Global
Address Space
Programming Interface
GASPI

GASPI Tutorial

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Sponsored by the European Commission through

Schedule

- 9:00h begin
- 10:15h-10:30h break
- 11:45h-12:00h break
- 13:00h-14:00h lunch
- 15:15h-15:30h break
- 17:00 end

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GASPI Tutorial Questionnaire

https://www.surveymonkey.co.uk/r/8P7QTC2

INTERTWinE - Programming Model INTERoperability ToWards Exascale

INTERTWinE

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Round of Introductions

- Who are you?
- What are you doing?
- How did you get in contact with GASPI?
- What is your interest in / expectation to GASPI?

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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

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Outline

- GASPI programming model
  - Dataflow model
  - Fault tolerance

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Introduction to GASPI

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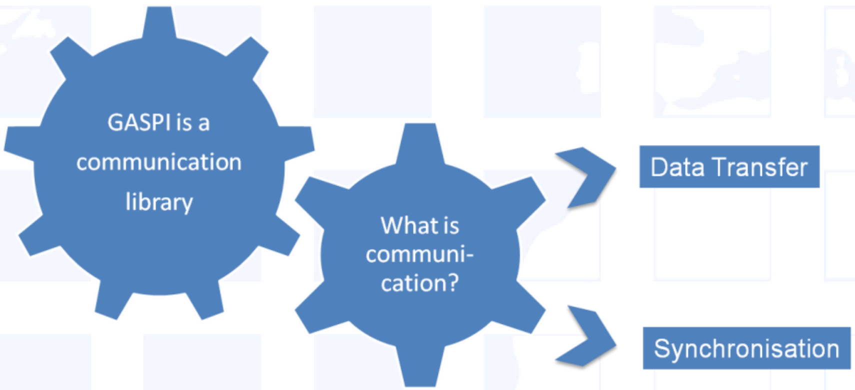
GASPI at a Glance



Nuts and Bolts for Communication Engines

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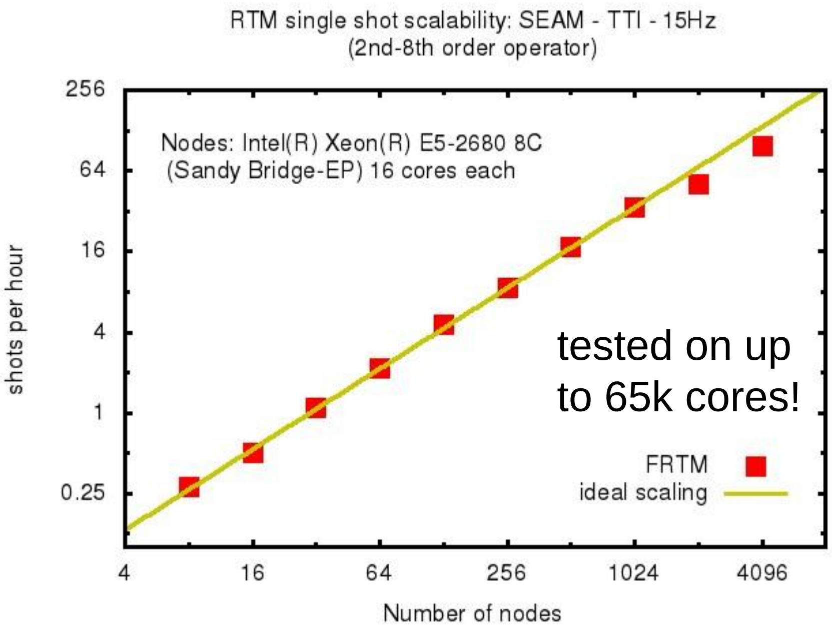
GASPI at a Glance

Features:

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



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

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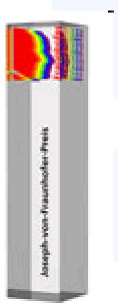
GASPI History

- **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



Winner of the „Joseph von Fraunhofer Preis 2013“

Finalist of the „European Innovation Radar 2016“.

www.gpi-site.com

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GASPI Standardization Forum

KTH
VETENSKAP OCH KONST

lrz

T · · Systems · · ·

Fraunhofer
ITWM

Founding Members

DLR

ZIH
Zentrum für Informationsdienste
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ECMWF

Fraunhofer
SCAI

Regionales
RechenZentrum
Erlangen
Der IT-Dienstleister der FAU

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GASPI in European Exascale Projects

EXascale Algorithms and Advanced Computational Techniques

Programming-model design and implementation for the Exascale

EPiGRAM

Exascale ProGRAmming Models

The University of Manchester

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

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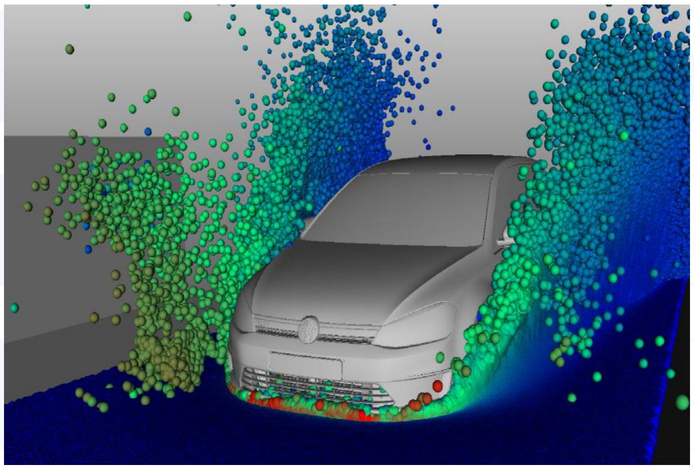
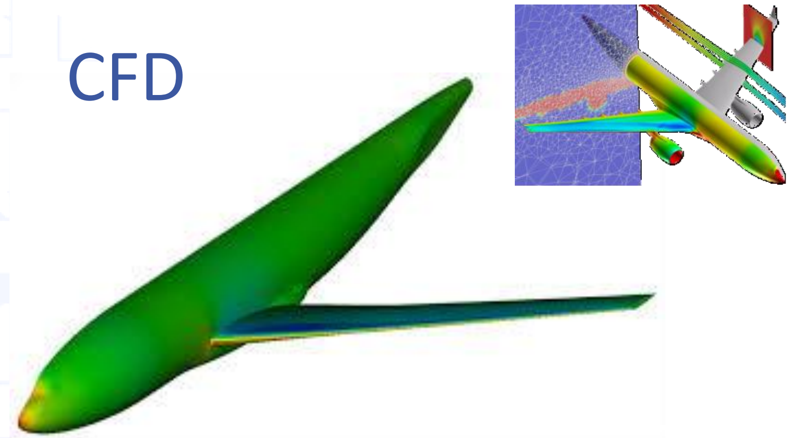
Some GASPI Applications

