Global
Address Space
Programming Interface
GASPI

GASPI Tutorial

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Global
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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

Outline

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

Outline

- GASPI programming model
  - Dataflow model
  - Fault tolerance

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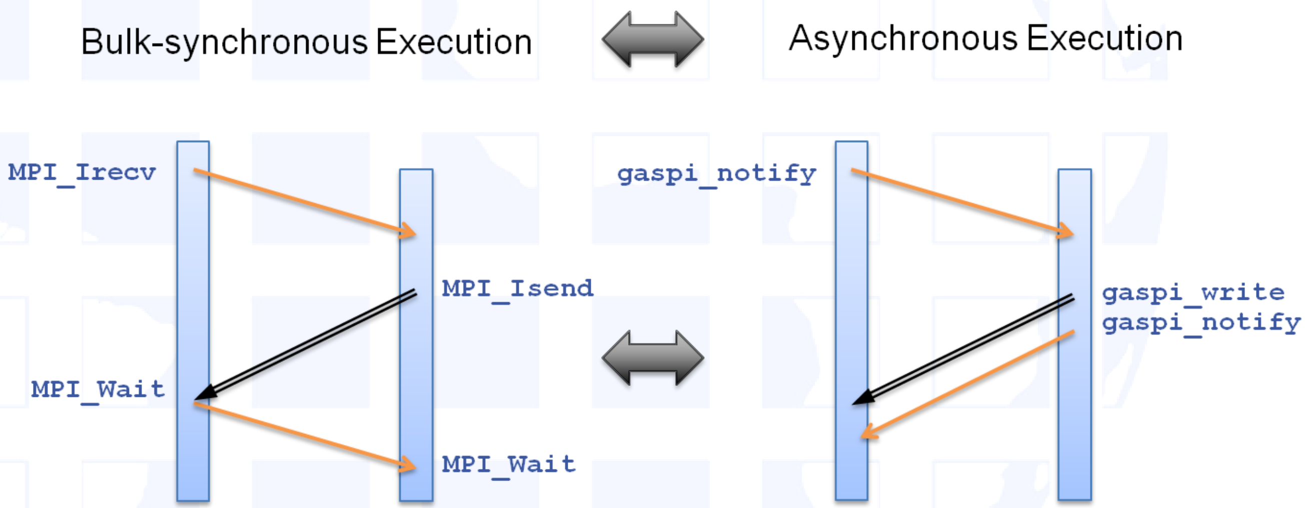
Introduction to GASPI

Motivation

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



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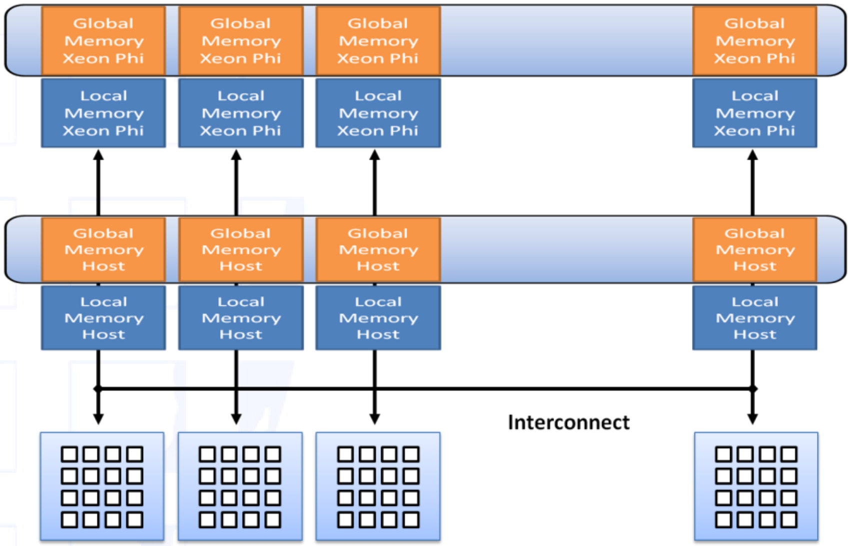
Key Objectives of GASPI

- **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.



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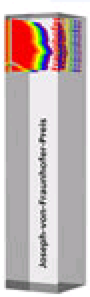
GASPI history

- **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

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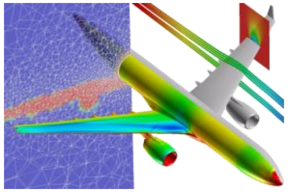
Scalability



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.

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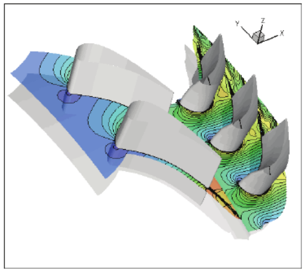
Scalability



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.

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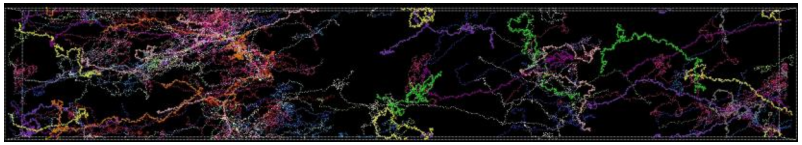
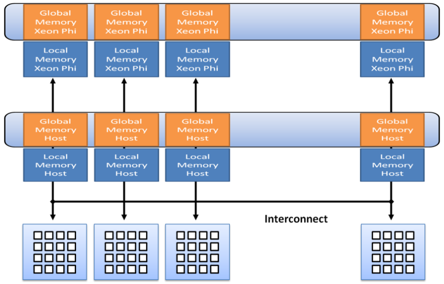


Flexibility and Versatility



- 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.

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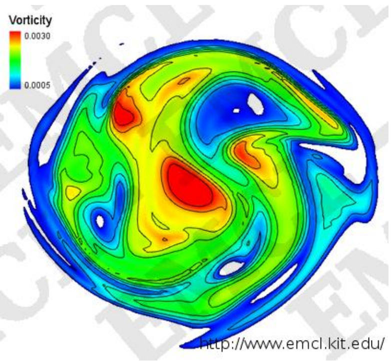
Flexibility



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.

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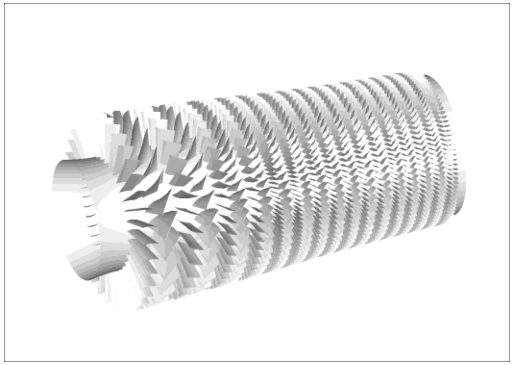
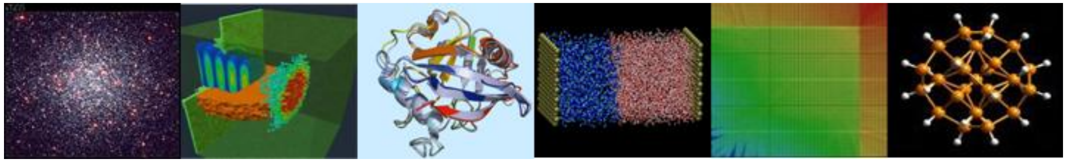
Flexibility



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.

