specified number of elements from the tail of ***deque*.**

Parameters;

deque Deque

size Number of elements to erase

4.4.19 acp_pop_front_deque

void acp_pop_front_deque(acp_deque_t *deque*, size_t *size*)

Erase specified number of elements from the head of ***deque*.**

Parameters;

deque Deque

size Number of elements to erase

4.4.20 acp_push_back_deque

void acp_push_back_deque(acp_deque_t *deque*, const acp_ga_t *ga*, size_t *size*)

Add specified number of elements to the tail of ***deque***.

Parameters;

deque Deque

ga Global address of the first element to be inserted

size Number of elements to be inserted

4.4.21 acp_push_front_deque

v**oid acp_push_front_deque(acp_deque_t *deque*, const acp_ga_t *ga*, size_t *size*)**

Add specified number of elements to the head of ***deque*.**

Parameters;

deque Deque

ga Global address of the first element to be inserted

size Number of elements to be inserted

4.4.22 acp_reserve_deque

void acp_reserve_deque(acp_deque_t *deque*, size_t *size*)

Change the area of ***deque*** so that it can store the specified number of elements.

Parameters;

deque Deque

size New number of elements that can be stored in deque

4.4.23 acp_size_deque

size_t acp_size_deque(acp_deque_t *deque*)

Query for the number of elements in ***deque***.

Parameters;

deque Deque

Return values;

Number of elements stored in ***deque***

4.4.24 acp_swap_deque

`void acp_swap_deque(acp_deque_t deque1, acp_deque_t deque2)`

Swap elements between two ***deques***.

Parameters;

deque1 Deque

deque2 Another deque

4.4.25 acp_advance_deque

`acp_deque_it_t acp_advance_deque_it(acp_deque_it_t it, int n)`

Make advance of an iterator of a deque.

Parameters;

it Iterator of a deque

n Number of elements to make advance (Minus number is also valid)

Return values;

Iterator of the result of the advance.

4.4.26 acp_dereference_deque

`acp_ga_t acp_dereference_deque_it(acp_deque_it_t it)`

Query for the global address of an iterator of a deque.

Parameters;

it Iterator of a deque

Return values;

Global address of the specified iterator

4.4.27 acp_distance_deque

`int acp_distance_deque_it(acp_deque_it_t *first*, acp_deque_it_t *last*)`

Query for the distance between two iterators in a deque.

Parameters;

`first` Iterator of a deque

`last` Another iterator of the deque

Return values;

Distance between two iterators

4.5 List

The list interface provides functions for establishing the data structure and algorithms of bidirectional linked list. Each element of a list can be manipulated by an iterator. An iterator is valid only at the process that retrieved it. Iterators will be invalid after modification of the list by: **acp_assign_list, acp_assign_range_list, acp_clear_list, acp_destroy_list, acp_erase_list, acp_erase_range_list, acp_insert_list, acp_insert_range_list, acp_merge_list, acp_remove_list, acp_reverse_list, acp_splice_list, acp_swap_list and acp_unique_list**

4.5.1 Data types and macros

Data types:

```
typedef struct {
        acp_ga_t ga;
} acp_list_t
typedef struct {
        acp_list_t list;
        acp_ga_t elem;
} acp_list_it_t
```

4.5.2 acp_assign_list

```
void acp_assign_list(acp_list_t list1, acp_list_t list2);
```

Copy elements from ***list2*** to ***list1***. Old elements of ***list1*** are overwritten.

Parameters:

list1 Destination deque

list2 Source deque

4.5.3 acp_assign_range_list

void acp_assign_range_list(acp_list_t *list*,
acp_list_it_t *start*, acp_list_it_t *end*)

Copy a range of elements in a list, specified by **start** and **end**, to **list**. **start** and **end** must be in the same **list**. Old data in list is overwritten. New elements are located in the same process of the source list.

Parameters:

list Destination list

start Iterator that specifies the start of the range of the list to be copied

end Iterator that specifies the end of the range of the list to be copied

4.5.4 acp_begin_list

acp_list_it_t acp_begin_list(acp_list_t *list*)

Query for the head element of ***list***.

Parameters:

list List

Return values:

Iterator of the head of ***list***

4.5.5 acp_clear_list

void acp_clear_list(acp_list_t *list*)

Make ***list*** to be empty.

Parameters:

list List

4.5.6 acp_create_list

`acp_list_t acp_create_list(int rank)`

Creates an empty list on the specified process.

Parameters:

`rank` Rank of the process on which the list is located

Return values:

`ga == ACP_GA_NULL` Fail

otherwise Created list

4.5.7 acp_destroy_list

`void acp_destroy_list(acp_list_t list)`

Destroy ***`list`***.

Parameters:

`list` List

4.5.8 acp_empty_list

`int acp_empty_list(acp_list_t list)`

Query for the emptiness of ***`list`***.

Parameters:

`list` List

Return values:

`1` Empty

`0` Not empty

4.5.9 acp_end_list

acp_list_it_t acp_end_list(acp_list_t *list*)

Query for the iterator just after the tail element of ***list***.

Parameters:

list List

Return values:

Iterator just after the tail element of ***list***.

4.5.10 acp_erase_list

acp_list_it_t acp_erase_list(acp_list_it_t *it*)

Erase an element from a list.

Parameters:

it Iterator that points to the beginning of the range of the list to be erased

Return values:

Iterator of the element of the list immediately after the erased element

4.5.11 acp_erase_range_list

acp_list_it_t acp_erase_range_list(acp_list_it_t *start*,
acp_list_it_t *end*)

Erase a range of elements from a list.

