



Global
Address Space
Programming Interface
GASPI
GASPI

GASPI Tutorial

Christian Simmendinger
Mirko Rahn
Daniel Grünwald

Sponsored by the European Commission through





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



Global
Address Space
Programming Interface
GASPI
GPI-Site

Outline

- GASPI programming model
 - Dataflow model
 - Fault tolerance

www.gaspi.de

www.gpi-site.com



Global
Address Space
Programming Interface
GASPI
GSAI

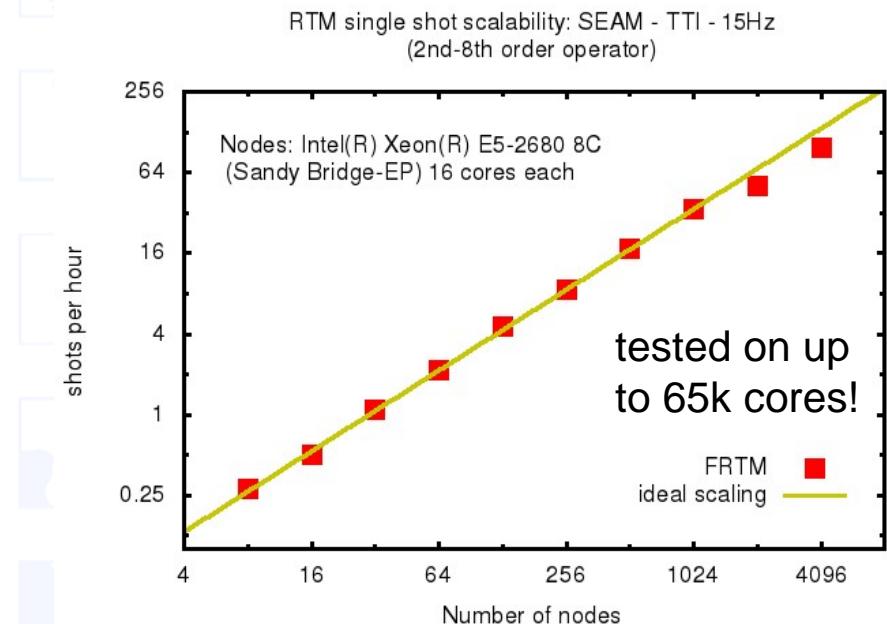
Introduction to GASPI



GASPI at a glance

Features:

- Global partitioned address space
- Asynchronous, one-sided communication
- Threadsafe, every thread can communicate
- Supports fault tolerance
- Open Source
- Standardized API (**GASPI**)



Infiniband, Cray, Ethernet, GPUs, Intel Xeon Phi,
Open Source (GPL), standardized API



Global
Address Space
Programming Interface
GASPI
GSAI

GASPI history

- **GPI is the implementation of the GASPI standard**
 - 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

GASPI

standardization forum



T...Systems...



Founding
members



Regionales
RechenZentrum
Erlangen
Der IT-Dienstleister der FAU



Global
Address Space
Programming Interface
GASPI
GASPI

GASPI in European Exascale Projects



EXascale Algorithms and Advanced Computational Techniques

EPiGRAM

Exascale ProGRAMming Models



Programming-model design and implementation for the Exascale

Inria
INVENTORS FOR THE DIGITAL WORLD

MANCHESTER
1824

The University of Manchester

BSC
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

DLR

T...Systems...

KTH
VETENSKAP OCH KONST

epcc

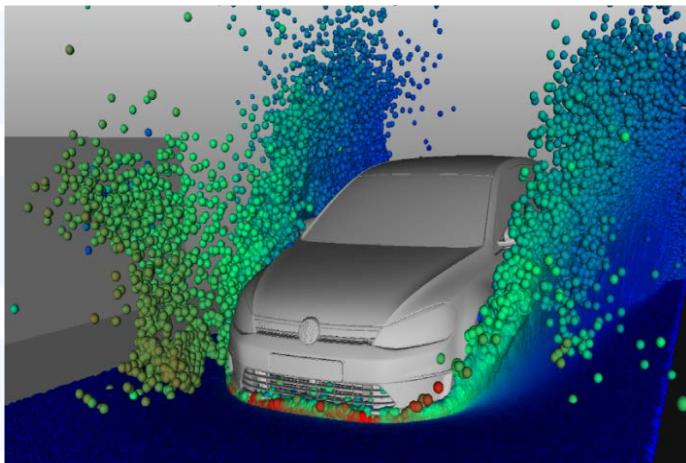
Fraunhofer
ITWM



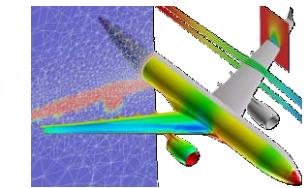
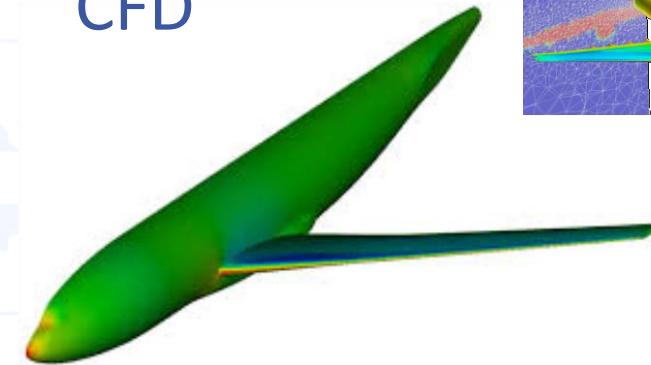
Global
Address Space
Programming Interface
GASPI
gaspi

Some GASPI applications

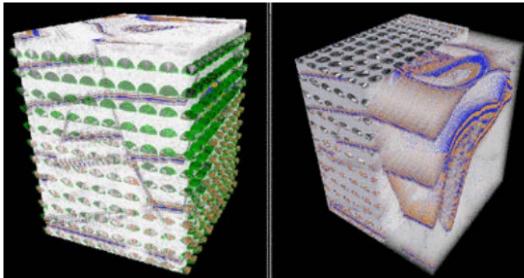
Visualization



CFD

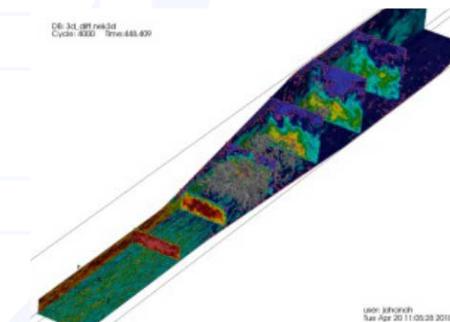


Seismic Imaging & Algorithms

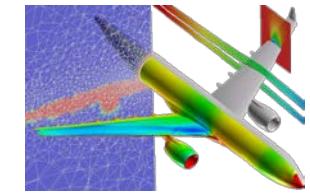


Machine Learning
Big Data
Iterative Solvers

D8-3d_dft_nx3d
Cycle: 4000 - Time: 483.409



User: johndoe
Tue Apr 20 11:05:33 2010



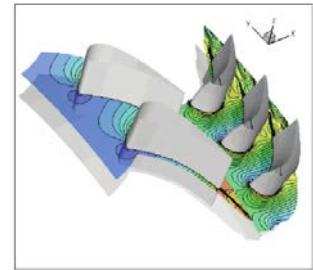
Concepts: Communication



Data Transfer



Synchronisation



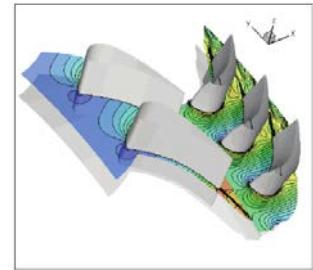
Concepts: one-sided communication

- One-sided operations between parallel processes include remote reads and writes
- Data can be accessed without participation of the remote site
- The initiator specifies all parameters
 - Source location
 - Target location
 - Message size



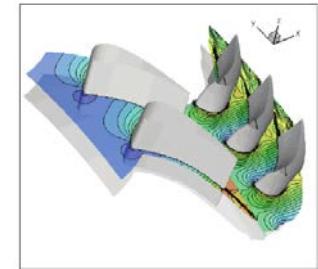
Concepts: segments

- Data can be accessed without participation of the remote site.
- Remote sides have to know about designated communication area(s) before hand
- Designated communication areas in GASPI are called segments



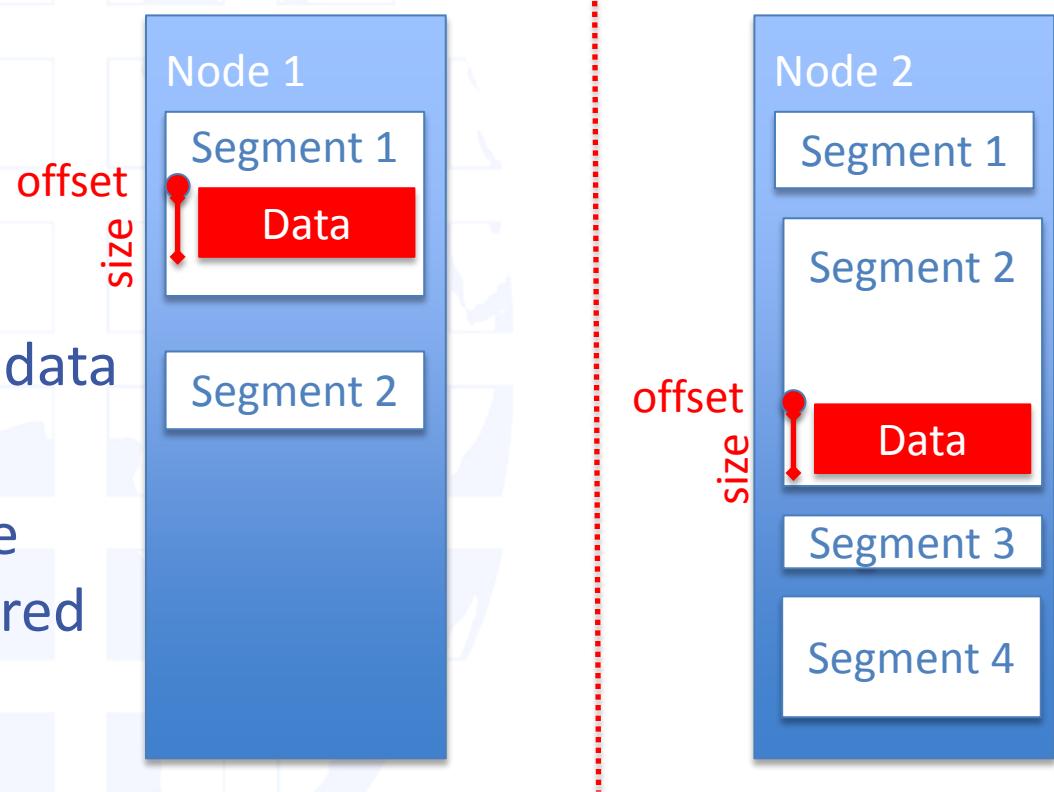


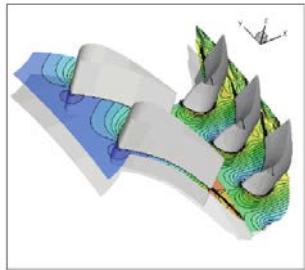
Concepts: segments



Application has to manage data transfer completely:

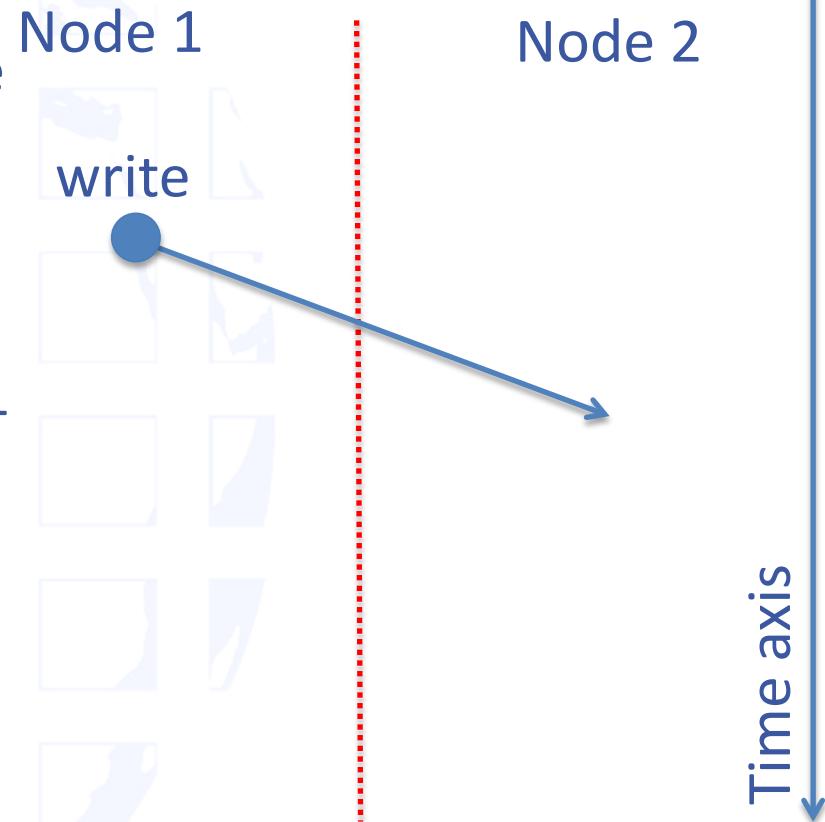
- Specify which part of the segment will be transferred (offset and size)

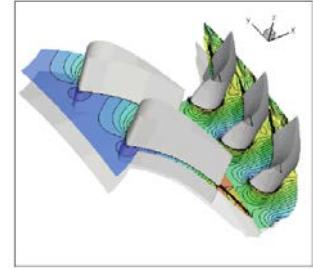




Concepts: one-sided communication

- One-sided operations between parallel processes include remote reads and writes.
- Data can be accessed without participation of the remote site.
- One-sided communication is non-blocking: communication is triggered but may not be finished