Visualization

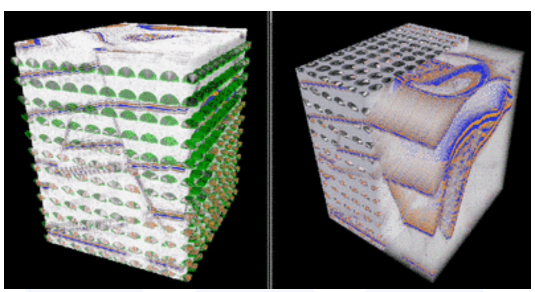


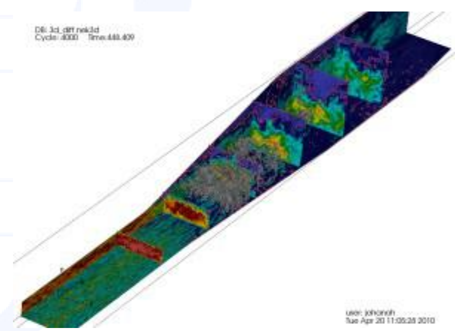
CFD

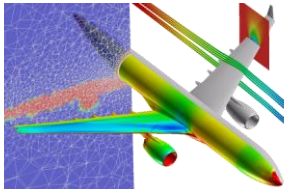


Machine Learning
Big Data
Iterative Solvers

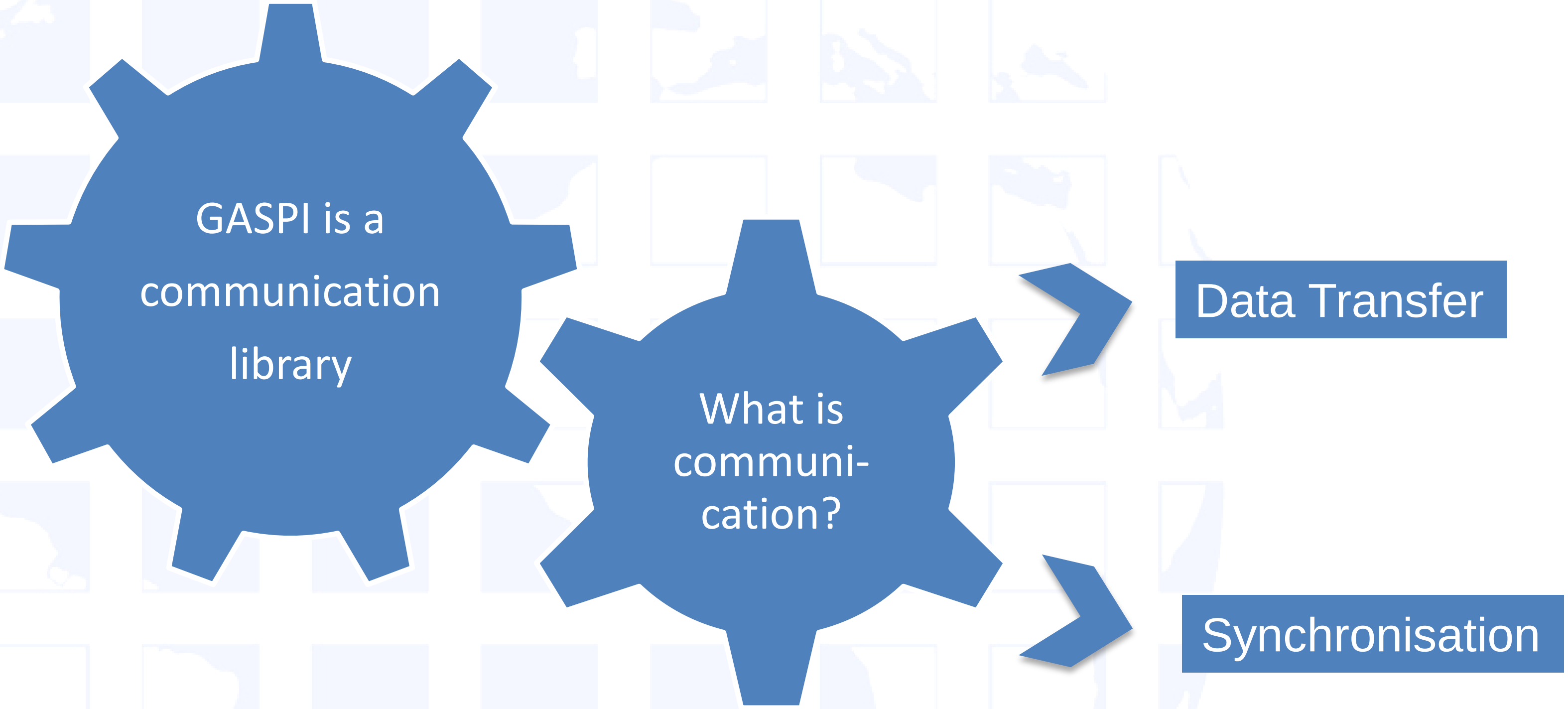
Seismic Imaging & Algorithms



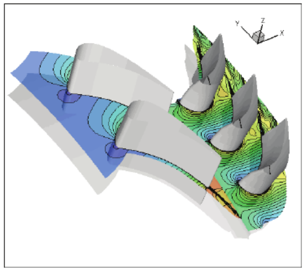




Concepts: Communication



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

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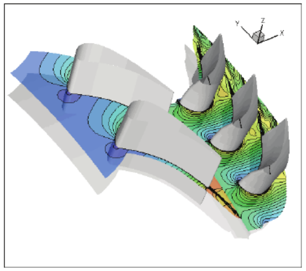