Parameters:

start Iterator that points to the beginning of the range of the list to be erased

end Iterator that points to the end of the range of the list to be erased

Return values:

Iterator of the element of the list immediately after the erased range

4.5.12 acp_insert_list

acp_list_it_t acp_insert_list(acp_list_it_t *it*,
const acp_element_t *elem*, int *rank*)

Create an element on the specified process and insert it into the specified position of another list.

Parameters:

it Iterator of a list that specifies the position to insert the element

elem Contents of the new element

size Rank of process to locate the new element

Return values:

Iterator that points to the new element

4.5.13 acp_insert_range_list

acp_list_it_t acp_insert_range_list(acp_list_it_t *it*,
acp_list_it_t *start*, acp_list_it_t *end*)

Insert a range of elements in a list to another list.

Parameters:

it Iterator of a list that specifies the position to insert elements

start Iterator of a list that specifies the beginning position of the range of elements to be inserted

end Iterator of a list that specifies the ending position of the range of elements to be inserted

Return values:

Iterator that points to the beginning of the inserted elements

4.5.14 acp_merge_list

void acp_merge_list(acp_list_t *list1*, acp_list_t *list2*,
int (comp*)(const acp_element_t elem1, const acp_element_t elem2))**

Marge two sorted lists.

Parameters:

list1 List to be marged

list2 Another list to be marged

comp Pointer to a function that returns:

minus for elem1 < elem2

0 for elem1 == elem2

plus for elem1 > elem2

4.5.15 acp_pop_back_list

void acp_pop_back_list(acp_list_t *list*)

Erase an element from the tail of ***list*.**

Parameters:

list List

4.5.16 acp_pop_front_list

void acp_pop_front_list(acp_list_t *list*)

Erase an element from the head of ***list*.**

Parameters:

list List

4.5.17 acp_push_back_list

void acp_push_back_list(acp_list_t *list*, const acp_element_t *elem*, int *rank*)

Create an element on the specified process and add it to the tail of ***list***.

Parameters:

list	List
elem	Contents of the new element
rank	Rank of process to locate the new element

4.5.18 acp_push_front_list

void acp_push_front_list(acp_list_t *list*, const acp_element_t *elem*, int *rank*)

Create an element on the specified process and add it to the head of ***list***.

Parameters:

list	List
elem	Contents of the new element
rank	Rank of process to locate the new element

4.5.19 acp_remove_list

void acp_remove_list(acp_list_t *list*, const acp_element_t *elem*)

Remove elements that has the same contents with ***elem*** from **list.**

Parameters:

list	List
elem	Contents of the element to compare

4.5.20 acp_ reverse_list

void acp_reverse_list(acp_list_t *list*)

Reverse the order of elements of ***list***.

Parameters:

list List

4.5.21 acp_size_list

size_t acp_size_list(acp_list_t list);

Query for the number of elements in ***list***.

Parameters:

list List

Return values:

Number of elements in ***list***

4.5.22 acp_sort_list

void acp_sort_list(acp_list_t *list*,
int (comp*)(const acp_element_t elem1, const acp_element_t elem2))**

Sort elements of ***list***.

Parameters:

list List

comp Pointer to a function that returns:
minus for elem < elem2
0 for elem1 == elem2
plus for elem1 > elem2

4.5.23 acp_splice_list

void acp_splice_list(acp_list_it_t *it1*, acp_list_it_t *is2*)

Move an element from a list to the specified place of another list.

Parameters:

it1 Iterator that points to the position to insert the element

it2 Iterator of the element to move

4.5.24 acp_splice_range_list

void acp_splice_range_list(acp_list_it_t *it*, acp_list_it_t *start*, acp_list_it_t *end*)

Move a range of elements from a list to the specified place of another list.

Parameters:

it Iterator that points to the position to insert the elements

start Iterator that points to the beginning of the range to be moved

end Iterator that points to the end of the range to be moved

4.5.25 acp_swap_list

void acp_swap_list(acp_list_t *list1*, acp_list_t *list2*)

Swap elements between two lists.

Parameters:

list1 List

list2 Another list

4.5.26 acp_unique_list

void acp_unique_list(acp_list_t *list*)

Erase redundant elements from **list.**

Parameters:

list List

4.5.27 acp_advance_list

acp_list_it_t acp_advance_list_it(acp_list_it_t *it*, int *n*)

Make advance of an iterator of a list.

Parameters:

it Iterator of a list

n Number of elements to make advance (Minus number is also valid)

Return values:

Iterator of the result of the advance.

4.5.28 acp_decrement_list

acp_list_it_t acp_decrement_list_it(acp_list_it_t *it*)

Decrement iterator of a list.

Parameters:

it Iterator of a list

Return values:

Previous iterator of **it**

4.5.29 acp_deregerence_list

`acp_element_t acp_dereference_list_it(acp_list_it_t it)`

Query for the global address and the size of an iterator of a list.

Parameters:

`it` Iterator of a list

Return values:

Element of ***`it`***

4.5.30 acp_distance_list_it

`int acp_distance_list_it(acp_list_it_t first, acp_list_it_t last)`

Query for the distance between two iterators in a list.

Parameters:

`first` Iterator of a list

`last` Another iterator of the list

Return values:

Distance between two iterators

4.5.31 acp_increment_list

`acp_list_it_t acp_increment_list_it(acp_list_it_t it)`

Increment iterator of a list.

Parameters:

`it` Iterator of a list

Return values:

Next iterator of ***`it`***

4.6 Set

The set interface provides functions for establishing the data structure and algorithms of set.