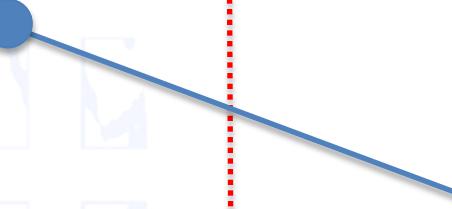
Concepts: one-sided communication

- Node 2 has not participated, it does not know that communication has started

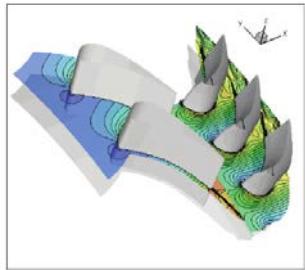
Node 1

Node 2

write

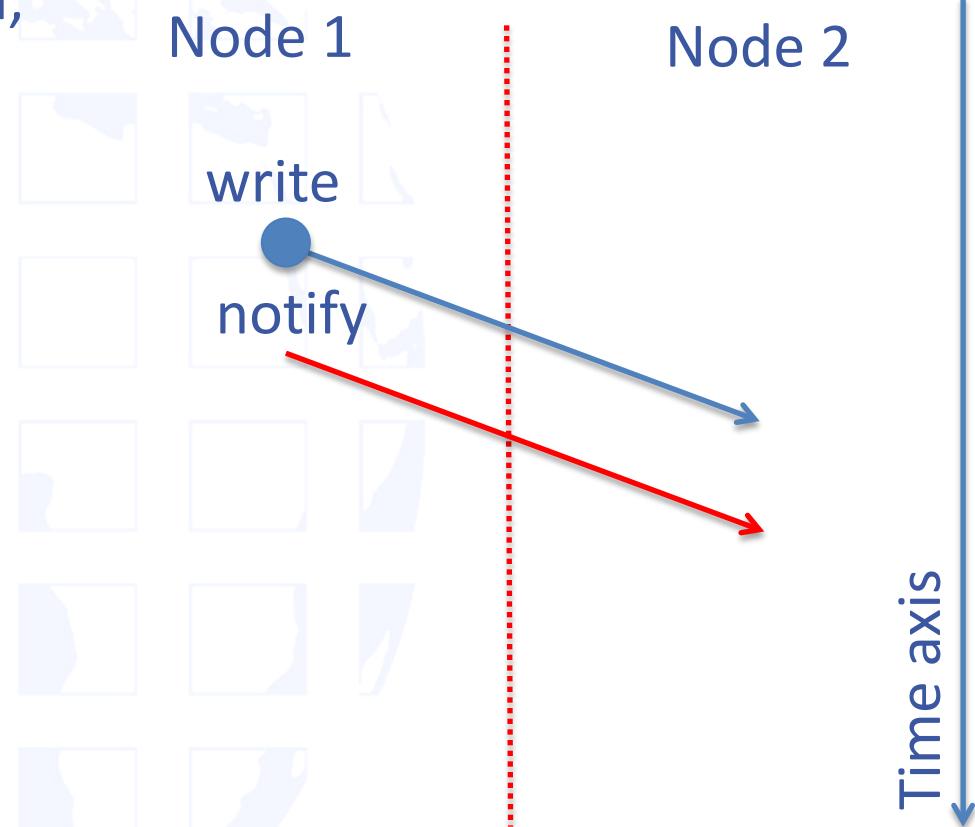


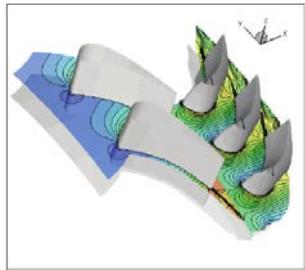
Time axis



Concepts: synchronisation with notifications

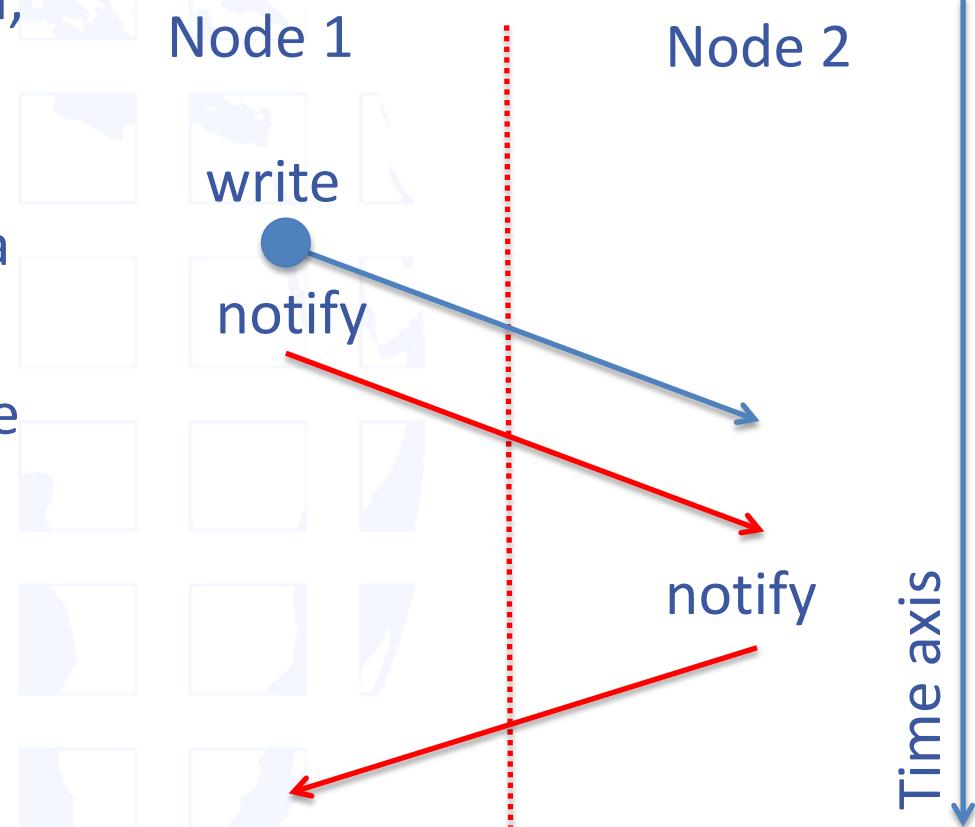
- Node 2 has not participated, it does not know that communication has started
- It has to be notified.

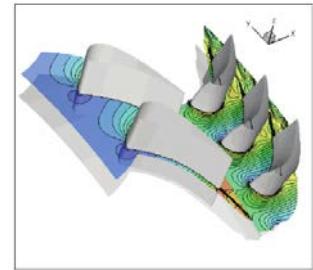




Concepts: synchronisation with notifications

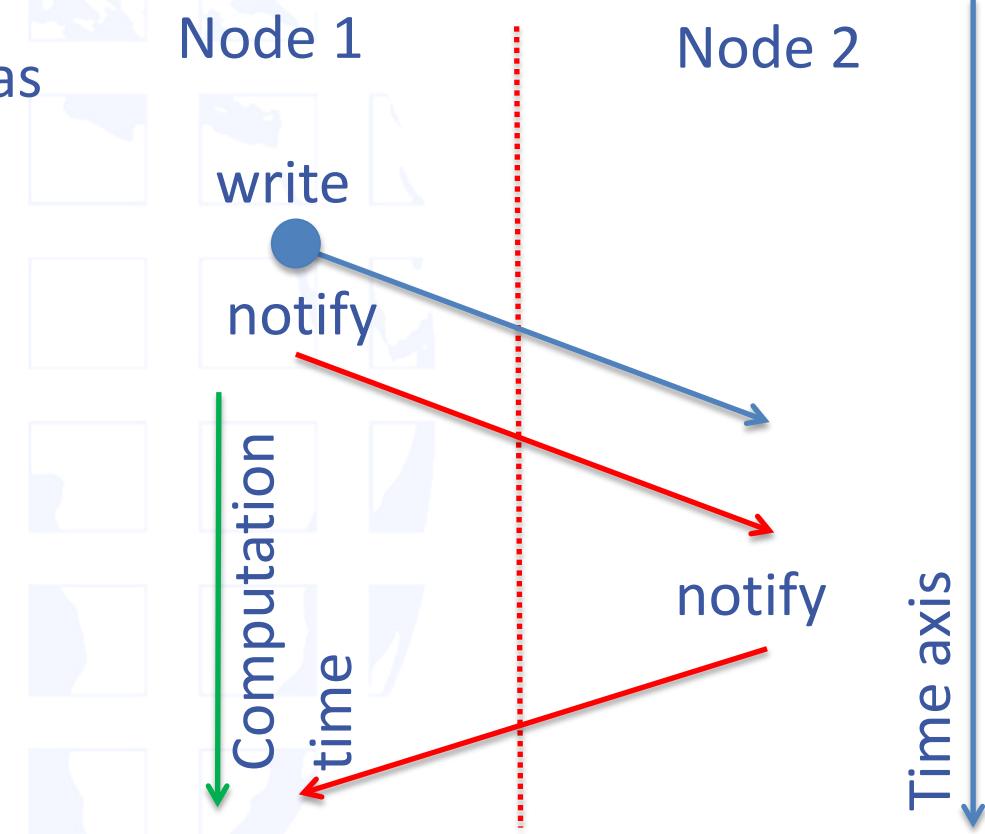
- Node 2 has not participated, it does not know that communication has started
- It has to be notified for data movement completion.
- Node 1 does not know if the write has finished.
- If it needs to know, it also has to be notified





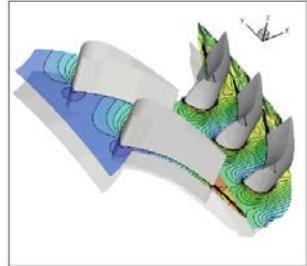
Concepts: overlap of communication and computation

- Due to the non-blocking nature of the call Node 1 has gained some computation time which it can use
- Communication and computation happen in parallel
- Communication latency is hidden

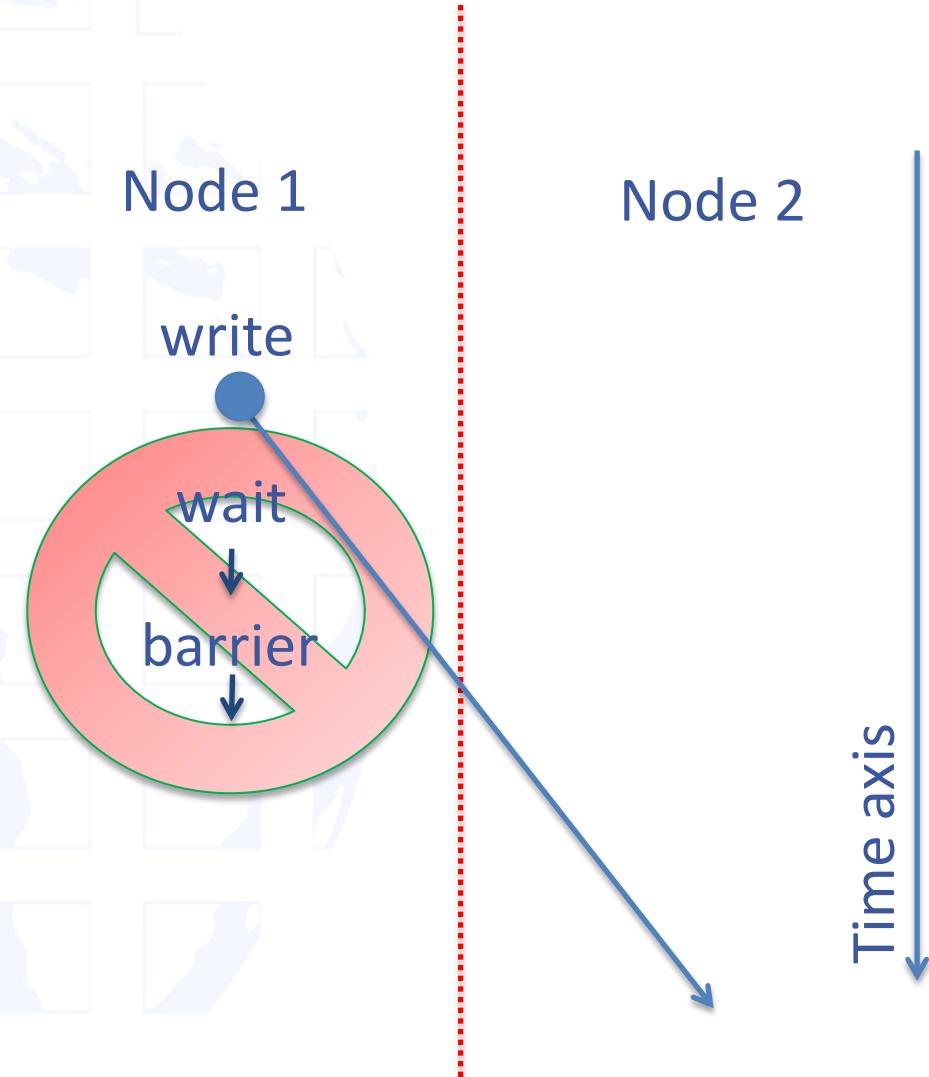


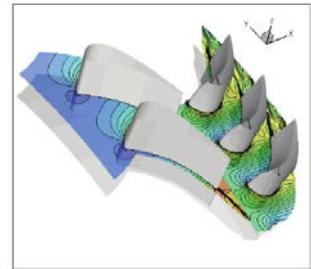


Concepts: warning!



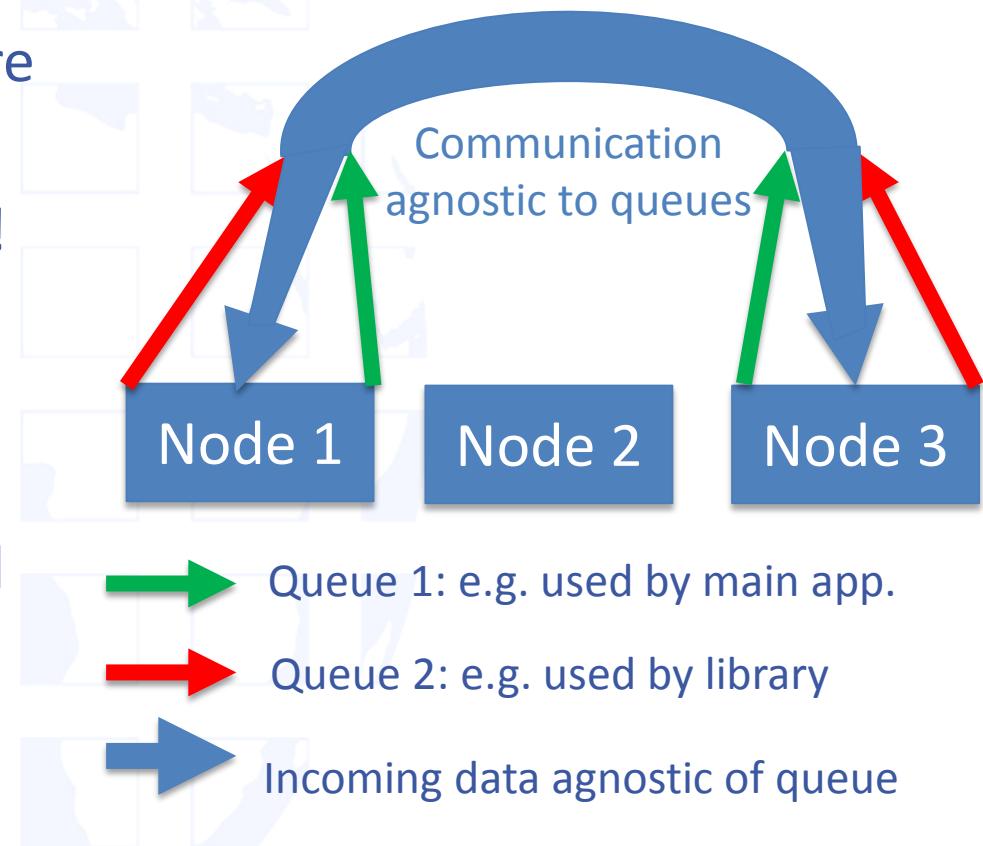
- Data synchronisation by wait + barrier does not work!
- Wait does wait on local queue on Node 1, does not know about write in Node 2, barrier() has no relation with communication
- Data synchronization only by notifications





Concepts: communication queues

- Communication requests are posted to queues
- Queues are a local concept!
- Used to separate concerns between different parts of the applications
- Data movement (write) and synchronization (notify) have to be posted to the same queue





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



Global
Address Space
Programming Interface
GASPI
GASPI

Execution Model



GASPI Execution 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 !