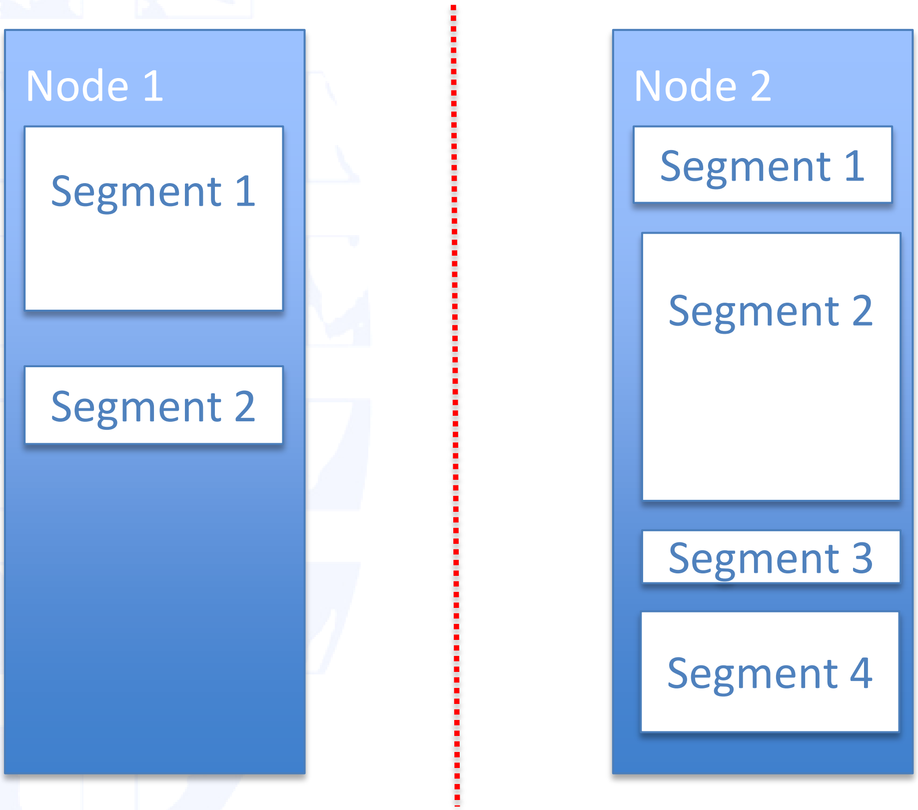


Concepts: Segments

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



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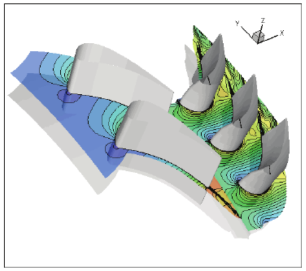
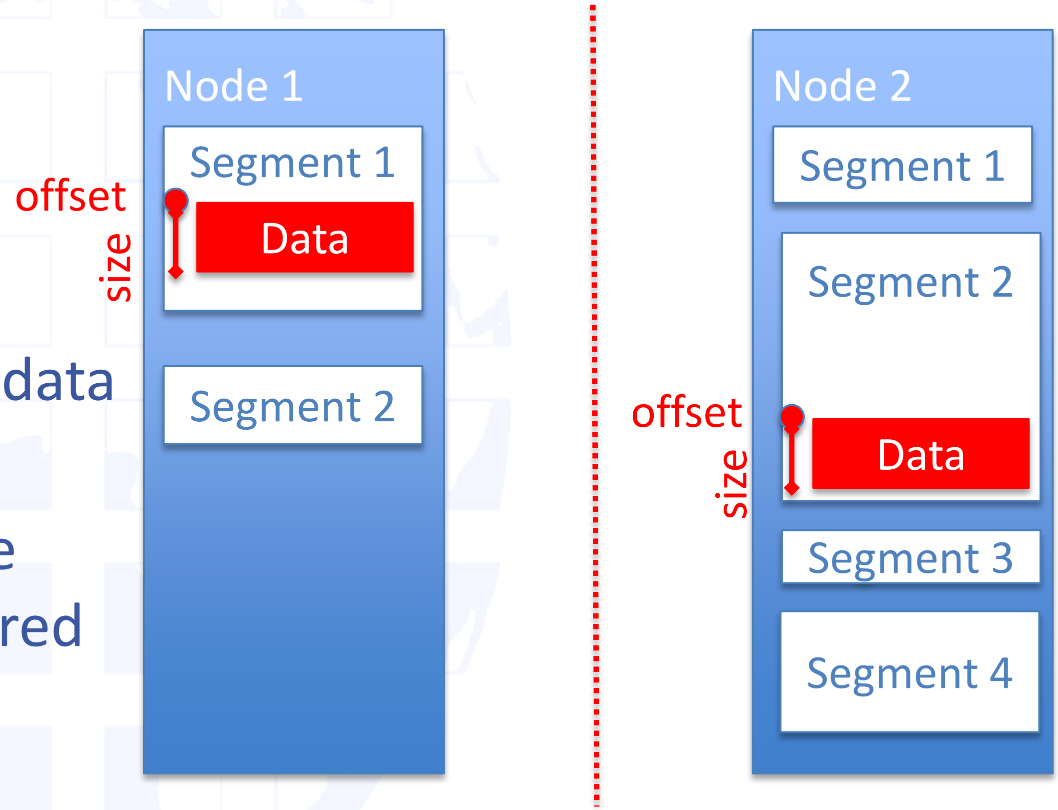


Concepts: Segments



Application has to manage data transfer completely:

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

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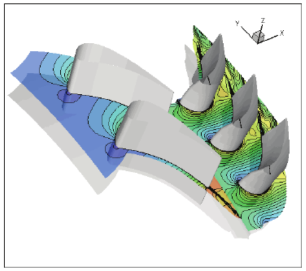
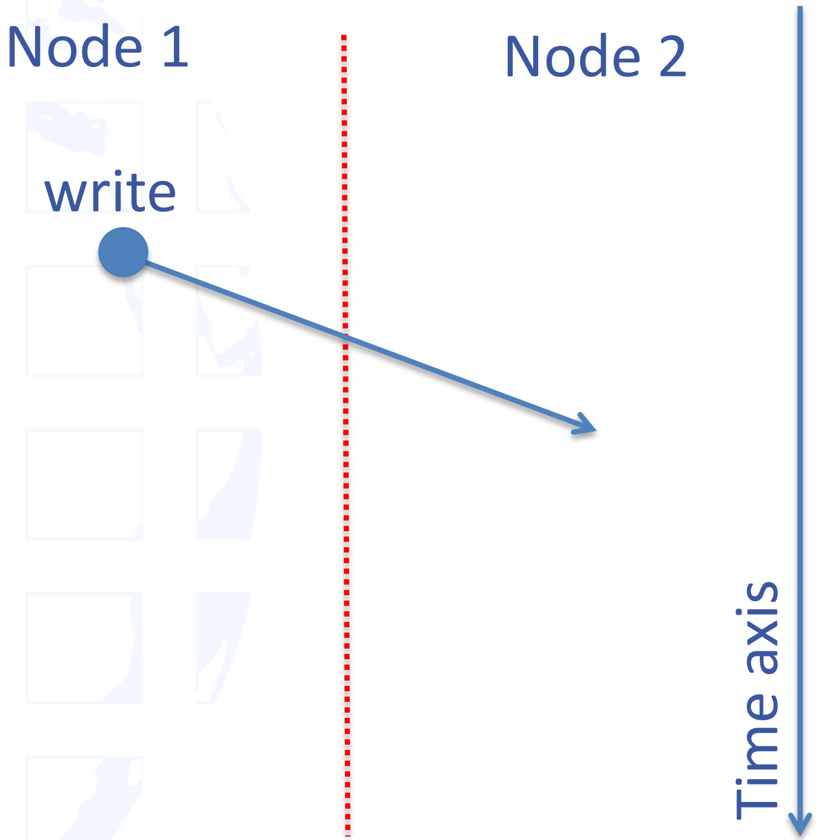