4.6.1 Data types and macros

Data types:

```
typedef struct {
        acp_ga_t ga;
        uint64_t num_ranks;
        uint64_t num_slots;
} acp_set_t;

typedef struct {
        acp_set_t map;
        int rank;
        int slot;
        acp_ga_t elem;
} acp_set_it_t;
```

4.6.2 acp_assign_local_set

void acp_assign_local_set (acp_set_t *set1*, acp_set_t *set2*)

Among the keys of ***set2***, copy the keys that are allocated in the caller process. Keys of the destination set (***set1***) are destroyed.

Parameters:

set1	Destination of the copy.
set2	Source of the copy.

4.6.3 acp_assign_set

void acp_assign_set (acp_set_t set1, acp_set_t set2)

Copy keys of ***set2***. Keys of the destination set (***set1***) are destroyed.

Parameters:

set1	Destination of the copy.
set2	Source of the copy.

4.6.4 acp_begin_local_set

acp_set_it acp_begin_local_set (acp_set_t *set*)

Among the keys of ***set***, query for the first key of the keys that are allocated in the caller process.

Parameters:

set	Set.

Return values:

An iterator of a set.

4.6.5 acp_begin_set

acp_set_it acp_begin_set (acp_set_t *set*)

Query for the iterator that points to the first key of ***set***.

Parameters:

set	Set.

Return values:

An iterator of a set.

4.6.6 acp_clear_local_set

void acp_clear_local_set (acp_set_t *set*)

Among the keys of ***set***, delete all of the keys that are allocated in the caller process.

Parameters:

set	Set.

4.6.7 acp_clear_set

void acp_clear_set (acp_set_t *set*)

Make ***set*** empty.

Parameters:

set	Set.

4.6.8 acp_create_set

acp_set_t acp_create_set (int *num_ranks*, const int *ranks*, int *num_slots*, int *rank*)

Create a set on the specified processes.

Parameters:

num_ranks	Number of processes to allocate bucket of the set.
ranks	Array of ranks of processes to allocate bucket of the set.
num_slots	Number of slots of a bucket per process.
rank	Process to allocate the management information of the set.

Return values:

member ga == ACP_GA_NULL	Fail
otherwise	A reference of created set data.

4.6.9 acp_destroy_set

void acp_destroy_set (acp_set_t *set*)

Destroy ***set***.

Parameters:

set	Set.

4.6.10 acp_empty_local_set

int acp_empty_local_set (acp_set_t *set*)

Query if, among the keys of ***set***, the number of keys that are allocated in the caller

process is zero.

Parameters:

set Set.

Return values;

1 Empty.

0 Not empty.

4.6.11 acp_empty_set

```
int acp_empty_set (acp_set_t set)
```

Query for the emptiness of ***set***.

Parameters:

set Set.

Return values;

1 Empty.

0 Not empty.

4.6.12 acp_end_local_set

```
acp_set_it_t acp_end_local_set (acp_set_t set)
```

Among the keys of ***set***, query for the last key of the keys that are allocated in the caller process.

Parameters:

set Set.

Return values:

An iterator of a set.

4.6.13 acp_end_set

```
acp_set_it_t acp_end_set (acp_set_t set)
```

Query for the iterator that points to the last key of ***set***.

Parameters:

set Set.

Return values:

An iterator of a set.

4.6.14 acp_find_set

```
acp_set_it_t acp_find_set (acp_set_t set, acp_element_t key)
```

Search for the key in ***set*** that matches with ***key***.

Parameters:

set Set.

key Key.

Return values:

the end key of the set No matching key found.

otherwise

4.6.15 acp_insert_set

```
int acp_insert_set (acp_set_t set, acp_element_t key)
```

Insert ***key*** to ***set***. If the same key is already in the set, it returns successfully without inserting the new key.

Parameters:

set Set.

key Key.

Return values:

1 Success.

0 Fail.

4.6.16 acp_merge_local_set

void acp_merge_local_set (acp_set_t *set1*, acp_set_t *set2*)

Among the keys of ***set2***, merge the keys that are allocated in the caller process to ***set1***.

Parameters:

set1 Destination set.

set2 Source set.

4.6.17 acp_merge_set

void acp_merge_set (acp_set_t *set1*, acp_set_t *set2*)

Merge ***set2*** to ***set1***.

Parameters:

set1 Destination set.

set2 Source set.

4.6.18 acp_move_local_set

void acp_move_local_set (acp_set_t *set1*, acp_set_t *set2*)

Among the keys of ***set2***, move the keys that are allocated in the caller process to ***set1***.

Parameters:

set1 Destination set.

set2 Source set.

4.6.19 acp_move_set

void acp_move_local_set (acp_set_t *set1*, acp_set_t *set2*)

Move the keys of ***set2*** to ***set1***.

Parameters:

set1 Destination set.

set2 Source set.

4.6.20 acp_remove_set

void acp_remove_set (acp_set_t *set*, acp_element_t *key*)

Delete the key of ***set*** that matches with ***key***.

Parameters:

set Set.

key Key.

4.6.21 acp_size_local_set

size_t acp_size_local_set (acp_set_t *set*)

Among the keys of ***set***, query for the number of keys that are allocated in the caller process.

Parameters:

set Set.

Return values:

Number of keys.

4.6.22 acp_size_set

size_t acp_size_set (acp_set_t *set*)

Query for the number of keys of ***set***.

Parameters:

set Set.

Return values:

Number of keys.

4.6.23 acp_swap_set

void acp_swap_set (acp_set_t *set1*, acp_set_t *set2*)

Swap keys between ***set1*** and ***set2***.

Parameters:

set1 Destination set.

set2 Source set.

4.6.24 acp_dereference_set_it

```
acp_element_t acp_dereference_set_it(acp_set_it_t it);
```

Query for the key referenced by ***it***.

Parameters:

it Iterator of a set.

Return values:

The key referenced by ***it***

4.6.25 acp_increment_set_it

```
acp_set_it_t acp_increment_set_it(acp_set_it_t it);
```

Increment iterator of a set.

