Global
Address Space
Programming Interface
GASPI

GASPI Tutorial

ZIH – Dresden

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

Outline

- GASPI programming model
  - Dataflow model
  - Fault tolerance

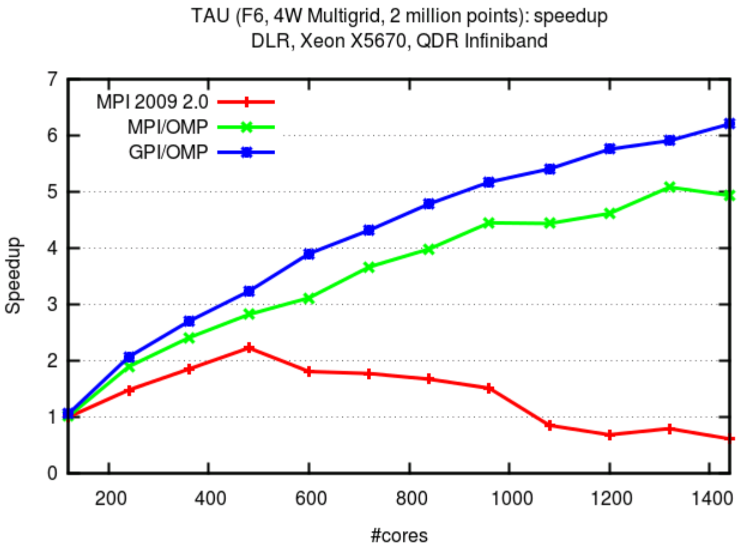
www.gaspi.de www.gpi-site.com

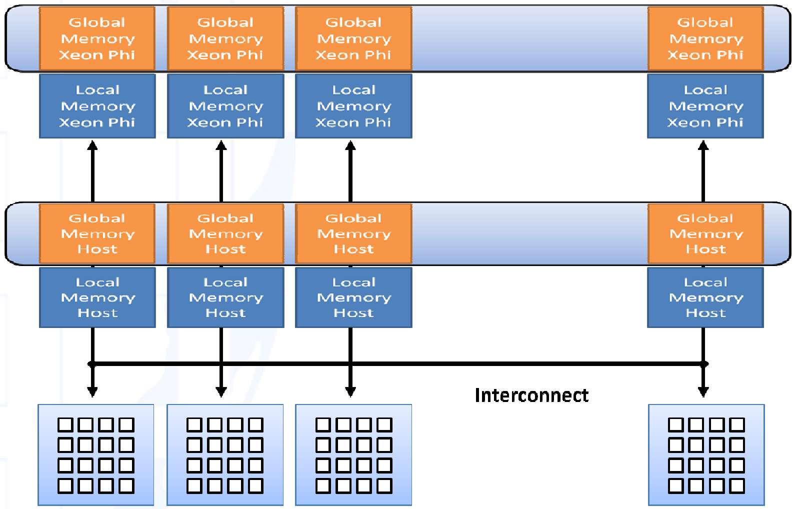
Introduction to GASPI

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 !