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
```



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`



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



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 startup

- **gaspi_run**

Usage:

```
gaspi_run -m <machinefile>[OPTIONS] <path2bin>
```

Available options:

-b <binary file> Use a different binary for master

-N Enable NUMA for procs on same node

-n <procs> start as many <procs> from machinefile

-d Run with gdb on master node



On Hazel Hen (Cray system)

- Use aprun

```
aprun -n <nprocs> -N <procs_node> <path_to_binary>
```

With threads:

```
aprun -n <nprocs> -N 2 -d 12 -cc numa_node  
<path_to_binary>
```



Hello world – Hands on

- Write a GASPI „Hello World“ program which outputs

Hello world from rank xxx of yyy

- Use `hands_on/helloworld.c` as starting point
- Use `SUCCESS_OR_DIE` macro to check for return values
- Use the debug library (`libGPI2-dbg.a`)
- Execute the Hello World program and explore the several options of `gaspi_run`



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;
}
```



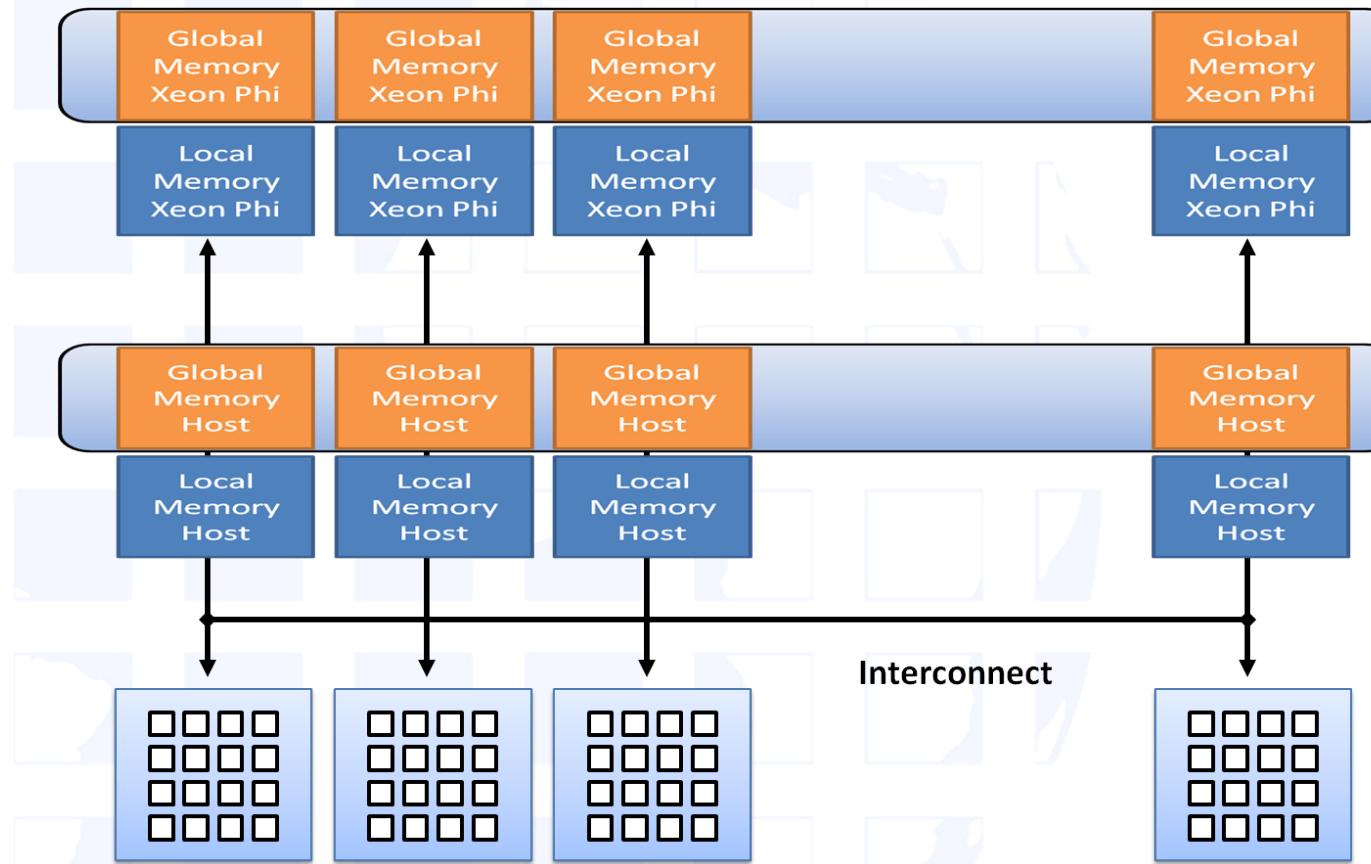
Global
Address Space
Programming Interface
GASPI
Globus API

Memory Segments



Global
Address Space
Programming Interface
GASPI
gaspi

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



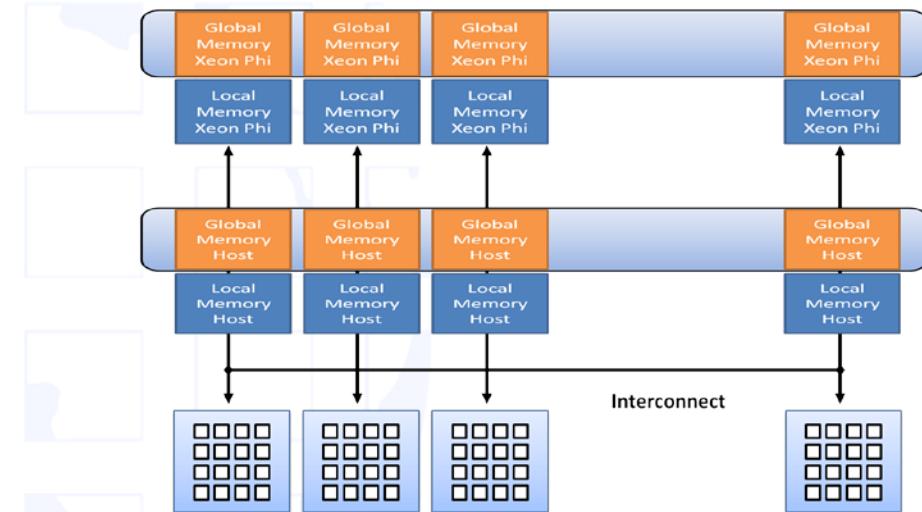
GASPI Segments

- 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)



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



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 with given buffer

- **gaspi_segment_bind**

```
gaspi_return_t gaspi_segment_bind
( gaspi_segment_id_t const segment_id
, gaspi_pointer_t const pointer
, gaspi_size_t const size
, gaspi_memory_description_t const memory_description
)
```

- Binds a buffer to a particular segment
- Same capabilities as allocated/created segment
- Locally accessible (requires `gaspi_segment_register`)



GASPI Segment with given buffer

- `gaspi_segment_use`

```
gaspi_return_t gaspi_segment_use
( gaspi_segment_id_t const segment_id
, gaspi_pointer_t const pointer
, gaspi_size_t const size
, gaspi_group_t const group
, gaspi_timeout_t const timeout
, gaspi_memory_description_t const memory_description
)
```

```
GASPI_SEGMENT_USE (id, pointer, size, group, timeout, memory)
{
    GASPI_SEGMENT_BIND (id, pointer, size, memory);

    foreach (rank : group)
    {
        timeout -= GASPI_CONNECT (id, rank, timeout);
        timeout -= GASPI_SEGMENT_REGISTER (id, rank, timeout);
    }

    GASPI_BARRIER (group, timeout);
}
```

- Equivalent to



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 )
```



GASPI Segment Utils

- `gaspi_segment_max`

```
gaspi_return_t  
gaspi_segment_max (gaspi_number_t *segment_max)
```

- Maximum number of segments
- Defines range of allowed segment IDs
[0,segment_max - 1)



Using Segments – Hands on

- Write a GASPI program which stores a NxM matrix in a distributed way: 1 row per process

0	1	...	M-1
M	M+1	...	2M-1
(N-1)M	(N-1)M+1	...	NM-1

- Create a segment
- Initialize the segment

Row 0

Row 1

Row N-1

- output the result



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 );

    gaspi_printf( "rank %d elem %d: %f \n",
                  , iProc, j, (double *)array )[j] );
}

SUCCESS_OR_DIE( gaspi_proc_term(GASPI_BLOCK) );

return EXIT_SUCCESS;
}
```



Global
Address Space
Programming Interface
GASPI
GASPI

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 transferring 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 transferring 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



Queues (III)

- Queues have a finite capacity
- Queues are not automatically flushed
 - Maximize time between posting the last request and flushing the queue
- ATTENTION: Queues can overflow
 - Always check remaining capacity before posting a request



GASPI Queue Utils

- **gaspi_queue_size**

```
gaspi_return_t  
gaspi_queue_size ( gaspi_queue_id_t queue  
                  , gaspi_number_t const *queue_size )
```

- **gaspi_queue_size_max**

```
gaspi_return_t  
gaspi_queue_size_max ( gaspi_number_t* queue_size_max )
```



GASPI Queue Utils

- **gaspi_queue_num**

```
gaspi_return_t  
gaspi_queue_num (gaspi_number_t *queue_num)
```

- **gaspi_queue_max**

```
gaspi_return_t  
gaspi_queue_max ( gaspi_number_t queue_max )
```



GASPI Queue Utils

- **gaspi_queue_create**

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

- **gaspi_queue_delete**

```
gaspi_return_t  
gaspi_queue_delete ( gaspi_queue_id_t queue )
```



wait_for_queue_entries

- Implements queue ring buffer
- Checks for remaining queue capacity to insert wanted_entries
- In case of missing capacity:
 - switch queue
 - flush (wait) new queue
 - > Time between posting requests and flushing the queue is maximized
 - > Minimized probability to really wait on outstanding requests

```
#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));
    }
}
```



wait_for_flush_queues

- Flush all queues

```
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;  
    }  
}
```



Data Synchronization By Notification

- 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 notification mechanism



GASPI Notification Mechanism

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



GASPI Notification Mechanism

- **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 Notification Mechanism

- **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 Notification Mechanism

- **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



wait_or_die

- Wait for a given notification and reset
- Sanity checks
- Input
 - segment_id
 - notification_id
 - expected notification value

```
#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);
}
```



test_or_die

- Test for a given notification and reset
- Sanity checks
- Input
 - segment_id
 - notification_id
 - expected notification value
- Return value
 - 1 in case that notification has arrived and notification value equals expected value
 - 0 in case that notification has not arrived yet

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

int test_or_die
( gaspi_segment_id_t segment_id
, gaspi_notification_id_t notification_id
, gaspi_notification_t expected
)
{
    gaspi_notification_id_t id;
    gaspi_return_t ret;

    if ( ( ret =
        gaspi_notify_waitsome (segment_id, notification_id, 1, &id, GASPI_TEST)
        ) == GASPI_SUCCESS
    )
    {
        ASSERT (id == notification_id);

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

        return 1;
    }
    else
    {
        ASSERT (ret != GASPI_ERROR);

        return 0;
    }
}
```



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`



GASPI extended one-sided

- **gaspi_write_notify**

```
gaspi_return_t
gaspi_write_notify ( 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_notification_id_t notification_id
                     , gaspi_notification_t notification_value
                     , gaspi_queue_id_t queue
                     , gaspi_timeout_t timeout )
```

- **gaspi_write with subsequent gaspi_notify**



GASPI extended one-sided

- **gaspi_write_list**

```
gaspi_return_t  
gaspi_write_list ( gaspi_number_t num  
                  , gaspi_segment_id_t const *segment_id_local  
                  , gaspi_offset_t const *offset_local  
                  , gaspi_rank_t rank  
                  , gaspi_segment_id_t const *segment_id_remote  
                  , gaspi_offset_t const *offset_remote  
                  , gaspi_size_t const *size  
                  , gaspi_queue_id_t queue  
                  , gaspi_timeout_t timeout )
```

- several subsequent `gaspi_write`



GASPI extended one-sided

- **gaspi_write_list**

```
gaspi_return_t  
gaspi_write_list ( gaspi_number_t num  
                  , gaspi_segment_id_t const *segment_id_local  
                  , gaspi_offset_t const *offset_local  
                  , gaspi_rank_t rank  
                  , gaspi_segment_id_t const *segment_id_remote  
                  , gaspi_offset_t const *offset_remote  
                  , gaspi_size_t const *size  
                  , gaspi_queue_id_t queue  
                  , gaspi_timeout_t timeout )
```

- several subsequent `gaspi_write`



GASPI extended one-sided

- **gaspi_write_list_notify**

```
gaspi_return_t
gaspi_write_list_notify
    ( gaspi_number_t num
    , gaspi_segment_id_t const *segment_id_local
    , gaspi_offset_t const *offset_local
    , gaspi_rank_t rank
    , gaspi_segment_id_t const *segment_id_remote
    , gaspi_offset_t const *offset_remote
    , gaspi_size_t const *size
    , gaspi_notification_id_t notification_id
    , gaspi_notification_t notification_value
    , gaspi_queue_id_t queue
    , gaspi_timeout_t timeout )
```

- several subsequent `gaspi_write` and a notification



GASPI extended one-sided

- **gaspi_read_list**

```
gaspi_return_t
gaspi_read_list ( gaspi_number_t num
                  , gaspi_segment_id_t const *segment_id_local
                  , gaspi_offset_t const *offset_local
                  , gaspi_rank_t rank
                  , gaspi_segment_id_t const *segment_id_remote
                  , gaspi_offset_t const *offset_remote
                  , gaspi_size_t const *size
                  , gaspi_queue_id_t queue
                  , gaspi_timeout_t timeout )
```

- several subsequent `gaspi_read`



Communication – Hands on

- Take your GASPI program which stores a NxM matrix in a distributed way and extend it by communication for rows

0	1	...	M-1
M	M+1	...	2M-1
(N-1)M	(N-1)M+1	...	NM-1

- Create a segment (sufficient size for a source and target row)
- Initialize the segment

Row 0

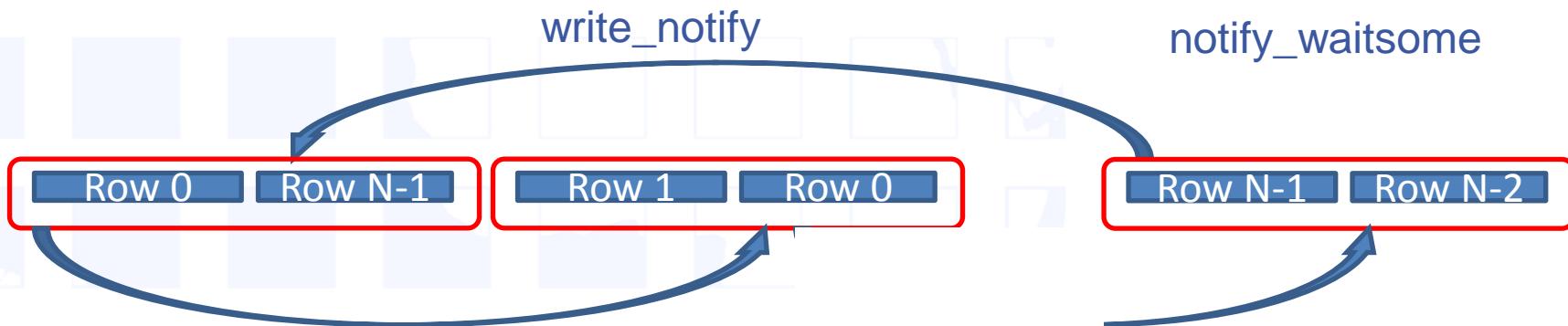
Row 1

Row N-1



Communication – Hands on

- Take your GASPI program which stores a NxM matrix in a distributed way and extend it by communication
 - Communicate your row to your right neighbour (periodic BC)



- Check that the data is available
- Output the result



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 );
    }
```



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
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`



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
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



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.