Parameters:

it Iterator of a set.

Return values:

Next iterator of ***it***

4.7 Map

The map interface provides functions for establishing the data structure and algorithms of map.

4.7.1 Data types and macros

Data types:

```
typedef struct {
        acp_ga_t ga;
        uint64_t num_ranks;
        uint64_t num_slots;
} acp_map_t;

typedef struct {
        acp_map_t map;
        int rank;
        int slot;
        acp_ga_t elem;
} acp_map_it_t;

typedef struct {
        acp_map_it_t it;
        int success;
} acp_map_ib_t;
```

4.7.2 acp_assign_local_map

void acp_assign_local_map (acp_set_t *map1*, acp_set_t *map2*)

Among the elements of ***map2***, copy the elements that are allocated in the caller process. Elements of the destination map (***map1***) are destroyed.

Parameters:

map1 Destination map.

map2 Source map.

4.7.3 acp_assign_map

void acp_assign_map (acp_set_t *map1*, acp_set_t *map2*)

Copy elements of ***map2*** to ***map1***.
Elements of the destination map (***map1***) are destroyed.

Parameters:

map1 Destination map.

map2 Source map.

4.7.4 acp_begin_local_map

acp_map_it acp_begin_local_map (acp_map_t *map*)

Among the elements of ***map***, query for the first element of the ones that are allocated in the caller process.

Parameters:

map Map.

Return values:

An iterator of a map.

4.7.5 acp_begin_map

acp_map_it acp_begin_map (acp_map_t *map*)

Query for the iterator that points to the first element of ***map***.

Parameters:

map Map.

Return values:

An iterator of a map.

4.7.6 acp_clear_local_map

void acp_clear_local_map (acp_map_t *map*)

Among the elements of ***map***, delete all of the ones that are allocated in the caller process.

Parameters:

map	A reference of a map to clear..

4.7.7 acp_clear_map

void acp_clear_map (acp_map_t *map*)

Delete elements of lists in a map type data.

Parameters:

map	A reference of a map to clear.

4.7.8 acp_create_map

acp_map_t acp_create_map (int *num_ranks*, const int* *ranks*, int *num_slots*, int *rank*)

Map creation.
Creates a map type data on any set of processes.

Parameters:

num_ranks	Number of processes.
ranks	Array of the rank numbers of the processes to distribute map.
num_slots	Number of slots.
rank	Rank number to place the information of the map.

Return values:

member ga == ACP_GA_NULL	Fail
otherwise	A reference of created map data.

4.7.9 acp_destroy_map

void acp_destroy_map (acp_map_t *map*)

Destroys a ***map*** type data.

Parameters:

map A reference of a map to destroy.

4.7.10 acp_empty_local_map

int acp_empty_local_map (acp_map_t *map*)

Query if, in the ***map***, the number of elements that are allocated in the caller process is zero.

Parameters:

map Map.

Return values:

1 Empty.

0 Not empty.

4.7.11 acp_empty_map

int acp_empty (acp_map_t *map*)

Query for the emptiness of ***map***.

Parameters:

map Map.

Return values:

1 Empty.

0 Not empty.

4.7.12 acp_end_local_map

acp_map_it_t acp_end_local_map (acp_map_t *map*)

Among the elements of ***map***, query for the iterator just after the last element of the elements that are allocated in the caller process.

Parameters:

map Map.

Return values:

An iterator of a map.

4.7.13 acp_end_map

acp_map_it_t acp_end_map(acp_map_t *map*)

Query for the iterator just after the tail element of a ***map***.

Parameters:

map A reference of a map type data.

Return values:

An iterator of a map.

4.7.14 acp_find_map

acp_map_it_t acp_find_map(acp_map_t *map*, const acp_element_t *key*)

Search for the key in ***map*** that matches with ***key***.

Parameters:

map A reference of a map type data.

key Address of the key to search.

Return values:

If found, the iterator of a map with matching key.

If not, the iterator just after the tail element of the map.

4.7.15 acp_insert_map

int acp_insert_map(acp_map_t *map*, acp_pair_t *pair*)

Inserts a key-value pair to a ***map.*** If the same key is already in the map, it fails.

Parameters:

map Map.

key Pair of key and value.

Return values:

1 Success.

0 Fail.

4.7.16 acp_merge_local_map

viod acp_merge_local_map (acp_map_t *map1*, acp_map_t *map2*)

Among the keys of ***map2***, merge the keys that are allocated in the caller process to ***map1***.

Parameters:

map1 Destination map.

map2 Source map.

4.7.17 acp_merge_map

void acp_merge_map (acp_map_t *map1*, acp_map_t *map2*)

Merge ***map2*** to ***map1***.

Parameters:

map1 Destination map.

map2 Source map.

4.7.18 acp_move_local_map

void acp_move_local_map (acp_map_t *map1*, acp_map_t *map2*)

Among the keys of ***map2***, move the keys that are allocated in the caller process to ***map1***.

Parameters:

map1 Destination map.

map2 Source map.

4.7.19 acp_move_map

void acp_move_map (acp_map_t *map1*, acp_map_t *map2*)

Move the keys of ***map2*** to ***map1***.

Parameters:

map1	Destination map.
map2	Source map.

4.7.20 acp_remove_map

void acp_remove_map (acp_map_t *map*, acp_element_t *key*)

Delete the key of ***map*** that matches with ***key***.

Parameters:

map	Map.
key	Key.

4.7.21 acp_retrieve_map

int acp_retrieve_map (acp_map_t *map*, acp_pair_t *pair*)

From ***map***, retrieve the element that matches with the specified key in ***pair***. The value of the element is copied in the second member of the pair.