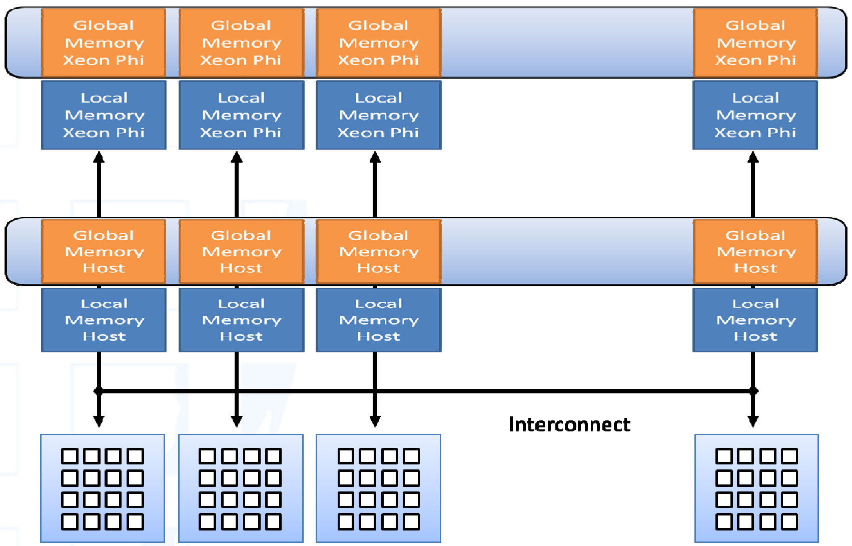




Global
Address Space
Programming Interface
GASPI

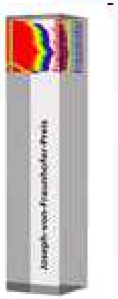
Key Objectives of GASPI

- **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

GASPI Project

- **Started in 2011**
- **Partners:**

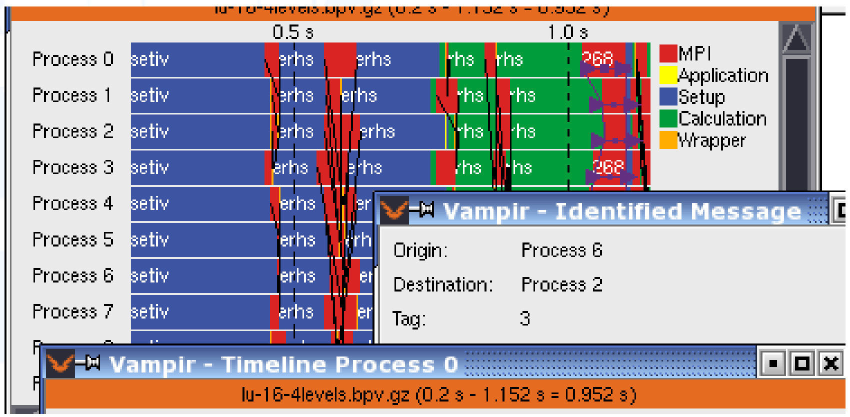
  Fraunhofer ITWM, Fraunhofer SCAI, TUD, T-Systems Sfr, DLR, KIT, FZJ, DWD and Scapos

- **Objectives:**
  - define a novel specification for a PGAS API (GASPI, Global Address Space Programming Interface)
  - make this novel GASPI specification a reliable, scalable and universal tool for the HPC community
- **Specification released**
  - June 14th, 2013 (www.gaspi.de)
- **GPI2.0 released**
  - GPLv3
  - June 15th (www.gpi-site.com)

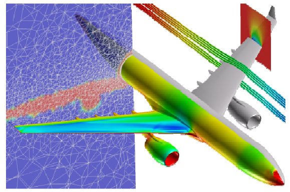
Global
Address Space
Programming Interface
GASPI

GASPI - Project Activities

- **Definition of a GASPI Standard for a PGAS-API**
  - Ensure interoperability with MPI.
- **Development of a highly scalable and highly efficient GASPI implementation**
  - one-sided and asynchronous communication
  - based on the Fraunhofer GPI
- **A Vampir Performance-Analysis suite for GASPI.**



Global
Address Space
Programming Interface
GASPI

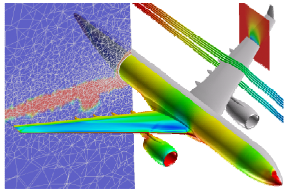


GASPI - Project Activities

- **Highly efficient GASPI enabled libraries**
  - sparse and dense linear algebra packages
  - GASPI enabled Linpack
- **GASPI enabled complex industrial applications**
  - CFD, MD, Weather & Climate, Turbo-Machinery, Oil & Gas
- **Evaluation, benchmarking, performance analysis**
- **Dissemination in HPC & scientific computing**
  - leverage application domains for dissemination
- **Usergroups, Training und Workshops.**

Global
Address Space
Programming Interface
GASPI

Scalability

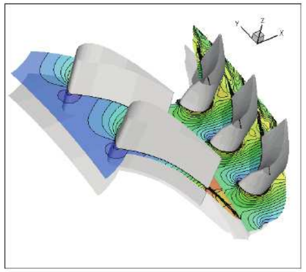


Performance

- 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

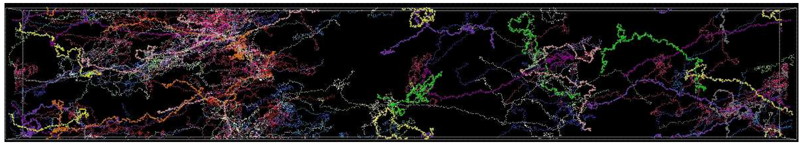
Scalability



Performance

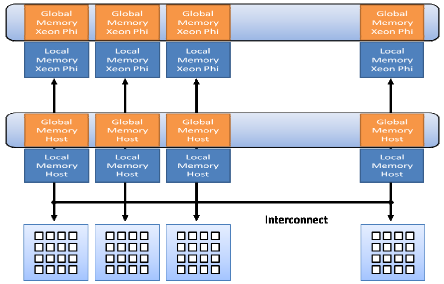
- No polling for outstanding receives/acknowledges for send
  - **no communication overhead**, true asynchronous RDMA read/write.
- Fast synchronous collectives with time-based blocking and timeouts
  - Support for asynchronous collectives in core API.
- Passive Receives two sided semantics, no Busy-Waiting
  - 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.