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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

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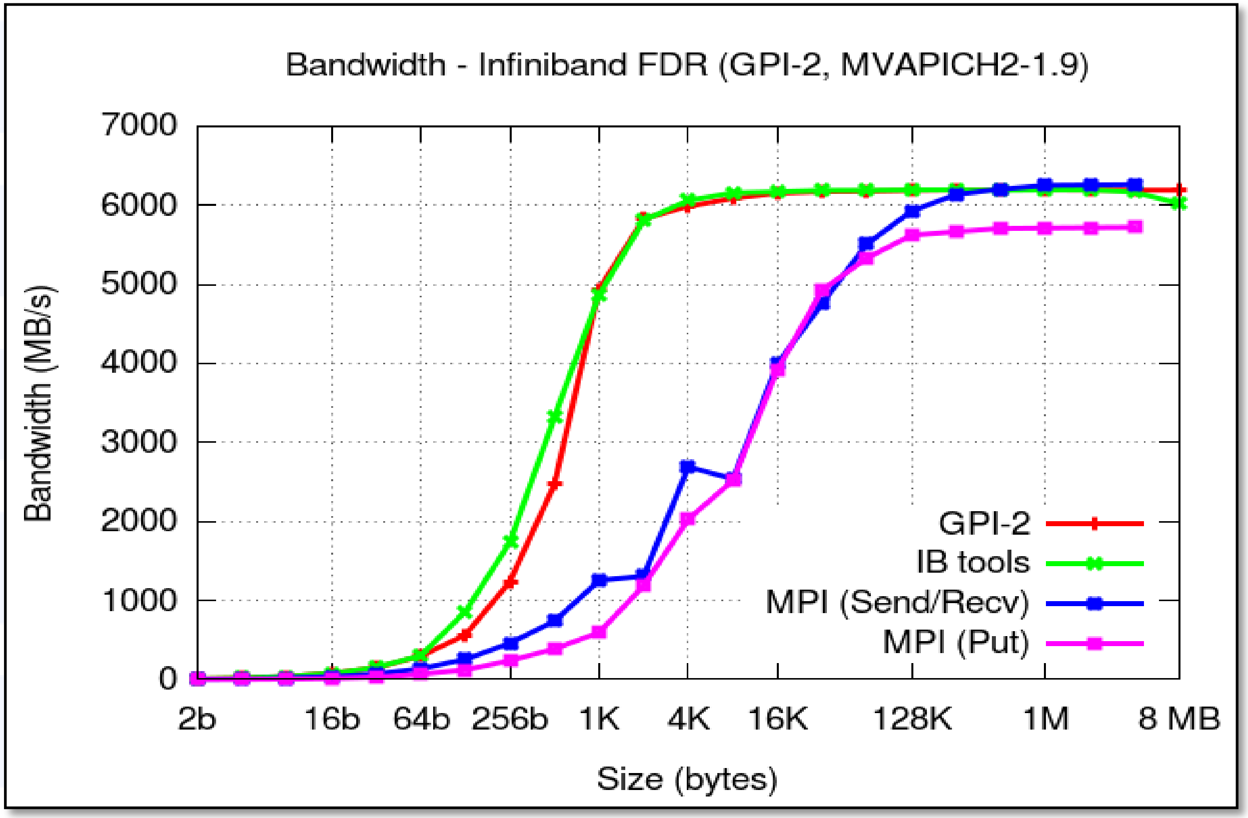
AP1

GASPI Implementation



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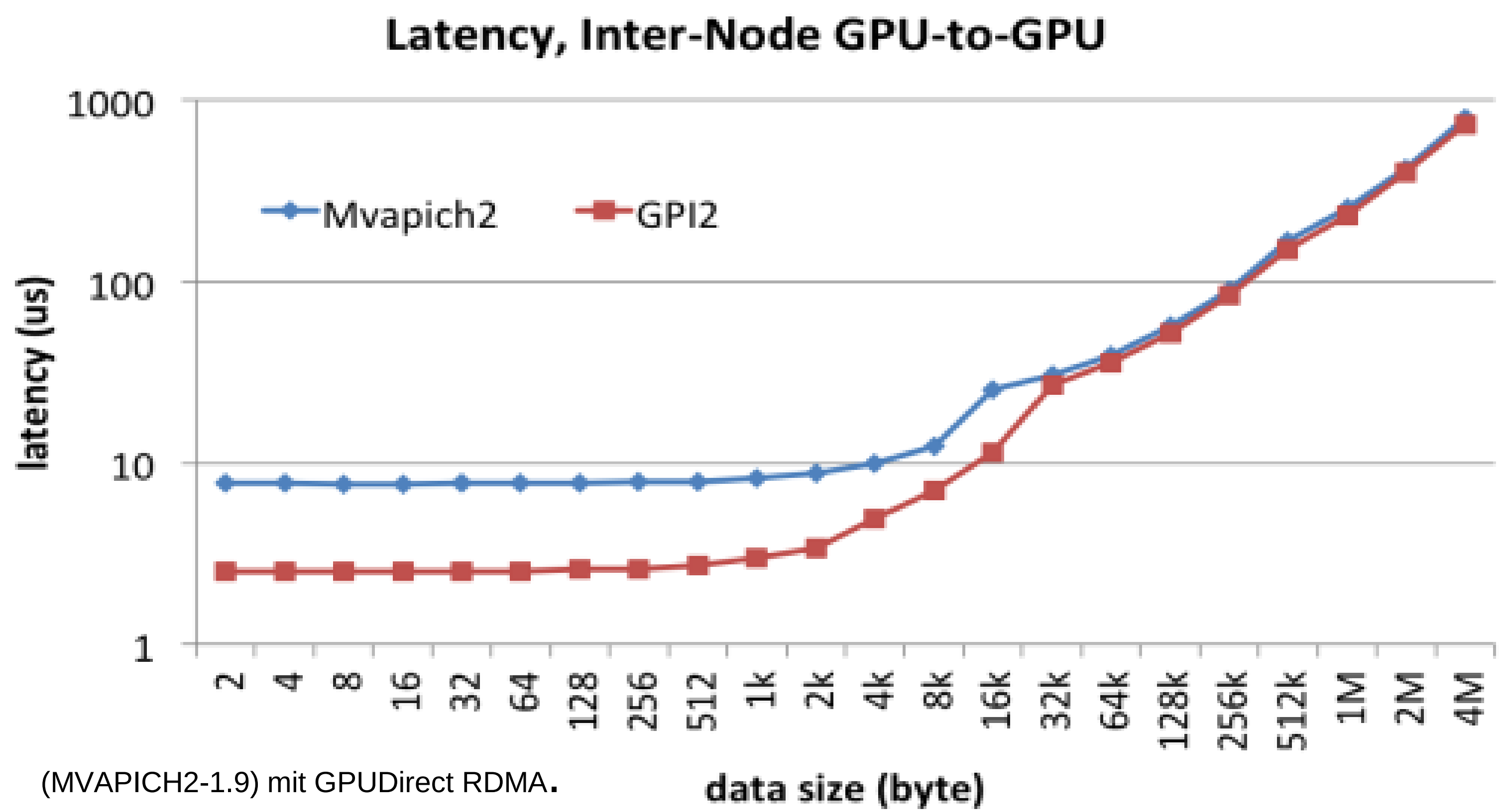
AP1

GASPI Implementation



(MVAPICH2-1.9) mit GPUDirect RDMA.

GASPI
Execution Model

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 !