Concepts: one-sided Communication

- 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



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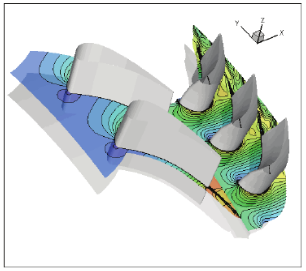
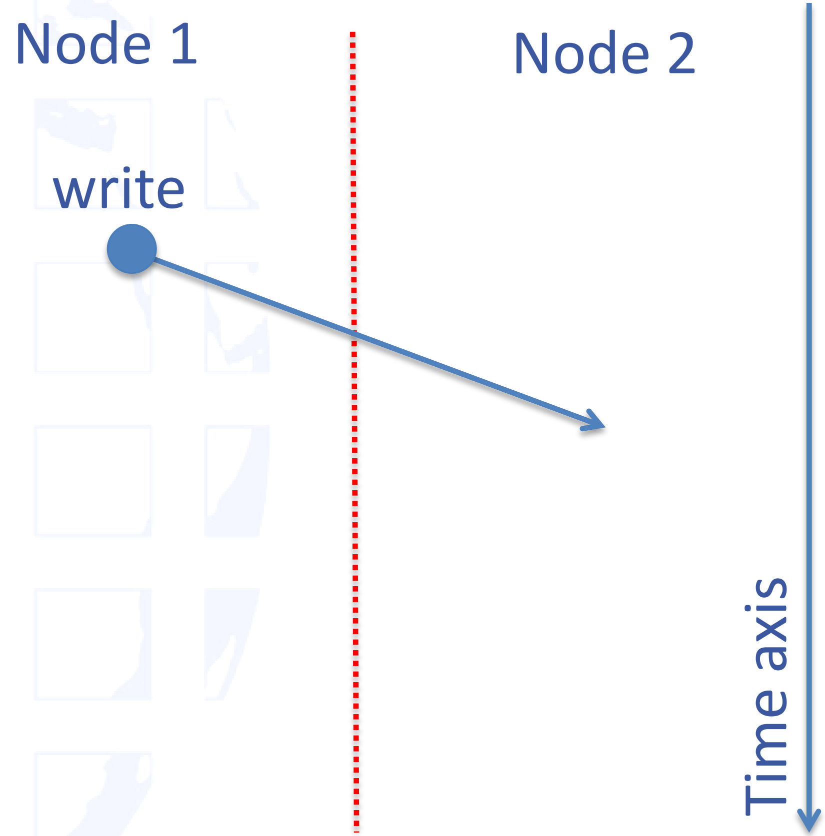


Concepts: one-sided Communication

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



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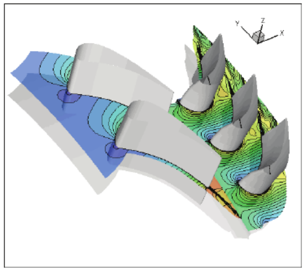
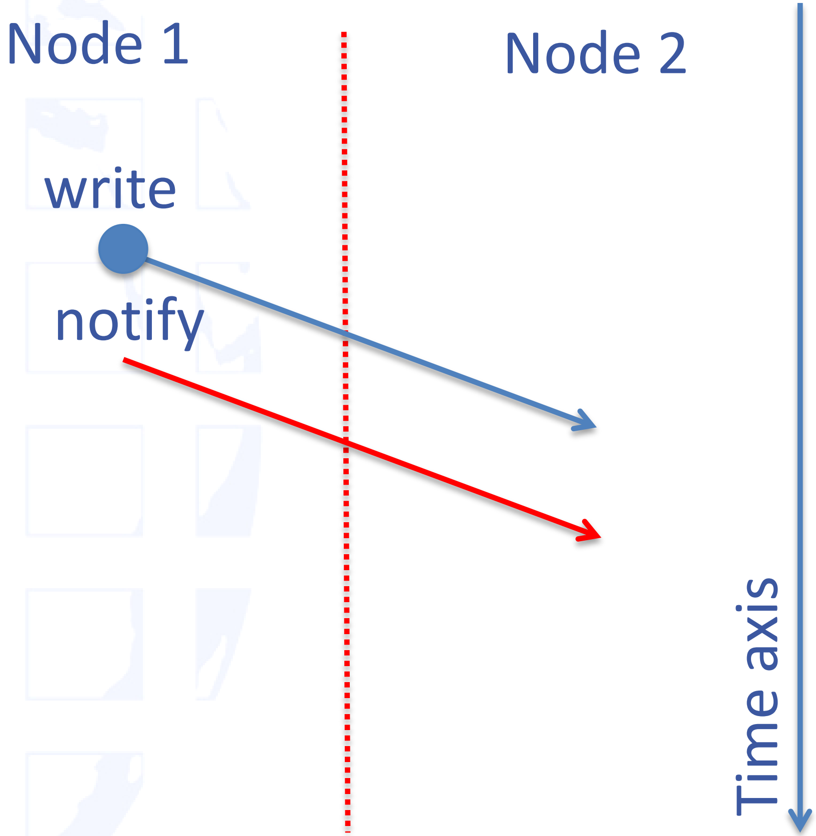