Global
Address Space
Programming Interface
GASPI



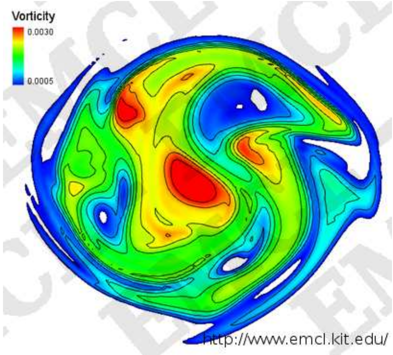
Flexibility and Versatility

- 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.



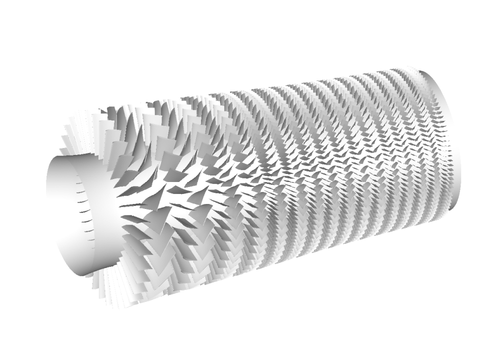
Global
Address Space
Programming Interface
GASPI

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.

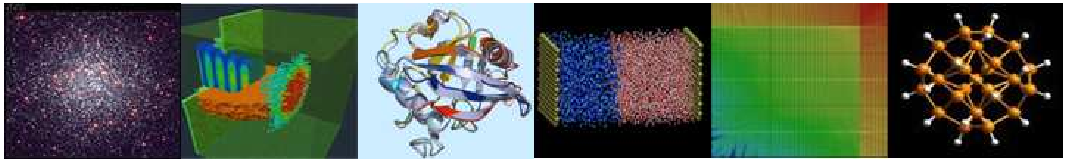


Flexibility

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.

Global Address Space Programming Interface GASPI



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

www.gaspi.de

```
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

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

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 !

Global
Address Space
Programming Interface
GASPI

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

Global
Address Space
Programming Interface
GASPI

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

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 !

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

- Configureing
  - 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;
```

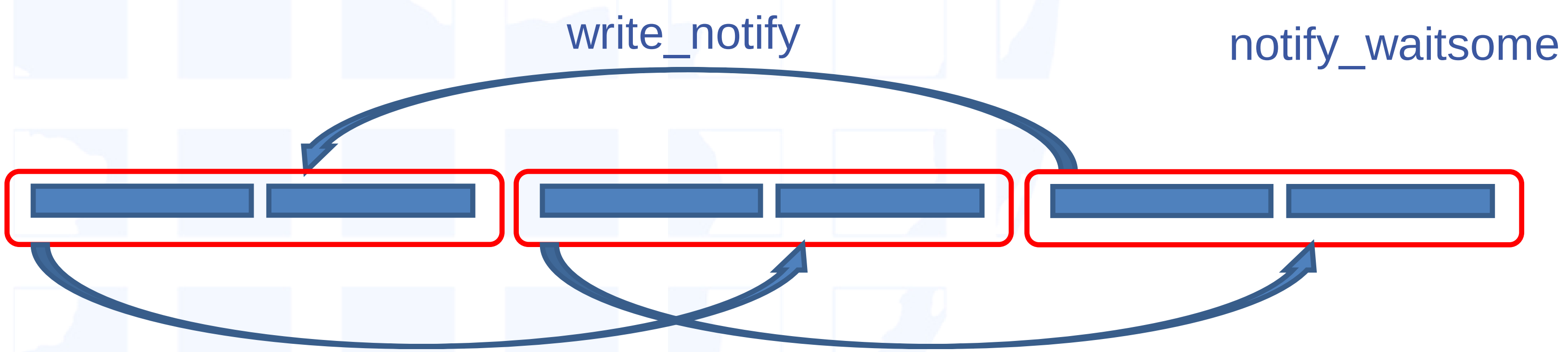
Global
Address Space
Programming Interface
GASPI

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;
}
```

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 const iProc = proc_rank_or_die();
  gaspi_rank_t const nProc = proc_num_or_die();

  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 ); }
```