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

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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

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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 )
```

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

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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) );

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

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

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)               \
  {                                     \
    printf ("Error: '%s' [%s:%i]: %i\n", #f, __FILE__, __LINE__, r);\
    exit (EXIT_FAILURE);                \
   }                                    \
} while (0)

#endif
```

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Hands-On

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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

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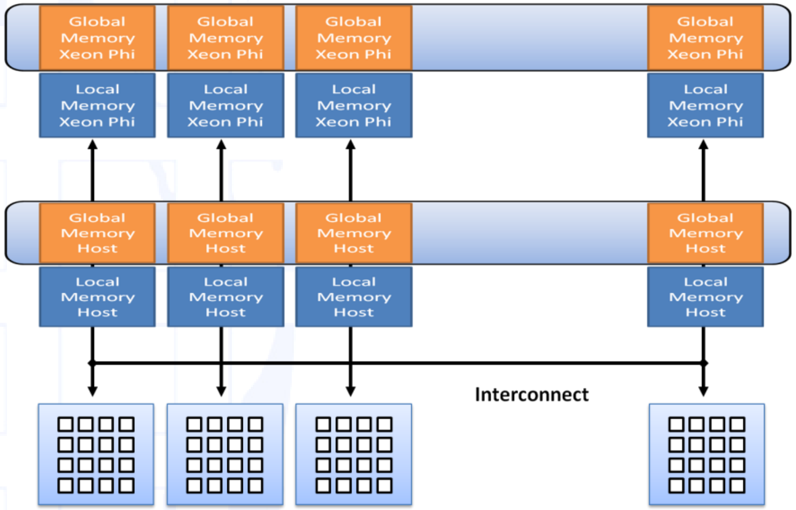
GASPI Segments

- 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



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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

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

GASPI Segment Deletion

- gaspi_segment_delete

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

  - free segment memory

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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 )
```

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Using Segments (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 = VLEN * sizeof (double);

     SUCCESS_OR_DIE ( gaspi_segment_create ( segment_id, segment_size
                                           , GASPI_GROUP_ALL, GASPI_BLOCK
                                           , GASPI_MEM_UNINITIALIZED ) );
```

Using Segments (II)

```
    gaspi_pointer_t array;
    SUCCESS_OR_DIE( gaspi_segment_ptr (segment_id, &array) );

    for (int j = 0; j < VLEN; ++j)
   {
         ( (double *)array )[j]= (double)( iProc * VLEN + j );
         printf( "rank %d elem %d: %f \n„
                              , iProc,j,( (double *)array )[j] );
   }

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

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One-sided Communication

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

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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

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

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Weak Synchronization

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

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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

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

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GASPI Weak Synchronization

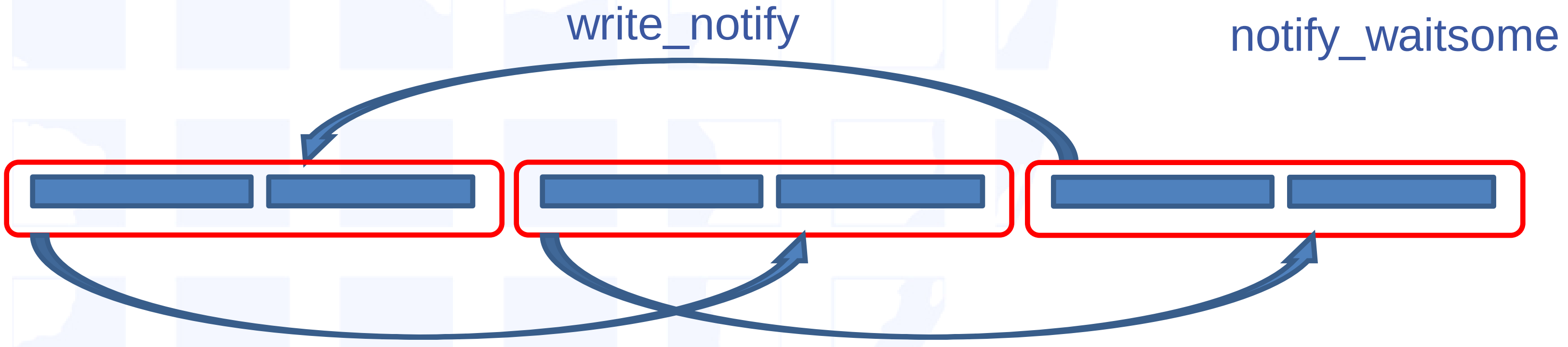
- gaspi_notify_reset

```
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

Communication example

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



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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 ); }
```

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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)
  {
  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;
}
```

waitsome.c

```
include "waitsome.h„
#include "assert.h„
#include "success_or_die.h„

void wait_or_die ( gaspi_segment_id_t segment_id
                 , gaspi_notification_id_t notification_id
                 , gaspi_notification_t expected  )
{
    gaspi_notification_id_t id;
    SUCCESS_OR_DIE (gaspi_notify_waitsome (segment_id, notification_id,
                                           1, &id, GASPI_BLOCK) );

    ASSERT (id == notification_id);

    gaspi_notification_t value;
    SUCCESS_OR_DIE (gaspi_notify_reset (segment_id, id, &value));
    ASSERT (value == expected);
}
```

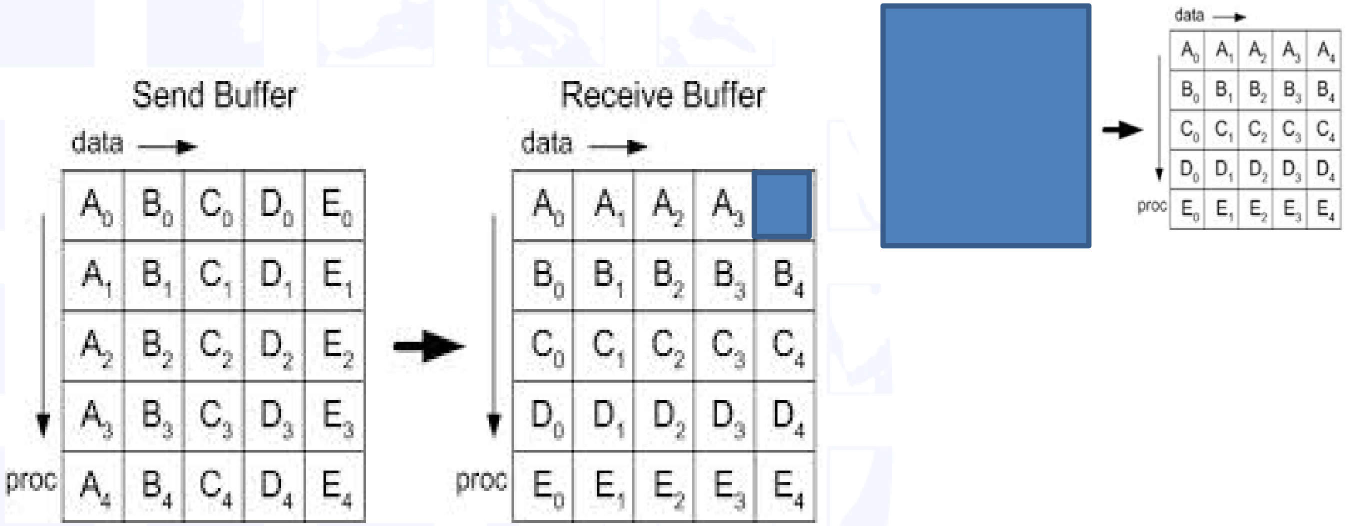
Global
Address Space
Programming Interface
GASPI