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
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



Global
Address Space
Programming Interface
GASPI
GASPI

Interoperability with MPI



Interoperability with MPI

- GPI-2 supports interoperability with MPI in a so-called mixed-mode, where the MPI and GASPI interfaces can be mixed
- The mixed-mode allows for
 - either entirely porting an MPI application to GASPI
 - or replacing performance-critical parts of an MPI based application with GASPI code (useful when dealing with large MPI code bases)
- Porting guides available at:
<http://www.gpi-site.com/gpi2/docs/whitepapers/>



Mixing GASPI and MPI in Parallel Programs

- GPI-2 must be installed with MPI support, using the option
 --with-mpi <path_to_mpi_installation>
- MPI must be initialized before GPI-2, as shown in the joined example
- The same command or script as the one provided by the MPI installation should be used for starting programs (mpirun or similar)
- `gaspi_run` should not be used!

```
#include <assert.h>
#include <GASPI.h>
#include <mpi.h>

int main (int argc, char *argv[ ])
{
    // initialize MPI and GASPI
    MPI_Init (&argc, &argv);
    gaspi_proc_init (GASPI_BLOCK);

    // Do work ...

    // shutdown GASPI and MPI
    gaspi_proc_term (GASPI_BLOCK);
    MPI_Finalize();

    return 0;
}
```



GPI-2 Preserves the MPI Ranks

- GPI-2 is able to detect at runtime the MPI environment and to setup its own environment based on this
- GPI-2 can deliver the same information about ranks and number of processes as MPI
- This helps to preserve the application logic

```
...
int my_mpi_rank, n_mpi_procs;
MPI_Init (&argc, &argv);
MPI_Comm_rank (MPI_COMM_WORLD, &my_mpi_rank);
MPI_Comm_size (MPI_COMM_WORLD, &n_mpi_procs);

gaspi_rank_t my_gaspi_rank, n_gaspi_procs;

SUCCESS_OR_DIE
    (gaspi_proc_init,GASPI_BLOCK);
SUCCESS_OR_DIE
    (gaspi_proc_rank,&my_gaspi_rank);
SUCCESS_OR_DIE
    (gaspi_proc_num,&n_gaspi_procs);

assert(my_mpi_rank == my_gaspi_rank);
assert(n_mpi_procs == n_gaspi_procs);

...
```



Using User Provided Memory for Segments

- New feature added in version 1.3 of GPI-2: a user may provide already allocated memory for segments
- Memory used in MPI communication can be used in GASPI communication
- However, the feature should be used with care because the segment creation is an expensive operation

```
//initialize and allocate memory
double *buffer = calloc ( num_elements
                        , sizeof(double)
                      );
gaspi_segment_id_t segment_id = 0;

//use the allocated buffer as underlying
//memory support for a segment
SUCCESS_OR_DIE
(
  gaspi_segment_use
  , segment_id
  , buffer
  , n*sizeof (double)
  , GASPI_GROUP_ALL
  , GASPI_BLOCK
  , 0
);
```



Using GPI-2 Segment Allocated Memory in MPI Communication

```
// create segment
gaspi_segment_id_t segment_id = 1;
SUCCESS_OR_DIE
(
    gaspi_segment_create
    , segment_id
    , n * sizeof (double)
    , GASPI_GROUP_ALL
    , GASPI_BLOCK
    , GASPI_MEM_UNINITIALIZED
);
// do work
...
// use GPI-2 allocated memory as a buffer in MPI communication
MPI_Bcast (gaspi_ptr_from, n, MPI_DOUBLE, 0, MPI_COMM_WORLD);
// do work
```



Mixing MPI Code with GPI-2 Code From a Library

- In mixed-mode, an MPI based code may call GASPI code that is embedded into a library

```
int n, my_mpi_rank, n_mpi_procs;  
MPI_Init (&argc, &argv);  
MPI_Comm_rank (MPI_COMM_WORLD, &my_mpi_rank);  
MPI_Comm_size (MPI_COMM_WORLD, &n_mpi_procs);  
SUCCESS_OR_DIE  
    (gaspi_proc_init, GASPI_BLOCK);  
// initialize data  
// distribute data, do MPI communication  
// call GPI library function for iteratively  
// solving a linear system  
jacobi ( n, n_local_rows, local_a, local_b  
        , &x, x_new, n_max_iter, tol  
        );  
SUCCESS_OR_DIE (gaspi_proc_term, GASPI_BLOCK);  
MPI_Finalize();
```

- The GASPI environment must be initialized and cleaned up within the calling program



Interoperability - Hands on - I

```
#include "mpi.h"
#include <assert.h>
#include <stdlib.h>
#include <time.h>

int main(int argc, char* argv[])
{
    int n, my_mpi_rank, n_mpi_procs;

    MPI_Init (&argc, &argv);
    MPI_Comm_rank (MPI_COMM_WORLD, &my_mpi_rank);
    MPI_Comm_size (MPI_COMM_WORLD, &n_mpi_procs);

    if (my_mpi_rank == 0)
    {
        printf ("Please, introduce an integer number:\n");
        scanf ("%d", &n);
        assert (n > 0);
    }
```

```
// broadcast n to all ranks
MPI_Bcast (&n, 1, MPI_INT, 0, MPI_COMM_WORLD);

srand (my_mpi_rank + 1);
int my_bid = rand() % n + 1;
printf ("rank %d: my bid is %d\n", my_mpi_rank, my_bid);

int max = my_bid;

for (int rank = 0; rank < n_mpi_procs; rank++)
{
    if (rank == my_mpi_rank)
        continue;

    MPI_Send
        (&my_bid, 1, MPI_INT, rank, 100, MPI_COMM_WORLD);

    printf ("Sent %d to rank %d\n", my_bid, rank);
}
```



Interoperability - Hands on - II

```
for (int rank = 0; rank < n_mpi_procs; rank++)  
{  
    if (rank == my_mpi_rank)  
        continue;  
  
    int bid;  
    MPI_Status status;  
    MPI_Recv ( &bid, 1, MPI_INT , rank, 100, MPI_COMM_WORLD , &status);  
    printf ("Received %d from rank %d\n", bid, rank);  
  
    if (bid >max) max = bid;  
}  
  
if (my_mpi_rank == 0) printf ("The maximum bid is %d\n", max);  
MPI_Finalize();  
return 0;  
}
```



Interoperability - Hands on - III

1. Modify the above MPI program, such that the GASPI environment is initialized after MPI
2. Check if the MPI ranks and GASPI ranks are identical
3. Create a GASPI segment and replace the MPI_Send/Recv calls with GASPI one sided communication, using the `gaspi_write_notify`, `gaspi_waitsome` and `gaspi_notify_reset` primitives
4. Use GASPI segment allocated memory as a communication buffer in the MPI broadcast operation
5. Allocate memory for a buffer and use this in the MPI broadcast operation and as user provided memory for the GASPI segment used in the GASPI communication



Global
Address Space
Programming Interface
GASPI
GASPI

The GASPI programming model



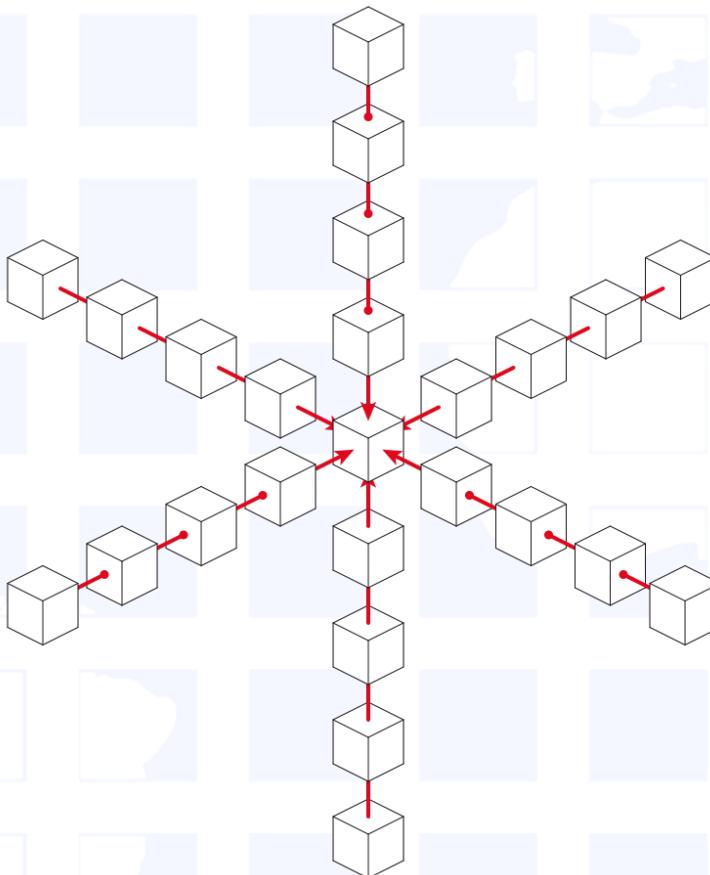
Global
Address Space
Programming Interface
GASPI
GASPI

From bulk synchronous communication to a fully asynchronous execution
with maximal overlap of communication and computation

THINK PERFORMANCE



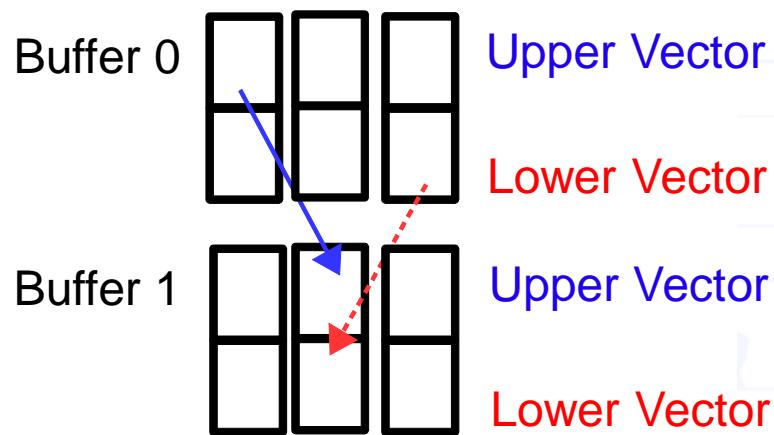
Example: Stencil applications



- Important class of algorithms
 - FD methods
 - Image processing
 - PDEs
- Iterative method
- Non-local updates
-> data dependencies



Stencil application proxy



Update step:

- Update upper part
- Update lower part

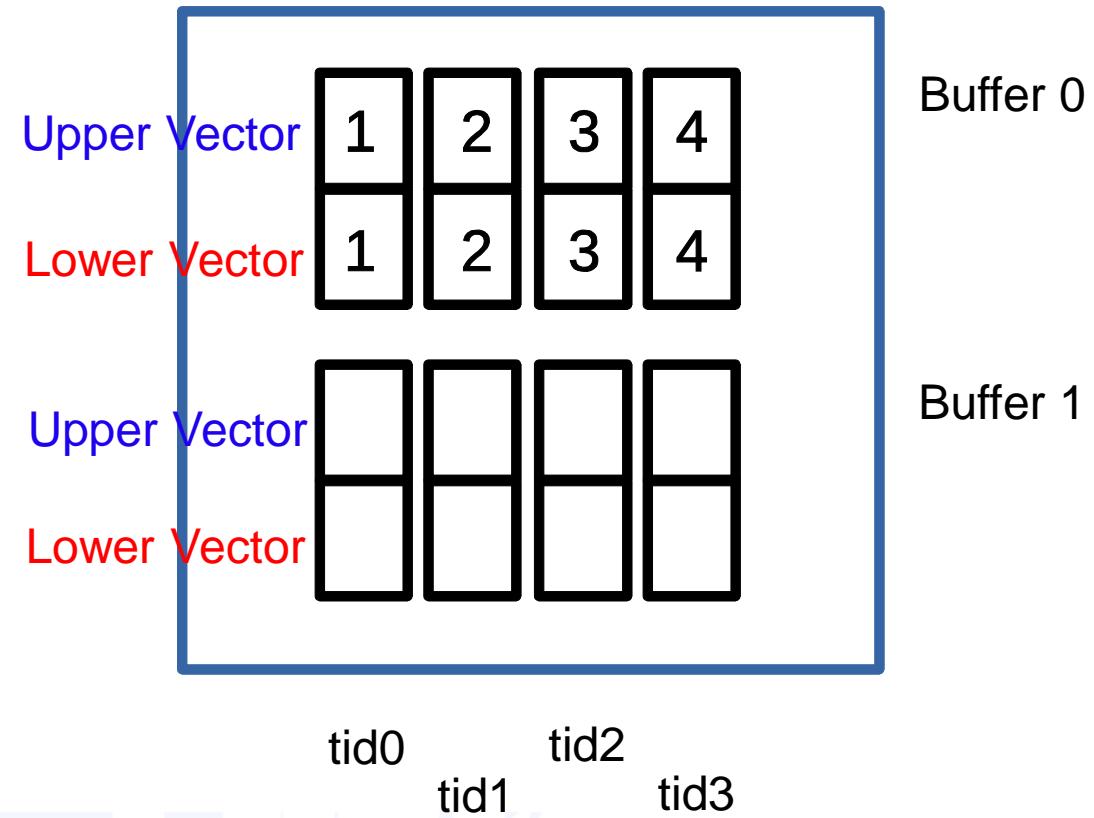
- 2 buffers per element
 - Buffer 0
 - Buffer 1
- 2 vectors per buffer
 - Upper vector
 - Lower vector
- Data dependencies
 - Left element
 - Right element



Global
Address Space
Programming Interface
GASPI
GASPI

Stencil application proxy

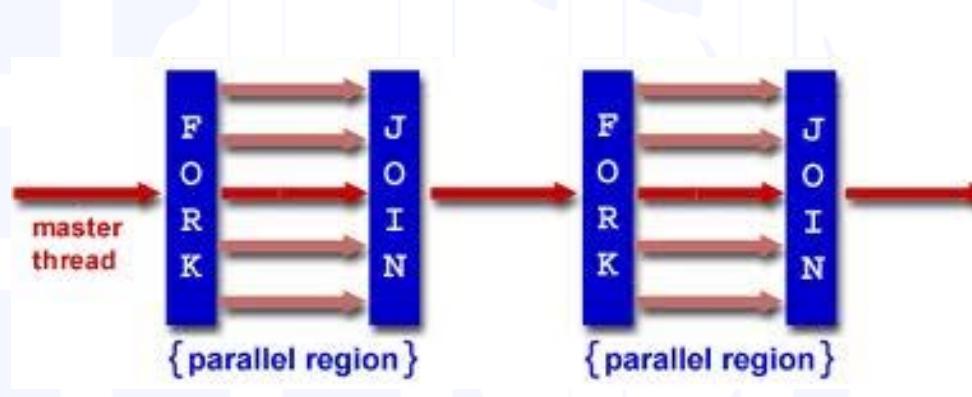
- Nthread omp threads
- static domain decomposition / assignment
- Two buffers per thread
- Two vectors per buffer
- Vector length: nvector





Global
Address Space
Programming Interface
GASPI
Globally Addressed Shared Memory Interface