Concepts: Synchronisation with Notifications

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



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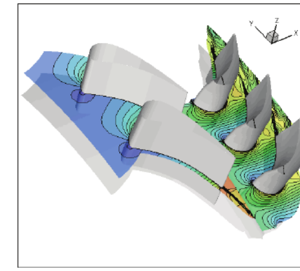
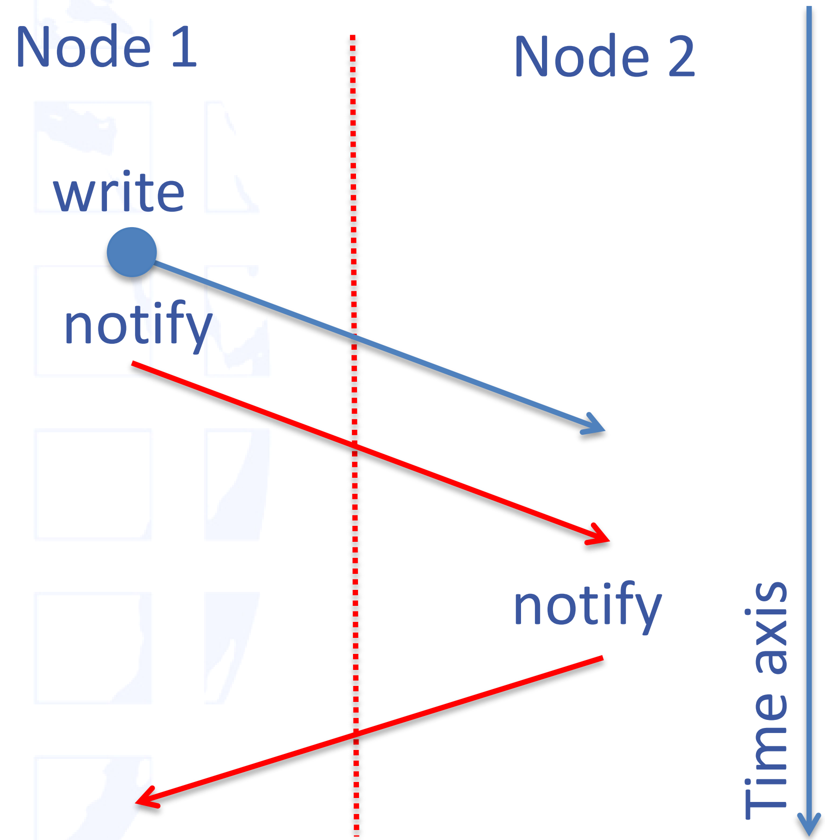


Concepts: Synchronisation with Notifications

- 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



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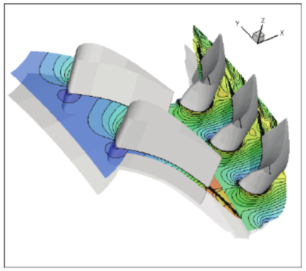
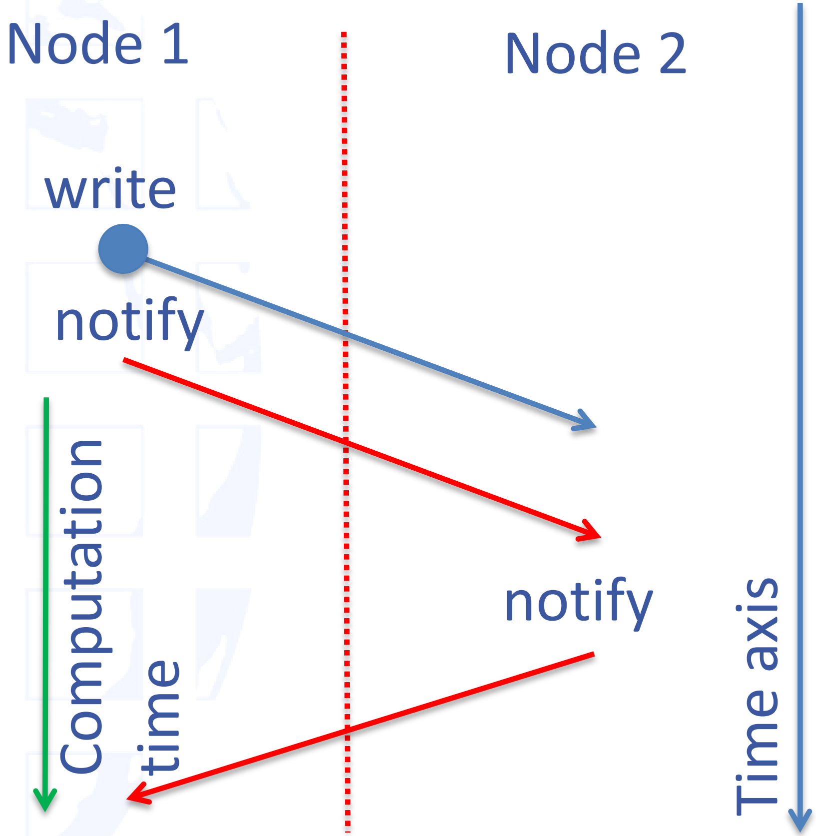
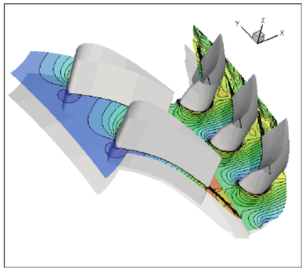