Hands-On

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

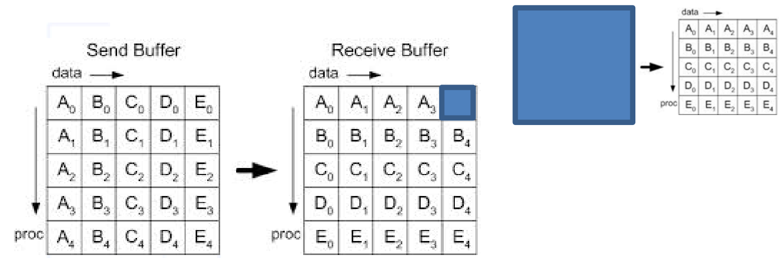
Matrix Transpose



Matrix Transpose => Global Transpose + Local Transpose

=> MPI_Alltoall + Local Transpose

MPI Matrix Transpose




```
// pseudocode
#pragma omp parallel
{
#pragma omp master
  MPI_Alltoall()
#pragma omp barrier
  for_all_threadprivate_tiles
     do_local_transpose(tile);
}
```

Global
Address Space
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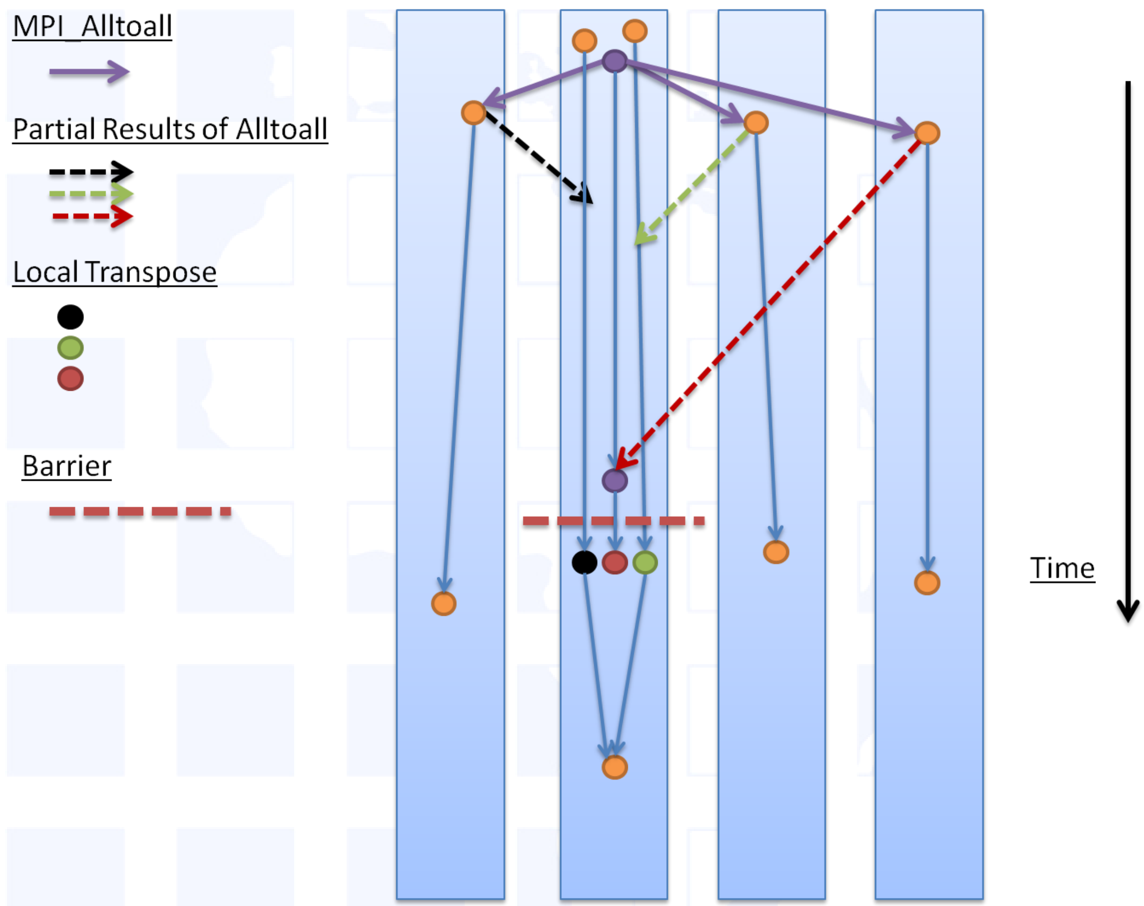
MPI - Alltoall



Global
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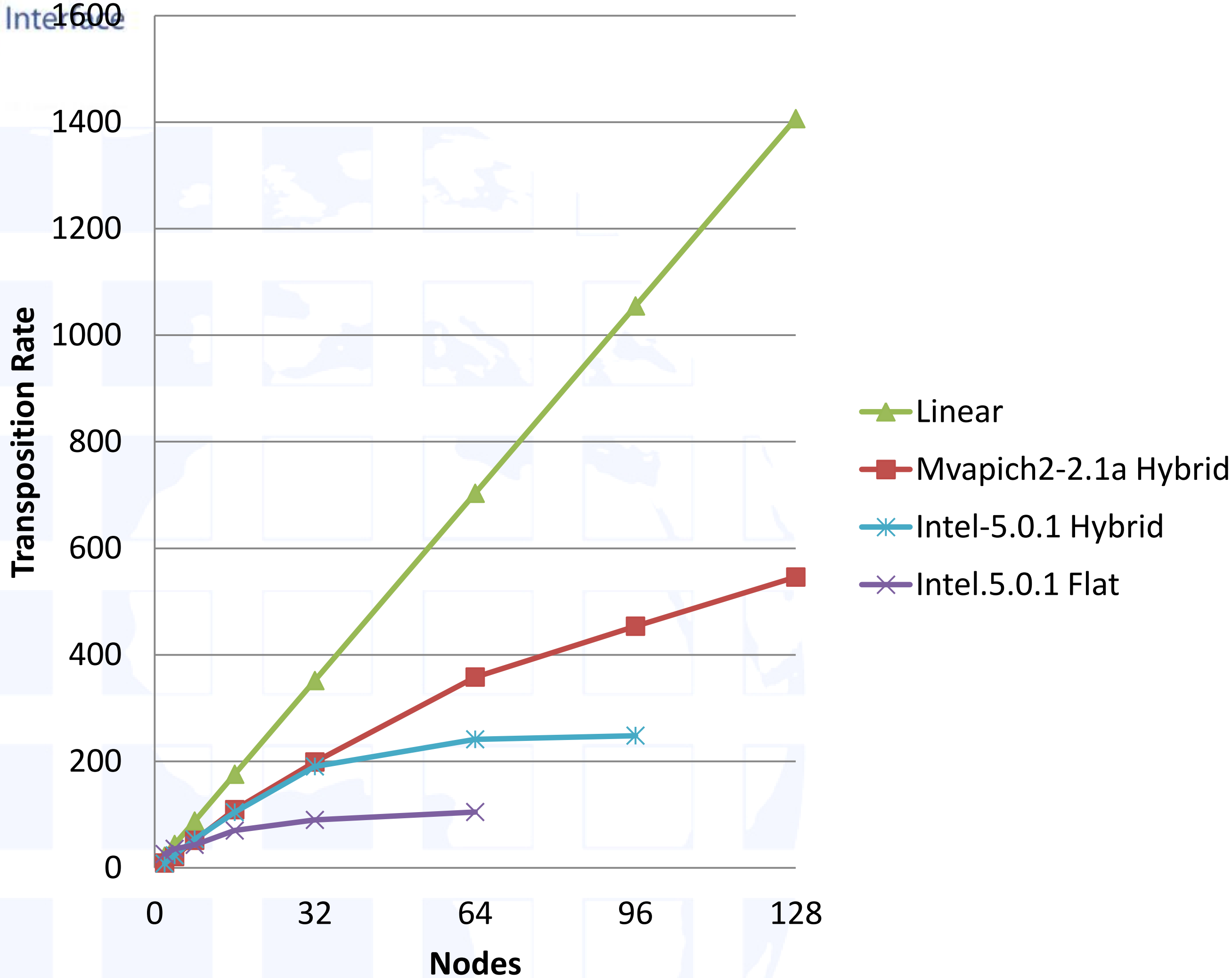