Fork-Join model





Iteration 1

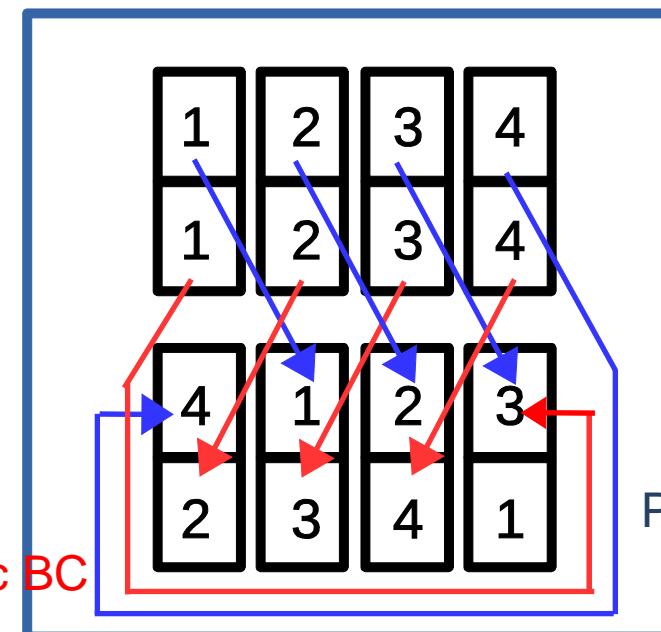
Lower half: move
to the left

Periodic BC

Upper half: move
to the right

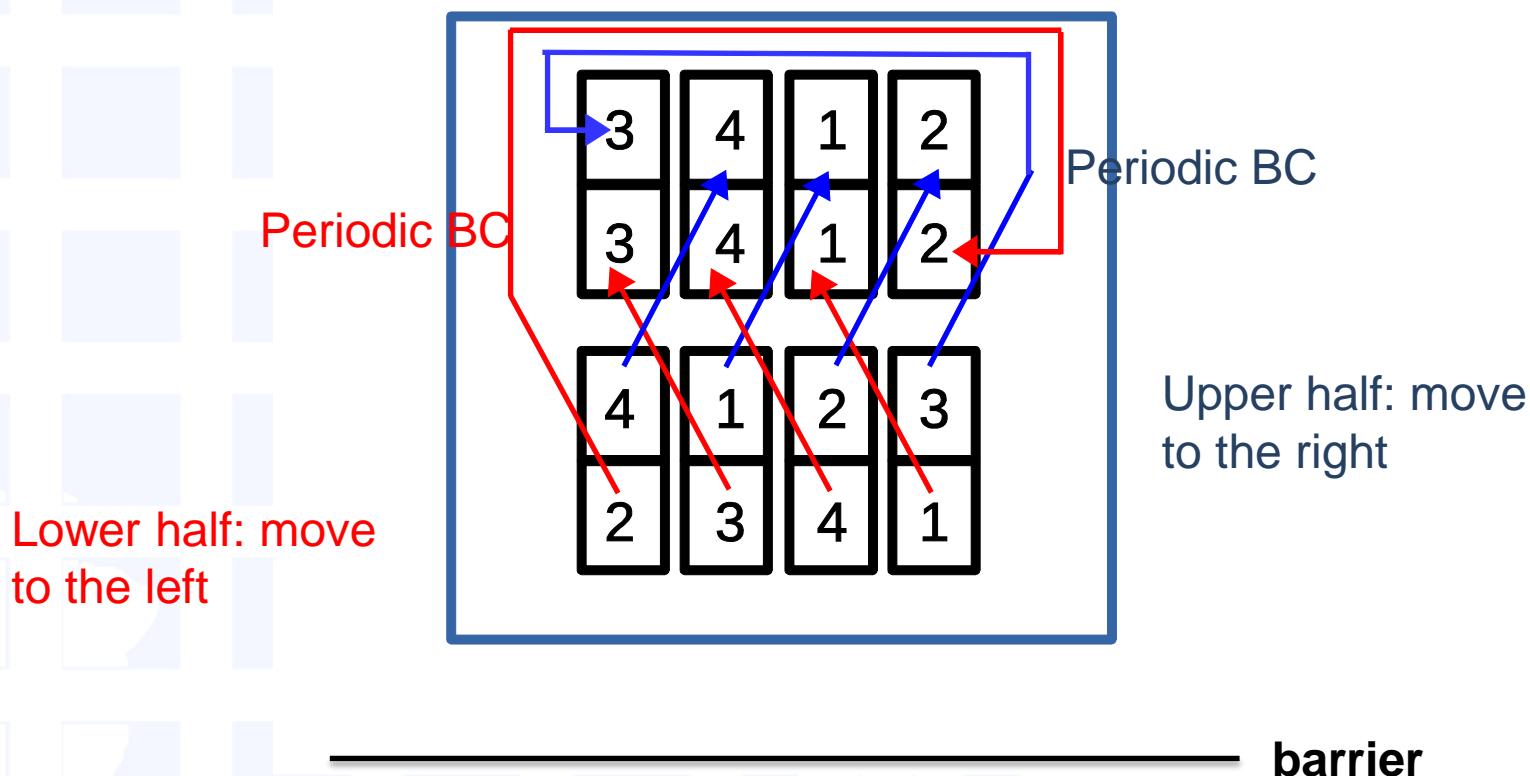
Periodic BC

barrier





Iteration 2





Iteration 3

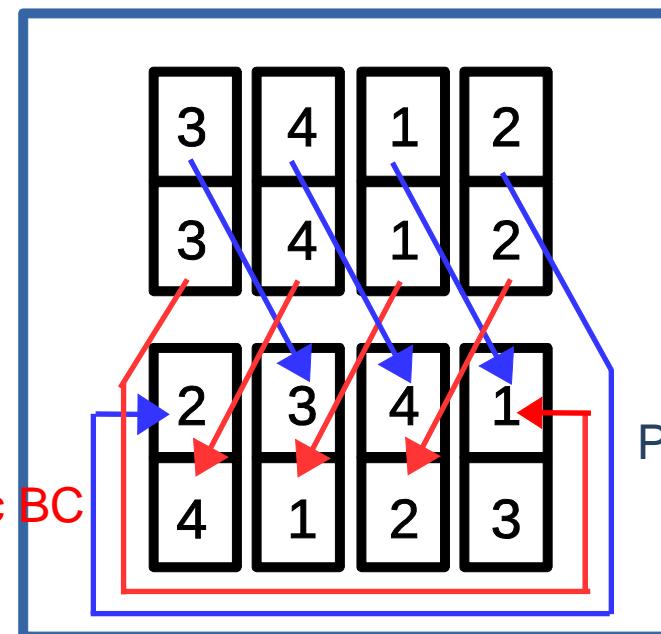
Lower half: move
to the left

Periodic BC

Upper half: move
to the right

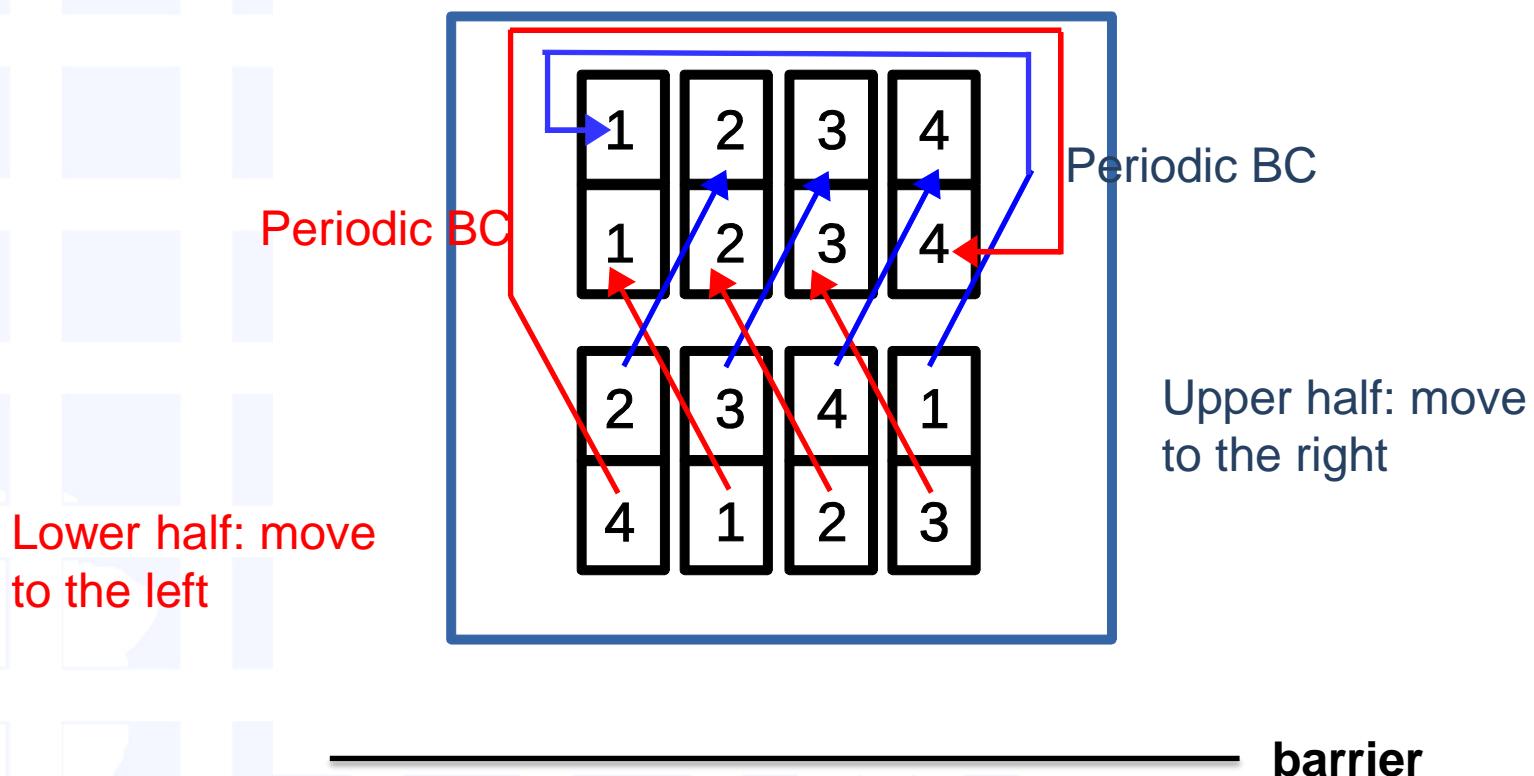
Periodic BC

barrier





Iteration 4





Global
Address Space
Programming Interface
GASPI
GASPI

- Nelem many iterations:

- Initial configuration recovered
- > Easy to check

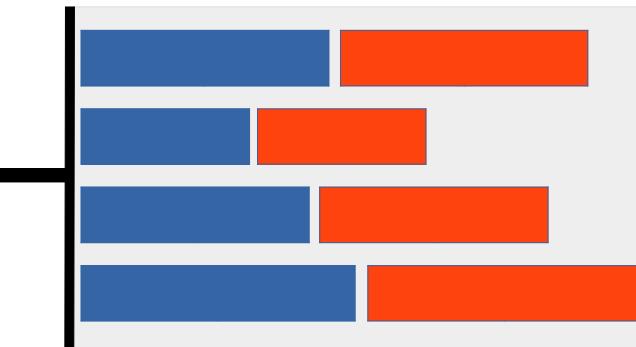


Global
Address Space
Programming Interface
GASPI
gaspi

Temporal evolution

single iteration

tid 0
tid 1
tid 2
tid 3



Fork / barrier

Join / barrier

Time

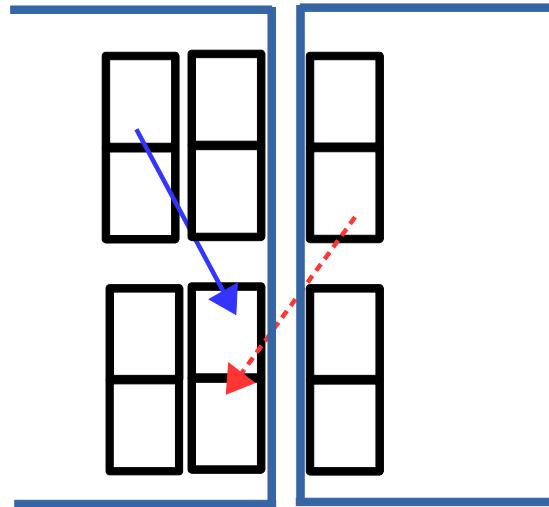


Global
Address Space
Programming Interface
GASPI
GASPI

MORE THAN ONE PROCESS ...



Elementary update

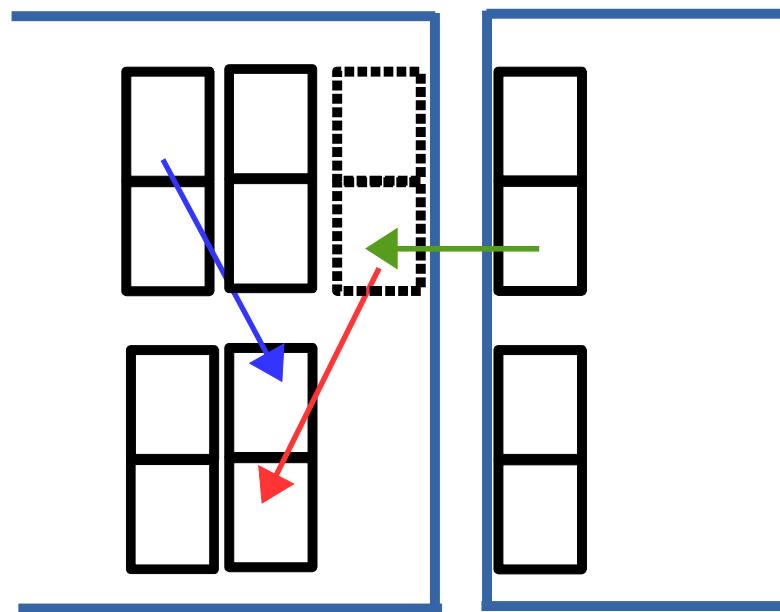


- Each process hosts some part of the information
- Part of the information is no longer directly accessible



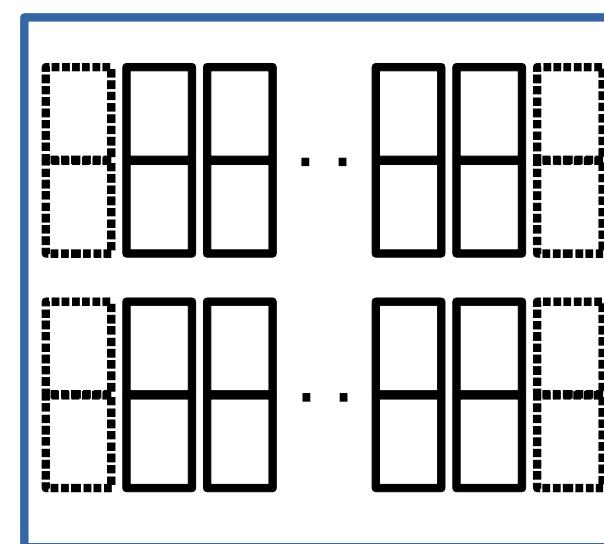
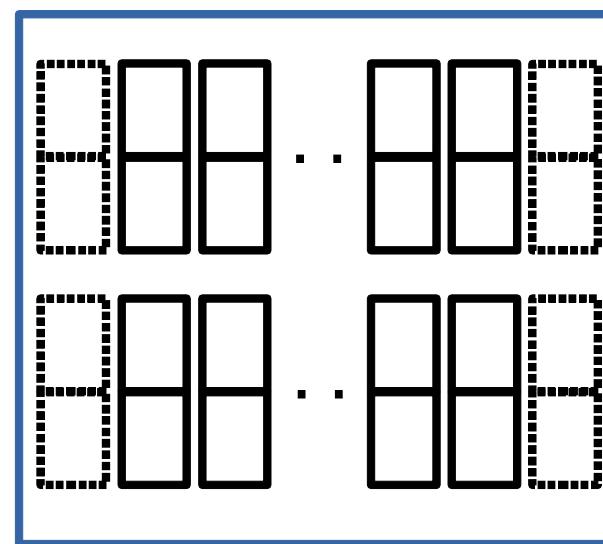
Global
Address Space
Programming Interface
GASPI
gaspi

