Global
Address Space
Programming Interface
GASPI

GASPI Tutorial

Christian Simmendinger
Mirko Rahn
Daniel Grünewald

Global
Address Space
Programming Interface
GASPI

Goals

- Get an overview over GASPI
- Learn how to
  - Compile a GASPI program
  - Execute a GASPI program
- Get used to the GASPI programming model
  - one-sided communication
  - weak synchronization
  - asynchronous patterns / dataflow implementations

Global
Address Space
Programming Interface
GASPI

Outline

- Introduction to GASPI
- GASPI API
  - Execution model
  - Memory segments
  - One-sided communication
  - Collectives
  - Passive communication

Global
Address Space
Programming Interface
GASPI

Outline

- GASPI programming model
  - Dataflow model
  - Fault tolerance

www.gaspi.de www.gpi-site.com

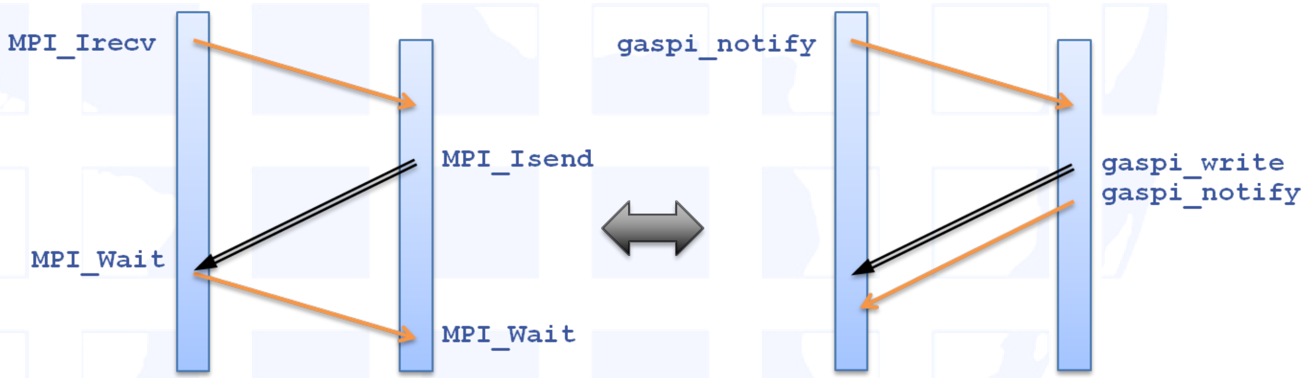
Introduction to GASPI

Global
Address Space
Programming Interface
GASPI

Motivation

- A PGAS API for SPMD execution
- Take your existing MPI code
- Rethink your communication patterns !
- Reformulate towards an asynchronous data flow model !

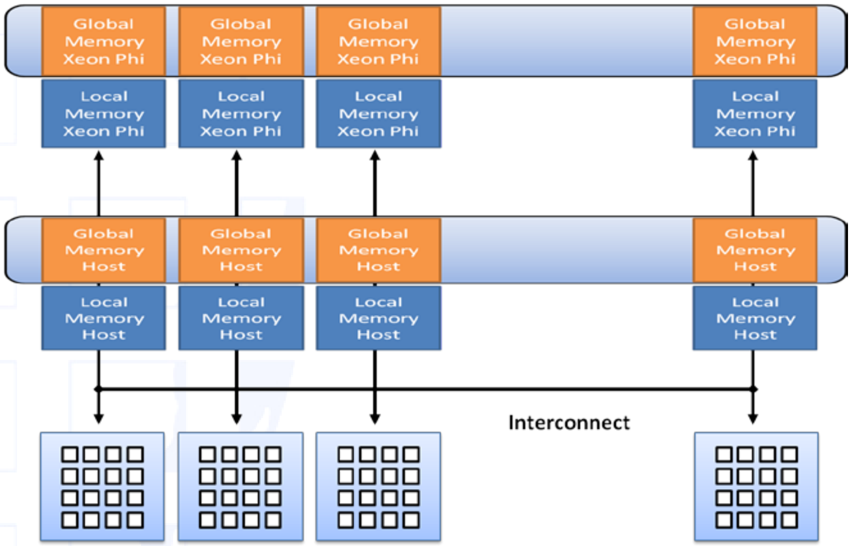
Bulk-synchronous Execution ⟺ Asynchronous Execution



Global
Address Space
Programming Interface
GASPI

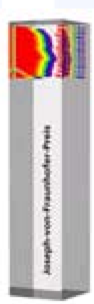
Key Objectives of GASPI

- **Scalability**
  - From bulk–synchronous two sided communication patterns to asynchronous one-sided communication
  - remote completion
- **Flexibility and Versatility**
  - Multiple Segments,
  - Configurable hardware ressources
  - Support for multiple memory models
- **Failure Tolerance**
  - Timeouts in non-local operations
  - dynamic node sets.



GASPI history

- **GPI**
  - originally called Fraunhofer Virtual Machine (**FVM**)
  - developed since 2005
  - used in many of the industry projects at CC-HPC of Fraunhofer ITWM

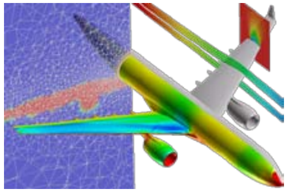


GPI: Winner of the „Joseph von Fraunhofer Preis 2013“

www.gpi-site.com

Global
Address Space
Programming Interface
GASPI

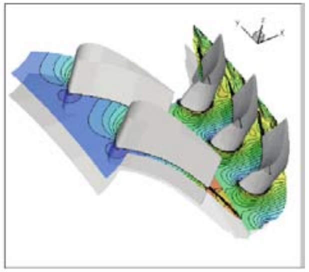
Scalability



Performance

- One-sided read and writes
- **remote completion in PGAS** with notifications.
- Asynchronous execution model
  - **RDMA queues** for one-sided read and write operations, including support for arbitrarily distributed data.
- Threadsafety
  - Multithreaded communication is the default rather than the exception.
- Write, Notify, Write_Notifiy
  - **relaxed synchronization** with double buffering
  - traditional (asynchronous) handshake mechanisms remain possible.
- No Buffered Communication - Zero Copy.

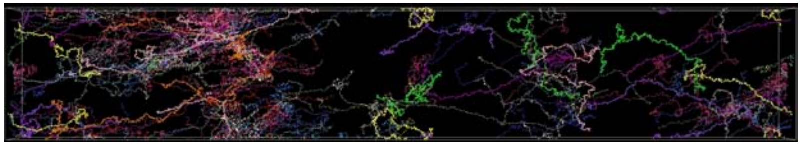
Global
Address Space
Programming Interface
GASPI



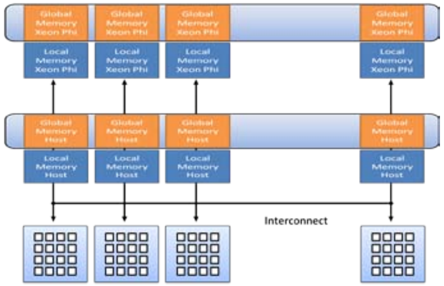
Scalability

Performance

- No polling for outstanding receives/acknowledges for send
  - **no communication overhead**, true asynchronous RDMA read/write.
- Fast synchronous collectives with time-based blocking and timeouts
  - Support for asynchronous collectives in core API.
- Passive Receives two sided semantics, no Busy-Waiting
  - Allows for distributed updates, non-time critical asynchronous collectives. Passive Active Messages, so to speak ☺.
- Global Atomics for all data in segments
  - FetchAdd
  - cmpSwap.
- Extensive profiling support.