Infiniband FDR Fat Tree. Flat MPI vs. Hybrid OpenMP/MPI

Global
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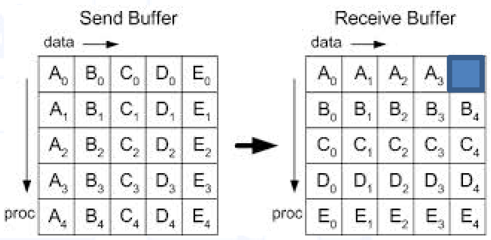
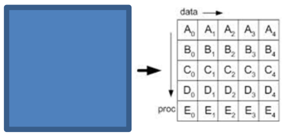
GASPI

Hands-On

GASPI Matrix Transpose





```
// pseudocode - write_notify
#pragma omp parallel
{
#pragma omp master
  for_all_other_ranks
      gaspi_write_notify(tile)
  while (!complete)
  {
        test_or_die(thread_local tile) // test for notifications for
                                       // thread local tiles
        do_local_transpose(tile)
  }
}
```

Global
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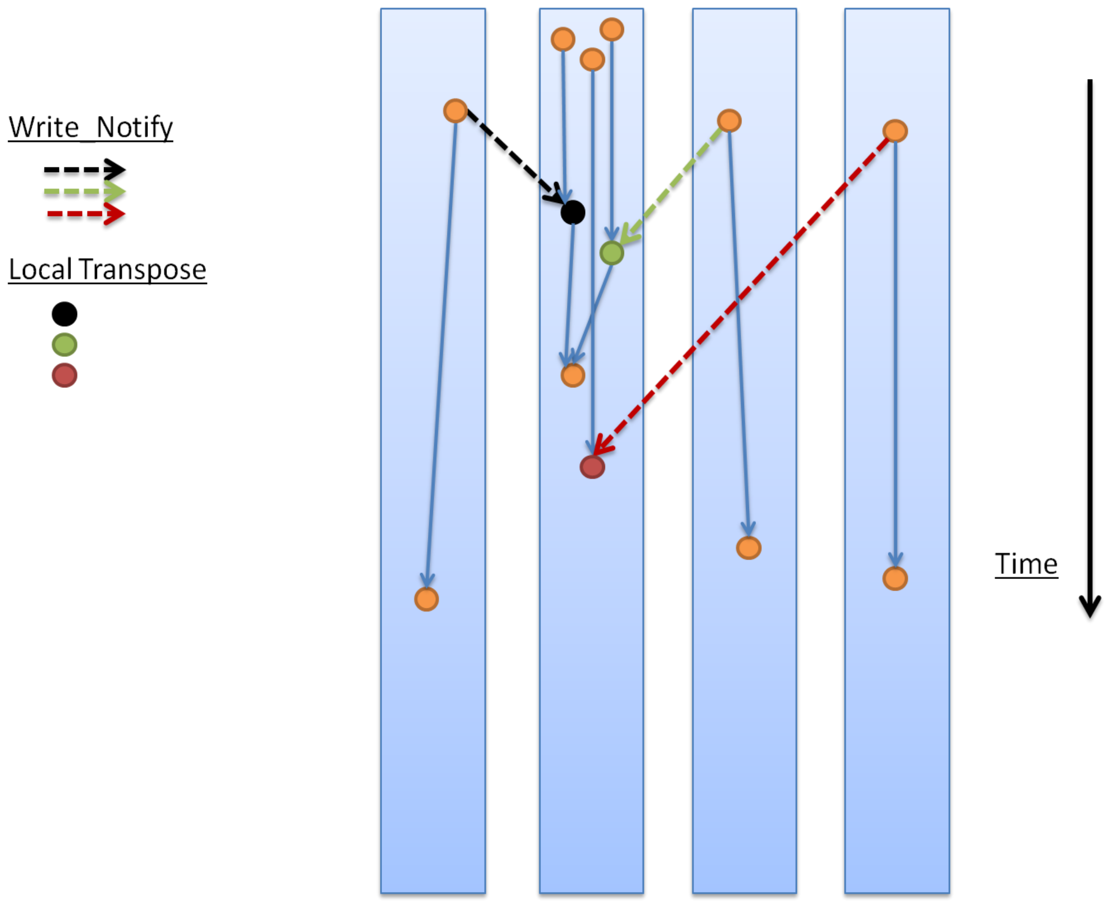
GASPI - Notification



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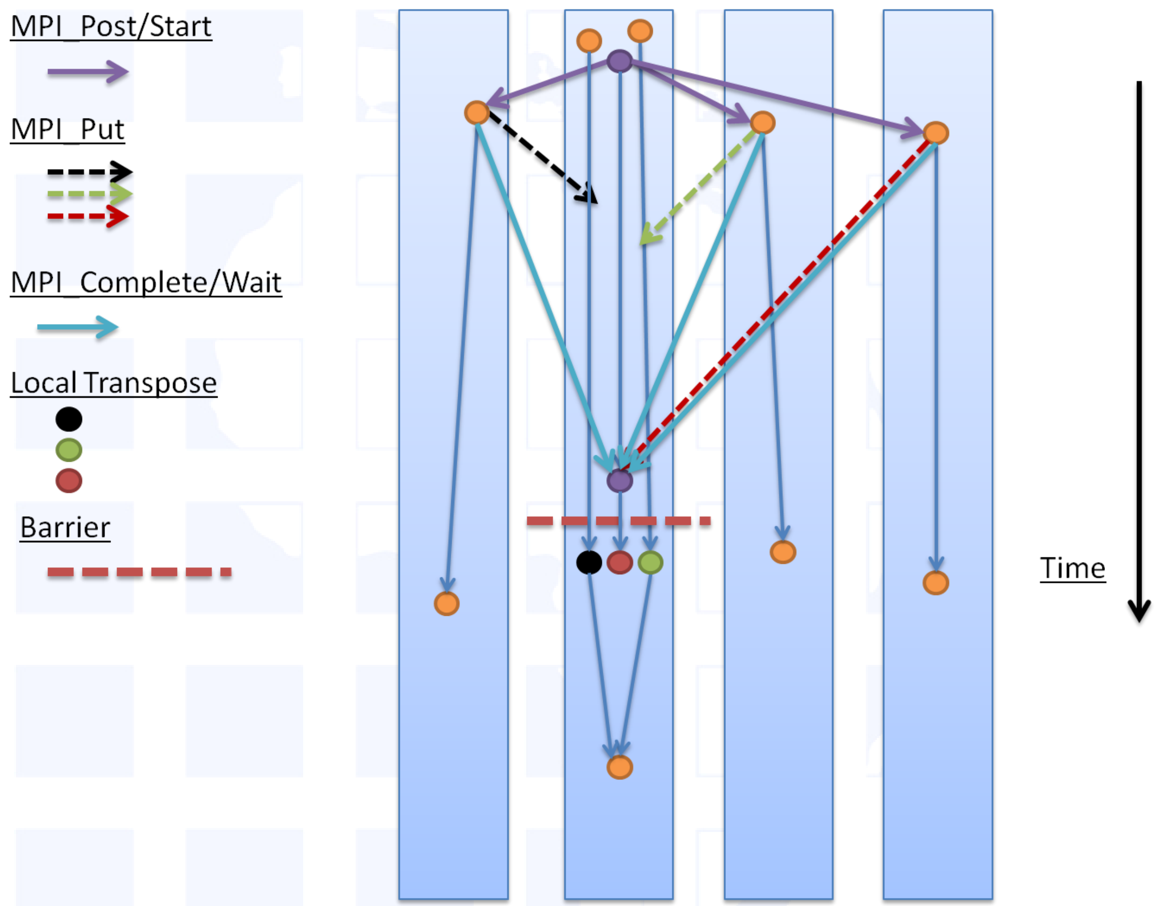
Hands-On