Boundary / Halo domains





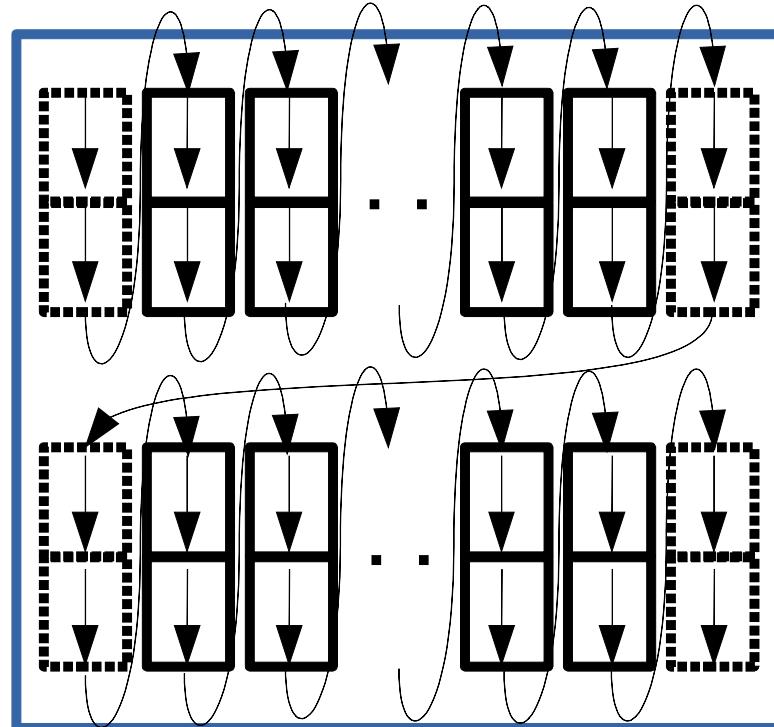
Global
Address Space
Programming Interface
GASPI
GASPI





Global
Address Space
Programming Interface
GASPI
gaspi

Memory layout





Global
Address Space
Programming Interface
GASPI
GASPI

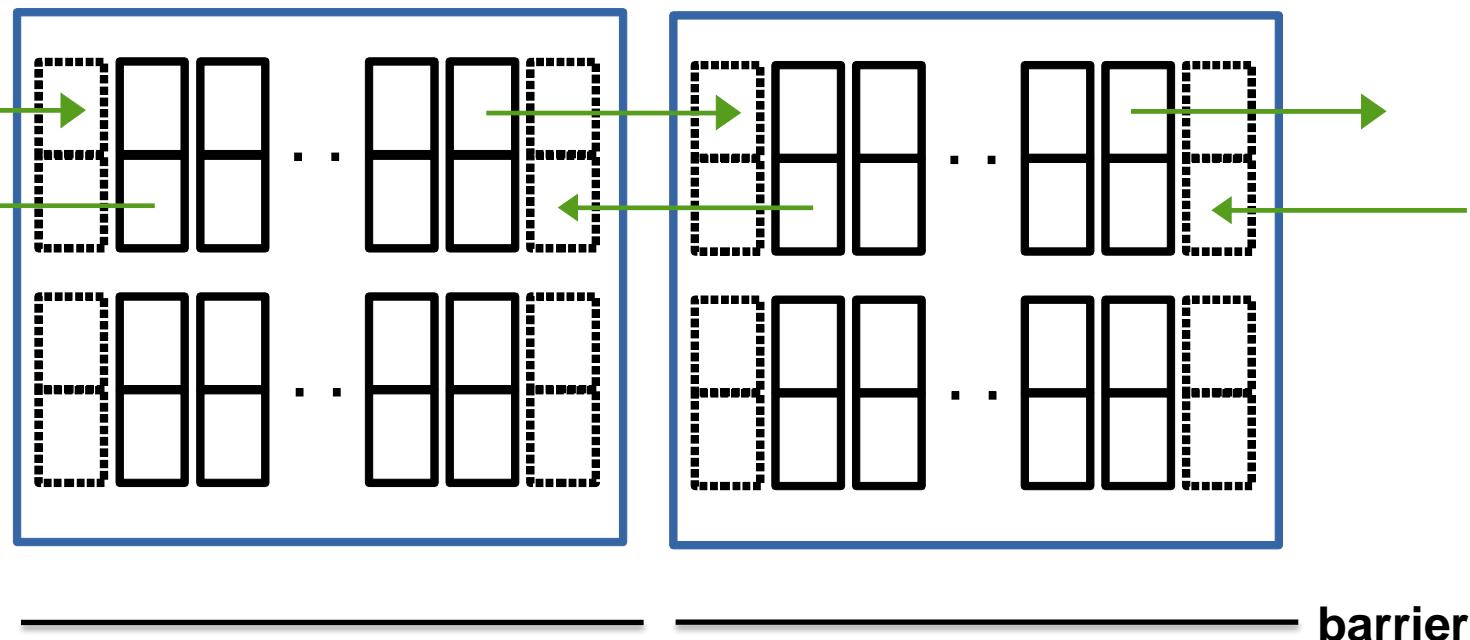
Separate communication / computation phases

BULK SYNCHRONOUS



Global
Address Space
Programming Interface
GASPI
gaspi

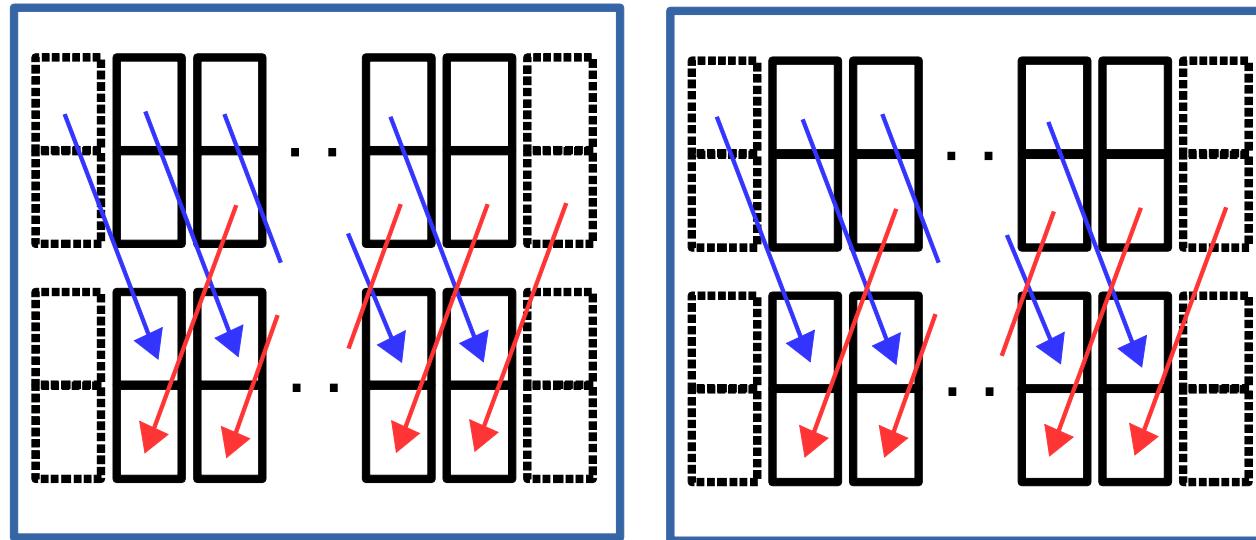
Communication phase





Global
Address Space
Programming Interface
GASPI
gaspi

Computation phase



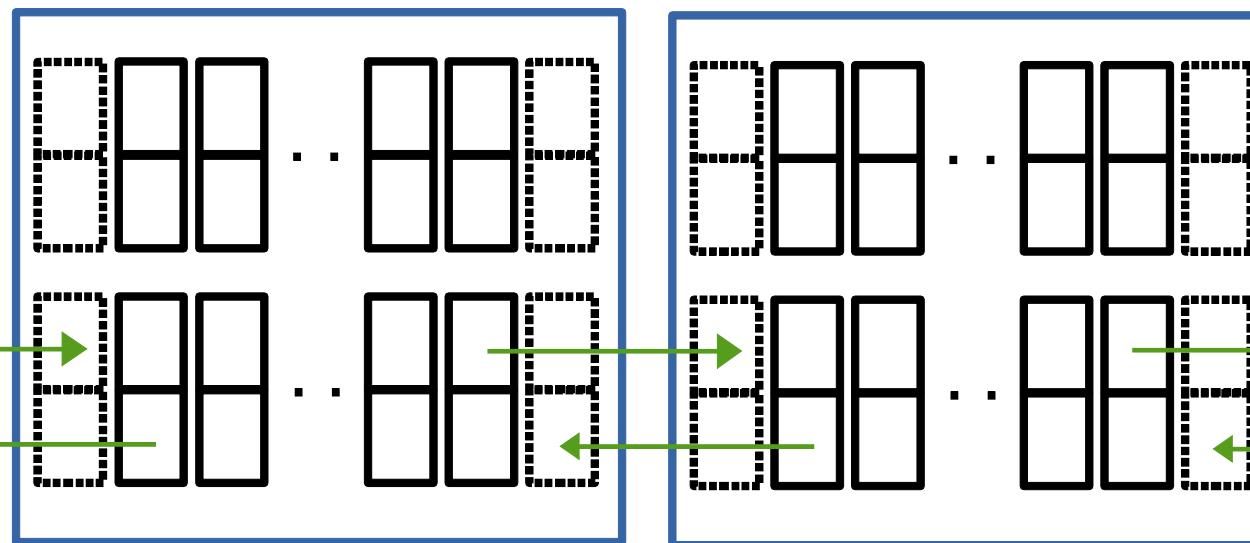
barrier

barrier



Global
Address Space
Programming Interface
GASPI
gaspi

Communication phase



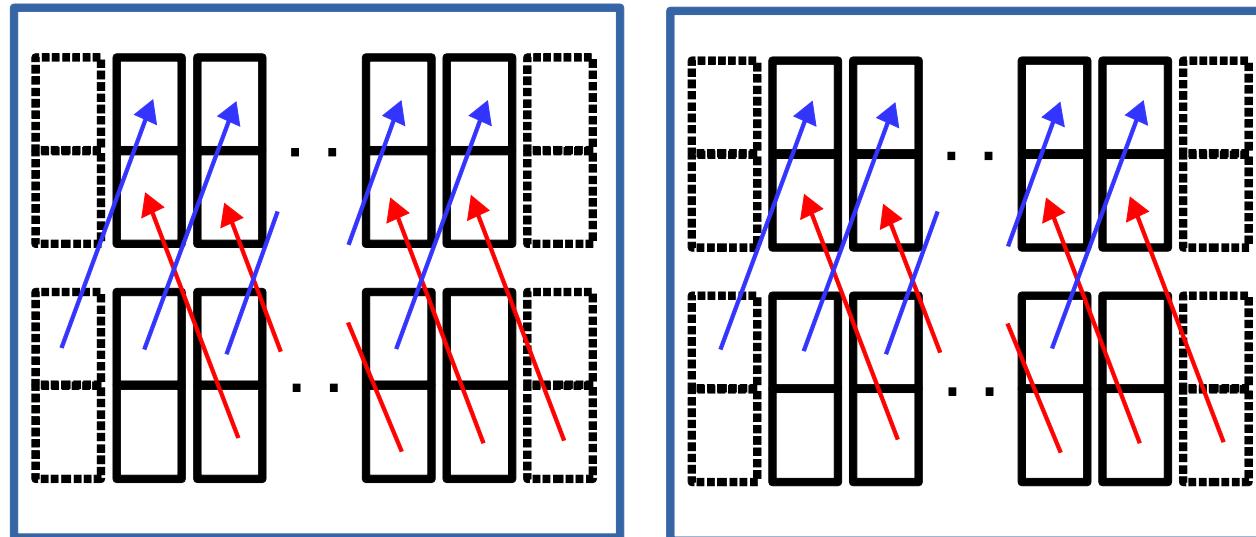
barrier

barrier



Global
Address Space
Programming Interface
GASPI
gaspi

Computation phase



barrier

barrier



Hands-on

- Implement the bulk-synchronous algorithm
 - use `left_right_double_buffer_funneld.c` as template