Parameters:

map	Map.
key	Pair of the key and the buffer for retrieving value.

Return values:

0	No matching key.
otherwise	Size of the data retrieved to the buffer in the pair.

4.7.22 acp_size_local_map

size_t acp_size_local_map (acp_map_t *map*)

Among the elements of ***map***, query for the number of elements that are allocated in the caller process.

Parameters:

map Map.

Return values:

Number of elements.

4.7.23 acp_size_map

```
size_t acp_size _map (acp_map_t map)
```

Query for the number of elements of ***map***.

Parameters:

map Map.

Return values:

Number of elements.

4.7.24 acp_swap_map

```
void acp_swap_map (acp_map_t map1, acp_map_t map2)
```

Swap keys between ***map1*** and ***map2***.

Parameters:

map1 Destination map.

map2 Source map.

4.7.25 acp_dereference_map_it

```
acp_element_t acp_dereference_map_it(acp_map_it_t it);
```

Query for the element referenced by ***it***.

Parameters:

it Iterator of a map.

Return values:

The element referenced by ***it***

4.7.26 acp_increment_map_it

`acp_map_it_t acp_increment_map_it(acp_map_it_t *it*);`

Increment iterator of a map.

Parameters:

`it` Iterator of a map.

Return values:

Next iterator of ***`it`***

4.8 Workspace

Workspace is a temporal memory space shared among all processes.

4.8.1 Data types and macros

Data types:

```
typedef acp_wsditem *acp_wsd_t;
```

Macros:

`ACP_WSD_NULL` Represents no workspace.

4.8.2 acp_create_ws

```
acp_wsd_t acp_create_ws(size_t size)
```

Create a workspace with the specified ***`size`***.

Parameters:

`size` Total size of the workspace.

Return values:

`ACP_WSD_NULL` Fail

otherwise The handle for the workspace.

4.8.3 acp_destroy_ws

```
void acp_destroy_ws(acp_wsd_t wsd)
```

Destruct workspace specified by ***`wsd`***.

Parameters:

`wsd` The handle for the workspace to destruct.

4.8.4 acp_read_ws

int acp_read_ws(acp_wsd_t *wsd*, acp_ga_t *ga*, size_t *size*, size_t *offset*)

Read data from the specified position in the workspace.

Parameters:

wsd	The handle for the workspace to read from.
ga	The global address to store the read data.
size	Size of the data to be read.
offset	Relative position of the workspace from where data is read.

Return values:

0	Success
1	Fail

4.8.5 acp_setparams_ws

int acp_setparams_ws(size_t *proc_start*, size_t *size_default*)

Set parameters for distributing workspace among processes. Every process need to specify the same value.

Parameters:

proc_start	The process number from which the distribution begins.
size_default	Size of the part of workspace allocated on each process.

Return values:

0	Success

4.8.6 acp_write_ws

```
int acp_write_ws(acp_wsd_t wsd, const acp_ga_t ga, size_t size,
                 size_t offset)
```

Write data to the specified position in the workspace.

Parameters:

wsd	The handle for the workspace to write to.
ga	The global address of the data to write.
size	Size of the data to be write.
offset	Relative position of the workspace to where data is written.

Return values:

0	Success
1	Fail

4.9 Malloc

The malloc interface provides functions for asynchronous allocation and de-allocation of global memory.

4.9.1 acp_malloc

```
acp_ga_t acp_malloc (size_t size, int rank)
```

Allocate global memory with ***size*** bytes on the process specified by ***rank***.

Parameters:

size	Size of the global memory region to allocate.
rank	Rank of the process to allocate the region.

Return values:

ACP_GA_NULL	Fail

otherwise Global address of the head of the allocated region.

4.9.2 acp_free

`void acp_free (acp_ga_t ga)`

Free the global memory region specified by ***ga***.

Parameters:

ga Global address of the region to free.

4.10 Global Memory Management

The global memory management interface provides functions for manipulating memory regions of the global address space.

4.10.1 Data types and macros

Data types:

`typedef uint64_t acp_atkey_t`

Key for address translation of the registered memory region.

`typedef uint64_t acp_ga_t`

Global address. Byte-wise address unique among all of the processes.

Macros:

`ACP_ATKEY_NULL` Represents no address translation key.

`ACP_GA_NULL` Represents no global address.

4.10.2 acp_register_memory

`acp_atkey_t acp_register_memory (void * addr, size_t size, int color)`

Memory registration.

Registers the specified memory region to global memory and returns an address translation key for it. The ***`color`*** that will be used for GMA with the address is also included in the key.

Parameters:

`addr` Logical address of the top of the memory region to be registered.

`size` Size of the region to be registered.

`color` Color number that will be used for GMA with the global memory.

Return values:

`ACP_ATKEY_NULL` Fail

otherwise Address translation key.

4.10.3 acp_unregister_memory

int acp_unregister_memory (acp_atkey_t *atkey*)

Memory unregistration.
Unregister the memory region with the specified address translation key.

Parameters:

atkey Address translation key.

Return values:

0 Success

-1 Fail

4.10.4 acp_query_ga

acp_ga_t acp_query_ga (acp_atkey_t *atkey*, void * *addr*)

Query for the global address.
Returns the global address of the specified logical address translated by the specified address translation key.

Parameters:

atkey Address translation key.

addr Logical address.

Return values:

ACP_GA_NULL Fail

otherwise Global address of starter memory.

4.10.5 acp_colors

`int acp_colors (void)`

Query for the maximum number of colors.
Returns the maximum number of colors on this environment.