MPI - GATS/PSCW



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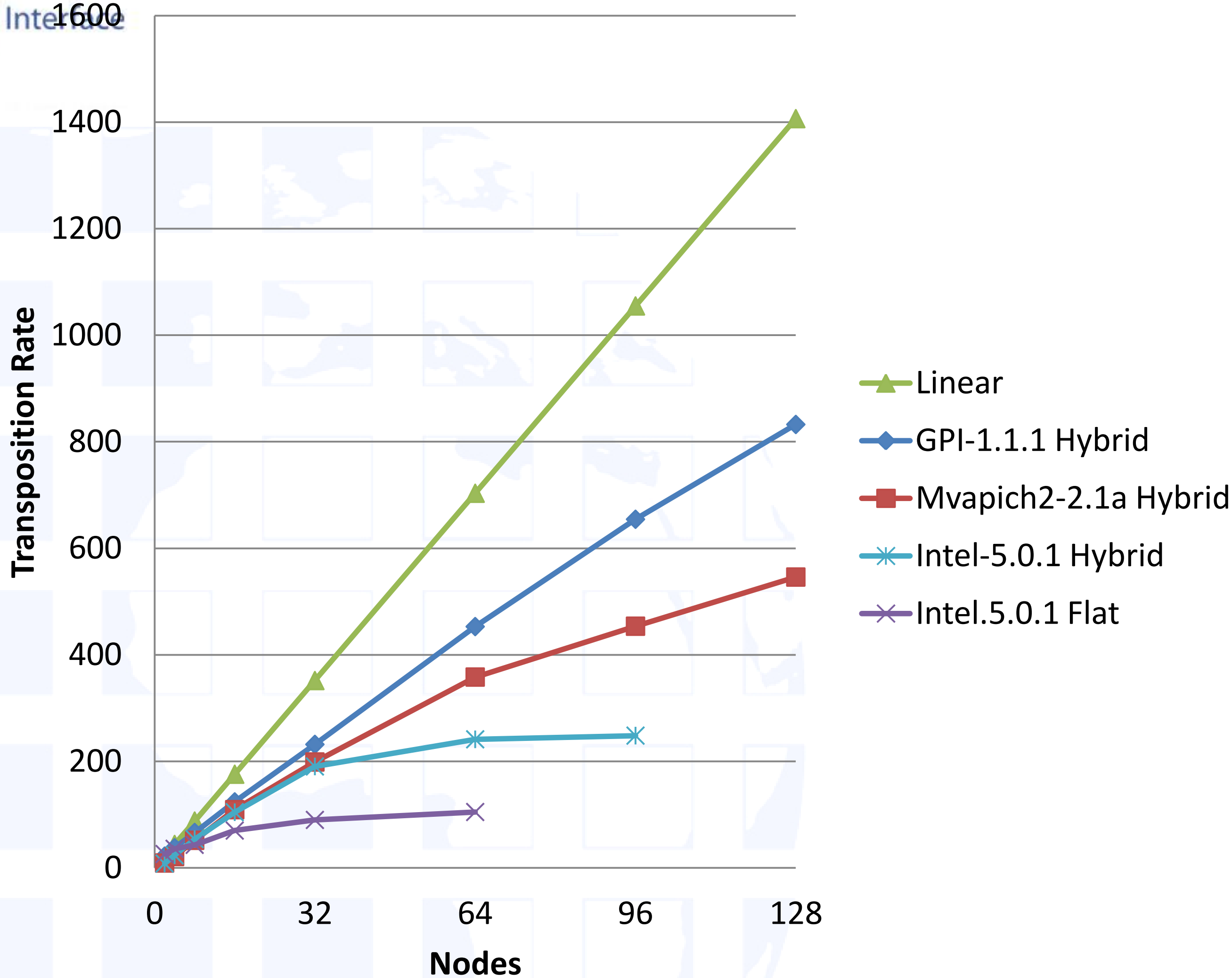
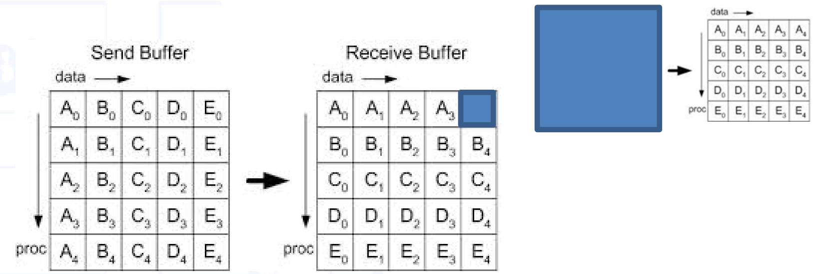
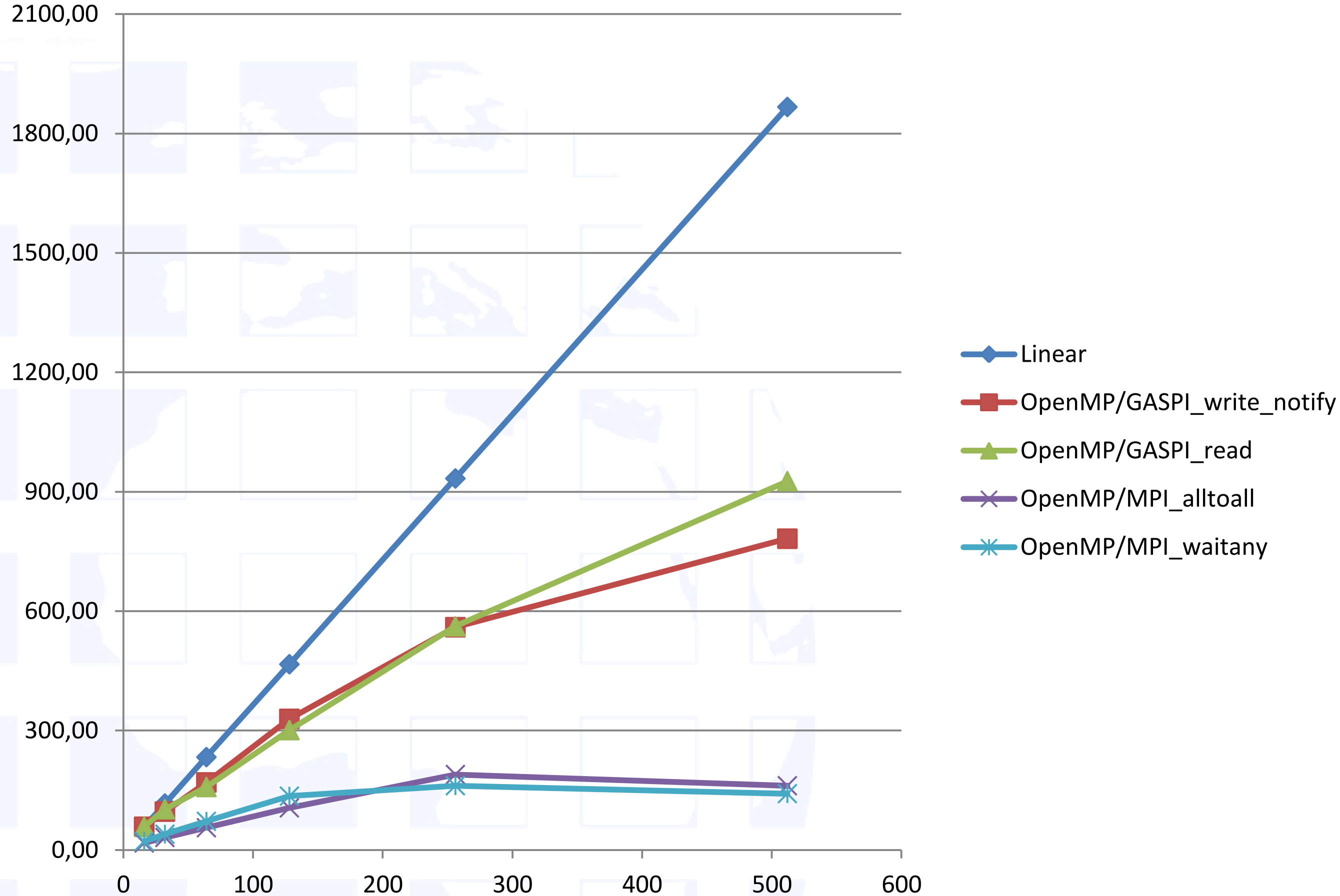