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

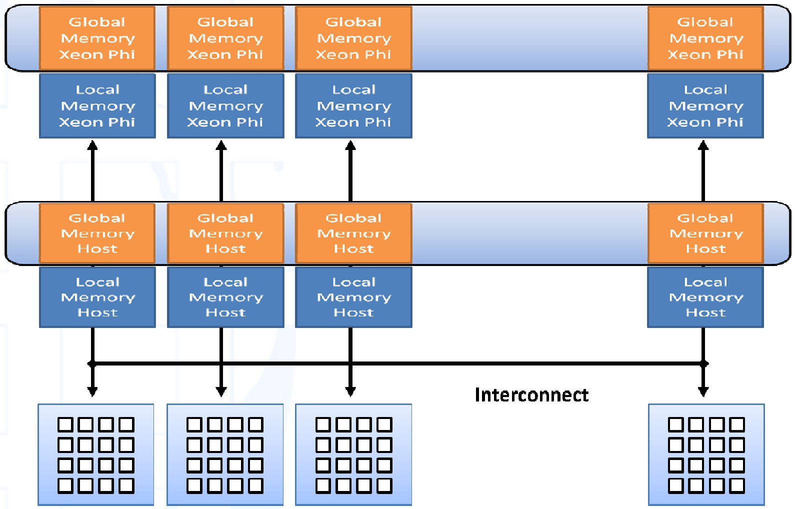
GASPI Segments

- 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)

Global
Address Space
Programming Interface
GASPI

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



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

Features

- One-sided
  - All parameters set by invoking thread
    - local / remote segment
    - local / remote offset
    - remote rank
  - Remote process not involved
  - Local process not involved
    - Actual delivery asynchronously managed by NIC
      - CPU not bothered by synchronization
      - CPU not bothered by communication
      - Full CPU performance available for computation

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

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

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

Global
Address Space
Programming Interface
GASPI

queue.c (I)

```
include "queue.h„
#include "success_or_die.h„

static void wait_for_queue_entries ( gaspi_queue_id_t* queue
                                       , int wanted_entries )
{
    gaspi_number_t queue_size_max;
    gaspi_number_t queue_size;
    gaspi_number_t queue_num;
    SUCCESS_OR_DIE (gaspi_queue_size_max (&queue_size_max));
    SUCCESS_OR_DIE (gaspi_queue_size (*queue, &queue_size));
    SUCCESS_OR_DIE (gaspi_queue_num (&queue_num));

    if (! (queue_size + wanted_entries <= queue_size_max))
    {
        *queue = (*queue + 1) % queue_num;
        SUCCESS_OR_DIE (gaspi_wait (*queue, GASPI_BLOCK));
    }
}
```

queue.c (II)

```
void wait_for_queue_entries_for_write_notify (gaspi_queue_id_t* queue_id)
{
  wait_for_queue_entries (queue_id, 2);
}
void wait_for_queue_entries_for_notify (gaspi_queue_id_t* queue_id)
{
  wait_for_queue_entries (queue_id, 1);
}

void wait_for_flush_queues ()
{
    gaspi_number_t queue_num;
    SUCCESS_OR_DIE (gaspi_queue_num (&queue_num));
    gaspi_queue_id_t queue = 0;   while( queue < queue_num )
    {
        SUCCESS_OR_DIE (gaspi_wait (queue, GASPI_BLOCK));
        ++queue;
    }
}
```

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

Weak Synchronization

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

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

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

Global
Address Space
Programming Interface
GASPI

Collectives

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

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

Global
Address Space
Programming Interface
GASPI

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

Passive Communication Functions (III)

- Higher latency than one-sided comm.
  - Use cases:
    - Parameter exchange
    - management tasks

Global
Address Space
Programming Interface
GASPI

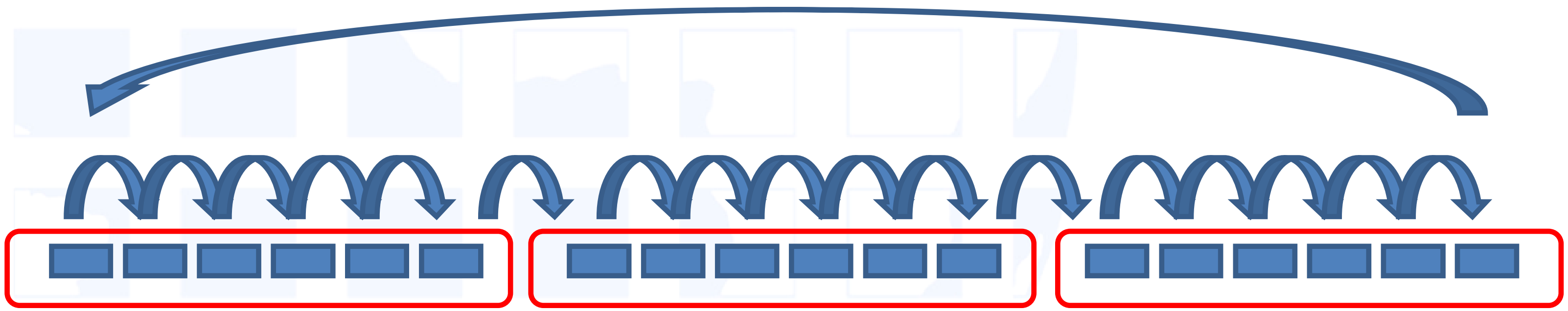
Dataflow model

Hands On Session
The MPI/GASPI Ring Exchange

The MPI Ring Exchange

MPI – MPI_Issend/MPI_Recv

- N Iterations of MPI Ring Exchange across N cores
- Update of vector of length NVEC
- A[core][:] = A[core-1][:]