Concepts: overlap of Communication and Computation

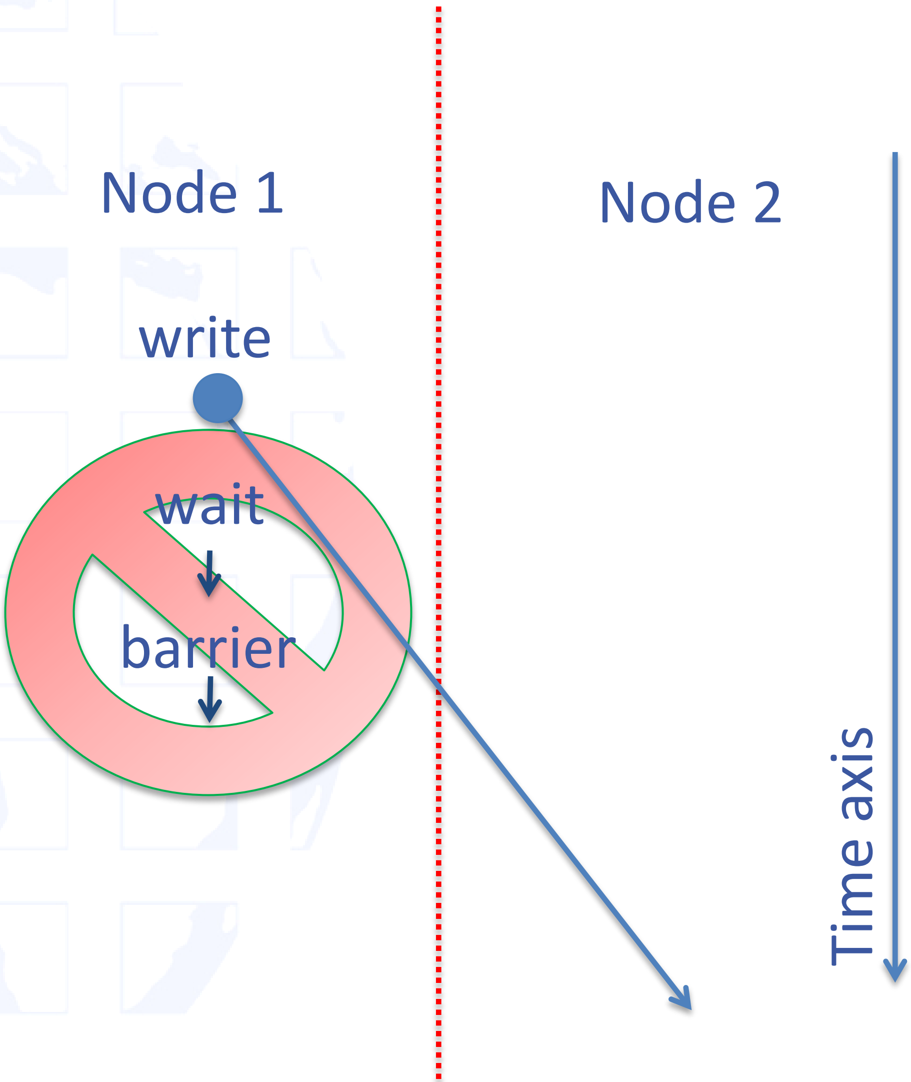
- Due to the non-blocking nature of the call Node 1 has gained some computation time which it can use
- Communication and computation happen in parallel
- Communication latency is hidden



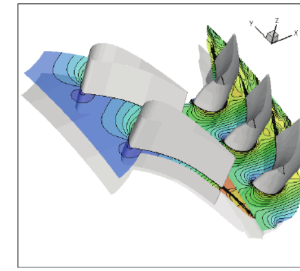


Concepts: Warning!

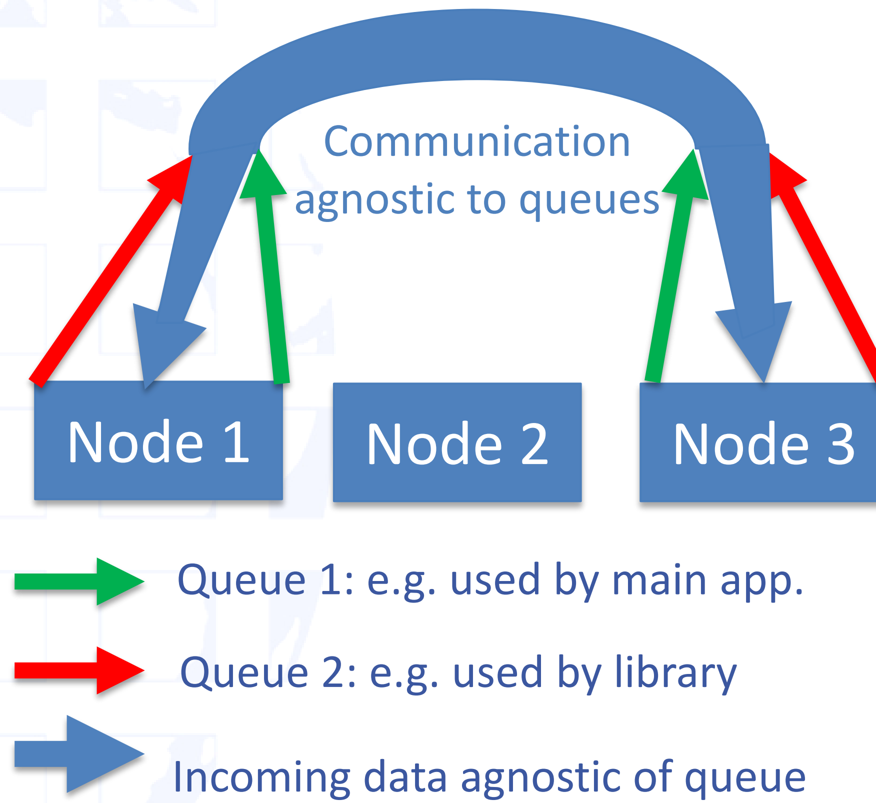
- Data synchronisation by wait + barrier does not work!
- Wait does wait on local queue on Node 1, does not know about write in Node 2, barrier() has no relation with communication
- Data synchronization only by notifications



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



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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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Execution Model

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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

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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
```

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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 !

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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
```

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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