https://github.com/PGAS-community-benchmarks

GASPI Matrix Transpose




```
// pseudocode - read
#pragma omp parallel
{
#pragma omp master
  for_all_other_ranks
      gaspi_read(tile) // flip queue, wait and read !
  while (!complete)
  {
         test_or_die(thread_local tile) // test for notifications for
                                        // thread local tiles
         do_local_transpose(tile)
  }
}
```



Infiniband 7D Enhanced hypercube. GASPI read vs notified write.

Hands-On

Task (Graph) Models

Bottom up: Complement local task dependencies with remote data dependencies.

Task (Graph) Models

Targets

- Node local execution on (heterogeneous) manycore architectures.
- Scalability issues in Fork-Join models
- Vertically fragmented memory, separation of access and execution, handling of data marshalling, tiling, etc.
- Inherent node local load imbalance

GASPI

Targets:

- Latency issues, overlap of communication and computation.
- Asynchronous fine-grain dataflow model
- Fault tolerance, system noise, jitter.

Top Down: Reformulate towards asynchronous dataflow model. Overlap communication and computation.

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Dataflow model

Hands On Session

The MPI/GASPI Ring Exchange

Ghost Cell Exchange with Double Buffering

Global
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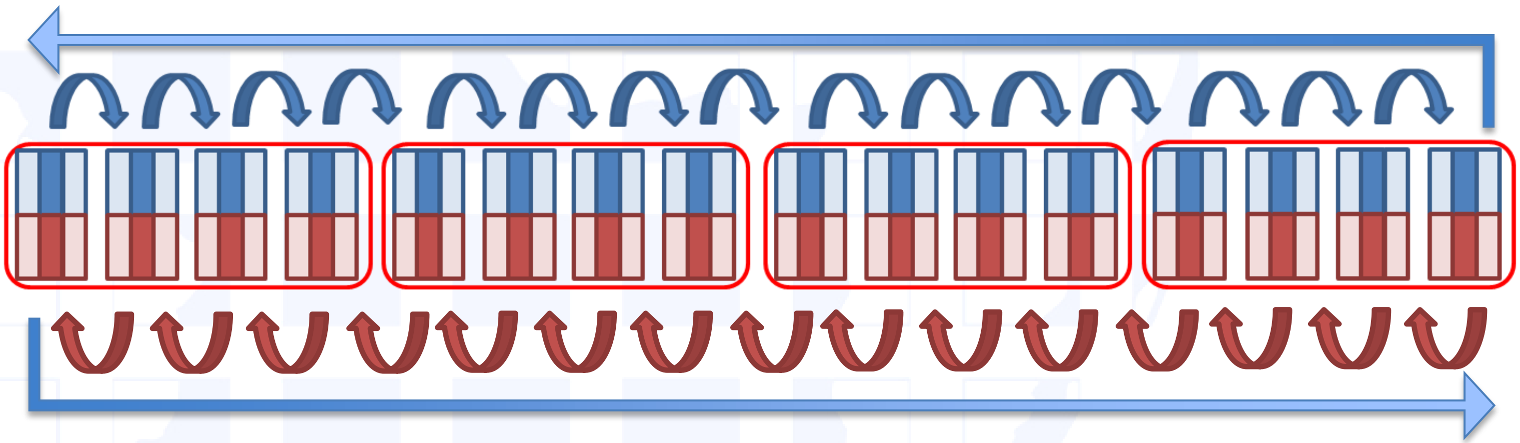
The MPI Ring Exchange

MPI – MPI_Issend/MPI_Recv

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



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

Global
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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;
  }
```

Global
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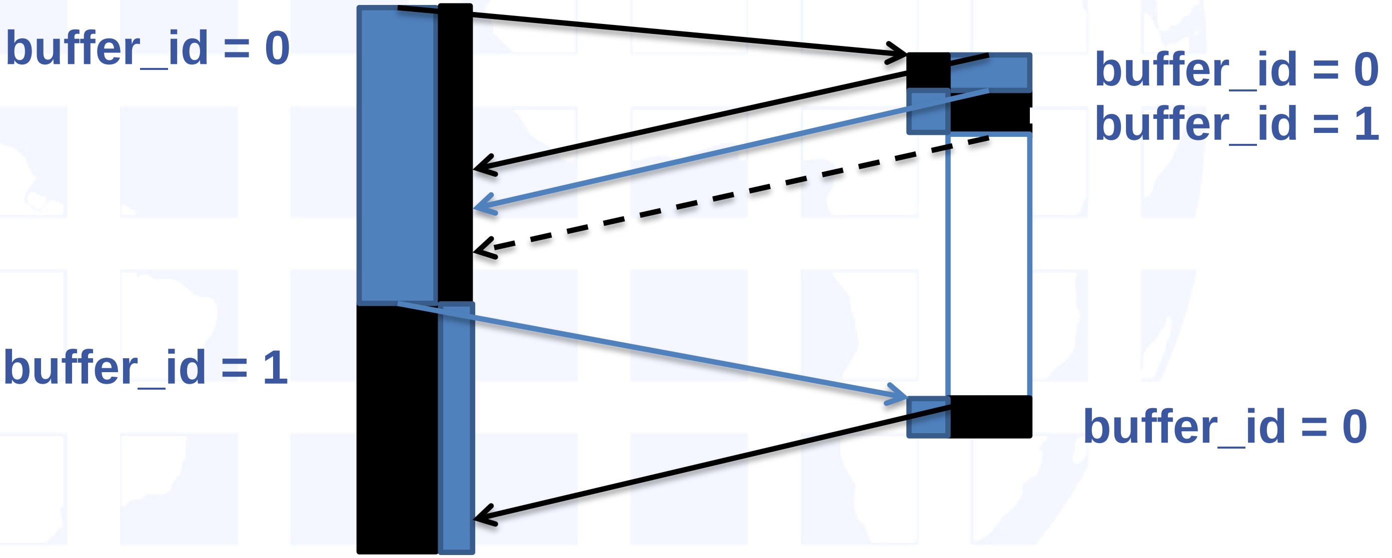
The MPI Ring Exchange

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;
  }
```