The GASPI Ring Exchange

- GASPI – left_right_double_buffer_funneler.c

```
if (tid == 0) {  
    wait_for_queue_entries_for_write_notify (&queue_id);  
    SUCCESS_OR_DIE ( gaspi_write_notify  
    ( segment_id, array_OFFSET_lower(buffer_id, left_halo+1, 0), left,  
      segment_id, array_OFFSET_lower(buffer_id,right_halo,0),VLEN* sizeof(double),  
      right_data_available[buffer_id], 1 + i, queue_id, GASPI_BLOCK ));  
    wait_for_queue_entries_for_write_notify (&queue_id);  
    SUCCESS_OR_DIE ( gaspi_write_notify  
        ( segment_id, array_OFFSET_upper (buffer_id, right_halo-1, 0), right,  
          segment_id, array_OFFSET_upper(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
gaspi

Basic ingredients

EXCURSION: EFFICIENT PARALLEL EXECUTION



Efficient parallel execution

- Question: What is the measure for „efficient parallel execution“ ?



Global
Address Space
Programming Interface
GASPI
GASPI

Efficient parallel execution

- Question: What is the measure for „efficient parallel execution“ ?

SCALABILITY



Scalability S

- Definition: $S(N_{proc}) = \frac{T(1)}{T(N_{proc})}$
- Interpretation:

Measure for the additional benefit generated by employing additional resources



Scalability S

- Optimal: linear scalability, i.e.

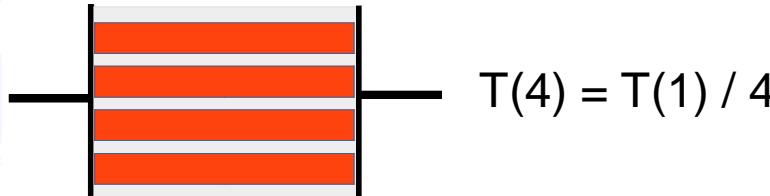
$$T(N_{proc}) = T(1)/N_{proc}$$

-> doubling the resources implies doubling
the generated benefit



Implications for parallelization

- $T(N_{proc}) := T(1)/N_{proc}$



Time



Implications for parallelization

- $T(N_{proc}) := T(1)/N_{proc}$
- $T(1)$ is pure computation time, i.e.
 - communication latencies need to be completely hidden by the parallel implementation
 - Optimal load balancing is required
 - No synchronization points
(Potential aggregation of imbalances, imbalances are per se unavoidable, e.g. OS jitter etc.)
 - Contiguous stream of computational tasks

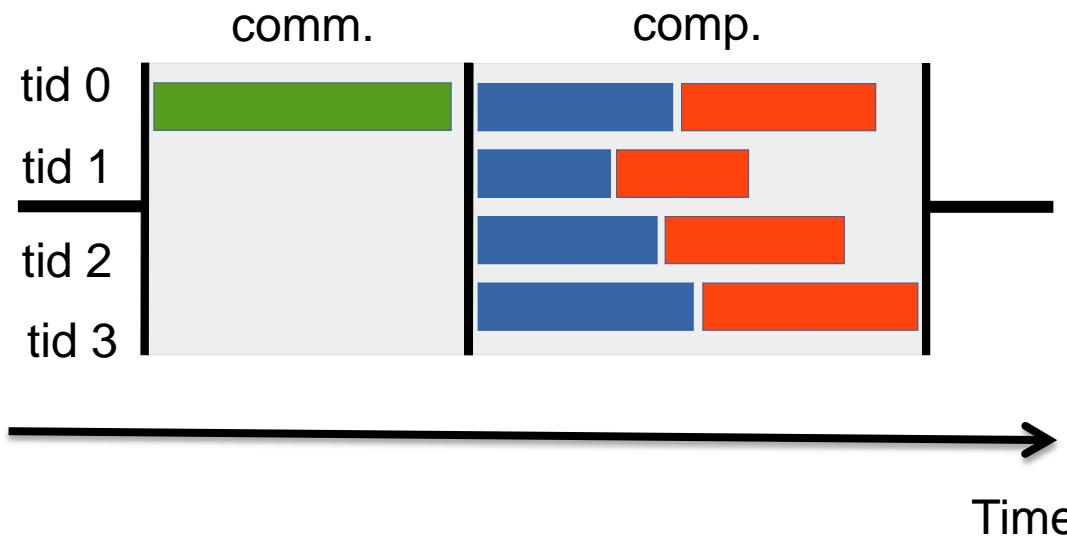


Global
Address Space
Programming Interface
GASPI
GASPI

END OF EXCURSION



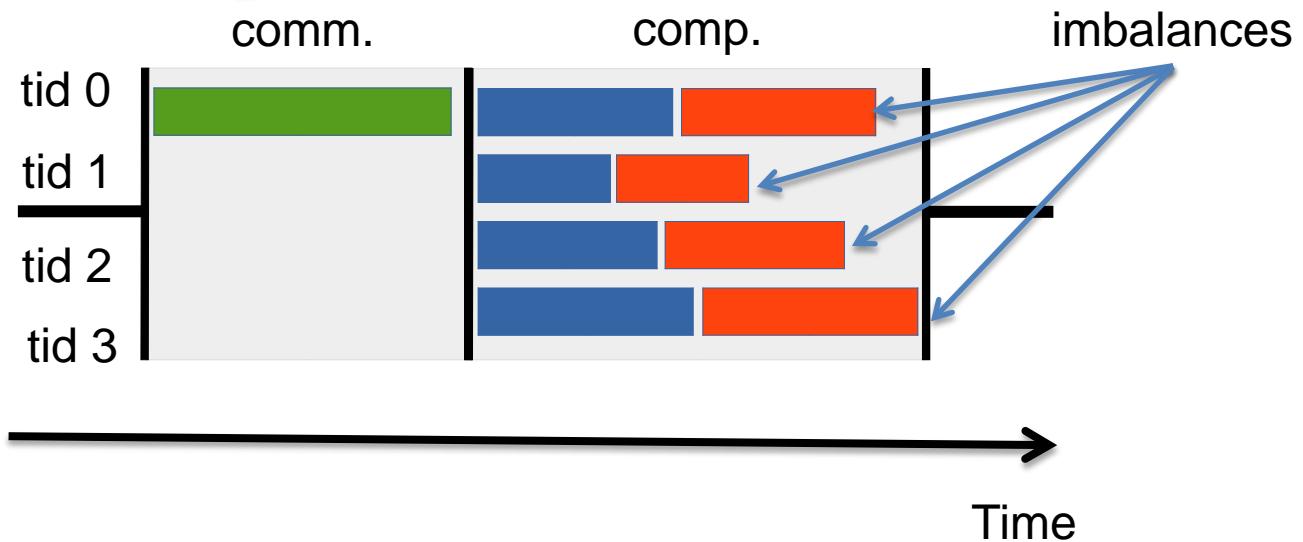
Temporal evolution: one iteration





Temporal evolution: one iteration

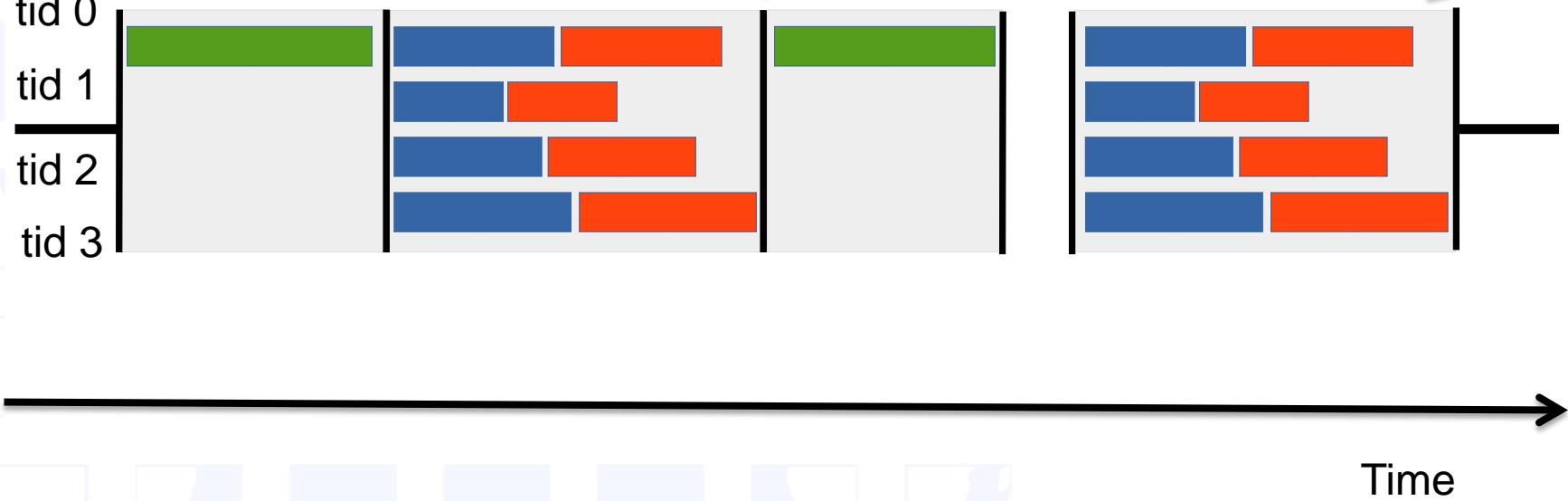
bad: explicitly visible communication latency





Temporal evolution: all iterations

bad: barrier aggregates imbalances





Temporal evolution: all iterations

bad: barrier aggregates imbalances





Global
Address Space
Programming Interface
GASPI
gaspi

Hide communication behind computation

COMMUNICATION / COMPUTATION OVERLAP



Strategy

- Hide communication latencies behind computation
- Split data into inner / boundary part
 - Inner data \Leftrightarrow no dependence on remote information
 - Boundary data \Leftrightarrow has dependence on remote information



Global
Address Space
Programming Interface
GASPI
GASPI

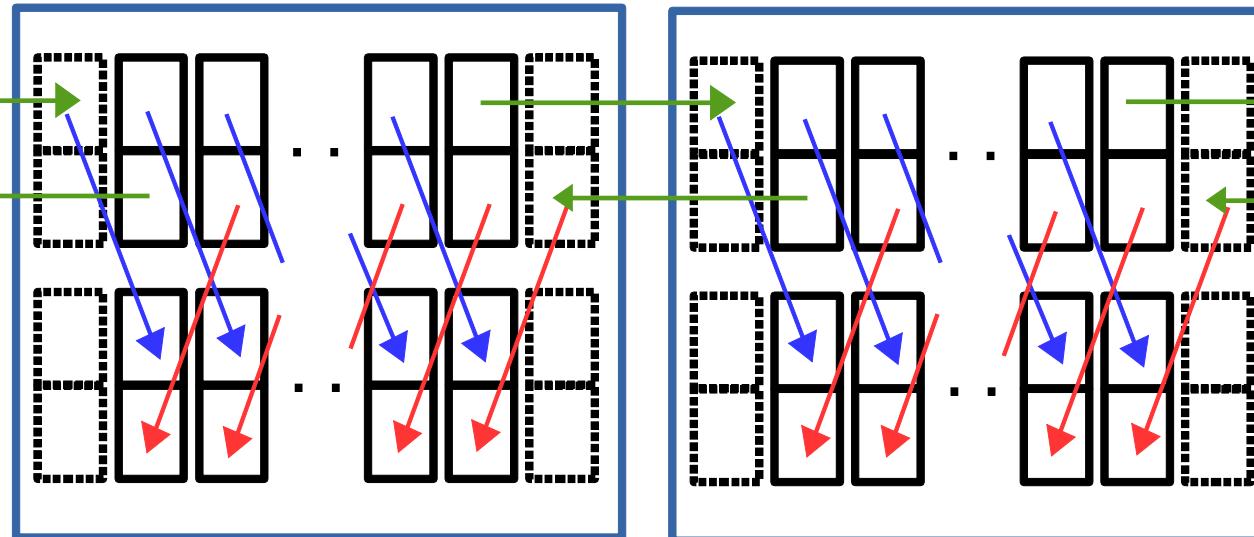
Strategy

- Algorithmic phases:
 - Init boundary data transfer
 - Update inner data along data transfer
 - Update boundary data



Global
Address Space
Programming Interface
GASPI
gaspi

Single iteration



barrier

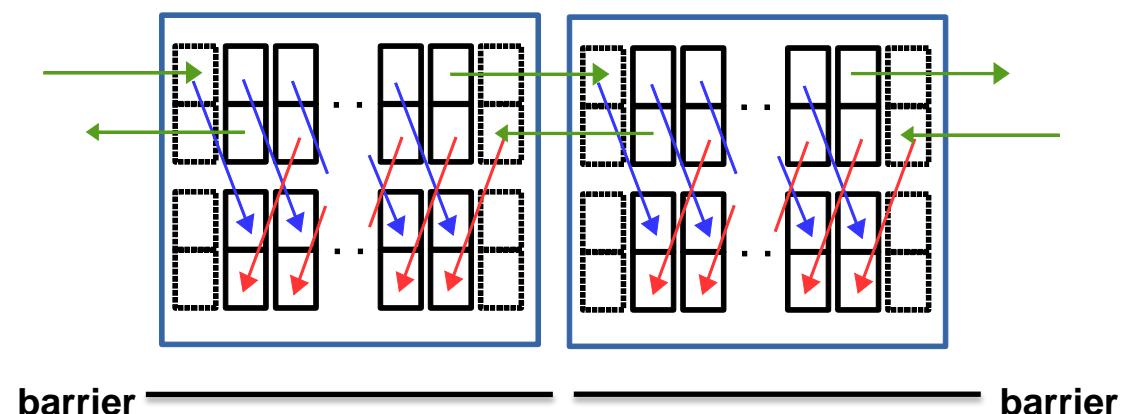
barrier



Single iteration: details

Left boundary element:

1. Initiate boundary data transfer to remote halo

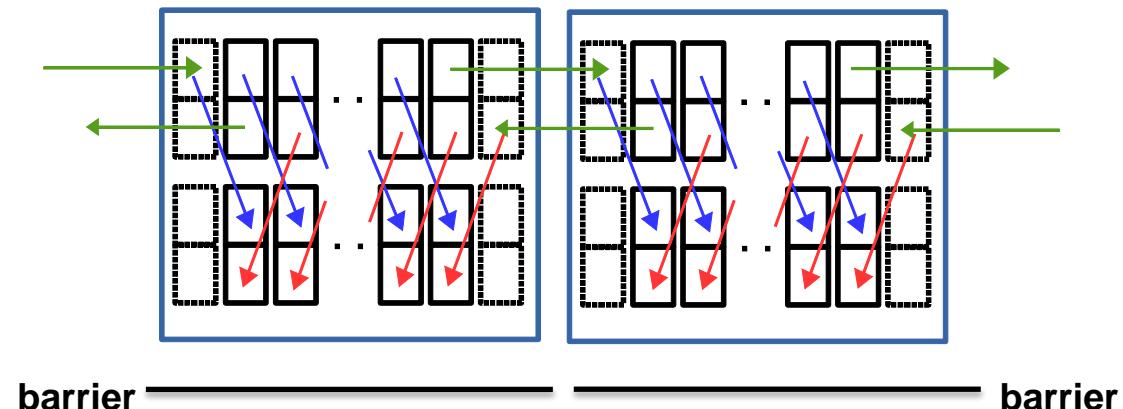




Global
Address Space
Programming Interface
GASPI
gaspi

Left boundary element:

1. Initiate boundary data transfer to remote halo
2. Wait for boundary data transfer to local halo completion

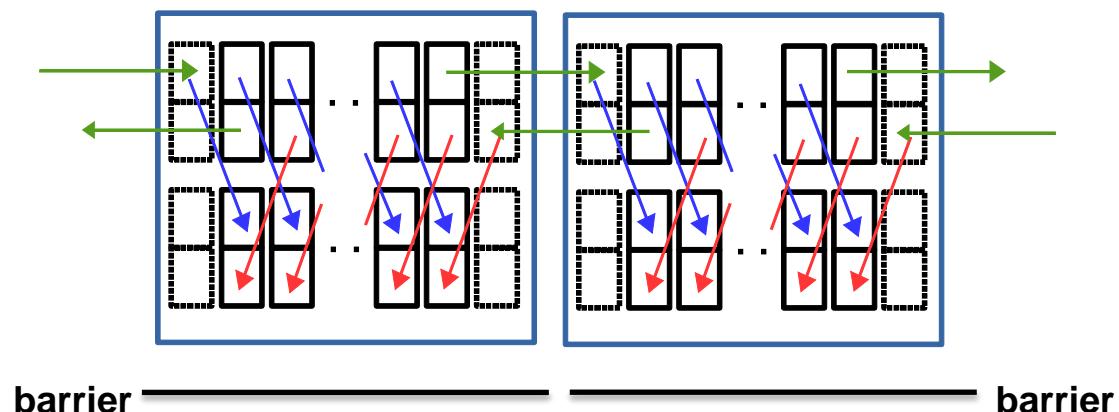




Global
Address Space
Programming Interface
GASPI
gaspi

Left boundary element:

1. Initiate boundary data transfer to remote halo
2. Wait for boundary data transfer to local halo completion
3. Update vector



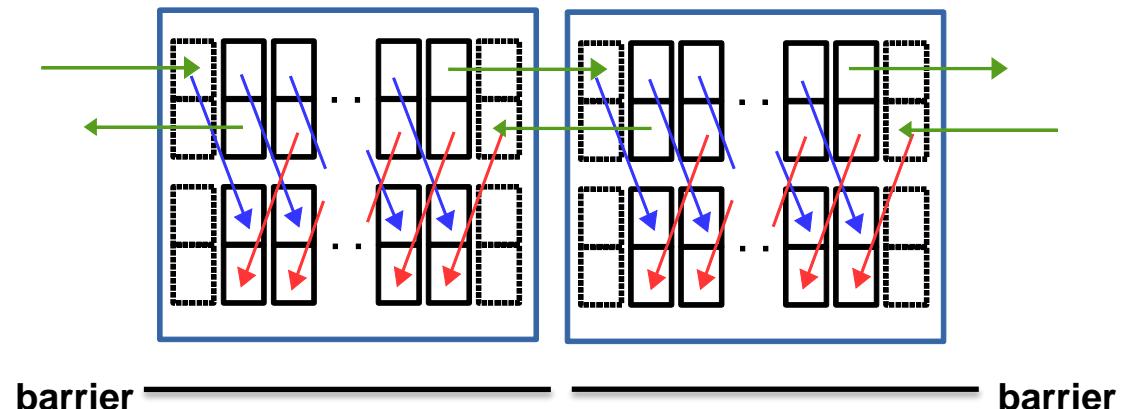


Global
Address Space
Programming Interface
GASPI
gaspi

Left boundary element:

1. Initiate boundary data transfer to remote halo
2. Wait for boundary data transfer to local halo completion
3. Update vector

-> Right boundary element
handled analogously

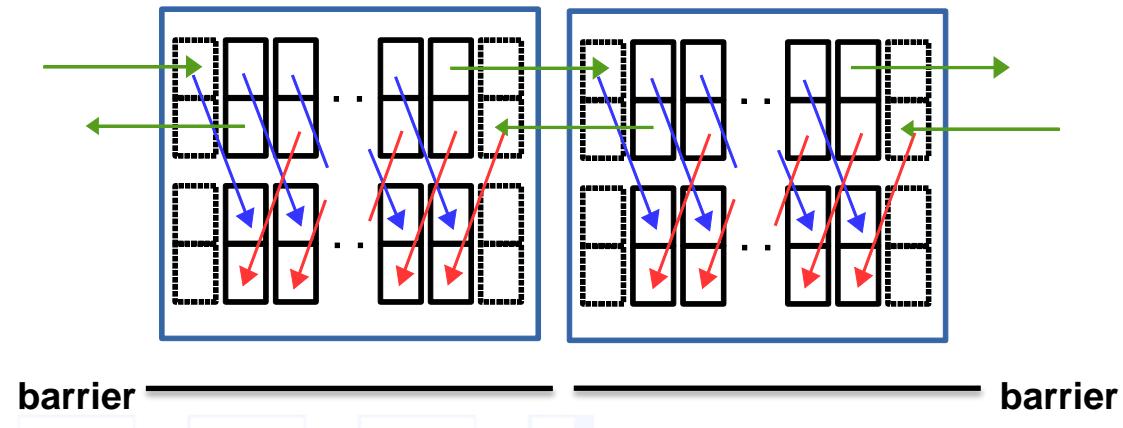




Left boundary element:

1. Initiate boundary data transfer to remote halo
2. Wait for boundary data transfer to local halo completion
3. Update vector

-> Right boundary element
handled analogously

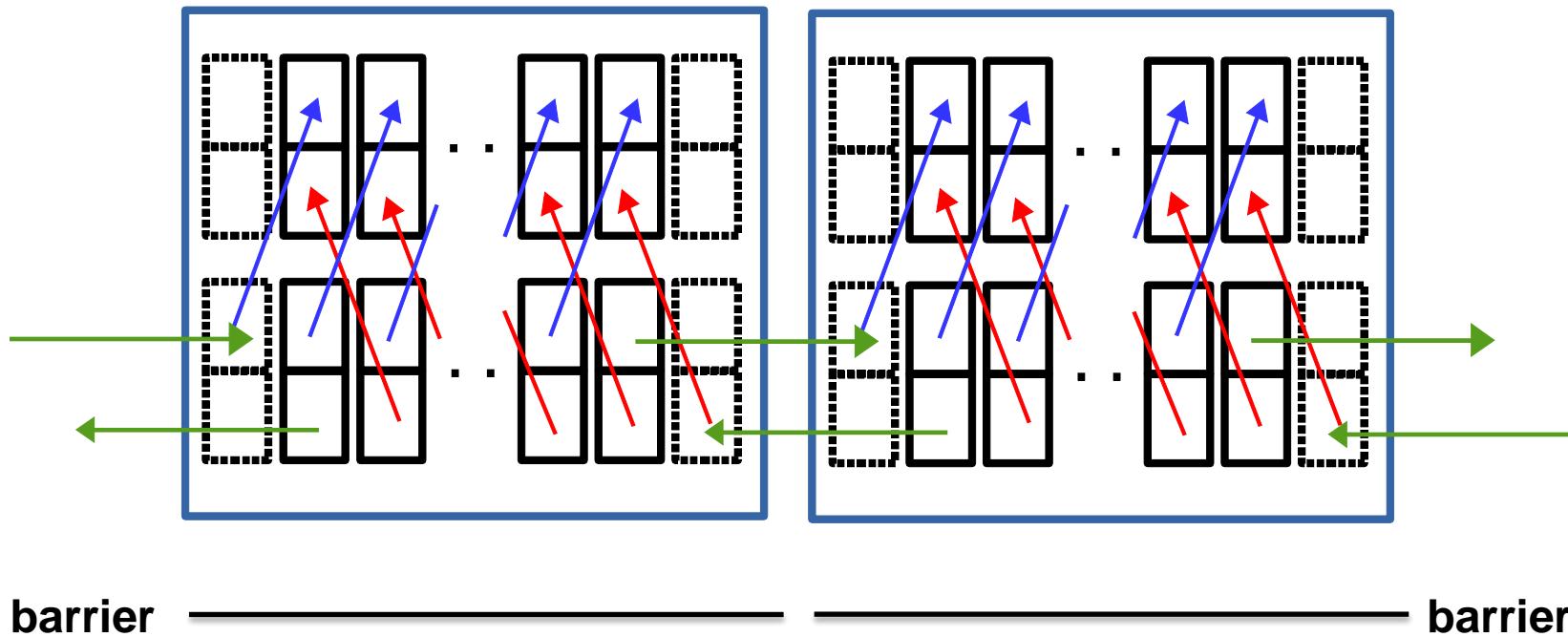


In the meanwhile inner elements are
done in parallel!



Global
Address Space
Programming Interface
GASPI
gaspi

Single iteration





Hands-on

- Implement the overlap of communication and computation
 - use `left_right_double_buffer_multiple.c` as template



The GASPI Ring Exchange

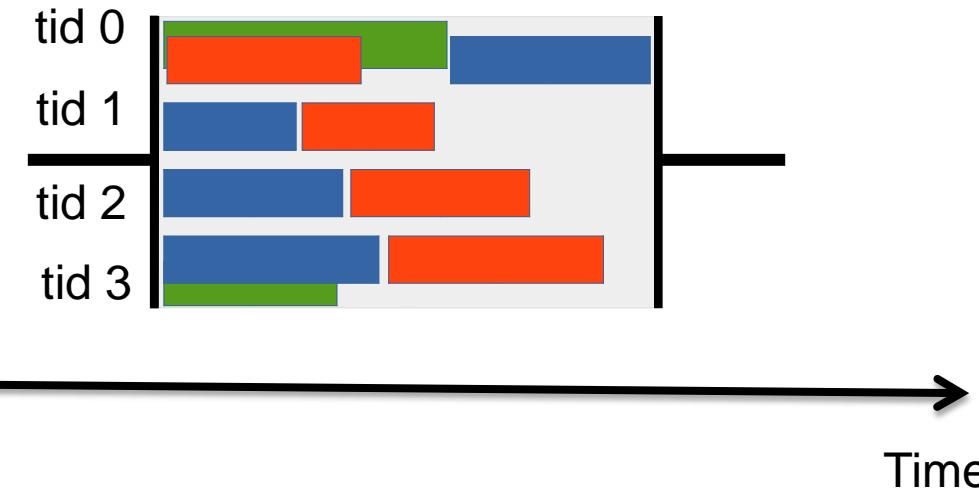
- GASPI – left_right_double_buffer_multiple.c