The MPI Ring Exchange

MPI – MPI_Issend/MPI_Recv

```
for (int i = 0; i < nProc; ++i)
   {
     MPI_Request request;
     SUCCESS_OR_DIE( MPI_Issend ( &ELEM (0, 1, 0), VLEN,
       MPI_DOUBLE, RIGHT (iProc, nProc), i, MPI_COMM_WORLD,
       &request ));
     SUCCESS_OR_DIE ( MPI_Recv ( &ELEM (0, 0, 0), VLEN,
       MPI_DOUBLE, LEFT (iProc, nProc), i, MPI_COMM_WORLD,
       MPI_STATUS_IGNORE));
     SUCCESS_OR_DIE (MPI_Wait (&request, MPI_STATUS_IGNORE));
     data_compute (NTHREADS, array, buffer_id, buffer_id, 0);
   }
```

Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

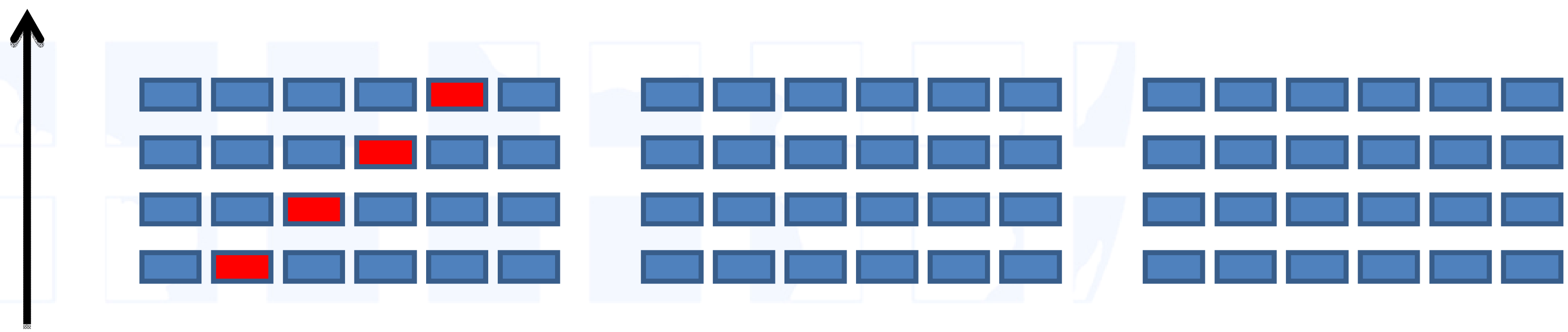
MPI – Double Buffering

```
for (int i = 0; i < nProc; ++i, buffer_id = nway_next (NWAY, buffer_id))
    {
      MPI_Request request;
      SUCCESS_OR_DIE  ( MPI_Issend ( &ELEM (buffer_id, 1, 0), VLEN,
        MPI_DOUBLE , RIGHT(iProc, nProc), i, MPI_COMM_WORLD, &request));
      SUCCESS_OR_DIE ( MPI_Recv ( &ELEM (buffer_id, 0, 0), VLEN,
        MPI_DOUBLE, LEFT (iProc, nProc), i, MPI_COMM_WORLD,
        MPI_STATUS_IGNORE));
      data_compute (NTHREADS, array, nway_next (NWAY, buffer_id),
       buffer_id, 0);
      SUCCESS_OR_DIE (MPI_Wait (&request, MPI_STATUS_IGNORE));
    }
```

Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

- Synchronous Lockstep Execution



Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

- MPI – Hybrid OpenMP/MPI, Fork Join

```
for ( int i = 0 ; i < nProc * NTHREADS; ++i,
       buffer_id = nway_next (NWAY, buffer_id)) {
    MPI_Request request;
#pragma omp master
     {
       SUCCESS_OR_DIE ( MPI_Issend ( &ELEM (buffer_id, NTHREADS, 0), VLEN,
         MPI_DOUBLE, RIGHT (iProc, nProc), i, MPI_COMM_WORLD, &request));
       SUCCESS_OR_DIE ( MPI_Recv ( &ELEM (buffer_id, 0, 0),VLEN, MPI_DOUBLE,
         LEFT (iProc, nProc), i, MPI_COMM_WORLD, MPI_STATUS_IGNORE));
      }
#pragma omp barrier
#pragma omp for
      for (int tid = 0; tid < NTHREADS; ++tid)
          data_compute ( NTHREADS, array
                       , nway_next (NWAY, buffer_id), buffer_id, tid);
#pragma omp master
       SUCCESS_OR_DIE (MPI_Wait (&request, MPI_STATUS_IGNORE));
    }
```

Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

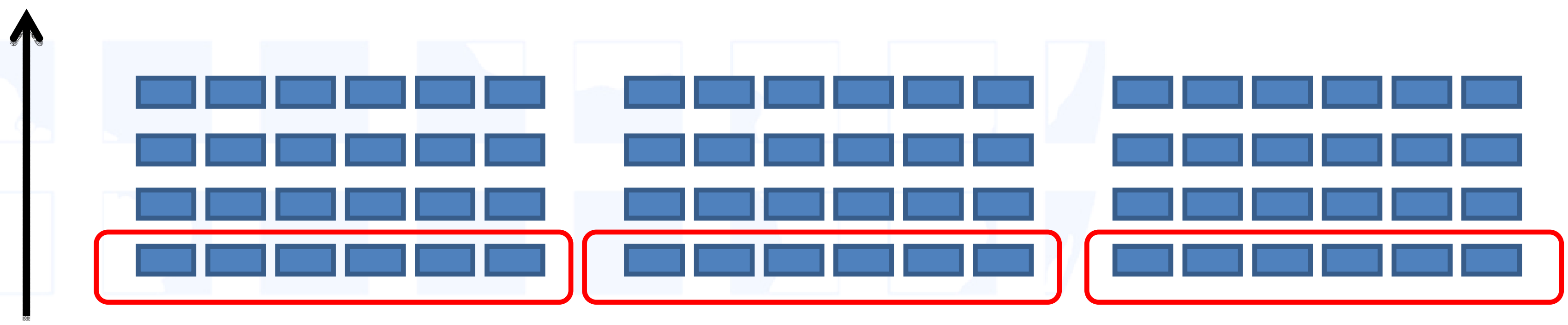
- MPI – Hybrid OpenMP/MPI, Task Model

```
for ( int i = 0; i < nProc * NTHREADS ; ++i,
      buffer_id = nway_next (NWAY, buffer_id)) {
       if (tid == 0) {
         MPI_Request request;
         SUCCESS_OR_DIE ( MPI_Issend ( &ELEM (buffer_id, NTHREADS, 0), VLEN,
           MPI_DOUBLE, RIGHT (iProc, nProc), i, MPI_COMM_WORLD, &request));
         SUCCESS_OR_DIE ( MPI_Recv ( &ELEM (buffer_id, 0, 0), VLEN,
           MPI_DOUBLE, LEFT (iProc, nProc), i, MPI_COMM_WORLD,
           MPI_STATUS_IGNORE));
         data_compute ( NTHREADS, array, nway_next (NWAY, buffer_id),
           buffer_id, tid);
         SUCCESS_OR_DIE (MPI_Wait (&request, MPI_STATUS_IGNORE));
       } else {
         data_compute ( NTHREADS, array
                      , nway_next (NWAY, buffer_id), buffer_id, tid);
       }
#pragma omp barrier
      }
```

Global
Address Space
Programming Interface
GASPI

The MPI Ring Exchange

- Synchronous Lockstep Execution per Socket/Node



Global
Address Space
Programming Interface
GASPI

The GASPI Ring Exchange

- GASPI – Hybrid OpenMP/GASPI, Task Model

```
for ( int i = 0; i < nProc * NTHREADS; ++i,
      buffer_id = nway_next (NWAY, buffer_id)) {
 if (tid == 0)
 {
   wait_for_queue_entries_for_write_notify (&queue_id);
   SUCCESS_OR_DIE ( gaspi_write_notify ( segment_id, OFFSET (buffer_id,
     NTHREADS, 0), RIGHT (iProc, nProc), segment_id, OFFSET (buffer_id, 0,0),
     VLEN * sizeof (double), data_available[buffer_id], 1 + i, queue_id,
     GASPI_BLOCK));
   wait_or_die (segment_id, data_available[buffer_id], 1 + i);
   data_compute ( NTHREADS, array, nway_next (NWAY, buffer_id),
      buffer_id, tid);
      wait_for_queue_entries_for_notify (&queue_id);
   SUCCESS_OR_DIE( gaspi_notify( segment_id, LEFT (iProc, nProc),
      buffer_writeable[buffer_id], 1 + (i + NWAY - 1) % (nProc * NTHREADS),
      queue_id, GASPI_BLOCK));
  }
```