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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;
}
```

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Memory Segments

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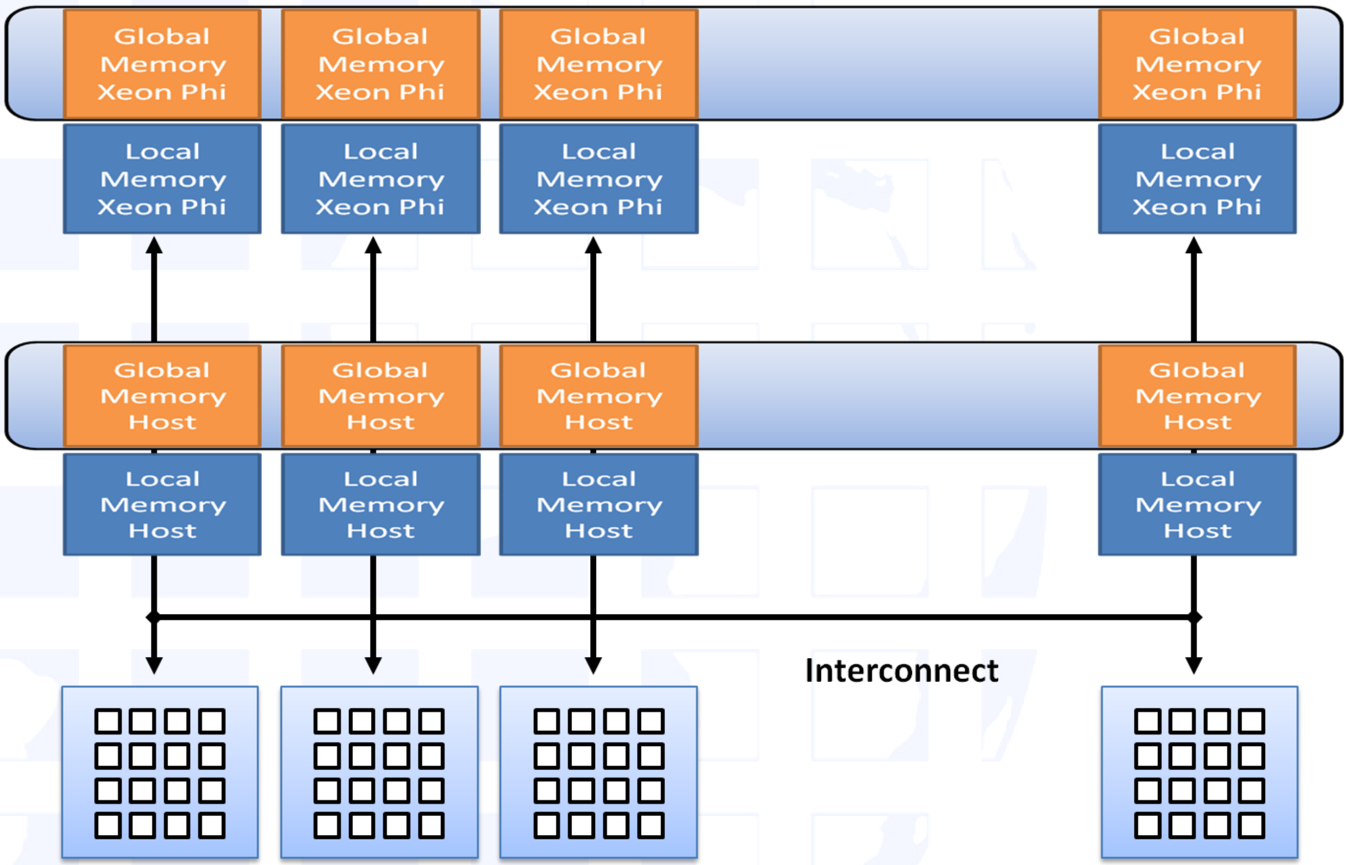
Segments



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)

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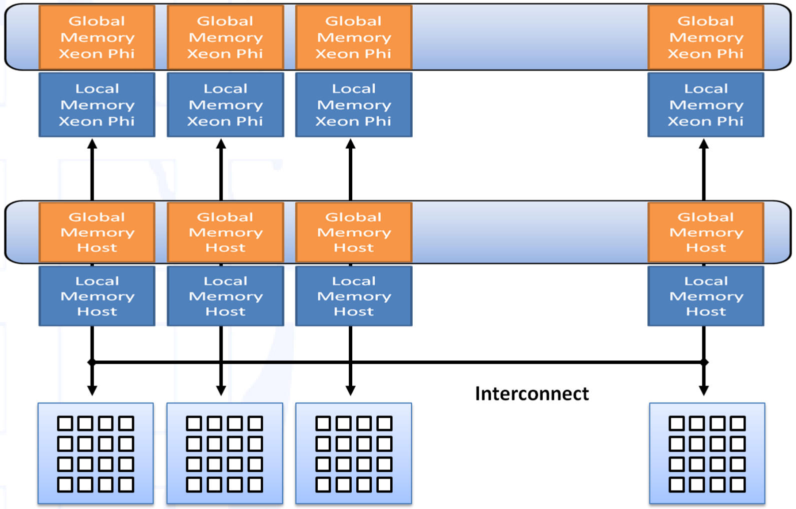
Segment Functions

- 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)

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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
  )
```

- Equivalent to

```
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);
}
```

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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 )
```

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)

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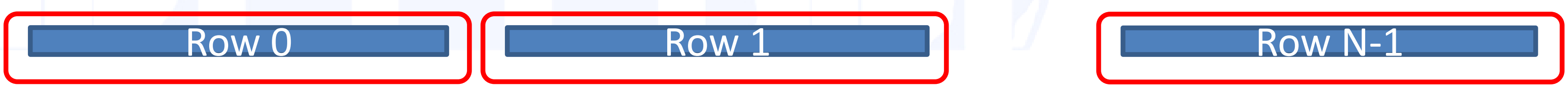
Using Segments – Hands on

- 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



  - 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;
}
```

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One-sided Communication

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GASPI One-sided Communication

- gaspi_write

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

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

GASPI One-sided Communication

- gaspi_read

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

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

GASPI One-sided Communication

- gaspi_wait

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

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

Queues (I)

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

Queues (II)

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

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 )
```

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write_and_wait

- serial wait on queue
- sanity checks

```
void
write_and_wait ( gaspi_segment_id_t const segment_id_local
               , gaspi_offset_t const offset_local
               , gaspi_rank_t const rank
               , gaspi_segment_id_t const segment_id_remote
               , gaspi_offset_t const offset_remote
               , gaspi_size_t const size
               , gaspi_queue_id_t const queue
               )
{
  gaspi_timeout_t const timeout = GASPI_BLOCK;
  gaspi_return_t ret;

  /* write, wait if required and re-submit */
  while ((ret = ( gaspi_write( segment_id_local, offset_local, rank,
                               segment_id_remote, offset_remote, size,
                               queue, timeout)
           )) == GASPI_QUEUE_FULL)
    {
      SUCCESS_OR_DIE (gaspi_wait (queue,
                                  GASPI_BLOCK));
    }
  ASSERT (ret == GASPI_SUCCESS);
}
```

write_notify_and_cycle

- cycle through queues
- sanity checks

```
void
write_notify_and_cycle ( gaspi_segment_id_t const segment_id_local
                       , gaspi_offset_t const offset_local
                       , gaspi_rank_t const rank
                       , gaspi_segment_id_t const segment_id_remote
                       , gaspi_offset_t const offset_remote
                       , gaspi_size_t const size
                       , gaspi_notification_id_t const notification_id
                       , gaspi_notification_t const notification_value
                       )
{
  gaspi_number_t queue_num;
  SUCCESS_OR_DIE(gaspi_queue_num (&queue_num));

  gaspi_timeout_t const timeout = GASPI_BLOCK;
  gaspi_return_t ret;


  /* write, cycle if required and re-submit */
  while ((ret = ( gaspi_write_notify( segment_id_local, offset_local, rank,
                                      segment_id_remote, offset_remote, size,
                                      notification_id, notification_value,
                                      my_queue, timeout)
                )) == GASPI_QUEUE_FULL)
    {
      my_queue = (my_queue + 1) % queue_num;
      SUCCESS_OR_DIE (gaspi_wait (my_queue,
                                  GASPI_BLOCK));
    }
  ASSERT (ret == GASPI_SUCCESS);
}
```

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;

  /* cycle all queues and wait */
  while (queue < queue_num)
    {
      SUCCESS_OR_DIE(gaspi_wait ( queue,
                                  GASPI_BLOCK));
      ++queue;
    }
}
```