```
if (tid == 0) {  
    wait_for_queue_entries (&queue_id, 2 * 2);  
    SUCCESS_OR_DIE ( gaspi_write_notify  
        (segment_id, array_OFFSET_lower (buffer_id, left_halo+1, 0), left,  
         segment_id, array_OFFSET_lower (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_entries (&queue_id, 2 * 2);  
    SUCCESS_OR_DIE ( gaspi_write_notify  
        (segment_id, array_OFFSET_upper (buffer_id, right_halo-1, 0), right,  
         segment_id, array_OFFSET_upper (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
gaspi.org

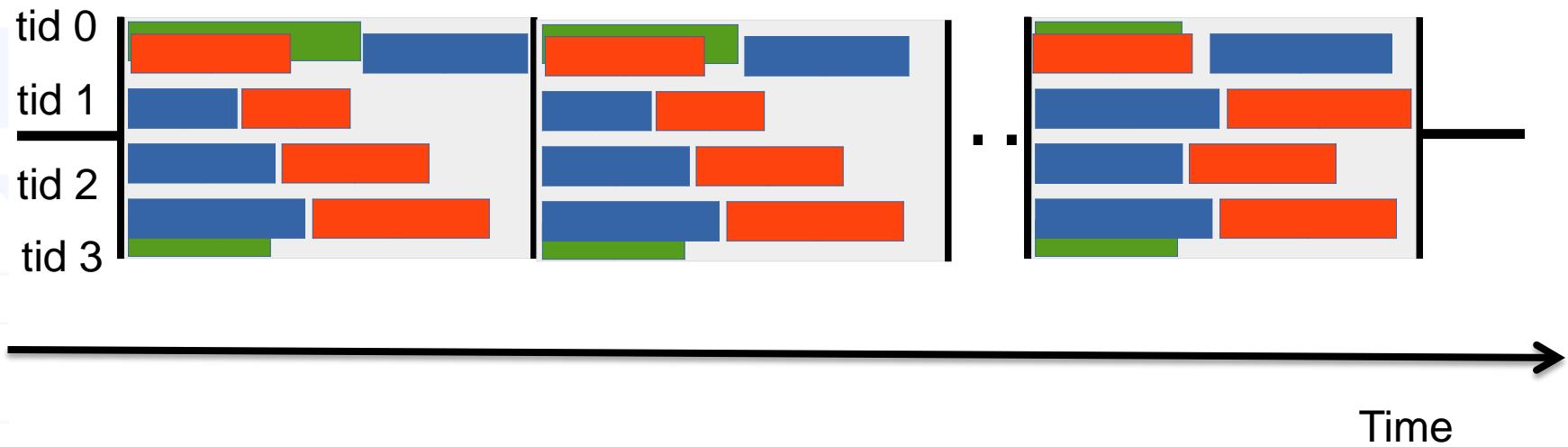
Temporal evolution





Global Address Space Programming Interface **GASPI**

Temporal evolution





Global
Address Space
Programming Interface
GASPI
Globally Addressed Space Programming Interface

Avoid synchronization point

DATA DEPENDENCY DRIVEN

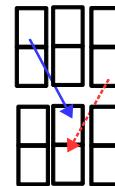


- What has been achieved?
 - Overlap of communication by computation
 - Communication latency is (partly) hidden
- What has not been achieved?
 - Fully Asynchronous execution
 - Still processwide synchronization after each iteration
 - > process wide aggregation of thread imbalances



- Why barrier?

- Need to know that buffers are ready for next iteration



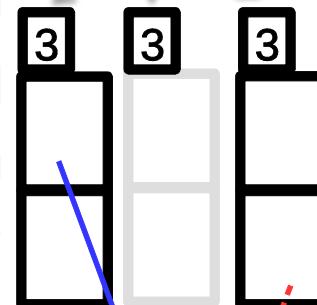
- Barrier provides too much information !!!
 - Only need to know that local neighbours (my dependency) are up to date



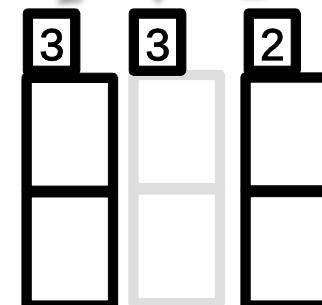
Reduce synchronicity

- Introduce stage counter for every buffer to account for local states
- check neighbourig stage counters before update
- In case of match: do update
- Increment stage counter after update

Stage counters



Stage counters



-> Only local dependencies remain

Update possible

Update not possible



- Avoid static assignment thread / subdomain
 - 1 „Task“ for each subdomain
 - Compute task for inner subdomain
 - Compute - Initiate data transfer task for boundary subdomains
 - Pre-Condition check before execution
 - Left / right neighbor element are do not have a higher iteration counter than me
 - Post-Condition set after execution
 - Increment iteration counter



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;
```



Hands-on

- Implement the data dependency driven algorithm
 - use slice.c as template
 - use left_right_dataflow.c as template



The GASPI Ring Exchange

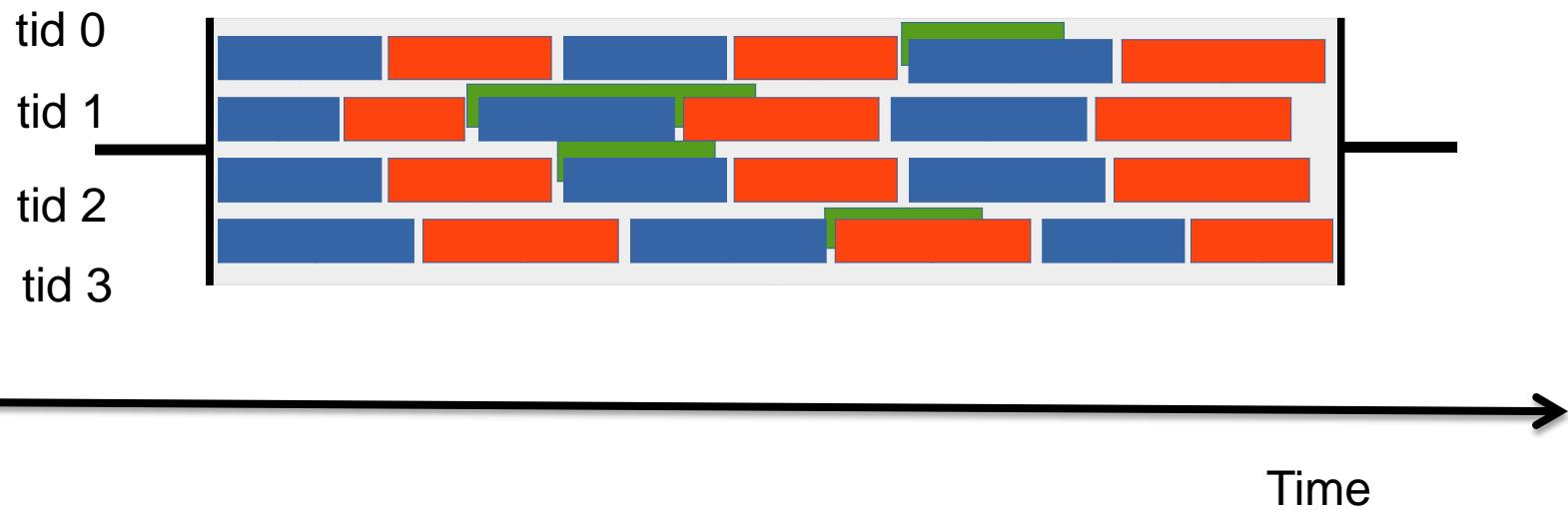
- GASPI – Dataflow - slice.c

```
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;
}
```



Global
Address Space
Programming Interface
GASPI
Globally Addressed Shared Memory Interface

Temporal evolution



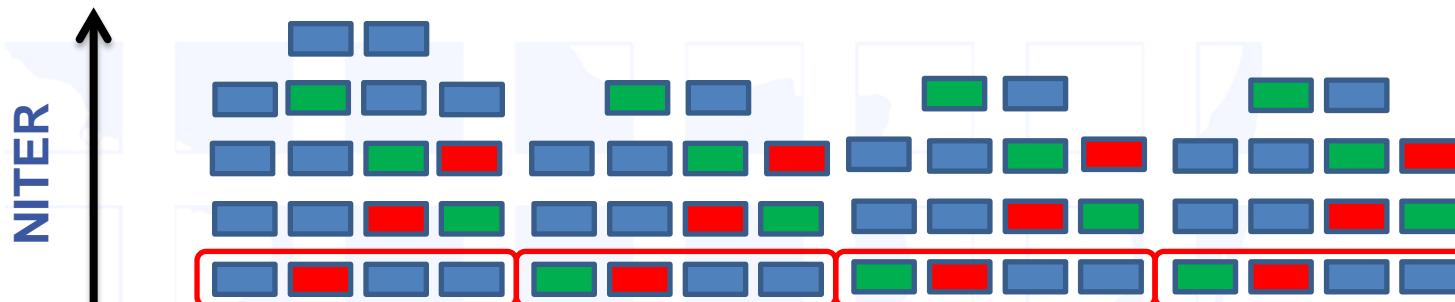


Global
Address Space
Programming Interface
GASPI
Globally Asynchronous
Synchronous Programming Interface

The GASPI Ring Exchange

GASPI – Dataflow

- Locally and globally asynchronous dataflow.





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.



Global
Address Space
Programming Interface
GASPI
GPI-Site

Questions?

Thank you for your attention

www.gaspi.de

www.gpi-site.com