The GASPI Ring Exchange

- GASPI – Hybrid OpenMP/GASPI, Task Model

```
  ...
   else if (tid < NTHREADS - 1)
    {
      data_compute ( NTHREADS, array, nway_next (NWAY, buffer_id),
        buffer_id, tid);
    } else {
      wait_or_die(segment_id, buffer_writeable[nway_next (NWAY, buffer_id)],
      1 + i);
      data_compute ( NTHREADS, array, nway_next (NWAY, buffer_id),
         buffer_id, tid);
    }
#pragma omp barrier
  } // for(;;)
```

Global
Address Space
Programming Interface
GASPI

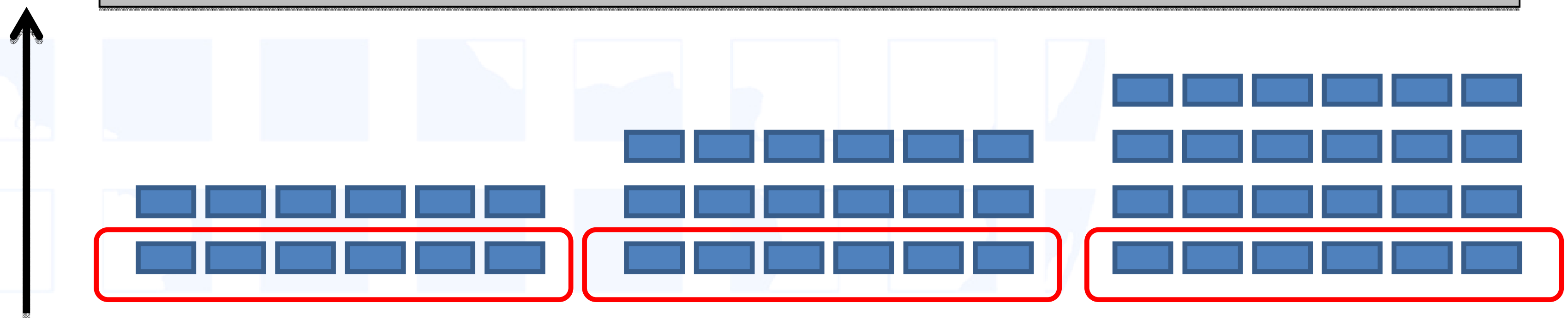
The GASPI Ring Exchange

- NWAY Buffering, blockwise Asynchronous Execution

GASPI requires two messages instead of three (Rendezvouz handshake)

• No waiting for late receiver.

•Overlaps communication and work request with computation.



The GASPI Ring Exchange

- Hybrid OpenMP/GASPI, Round Robin

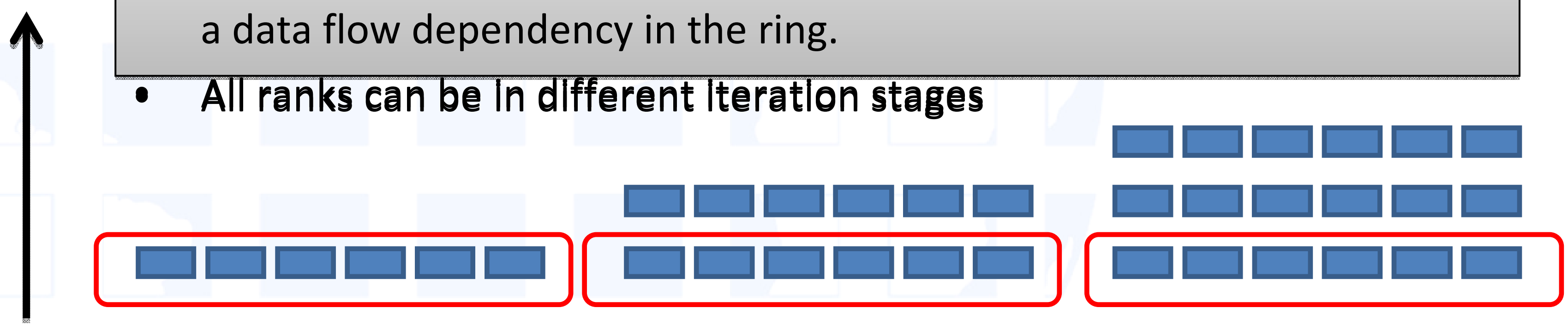
```
for ( int i = 0; i < nProc * NTHREADS
         ; ++i, buffer_id = nway_next (NWAY, buffer_id)) {
   if (tid == 0)
    {
      wait_for_queue_entries_for_write_notify (&queue_id);
      SUCCESS_OR_DIE( gaspi_write_notify( segment_id, OFFSET (buffer_id,
        NTHREADS, 0), RIGHT (iProc,nProc), segment_id, OFFSET (buffer_id, 0,
        0), VLEN * sizeof (double), data_available[buffer_id], 1 + i,
        queue_id, GASPI_BLOCK));
      wait_or_die (segment_id, data_available[buffer_id], 1 + i);
      data_compute ( NTHREADS, array, nway_next (NWAY, buffer_id),
        buffer_id, tid);
     } else {
      data_compute ( NTHREADS,array, nway_next (NWAY, buffer_id),
        buffer_id, tid);
     }
#pragma omp barrier
  }
```