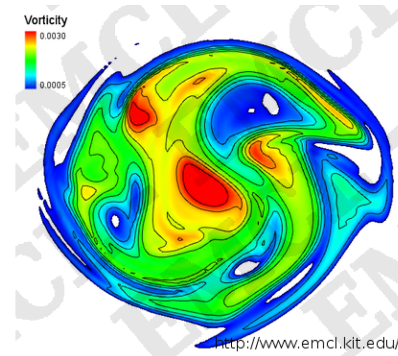
Flexibility and Versatility



- Segments
  - Support for **heterogeneous Memory Architectures** (NVRAM, GPGPU, Xeon Phi, Flash devices).
  - Tight coupling of Multi-Physics Solvers
  - Runtime evaluation of applications (e.g Ensembles)
- Multiple memory models
  - Symmetric Data Parallel (OpenShmem)
  - Symmetric Stack Based Memory Management
  - Master/Slave
  - Irregular.

Global
Address Space
Programming Interface
GASPI

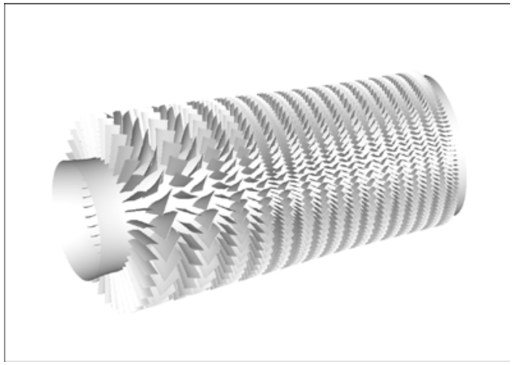
Flexibility



Interoperability and Compatibility

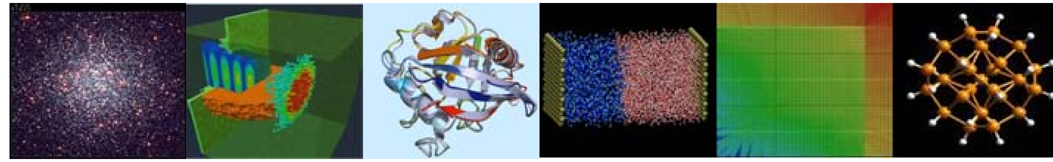
- Compatibility with most Programming Languages.
- Interoperability with MPI.
- Compatibility with the Memory Model of OpenShmem.
- Support for all Threading Models (OpenMP/Pthreads/..)
  - similar to MPI, GASPI is orthogonal to Threads.
- GASPI is a nice match for **tile architecture** with **DMA** engines.

Flexibility



Flexibility

- Allows for **shrinking and growing** node set.
- User defined global reductions with **time based blocking**.
- Offset lists for RDMA read/write (write_list, write_list_notify)
- **Groups** (Communicators)
- Advanced Ressource Handling, configurable setup at startup.
- Explicit connection management.



Failure Tolerance

Failure Tolerance.

- Timeouts in all non-local operations
- Timeouts for Read, Write, Wait, Segment Creation, Passive Communication.
- Dynamic growth and shrinking of node set.
- Fast Checkpoint/Restarts to NVRAM.
- State vectors for GASPI processes.

Global
Address Space
Programming Interface
GASPI

The GASPI API

- 52 communication functions
- 24 getter/setter functions
- 108 pages

… but in reality:

  - Init/Term
  - Segments
  - Read/Write
  - Passive Communication
  - Global Atomic Operations
  - Groups and collectives

```
GASPI_WRITE_NOTIFY ( segment_id_local
                   , offset_local
                   , rank
                   , segment_id_remote
                   , offset_remote
                   , size
                   , notification_id
                   , notification_value
                   , queue
                   , timeout )
```

Parameter:

(in) segment_id_local: the local segment ID to read from

(in) offset_local: the local offset in bytes to read from

(in) rank: the remote rank to write to

(in) segment_id_remote: the remote segment to write to

(in) offset_remote: the remote offset to write to

(in) size: the size of the data to write

(in) notification_id: the remote notification ID

(in) notification_value: the value of the notification to write

(in) queue: the queue to use

(in) timeout: the timeout

www.gaspi.de

Global
Address Space
Programming Interface
GASPI

Execution Model

Global
Address Space
Programming Interface
GASPI

GASPI Exection Model

- SPMD / MPMD execution model
- All procedures have prefix gaspi_

```
gaspi_return_t
gaspi_proc_init ( gaspi_timeout_t const timeout )
```

- All procedures have a return value
- Timeout mechanism for potentially blocking procedures

Global
Address Space
Programming Interface
GASPI

GASPI Return Values

- Procedure return values:
  - GASPI_SUCCESS
    - designated operation successfully completed
  - GASPI_TIMEOUT
    - designated operation could not be finished in the given period of time
    - not necessarily an error
    - the procedure has to be invoked subsequently in order to fully complete the designated operation
  - GASPI_ERROR
    - designated operation failed -> check error vector
- Advice: Always check return value !

success_or_die.h

```
#ifndef SUCCESS_OR_DIE_H
#define SUCCESS_OR_DIE_H

#include <GASPI.h>
#include <stdlib.h>

#define SUCCESS_OR_DIE(f...)         \
do                                   \
{                                    \
  const gaspi_return_t r = f;        \
                                     \
  if (r != GASPI_SUCCESS)            \
  {                                  \
    gaspi_printf ("Error: '%s' [%s:%i]: %i\n", #f, __FILE__, __LINE__, r);\
                                     \
      exit (EXIT_FAILURE);           \
   }                                 \
} while (0)

#endif
```

Global
Address Space
Programming Interface
GASPI

Timeout Mechanism

- Mechanism for potentially blocking procedures
  - procedure is guaranteed to return
- Timeout: gaspi_timeout_t
  - GASPI_TEST (0)
    - procedure completes local operations
    - Procedure does not wait for data from other processes
  - GASPI_BLOCK (-1)
    - wait indefinitely (blocking)
  - Value > 0
    - Maximum time in msec the procedure is going to wait for data from other ranks to make progress
    - != hard execution time

GASPI Process Management

- Initialize / Finalize
  - gaspi_proc_init
  - gaspi_proc_term
- Process identification
  - gaspi_proc_rank
  - gaspi_proc_num
- Process configuration
  - gaspi_config_get
  - gaspi_config_set

Global
Address Space
Programming Interface
GASPI

GASPI Initialization

- gaspi_proc_init

```
gaspi_return_t
gaspi_proc_init ( gaspi_timeout_t const timeout )
```

  - initialization of resources
    - set up of communication infrastructure if requested
    - set up of default group GASPI_GROUP_ALL
    - rank assignment
      - position in machinefile ⇔ rank ID
  - no default segment creation

Global
Address Space
Programming Interface
GASPI

GASPI Finalization

- gaspi_proc_term

```
gaspi_return_t
gaspi_proc_term ( gaspi_timeout_t timeout )
```

  - clean up
    - wait for outstanding communication to be finished
    - release resources
  - no collective operation !