Return values:

>=1	Maximum number of colors.
-1	Fail

4.10.6 acp_query_rank

`int acp_query_rank (acp_ga_t ga)`

Query for the rank of the global address.
Returns the rank of the process that keeps the logical region of the specified global address. It can be used for retrieving the rank of the starter memory. It returns -1 if the ACP_GA_NULL is specified as the global address.

Parameters:

ga	Global address.

Return values:

>=0	Rank number.
-1	Fail

4.10.7 acp_query_color

`int acp_query_color (acp_ga_t ga)`

Query for the color of the global address.
Returns the color of the specified global address. It returns -1 if the ACP_GA_NULL is specified as the global address.

Parameters:

`ga` Global address.

Return values:

`>=0` Color number.

`-1` Fail

4.10.8 acp_query_address

`void* acp_query_address (acp_ga_t ga)`

Query for the logical address.
Returns the logical address of the specified global address. It fails if the process that keeps the logical region of the global address is different from the caller. It can be used for retrieving logical address of the starter memory.

Parameters:

`ga` Global address.

Return values:

`NULL` FailLogical address.

otherwise Logical address.

4.10.9 acp_query_starter_ga

`acp_ga_t acp_query_starter_ga (int rank)`

Query for the global address of the starter memory.
Returns the global address of the starter memory of the specified ***`rank`***.

Parameters:

`rank` Rank number.

Return values:

`ACP_GA_NULL` Fail Global address of the starter memory.

otherwise Global address of the starter memory.

4.11 Global Memory Access

The global memory access interface provides functions for RDMA operations on the global address space.

4.11.1 Data types and macros

Data types:

`typedef uint64_t acp_handle_t`

Handle of GMA. Used to distinguish incomplete GMA.

Macros:

`ACP_HANDLE_ALL` Represents handles of all advancing GMAs.

`ACP_HANDLE_CONT` Represents continuation of the GMA invoked just before this one.

`ACP_HANDLE_NULL` Represents no GMA handle.

If ACP_HANDLE_CONT is specified as the order of a GMA, and if the GMA that is invoked immediately before this one has the same source rank, target rank, source color and target color, it can start its access with the same condition of the previous one, as far as it will not overtake the order. If there is any difference in those parameters, the behavior is same as the case with ACP_HANDLE_ALL. There can be an implementation that always performs the same way as the case with ACP_HANDLE_ALL, even if ACP_HANDLE_CONT is specified.

4.11.2 acp_copy

acp_handle_t acp_copy (acp_ga_t *dst*, acp_ga_t *src*, size_t *size*, acp_handle_t *order*)

Copy.

Copies data of the specified ***size*** between the specified global addresses of the global memory. Ranks of both of ***dst*** and ***src*** can be different from the rank of the caller process.

Parameters:

dst	Global address of the head of the destination region of the copy.
src	Global address of the head of the source region of the copy.
size	Size of the data to be copied.
order	The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL	Fail
otherwise	A handle for this GMA.

4.11.3 acp_add4

acp_handle_t acp_add4 (acp_ga_t *dst*, acp_ga_t *src*, uint32_t *value*, acp_handle_t *order*)

4byte Add

Performs an atomic add operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst***. The rank of the ***dst*** must be the rank of the caller process. The values to be added is 4byte. Global addresses must be 4byte aligned.

Parameters:

dst	Global address to store the result.
src	Global address to apply the operation.
value	Value to be added.
order	The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL	Fail
Otherwise	A handle for this GMA.

4.11.4 acp_add8

acp_handle_t acp_add8 (acp_ga_t *dst*, acp_ga_t *src*, uint64_t *value*, acp_handle_t order)

8byte Add

Performs an atomic add operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst***. The rank of the ***dst*** must be the rank of the caller process. The values to be added is 8byte. Global addresses must be 8byte aligned.

Parameters:

dst	Global address to store the result.
src	Global address to apply the operation.
value	Value to be added.
order	The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL	Fail
otherwise	A handle for this GMA.

4.11.5 acp_cas4

acp_handle_t acp_cas4 (acp_ga_t *dst*, acp_ga_t *src*, uint32_t *oldval*, uint32_t *newval*, acp_handle_t *order*)

4byte Compare and Swap

Performs an atomic compare-and-swap operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst***. The rank of the ***dst*** must be the rank of the caller process. The values to be compared and swapped is 4byte. Global addresses must be 4byte aligned.

Parameters:

dst	Global address to store the result.
src	Global address to apply the operation.
oldval	Old value to be compared.
newval	New value to be swapped.
order	The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL	Fail
otherwise	A handle for this GMA.

4.11.6 acp_cas8

acp_handle_t acp_cas8 (acp_ga_t *dst*, acp_ga_t *src*, uint64_t *oldval*, uint64_t *newval*, acp_handle_t *order*)

8byte Compare and Swap

Performs an atomic compare-and-swap operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst.*** The rank of the ***dst*** must be the rank of the caller process. The values to be compared and swapped is 8byte. Global addresses must be 8byte aligned.

Parameters:

dst	Global address to store the result.
src	Global address to apply the operation.
oldval	Old value to be compared.
newval	New value to be swapped.
order	The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL	Fail
otherwise	A handle for this GMA.

4.11.7 acp_and4

acp_handle_t acp_and4 (acp_ga_t *dst*, acp_ga_t *src*, uint32_t value, acp_handle_t *order*)

4byte AND

Performs an atomic AND operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst.*** The rank of the ***dst*** must be the rank of the caller process. The values to be applied is 4byte. Global addresses must be 4byte aligned.

Parameters:

dst	Global address to store the result.
src	Global address to apply the operation.
value	Value to be applied the AND operation.
order	The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL	Fail
otherwise	A handle for this GMA.