The MPI Ring Exchange

- Bi-directional halo exchange – **implicit synchronization**



Global
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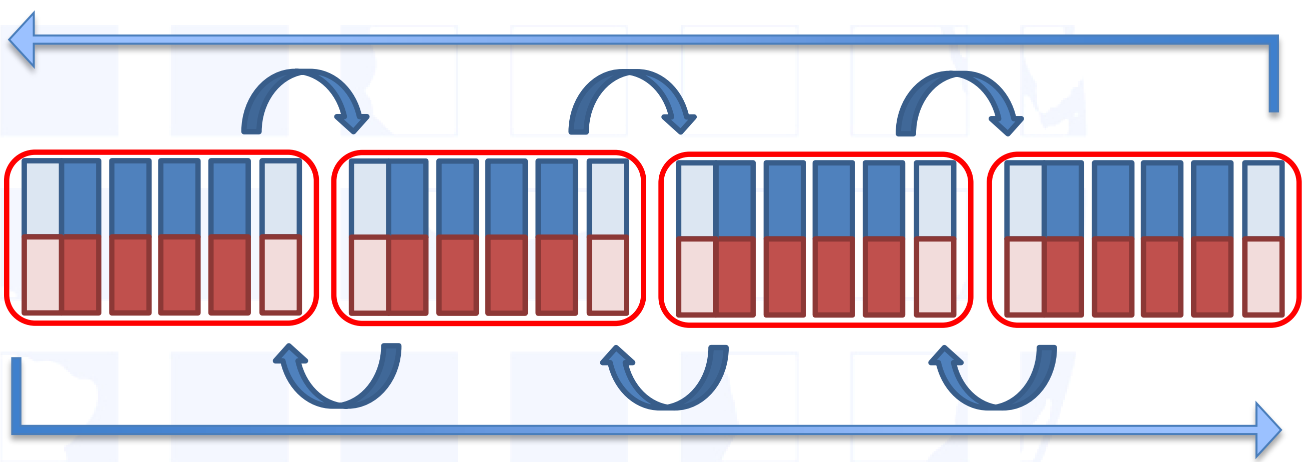
Programming Interface
GASPI

Hands-On

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

Global
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The MPI Ring Exchange

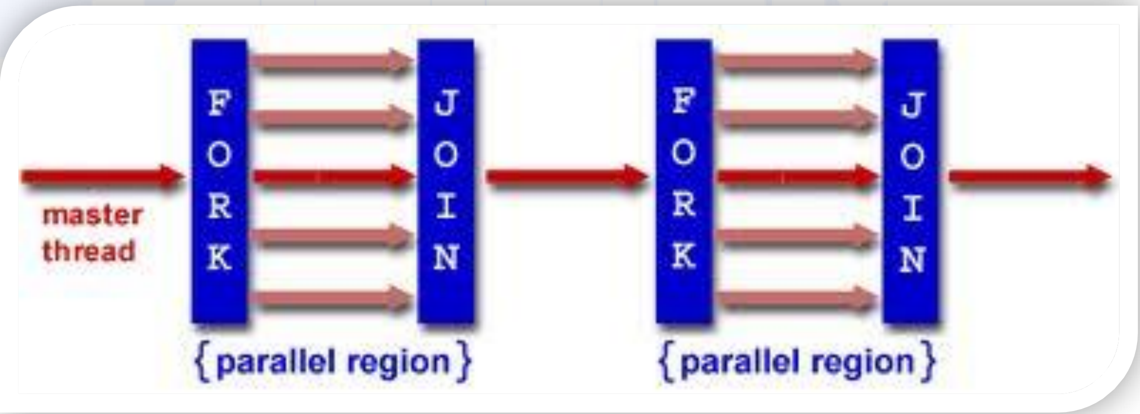
- MPI – left_right_double_buffer_funneled.c

```
 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; }
```

The MPI Ring Exchange

MPI – left_right_double_buffer_funneled.c

- Fork-join model



Global
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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
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Hands-On

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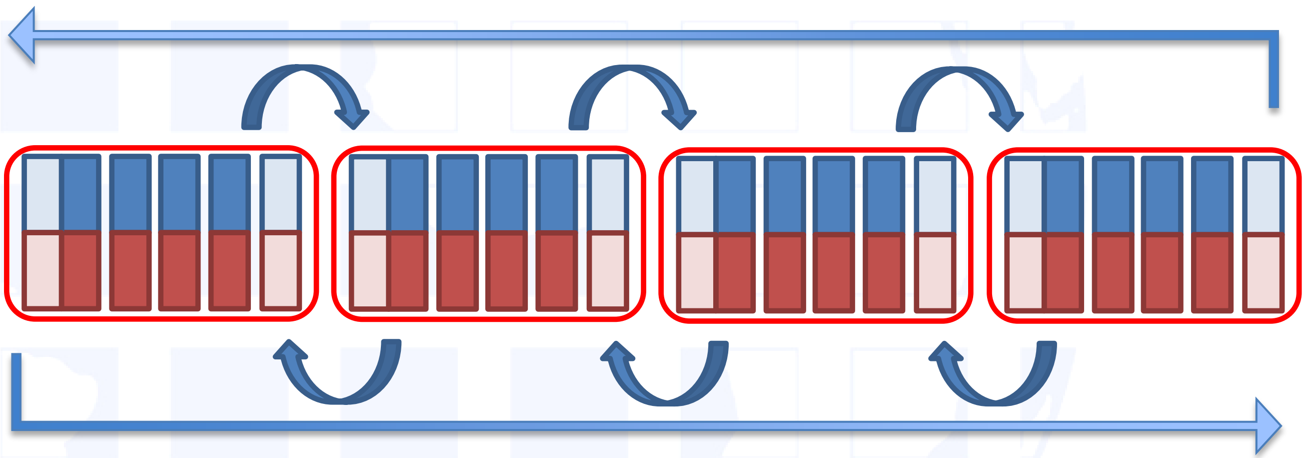
The GASPI Ring Exchange

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

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;
```

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;
```

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Hands-On

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

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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);
      sl->stage = sl->stage + 1;
      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;
```

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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 …)
  }
}
```

Global
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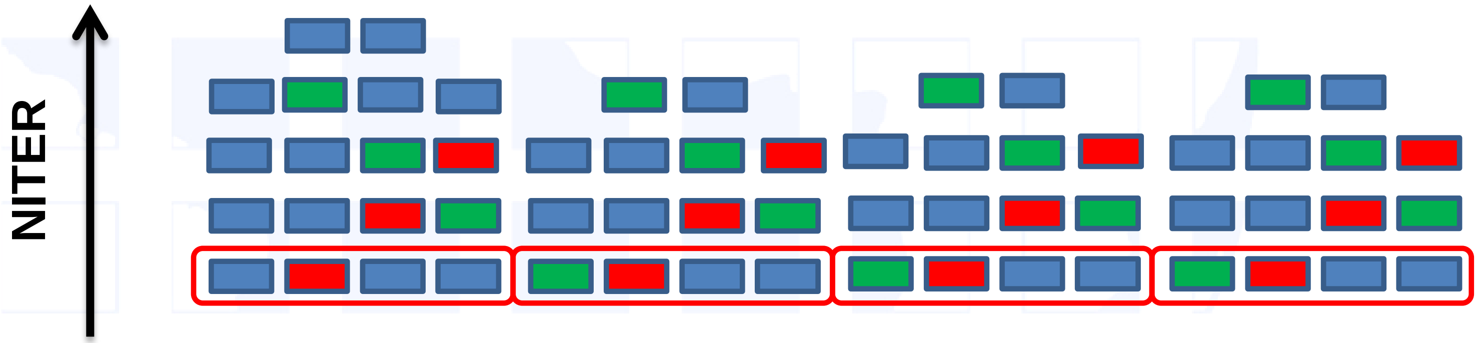
Hands-On

The GASPI Ring Exchange

GASPI – Dataflow

- Locally and globally asynchronous dataflow.



Collectives

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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

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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 )
```

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Passive communication

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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
    - „Passive“ Active Messages (see advanced tutorial code)
      - GASPI Swiss Army Knife.

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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

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Questions?

Thank you for your attention

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