Global
Address Space
Programming Interface
GASPI

GASPI Process Identification

- gaspi_proc_rank

```
gaspi_return_t
gaspi_proc_rank ( gaspi_rank_t *rank )
```

- gaspi_proc_num

```
gaspi_return_t
gaspi_proc_num ( gaspi_rank_t *proc_num )
```

Global
Address Space
Programming Interface
GASPI

GASPI Process Configuration

- gaspi_config_get

```
gaspi_return_t
gaspi_config_get ( gaspi_config_t *config )
```

- gaspi_config_set

```
gaspi_return_t
gaspi_config_set ( gaspi_config_t const config )
```

- Retrieveing and setting the configuration structure has to be done before gaspi_proc_init

Global
Address Space
Programming Interface
GASPI

GASPI Process Configuration

- Configuring
  - resources
    - sizes
    - max
  - network

```
typedef struct {
  // maximum number of groups
  gaspi_number_t      group_max;

  // maximum number of segments
  gaspi_number_t      segment_max

  // one-sided comm parameter
  gaspi_number_t      queue_num;
  gaspi_number_t      queue_size_max;
  gaspi_size_t        transfer_size_max;

  // notification parameter
  gaspi_number_t      notification_num;

  // passive comm parameter
  gaspi_number_t      passive_queue_size_max;
  gaspi_size_t        passive_transfer_size_max;

  // collective comm parameter
  gaspi_size_t        allreduce_buf_size;
  gaspi_number_t      allreduce_elem_max;

  // network selection parameter
  gaspi_network_t     network;

  // communication infrastructure build up notification
  gaspi_number_t        build_infrastructure;

  void *              user_defined;
} gaspi_config_t;
```

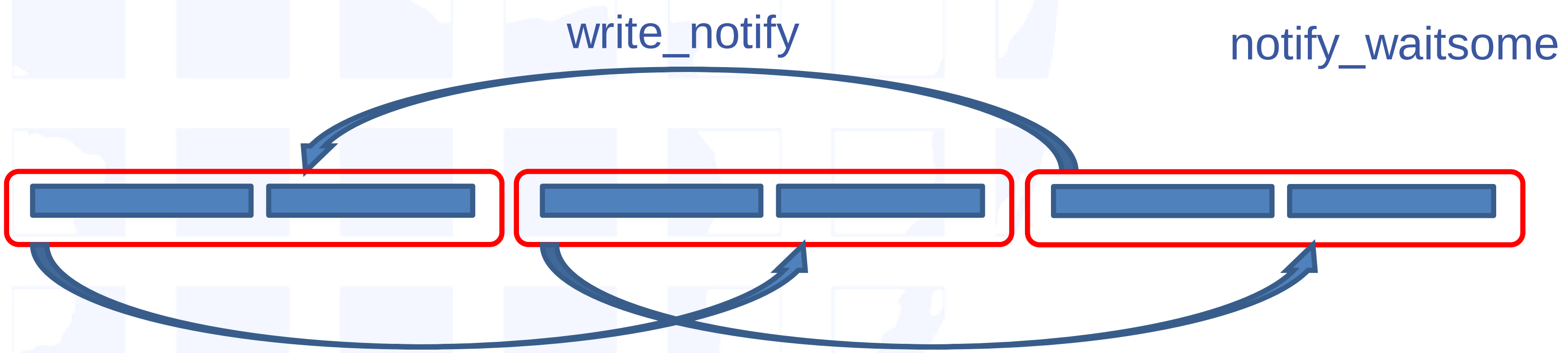
GASPI „hello world“

```
#include "success_or_die.h“
#include <GASPI.h>
#include <stdlib.h>

int main(int argc, char *argv[])
{
  SUCCESS_OR_DIE( gaspi_proc_init(GASPI_BLOCK) );

  gaspi_rank_t rank;
  gaspi_rank_t num;
  SUCCESS_OR_DIE( gaspi_proc_rank(&rank) );
  SUCCESS_OR_DIE( gaspi_proc_num(&num) );

  gaspi_printf("Hello world from rank %d of %d\n",rank, num);

  SUCCESS_OR_DIE( gaspi_proc_term(GASPI_BLOCK) );
  return EXIT_SUCCESS;
}
```

Global
Address Space
Programming Interface
GASPI

Communication example

- init local buffer
- write to remote buffer
- wait for data availability
- print



Global
Address Space
Programming Interface
GASPI

onesided.c (I)

```
// includes

int main(int argc, char *argv[])
{
  static const int VLEN = 1 << 2;
  SUCCESS_OR_DIE( gaspi_proc_init(GASPI_BLOCK) );
  gaspi_rank_t iProc, nProc;
  SUCCESS_OR_DIE( gaspi_proc_rank(&iProc));
  SUCCESS_OR_DIE( gaspi_proc_num(&nProc));
  gaspi_segment_id_t const segment_id = 0;
  gaspi_size_t       const segment_size = 2 * VLEN * sizeof (double);

  SUCCESS_OR_DIE ( gaspi_segment_create ( segment_id, segment_size
                                         , GASPI_GROUP_ALL, GASPI_BLOCK
                                         , GASPI_MEM_UNINITIALIZED ) );
  gaspi_pointer_t array;
  SUCCESS_OR_DIE ( gaspi_segment_ptr (segment_id, &array) );
  double * src_array = (double *)(array);
  double * rcv_array = src_array + VLEN;

  for (int j = 0; j < VLEN; ++j) {
    src_array[j]= (double)( iProc * VLEN + j ); }
```

Global
Address Space
Programming Interface
GASPI

onesided.c (II)

```
  gaspi_notification_id_t data_available = 0;
  gaspi_queue_id_t queue_id = 0;
  gaspi_offset_t loc_off = 0;
  gaspi_offset_t rem_off = VLEN * sizeof (double);

  wait_for_queue_entries_for_write_notify ( &queue_id );
  SUCCESS_OR_DIE ( gaspi_write_notify ( segment_id, loc_off
                                      , RIGHT (iProc, nProc)
                                      , segment_id, rem_off
                                      , VLEN * sizeof (double)
                                      , data_available, 1 + iProc, queue_id
                                      , GASPI_BLOCK )  );
  wait_or_die (segment_id, data_available, 1 + LEFT (iProc, nProc) );

  for (int j = 0; j < VLEN; ++j)
  { gaspi_printf("rank %d rcv elem %d: %f \n", iProc,j,rcv_array[j] );    }

  wait_for_flush_queues();
  SUCCESS_OR_DIE( gaspi_proc_term(GASPI_BLOCK) );
  return EXIT_SUCCESS;
}
```

Global
Address Space
Programming Interface
GASPI

Memory Segments

Segments

- software abstraction of hardware memory hierarchy
  - NUMA
  - GPU
  - Xeon Phi
- one partition of the PGAS
- contiguous block of virtual memory
  - no pre-defined memory model
  - memory management up to the application
- locally / remotely accessible
  - local access by ordinary memory operations
  - remote access by GASPI communication routines