4.11.8 acp_and8

acp_handle_t acp_and8 (acp_ga_t *dst*, acp_ga_t *src*, uint64_t *value*, acp_handle_t *order*)

8byte AND

Performs an atomic AND operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst***. The rank of the ***dst*** must be the rank of the caller process. The values to be applied is 8byte. Global addresses must be 8byte aligned.

Parameters:

dst	Global address to store the result.
src	Global address to apply the operation.
value	Value to be applied the AND operation.
order	The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL	Fail
otherwise	A handle for this GMA.

4.11.9 acp_or4

acp_handle_t acp_or4 (acp_ga_t *dst*, acp_ga_t *src*, uint32_t *value*, acp_handle_t *order*)

4byte OR

Performs an atomic OR operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst***. The rank of the ***dst*** must be the rank of the caller process. The values to be applied is 4byte. Global addresses must be 4byte aligned.

Parameters:

dst	Global address to store the result.
src	Global address to apply the operation.
value	Value to be applied the OR operation.
order	The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL	Fail
otherwise	A handle for this GMA.

4.11.10acp_or8

acp_handle_t acp_or8 (acp_ga_t *dst*, acp_ga_t *src*, uint64_t *value*, acp_handle_t *order*)

8byte OR

Performs an atomic OR operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst***. The rank of the ***dst*** must be the rank of the caller process. The values to be applied is 8byte. Global addresses must be 8byte aligned.

Parameters:

dst Global address to store the result.

src Global address to apply the operation.

value Value to be applied the OR operation.

order The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL Fail

otherwise A handle for this GMA.

4.11.11acp_xor4

acp_handle_t acp_xor4 (acp_ga_t *dst*, acp_ga_t *src*, uint32_t *value*, acp_handle_t *order*)

4byte Exclusive OR

Performs an atomic XOR operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst.*** The rank of the ***dst*** must be the rank of the caller process. The values to be applied is 4byte. Global addresses must be 4byte aligned.

Parameters:

dst	Global address to store the result.
src	Global address to apply the operation.
value	Value to be applied the XOR operation.
order	The handle to be used as a condition for starting this GMA

Return values:

ACP_HANDLE_NULL	Fail
otherwise	A handle for this GMA.

4.11.12acp_xor8

acp_handle_t acp_xor8 (acp_ga_t *dst*, acp_ga_t *src*, uint64_t *value*, acp_handle_t *order*)

Performs an atomic XOR operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst.*** The rank of the ***dst*** must be the rank of the caller process. The values to be applied is 8byte. Global addresses must be 8byte aligned.

Parameters:

dst	Global address to store the result.
src	Global address to apply the operation.
value	Value to be applied the XOR operation.
order	The handle to be used as a condition for starting this GMA

Return values:

ACP_HANDLE_NULL	Fail
otherwise	A handle for this GMA.

4.11.13acp_swap4

acp_handle_t acp_swap4 (acp_ga_t *dst*, acp_ga_t *src*, uint32_t *value*, acp_handle_t *order*)

4byte Swap

Performs an atomic swap operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst***. The rank of the ***dst*** must be the rank of the caller process. The values to be swapped is 4byte. Global addresses must be 4byte aligned.

Parameters:

dst Global address to store the result.

src Global address to apply the operation

value Value to be swapped.

order The handle to be used as a condition for starting this GMA

Return values:

ACP_HANDLE_NULL Fail

otherwise A handle for this GMA.

4.11.14acp_swap8

acp_handle_t acp_swap8 (acp_ga_t *dst*, acp_ga_t *src*, uint64_t *value*, acp_handle_t *order*)

8byte Swap

Performs an atomic swap operation on the global address specified as ***src***. The result of the operation is stored in the global address specified as ***dst***. The rank of the ***dst*** must be the rank of the caller process. The values to be swapped is 8byte. Global addresses must be 8byte aligned.

Parameters:

dst Global address to store the result.

src Global address to apply the operation.

value Value to be swapped.

order The handle to be used as a condition for starting this GMA.

Return values:

ACP_HANDLE_NULL Fail

otherwise A handle for this GMA.

4.11.15acp_complete

void acp_complete (acp_handle_t *handle*)

Completion of GMA.

Complete GMAs in order. It waits until the GMA of the specified ***handle*** completes. This means all the GMAs invoked before that one are also completed. If ACP_HANDLE_ALL is specified, it completes all of the out-standing GMAs. If the specified ***handle*** is ACP_HANDLE_NULL, the ***handle*** of the GMA that has already been completed, or the ***handle*** of the GMA that has not been invoked, this function returns immediately.

Parameters:

handle Handle of a GMA to be waited for the completion.

4.11.16acp_inquire

`int acp_inquire (acp_handle_t handle)`

Query for the completion of GMA.
Queries if any of the GMAs that are invoked earlier than the GMA of the specified ***`handle`***, including that GMA, are incomplete. It returns zero if all of those GMAs have been completed. Otherwise, it returns one. If ACP_HANDLE_ALL is specified, it checks of the out-standing GMAs. If the specified ***`handle`*** is ACP_HANDLE_NULL, the ***`handle`*** of the GMA that has already been completed, or the ***`handle`*** of the GMA that has not been invoked, it returns zero.

Parameters:

`handle` Handle of the GMA to be checked for the completion.

Return values:

`0` No incomlete GMAs.

`1` There is at least one incomplete GMA.

Appendix A Running ACP with Multiple MPI programs

A.1 Overview

Current ACP library supports mechanisms for connecting Multiple MPI applications (Multi-MPI ACP). This is similar to MPI-Spawn except spawning dynamical processes.

A.2 Installation

A.2.1 MPI Library

Install MPI library. Check PATH and LD_LIBRARY_PATH shell environment variables. Currently, OpenMPI 1.6.3 and OpenMPI 1.10.2 are tested.