Global
Address Space
Programming Interface
GASPI

The GASPI Ring Exchange

- Num-Cores Buffering – implicit Synchronization, Round-Robin Dataflow

- Write whenever we produce some result, one message instead of three.
- Bonus : we can remove the notification to the left neighbour – there is a data flow dependency in the ring.
- All ranks can be in different iteration stages



The GASPI Ring Exchange

- Hybrid OpenMP/GASPI, Dataflow

```
#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;
```

The GASPI Ring Exchange

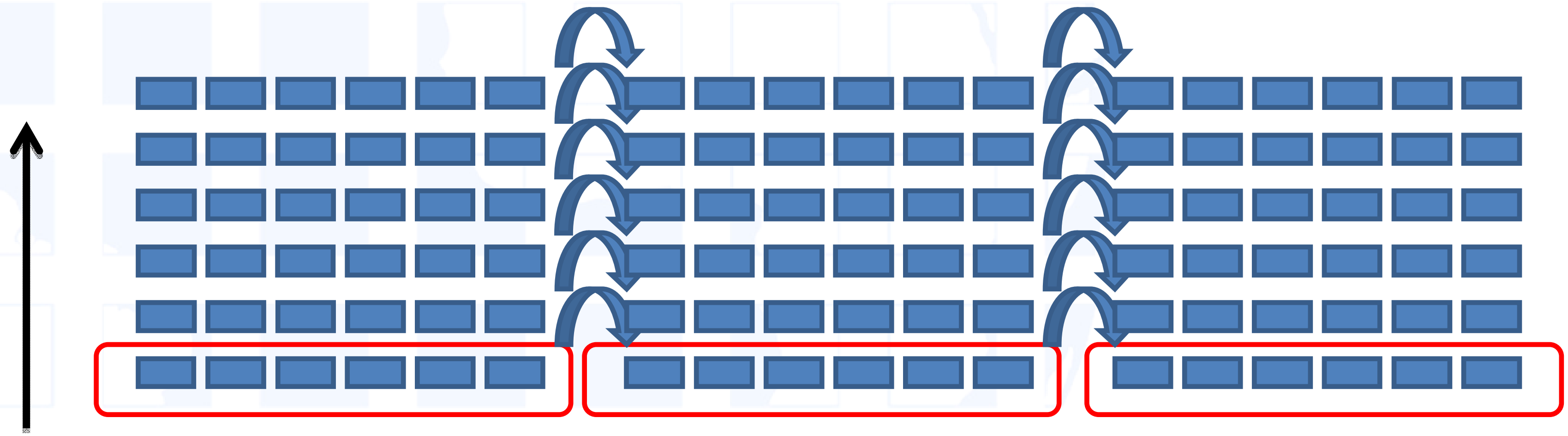
- Hybrid OpenMP/GASPI, Dataflow

```
void handle_slice ( …)
  ..
 if (sl->halo_type == LEFT) {
   if (! test_or_die (segment_id, data_available[old_buffer_id], 1)){ return;}
 } else {
   if (sl->stage > sl->left->stage) { return; }
 }
 data_compute (NTHREADS, array, new_buffer_id, old_buffer_id, sl->index);
  if (sl->halo_type == RIGHT)  {
     …
    SUCCESS_OR_DIE( gaspi_write_notify
        ( segment_id, OFFSET (new_buffer_id, NTHREADS, 0), RIGHT (iProc,nProc)
        , segment_id, OFFSET (new_buffer_id, 0, 0), VLEN * sizeof (double)
        , data_available[new_buffer_id], 1
        , queue_id, GASPI_BLOCK));
  }
  ++sl->stage;
}
```

The MPI Ring Exchange

- Hybrid OpenMP/GASPI, Dataflow

- Fully asynchronous data-driven execution, greedy task execution
- Extend for N-directional halo exchange



Global
Address Space
Programming Interface
GASPI

Fault Tolerance

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

Questions?

Thank you for your attention

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