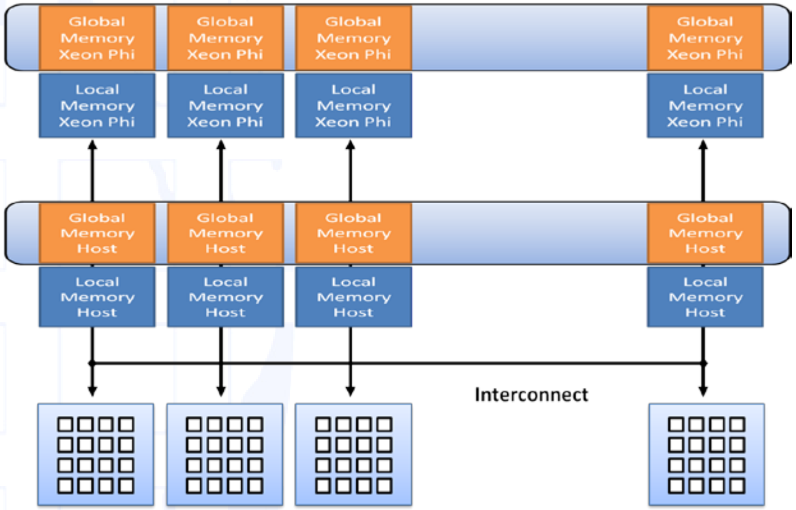
Global
Address Space
Programming Interface
GASPI

GASPI Segments

- GASPI provides only a few relatively large segments
  - segment allocation is expensive
  - the total number of supported segments is limited by hardware constraints
- GASPI segments have an allocation policy
  - GASPI_MEM_UNINITIALIZED
    - memory is not initialized
  - GASPI_MEM_INITIALIZED
    - memory is initialized (zeroed)

Segment Functions

- Segment creation
  - gaspi_segment_alloc
  - gaspi_segment_register
  - gaspi_segment_create
- Segment deletion
  - gaspi_segment_delete
- Segment utilities
  - gaspi_segment_num
  - gaspi_segment_ptr



Global
Address Space
Programming Interface
GASPI

GASPI Segment Allocation

- gaspi_segment_alloc

```
gaspi_return_t
gaspi_segment_alloc ( gaspi_segment_id_t segment_id
                    , gaspi_size_t size
                    , gaspi_alloc_t alloc_policy )
```

  - allocate and pin for RDMA
  - Locally accessible

- gaspi_segment register

```
gaspi_return_t
gaspi_segment_register ( gaspi_segment_id_t segment_id
                       , gaspi_rank_t rank
                       , gaspi_timeout_t timeout )
```

  - segment accessible by rank

Global
Address Space
Programming Interface
GASPI

GASPI Segment Creation

- gaspi_segment_create

```
gaspi_return_t
gaspi_segment_create ( gaspi_segment_id_t segment_id
                     , gaspi_size_t size
                     , gaspi_group_t group
                     , gaspi_timeout_t timeout
                     , gaspi_alloc_t alloc_policy )
```

  - Collective short cut to
    - gaspi_segment_alloc
    - gaspi_segment_register
  - After successful completion, the segment is locally and remotely accessible by all ranks in the group

Global
Address Space
Programming Interface
GASPI

GASPI Segment Deletion

- gaspi_segment_delete

```
gaspi_return_t
gaspi_segment_delete ( gaspi_segment_id_t segment_id )
```

  - free segment memory

GASPI Segment Utils

- gaspi_segment_num

```
gaspi_return_t
gaspi_segment_num ( gaspi_number_t *segment_num )
```

- gaspi_segment_list

```
gaspi_return_t
gaspi_segment_list ( gaspi_number_t num
                   , gaspi_segment_id_t *segment_id_list )
```

- gaspi_segment_ptr

```
gaspi_return_t
gaspi_segment_ptr ( gaspi_segment_id_t segment_id
                  , gaspi_pointer_t *pointer )
```

Global
Address Space
Programming Interface
GASPI

One-sided Communication

Global
Address Space
Programming Interface
GASPI

GASPI One-sided Communication

- gaspi_write

```
gaspi_return_t
gaspi_write ( gaspi_segment_id_t segment_id_local
            , gaspi_offset_t offset_local
            , gaspi_rank_t rank
            , gaspi_segment_id_t segment_id_remote
            , gaspi_offset_t offset_remote
            , gaspi_size_t size
            , gaspi_queue_id_t queue
            , gaspi_timeout_t timeout )
```

  - Post a put request into a given queue for transfering data from a local segment into a remote segment

Global
Address Space
Programming Interface
GASPI

GASPI One-sided Communication

- gaspi_read

```
gaspi_return_t
gaspi_read ( gaspi_segment_id_t segment_id_local
           , gaspi_offset_t offset_local
           , gaspi_rank_t rank
           , gaspi_segment_id_t segment_id_remote
           , gaspi_offset_t offset_remote
           , gaspi_size_t size
           , gaspi_queue_id_t queue
           , gaspi_timeout_t timeout )
```

  – Post a get request into a given queue for transfering data from a remote segment into a local segment

GASPI One-sided Communication

- gaspi_wait

```
gaspi_return_t
gaspi_wait ( gaspi_queue_id_t queue
           , gaspi_timeout_t timeout )
```

  - wait on local completion of all requests in a given queue
  - After successfull completion, all involved local buffers are valid

Queues (I)

- Different queues available to handle the communication requests
- Requests to be submitted to one of the supported queues
- Advantages
  - more scalability
  - channels for different types of requests
  - similar types of requests are queued and synchronized together but independently from other ones
  - separation of concerns

Global
Address Space
Programming Interface
GASPI

Queues (II)

- Fairness of transfers posted to different queues is guaranteed
  - No queue should see ist communication requests delayed indefinitely
- A queue is identified by its ID
- Synchronization of calls by the queue
- Queue order does not imply message order on the network / remote memory
- A subsequent notify call is guaranteed to be non-overtaking for all previous posts to the same queue and rank

Weak Synchronization

- One sided-communication:
  - Entire communication managed by the local process only
  - Remote process is not involved
  - Advantage: no inherent synchronization between the local and the remote process in every communication request
- Still: At some point the remote process needs knowledge about data availability
  - Managed by weak synchronization primitives

Global
Address Space
Programming Interface
GASPI

Weak Synchronization

- Several notifications for a given segment
  - Identified by notification ID
  - Logical association of memory location and notification

Global
Address Space
Programming Interface
GASPI

GASPI Weak Synchronization

- gaspi_notify

```
gaspi_return_t
gaspi_notify ( gaspi_segment_id_t segment_id
             , gaspi_rank_t rank
             , gaspi_notification_id_t notification_id
             , gaspi_notification_t notification_value
             , gaspi_queue_id_t queue
             , gaspi_timeout_t timeout )
```

  – posts a notification with a given value to a given queue
  – remote visibility guarantees remote data visibility of all previously posted writes in the same queue, the same segment and the same process rank

Global
Address Space
Programming Interface
GASPI

GASPI Weak Synchronization

- gaspi_notify_waitsome

```
gaspi_return_t
gaspi_notify_waitsome ( gaspi_segment_id_t segment_id
                      , gaspi_notification_id_t notific_begin
                      , gaspi_number_t notification_num
                      , gaspi_notification_id_t *first_id
                      , gaspi_timeout_t timeout )
```

  - monitors a contiguous subset of notification id‘s for a given segment
  - returns successfull if at least one of the monitored id‘s is remotely updated to a value unequal zero

Global
Address Space
Programming Interface
GASPI

GASPI Weak Synchronization

- gaspi_notify_reset

```
gaspi_return_t
gaspi_notify_reset ( gaspi_segment_id_t segment_id
                   , gaspi_notification_id_t notification_id
                   , gaspi_notification_t *old_notification_val)
```