A.2.2 ACP

Sources of Multi-MPI ACP is included inside of the ACP library. To install this library, add "`--with-mpi`" option to the configure command ACP.

```
shell$ ./configure --with-mpi --prefix=/where/to/install
[...lots of output...]
shell$ make all install
```

Original ACP libraries are also installed by this procedure. If your machine supports Infiniband (IB), this configure command detects and sets up as default IB library.

A.3 Compiling Programs

ACP provides "wrapper" compilers that should be used for compiling Multi-MPI ACP applications:

- Sources that use both MPI and ACP functions
  - C: `macpcc`, `macpgcc`
  - C++: `macpc++`, `macpcxx`
  - Fortran: `macpfc` (not provided yet)

- Sources used pure ACP functions
  - C: `acpcc`, `acpgcc`
  - C++: `acpc++`, `acpcxx`
  - Fortran: `acpfc` (not provided yet)

Example:

```
shell$ macpcc hello_world_macp.c -o hello_world_macp -g
shell$ acpcc  hello_world_acp.c  -o hello_world_acp -g
shell$
```

If your machine supports IB and you want to choose UDP environment, compile with "-ndev UDP" option.

A.4 Running Programs

Multi-MPI ACP library supports macprun program to launch Multi-MPI ACP appliations.

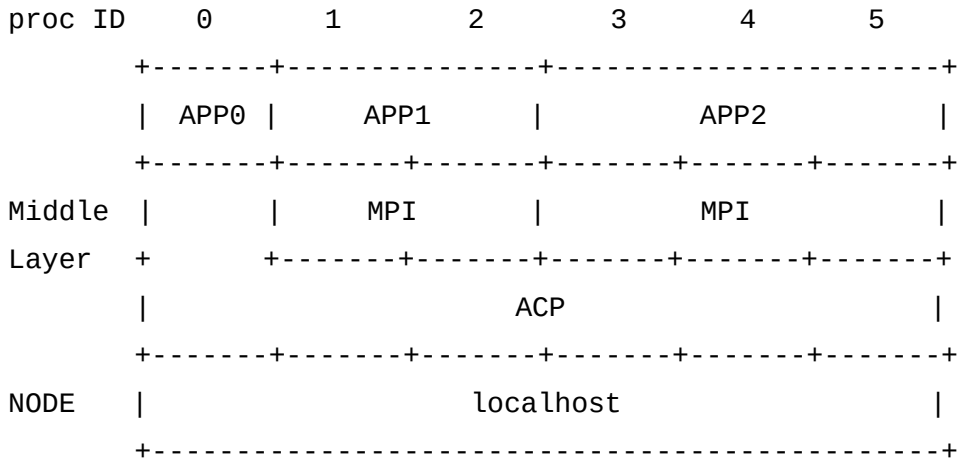
Example:

```
shell$ macprun -np 6 inputfile
```

with the following inputfile:

```
-----------------------------------------------------------------
# Number of runtime environments
3
# Runtime environments
acprun -smemsize 10240              # options can be specified
mpirun                              # options can be specified
mpirun                              # options can be specified
# Number of processes
1
2
3
# Commands
./hello_world_acp                   # options can be specified
./hello_world_macp                  # options can be specified
./hello_world_macp                  # options can be specified
-----------------------------------------------------------------
```

This launches one hello_world_acp application (APP0) consists with one process by acprun, and two hello_world_macp applications (APP1 and APP2) with two and three processes on localhost by mpirun. These three applications with six processes are connected by ACP library as shown in the following figure:



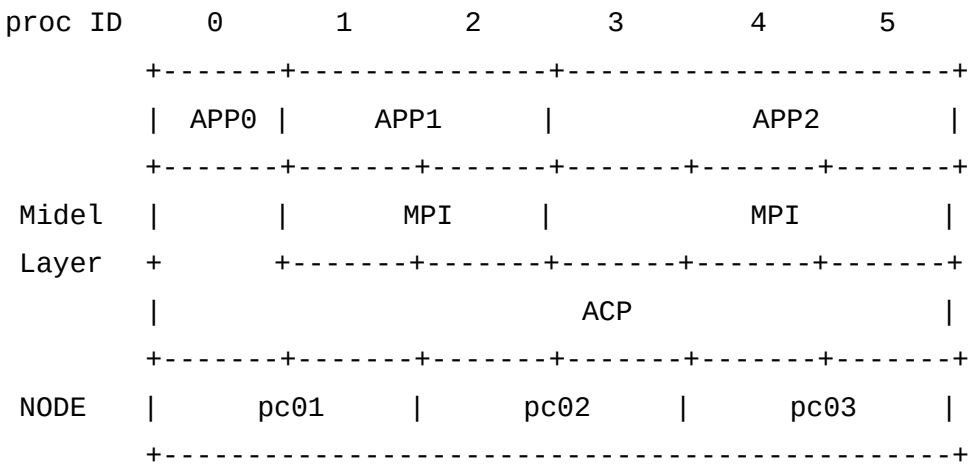
You can specify a "-nodefile nodefile" option to indicate hostnames on which hello_world_acp and hello_world_macp commands will be launched. If you want launch above processes on pc01 pc02 and pc03, use following command:

```
shell$ macprun -np 6 -nodefile nodefile inputfile
```

with the following nodefile:

```
---------------------------------------------------------------------
pc01
pc01
pc02
pc02
pc03
pc03
---------------------------------------------------------------------
```

This launches the programs as shown in the following figure:



To specify network device, for example infiniband (or udp), use "-net ib" (or udp) option as follows:

```
shell$ macprun -np 6 -nodefile nodefile -net ib inputfile
```