  - Atomically resets a given notification id and yields the old value

Global
Address Space
Programming Interface
GASPI

Extended One-sided Calls

- gaspi_write_notify
  - gaspi_write + subsequent gaspi_notify
- gaspi_write_list
  - several subsequent gaspi_writes to the same rank
- gaspi_write_list_notify
  - gaspi_write_list + subsequent gaspi_notify
- gaspi_read_list
  - several subsequent gaspi_reads

Dataflow model

Hands On Session

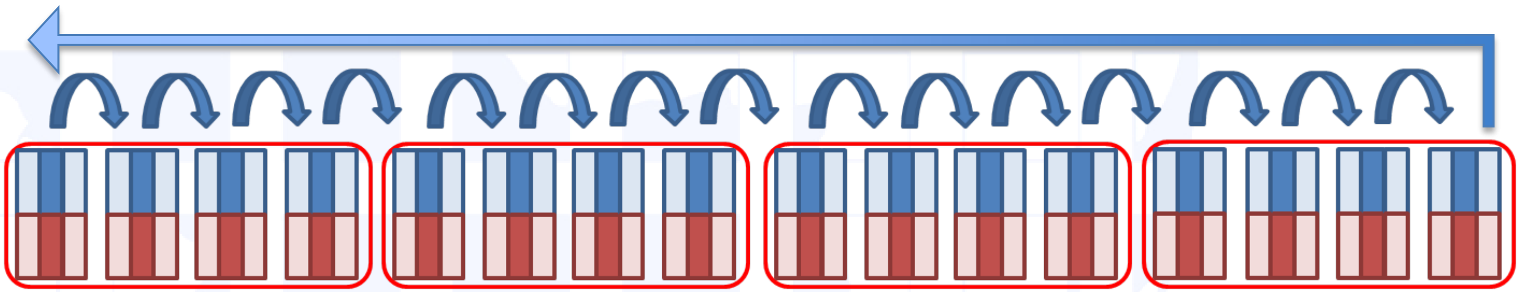
The MPI/GASPI Ring Exchange

Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

MPI – MPI_Issend/MPI_Recv

- NITER iterations of Ring Exchange with „nProc“ cores
- Shift upper half of vector to the right



Example: 4 Sockets/16 cores – each core holds a vector of length 2*VLEN

Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

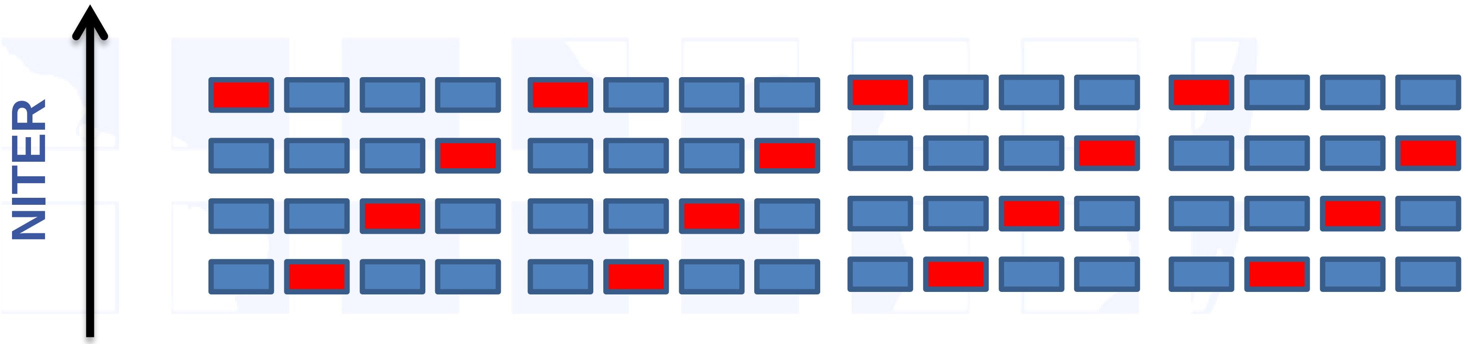
MPI – round_robin_double_buffer.c

```
for (int i = 0; i < nProc; ++i) {
     MPI_Request request;
     int left_halo   = 0;
     int slice_id    = 1;
     // issue send
     MPI_Isend ( &array_ELEM_right (buffer_id, slice_id, 0), VLEN,
       MPI_DOUBLE, right, i, MPI_COMM_WORLD, &request);
     // post recv
     MPI_Recv ( &array_ELEM_right (buffer_id, left_halo, 0), VLEN,
       MPI_DOUBLE, left, i, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
     // compute data, read from id "buffer_id", write to id "1 - buffer_id"
     data_compute (NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
     // wait for Issend
     MPI_Wait (&request, MPI_STATUS_IGNORE);
     // alternate the buffers
     buffer_id = 1 - buffer_id;
   }
```

The MPI Ring Exchange

MPI – MPI_Issend/MPI_Recv

- Synchronous Lockstep Execution



The MPI Ring Exchange

MPI – left_right_double_buffer.c

```
for (int i = 0; i < nProc; ++i) {
     MPI_Request send_req[2], recv_req[2];
     const int left_halo   = 0; slice_id    = 1; right_halo  = 2;
     MPI_Irecv ( &array_ELEM_right (buffer_id, left_halo, 0), VLEN,
       MPI_DOUBLE, left, i, MPI_COMM_WORLD, &send_req[0]);
     MPI_Irecv ( &array_ELEM_left (buffer_id, right_halo, 0), VLEN,
       MPI_DOUBLE, right, i, MPI_COMM_WORLD, &send_req[1]);
     MPI_Isend ( &array_ELEM_right (buffer_id, slice_id, 0), VLEN,
       MPI_DOUBLE, right, i, MPI_COMM_WORLD, &recv_req[0]);
     MPI_Isend ( &array_ELEM_left (buffer_id, slice_id, 0), VLEN,
       MPI_DOUBLE, left, i, MPI_COMM_WORLD, &recv_req[1]);
     MPI_Waitall (2, recv_req, MPI_STATUSES_IGNORE);
     data_compute (NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
     MPI_Waitall (2, send_req, MPI_STATUSES_IGNORE);
     buffer_id = 1 - buffer_id;
   }
```

The MPI Ring Exchange

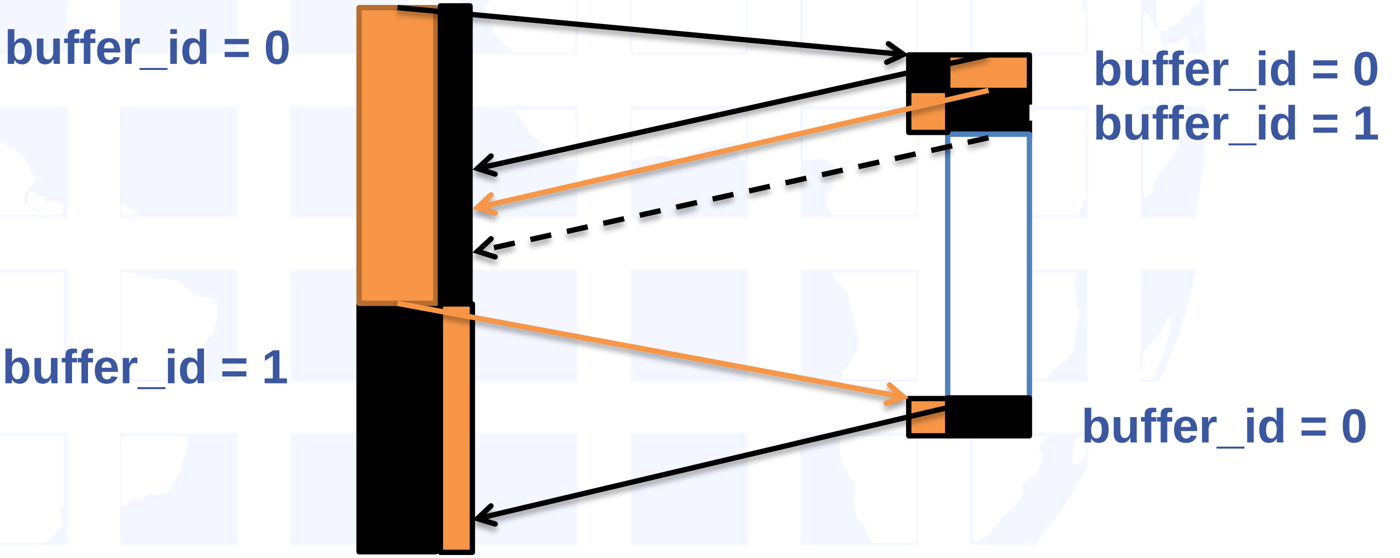
MPI – left_right_double_buffer_req_free.c

```
for (int i = 0; i < nProc; ++i) {
    MPI_Request send_req[2], recv_req[2];
    const int left_halo  = 0; slice_id   = 1; right_halo  = 2;
    MPI_Irecv ( &array_ELEM_right (buffer_id, left_halo, 0), VLEN,
      MPI_DOUBLE, left, i, MPI_COMM_WORLD, &send_req[0]);
    MPI_Irecv ( &array_ELEM_left (buffer_id, right_halo, 0), VLEN,
      MPI_DOUBLE, right, i, MPI_COMM_WORLD, &send_req[1]);
    MPI_Isend ( &array_ELEM_right (buffer_id, slice_id, 0), VLEN,
      MPI_DOUBLE, right, i, MPI_COMM_WORLD, &recv_req[0]);
    MPI_Isend ( &array_ELEM_left (buffer_id, slice_id, 0), VLEN,
      MPI_DOUBLE, left, i, MPI_COMM_WORLD, &recv_req[1]);
    MPI_Request_free(&send_req[0]);
    MPI_Request_free(&send_req[1]);
    MPI_Waitall (2, recv_req, MPI_STATUSES_IGNORE);
    data_compute (NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
    buffer_id = 1 - buffer_id;
  }
```

Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

- Bi-directional halo exchange – implicit synchronization

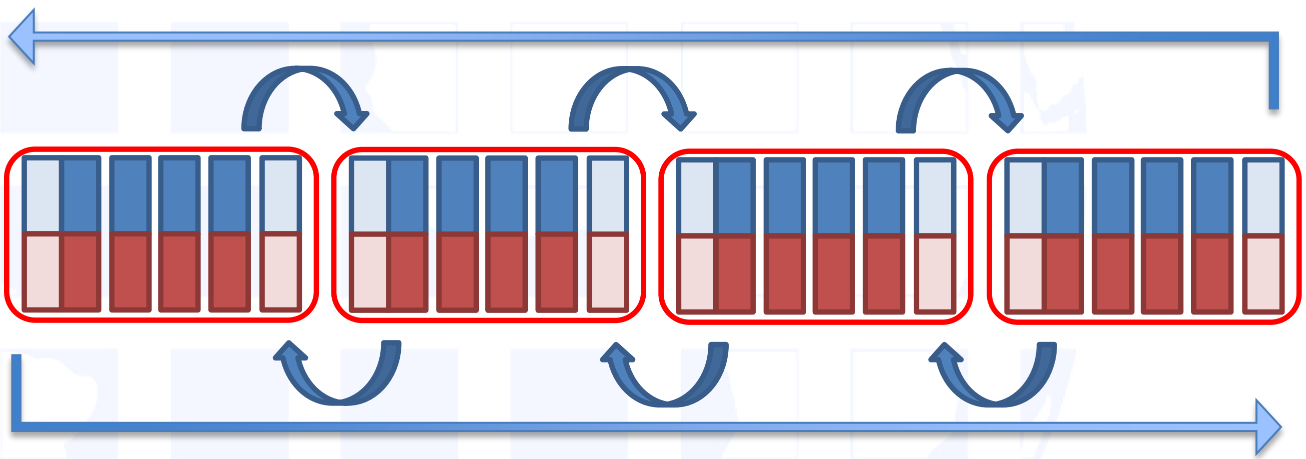


Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

MPI – **HYBRID MPI/OpenMP**

- Shift upper half of the vector to the right
- Shift lower half of the vector to the left



Example: 4 Sockets/16 cores – each core holds a vector of length 2*VLEN

The MPI Ring Exchange

- MPI – left_right_double_buffer_funneled.c

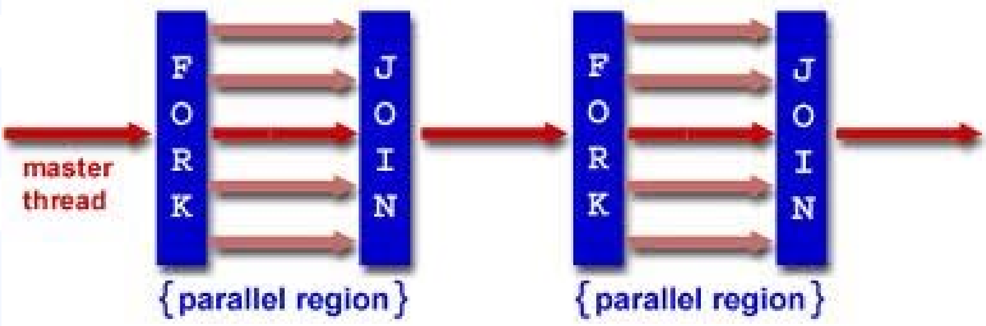
```
 for ( int i = 0; i < nProc * NTHREADS; ++i ) {
      const int left_halo = 0, slice_id = tid + 1, right_halo  = NTHREADS+1;
      if (tid == 0) {
        MPI_Request send_req[2], recv_req[2];
        MPI_Irecv ( &array_ELEM_right (buffer_id, left_halo, 0), VLEN,
            MPI_DOUBLE, left, i, MPI_COMM_WORLD, &recv_req[0]);
        MPI_Irecv ( &array_ELEM_left (buffer_id, right_halo, 0), VLEN,
            MPI_DOUBLE, right, i, MPI_COMM_WORLD, &recv_req[1]);
        MPI_Isend ( &array_ELEM_right (buffer_id, slice_id, 0), VLEN,
            MPI_DOUBLE, right, i, MPI_COMM_WORLD, &send_req[0]);
        MPI_Isend ( &array_ELEM_left (buffer_id, slice_id, 0), VLEN,
            MPI_DOUBLE, left, i, MPI_COMM_WORLD, &send_req[1]);
        MPI_Request_free(&send_req[0]);
        MPI_Request_free(&send_req[1]);
        MPI_Waitall (2, recv_req, MPI_STATUSES_IGNORE);
      }
#pragma omp barrier
      data_compute (NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
#pragma omp barrier
      buffer_id = 1 - buffer_id; }
```

Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

MPI – left_right_double_buffer_funneled.c

- Fork-join model



The MPI Ring Exchange

- MPI – left_right_double_buffer_multiple.c

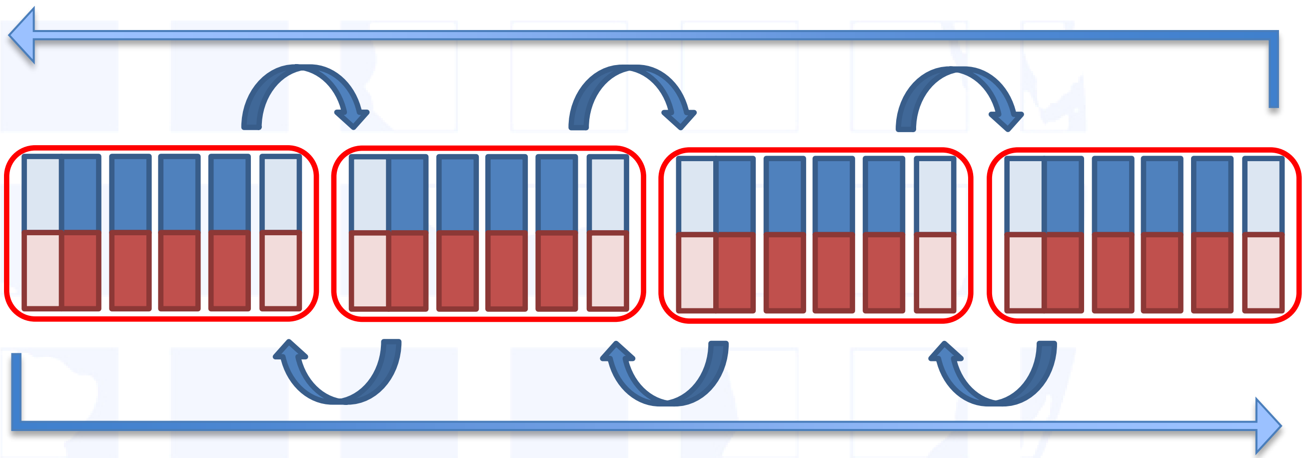
```
    if (tid == 0) {
      MPI_Request request;
      MPI_Isend ( &array_ELEM_left (buffer_id, slice_id, 0), VLEN,
        MPI_DOUBLE, left, i, MPI_COMM_WORLD, &request);
      MPI_Request_free(&request);
      MPI_Recv ( &array_ELEM_right (buffer_id, left_halo, 0), VLEN,
        MPI_DOUBLE, left, i, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
      data_compute (NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
} else if (tid < NTHREADS - 1){
      data_compute (NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
    } else {
      MPI_Request request;
      MPI_Isend ( &array_ELEM_right (buffer_id, slice_id, 0), VLEN,
        MPI_DOUBLE, right, i, MPI_COMM_WORLD, &request);
      MPI_Request_free(&request);
      MPI_Recv ( &array_ELEM_left (buffer_id, right_halo, 0), VLEN,
        MPI_DOUBLE, right, i, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
      data_compute (NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
    }
#pragma omp barrier
    buffer_id = 1 - buffer_id;
```

Global
Address Space
Programming Interface
GASPI

The GASPI Ring Exchange

GASPI – **HYBRID GASPI/OpenMP**

- Shift upper half of the vector to the right
- Shift lower half of the vector to the left



Example: 4 Sockets/16 cores – each core holds a vector of length 2*VLEN

Global
Address Space
Programming Interface
GASPI

The GASPI Ring Exchange

- GASPI – left_right_double_buffer_funneled.c

```
 if (tid == 0) {
  wait_for_queue_max_half (&queue_id);
  SUCCESS_OR_DIE ( gaspi_write_notify
    ( segment_id,array_OFFSET_left(buffer_id, slice_id, 0), left,
    segment_id,array_OFFSET_left(buffer_id,right_halo,0),VLEN* sizeof(double),
    right_data_available[buffer_id], 1 + i, queue_id, GASPI_BLOCK));
  wait_for_queue_max_half (&queue_id);
  SUCCESS_OR_DIE ( gaspi_write_notify
    ( segment_id, array_OFFSET_right (buffer_id, slice_id, 0), right,
    segment_id,array_OFFSET_right(buffer_id,left_halo,0),VLEN*sizeof (double),
    left_data_available[buffer_id], 1 + i, queue_id, GASPI_BLOCK));
  wait_or_die (segment_id, right_data_available[buffer_id], 1 + i);
  wait_or_die (segment_id, left_data_available[buffer_id], 1 + i);
 }
#pragma omp barrier
data_compute ( NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
#pragma omp barrier
buffer_id = 1 - buffer_id;
```

Global
Address Space
Programming Interface
GASPI

The GASPI Ring Exchange

- GASPI – left_right_double_buffer_multiple.c

```
if (tid == 0) {
  wait_for_queue_max_half (&queue_id);
  SUCCESS_OR_DIE ( gaspi_write_notify
   (segment_id, array_OFFSET_left (buffer_id, slice_id, 0), left,
    segment_id,array_OFFSET_left(buffer_id, right_halo,0),VLEN*sizeof(double),
    right_data_available[buffer_id], 1 + i, queue_id, GASPI_BLOCK));
  wait_or_die (segment_id, left_data_available[buffer_id], 1 + i);
  data_compute ( NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
} else if (tid < NTHREADS - 1) {
  data_compute ( NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
} else {
  wait_for_queue_max_half (&queue_id);
  SUCCESS_OR_DIE ( gaspi_write_notify
   ( segment_id, array_OFFSET_right (buffer_id, slice_id, 0), right,
   segment_id,array_OFFSET_right(buffer_id,left_halo, 0),VLEN*sizeof(double),
   left_data_available[buffer_id], 1 + i, queue_id, GASPI_BLOCK));
   wait_or_die (segment_id, right_data_available[buffer_id], 1 + i);
   data_compute ( NTHREADS, array, 1 - buffer_id, buffer_id, slice_id);
 }
#pragma omp barrier
buffer_id = 1 - buffer_id;
```

Global
Address Space
Programming Interface
GASPI

The GASPI Ring Exchange

- GASPI – left_right_double_buffer_multiple.c

- One message instead of three (MPI Rendezvouz)
- No waiting for late MPI_Recv
- No waiting for acknowledge for MPI_Issend
- Overlap of communication with computation

The GASPI Ring Exchange

- GASPI – Dataflow - left_right_dataflow_halo.c

```
#pragma omp parallel default (none) firstprivate (buffer_id, queue_id)  \
  shared (array, data_available, ssl, stderr)
  {
    slice* sl;
    while (sl = get_slice_and_lock (ssl, NTHREADS, num))
    {
      handle_slice(sl, array, data_available, segment_id, queue_id,
        NWAY, NTHREADS, num);
      omp_unset_lock (&sl->lock);
    }
  }
```

```
typedef struct slice_t
{
  omp_lock_t lock;
  volatile int stage;
  int index;
  enum halo_types halo_type;
  struct slice_t *left;
  struct slice_t *next;
} slice;
```

Global
Address Space
Programming Interface
GASPI

The GASPI Ring Exchange

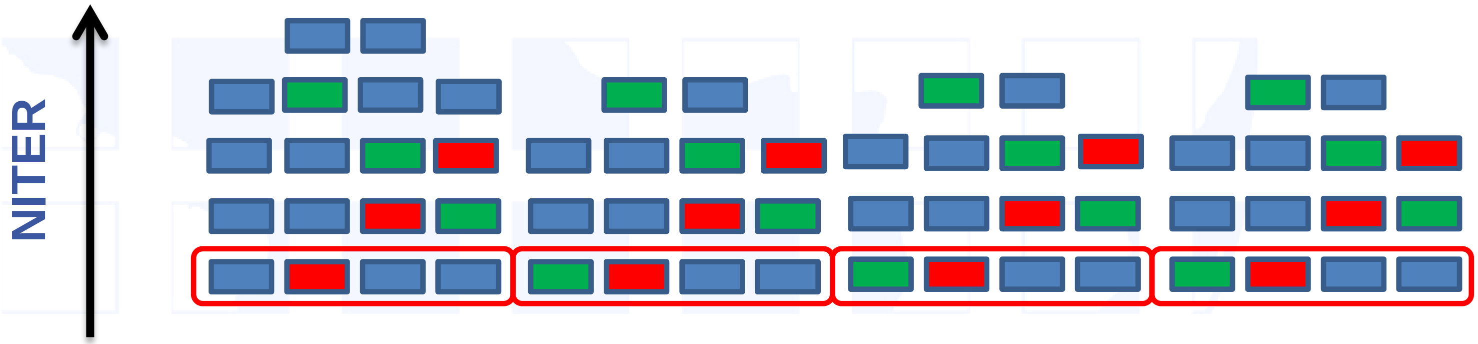
- GASPI – Dataflow - slice.c

```
void handle_slice ( …)
 if (sl->halo_type == LEFT){
    if (sl->stage > sl->next->stage) {return;}
    if (! test_or_die (segment_id, left_data_available[old_buffer_id], 1))
    { return; }
  } else if (sl->halo_type == RIGHT) {
    if (sl->stage > sl->left->stage) { return; }
    if (! test_or_die (segment_id, right_data_available[old_buffer_id], 1))
    { return; }
  } else if (sl->halo_type == NONE) {
    if (sl->stage > sl->left->stage || sl->stage > sl->next->stage) {return;}
  }
data_compute (NTHREADS, array, new_buffer_id, old_buffer_id, sl->index);
  if (sl->halo_type == LEFT) {
     SUCCESS_OR_DIE ( gaspi_write_notify …)
  } else if (sl->halo_type == RIGHT)
    SUCCESS_OR_DIE ( gaspi_write_notify …)
  }
 ++sl->stage;
}
```

The GASPI Ring Exchange

GASPI – Dataflow

- Locally and globally asynchronous dataflow.



Global
Address Space
Programming Interface
GASPI

Collectives

Global
Address Space
Programming Interface
GASPI

Collective Operations (I)

- Collectivity with respect to a definable subset of ranks (groups)
  - Each GASPI process can participate in more than one group
  - Defining a group is a three step procedure
    - gaspi_group_create
    - gaspi_group_add
    - gaspi_group_commit
  - GASPI_GROUP_ALL is a predefined group containing all processes

Collective Operations (II)

- All gaspi processes forming a given group have to invoke the operation
- In case of a timeout (GASPI_TIMEOUT), the operation is continued in the next call of the procedure
- A collective operation may involve several procedure calls until completion
- Completion is indicated by return value GASPI_SUCCESS

Collective Operations (III)

- Collective operations are exclusive per group
  - Only one collective operation of a given type on a given group at a given time
  - Otherwise: undefined behaviour
- Example
  - Two allreduce operations for one group can not run at the same time
  - An allreduce operation and a barrier are allowed to run at the same time

Global
Address Space
Programming Interface
GASPI

Collective Functions

- Built in:
  - gaspi_barrier
  - gaspi_allreduce
    - GASPI_OP_MIN, GASPI_OP_MAX, GASPI_OP_SUM
    - GASPI_TYPE_INT, GASPI_TYPE_UINT, GASPI_TYPE_LONG, GASPI_TYPE_ULONG, GASPI_TYPE_FLOAT, GASPI_TYPE_DOUBLE
- User defined
  - gaspi_allreduce user

Global
Address Space
Programming Interface
GASPI

GASPI Collective Function

- gaspi_barrier

```
gaspi_return_t
gaspi_barrier ( gaspi_group_t group
              , gaspi_timeout_t timeout )
```

- gaspi_allreduce

```
gaspi_return_t
gaspi_allreduce ( gaspi_const_pointer_t buffer_send
                , gaspi_pointer_t buffer_receive
                , gaspi_number_t num
                , gaspi_operation_t operation
                , gaspi_datatype_t datatype
                , gaspi_group_t group
                , gaspi_timeout_t timeout )
```

Global
Address Space
Programming Interface
GASPI

Passive communication

Passive Communication Functions (I)

- 2 sided semantics send/recv
  - gaspi_passive_send

```
gaspi_return_t
gaspi_passive_send ( gaspi_segment_id_t segment_id_local
                   , gaspi_offset_t offset_local
                   , gaspi_rank_t rank
                   , gaspi_size_t size
                   , gaspi_timeout_t timeout )
```

- time based blocking

Passive Communication Functions (II)

– Gaspi_passive receive

```
gaspi_return_t
gaspi_passive_receive ( gaspi_segment_id_t segment_id_local
                      , gaspi_offset_t offset_local
                      , gaspi_rank_t const *rank
                      , gaspi_size_t size
                      , gaspi_timeout_t timeout )
```

- Time based blocking
- Sends calling thread to sleep
- Wakes up calling thread in case of incoming message or given timeout has been reached

Global
Address Space
Programming Interface
GASPI

Passive Communication Functions (III)

- Higher latency than one-sided comm.
  - Use cases:
    - Parameter exchange
    - management tasks
    - „Passive“ Active Messages (see advanced tutorial code)
      - GASPI Swiss Army Knife.

Global
Address Space
Programming Interface
GASPI

Passive Communication Functions (III)

```
void *handle_passive(void *arg)
{
  gaspi_pointer_t _vptr;
  SUCCESS_OR_DIE(gaspi_segment_ptr(passive_segment, &_vptr));
  const gaspi_offset_t passive_offset = sizeof(packet);
  while(1)
    {
      gaspi_rank_t sender;
      SUCCESS_OR_DIE(gaspi_passive_receive(passive_segment
                                          , passive_offset
                                          , &sender
                                          , sizeof(packet)
                                          , GASPI_BLOCK
                                          ));
      packet *t = (packet *) (_vptr + passive_offset);
      passive_handler handler = t->handler;
      // execute requested remote procedure handler
      handler(t->rank, t->len, t->offset);
    }
  return NULL;
```

Global
Address Space
Programming Interface
GASPI

Fault Tolerance

Global
Address Space
Programming Interface
GASPI

Features

- Implementation of fault tolerance is up to the application
- But: well defined and requestable state guaranteed at any time by
  - Timeout mechanism
    - Potentially blocking routines equipped with timeout
  - Error vector
    - contains health state of communication partners
  - Dynamic node set
    - substitution of failed processes

Global
Address Space
Programming Interface
GASPI

Questions?

Thank you for your attention

www.gaspi.de

www.gpi-site.com