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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

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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

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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

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wait_or_die

- Wait for a given notification and reset
- Sanity checks

```
#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);
}
```

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test_or_die

- Test for a given notification and reset
- Sanity checks

```
#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
  - write + subsequent gaspi_notify, unordered with respect to „other“ writes.
- gaspi_write_list
  - several subsequent gaspi_writes to the same rank
- gaspi_write_list_notify
  - gaspi_write_list + subsequent gaspi_notify, non-ordered with respect to „other“ writes.
- gaspi_read_notify
  - read + subsequent gaspi_notify, unordered with respect to „other“ writes.
- gaspi_read_list
  - Several subsequent read from the same rank.

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

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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

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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

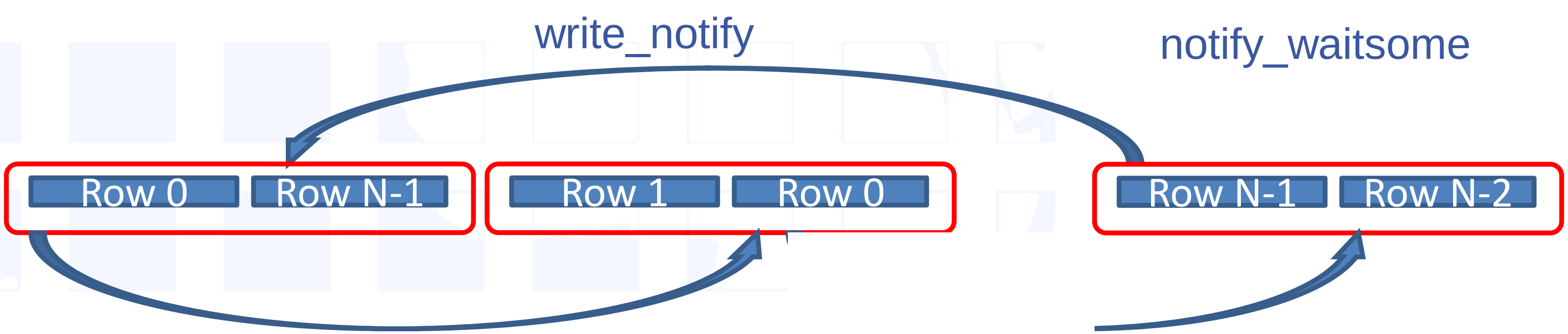
- Take your GASPI program which stores a NxM matrix in a distributed way and extend it by communication for rows

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

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 ); }
```

Global

```
/* write, cycle if required and re-submit */
 while ((ret = ( gaspi_write_notify( segment_id_local, offset_local, rank,
                                     segment_id_remote, offset_remote, size,
                                     notification_id, notification_value,
                                     my_queue, timeout)
                 )) == GASPI_QUEUE_FULL) {
     my_queue = (my_queue + 1) % queue_num;
     SUCCESS_OR_DIE (gaspi_wait (my_queue,
                                 GASPI_BLOCK));
 }
 ASSERT (ret == GASPI_SUCCESS);
```

```
gaspi_notification_id_t data_available = 0;
gaspi_offset_t loc_off = 0;
gaspi_offset_t rem_off = VLEN * sizeof (double);
write_notify_and_cycle ( segment_id
                       , loc_off
                       , RIGHT (iProc, nProc)
                       , segment_id
                       , rem_off
                       , VLEN * sizeof (double)
                       , data_available
                       , 1 + iProc
                       );
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;}
```

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

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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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;
```

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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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Interoperability with MPI

Interoperability with MPI

- GASPI supports interoperability with MPI in a so-called mixed-mode.
- 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

- GASPI must be installed with MPI support, using the option

  --with-mpi <path_to_mpi_installation>
- MPI must be initialized before GASPI, 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;
}
```

GASPI Preserves the MPI Ranks

- GASPI is able to detect at runtime the MPI environment and to setup its own environment based on this
- GASPI 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 GASPI: 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
  );
```

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Using GASPI 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 GASPI allocated memory as a buffer in MPI communication
MPI_Bcast (gaspi_ptr_from, n, MPI_DOUBLE, 0, MPI_COMM_WORLD);
// do work
…
```

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Mixing MPI Code with GASPI Code From a Library

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

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

```
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();
```

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 nu
      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;
}
```

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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

The GASPI programming model

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

THINK PERFORMANCE

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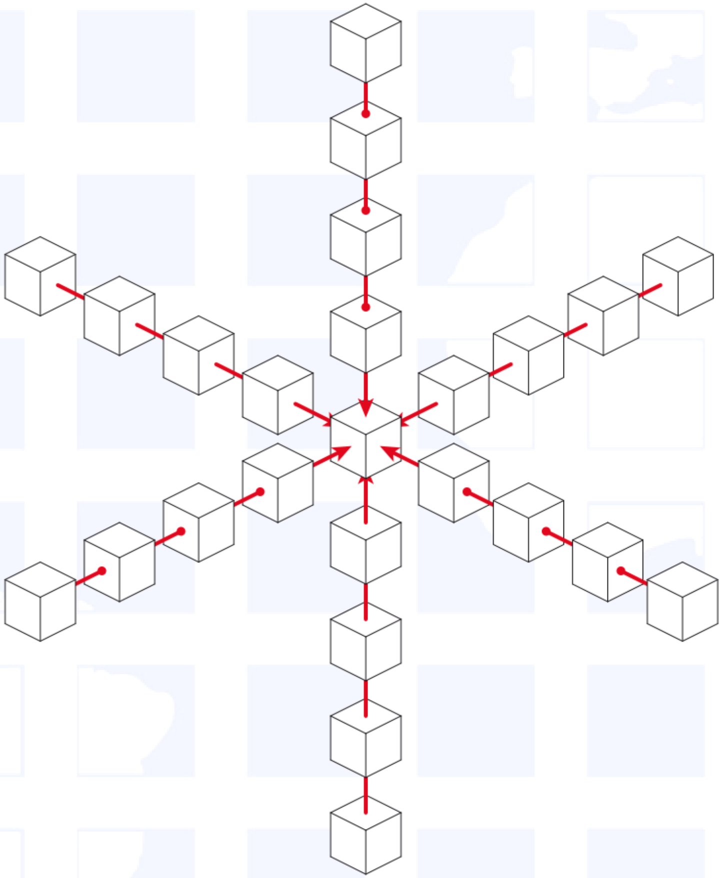
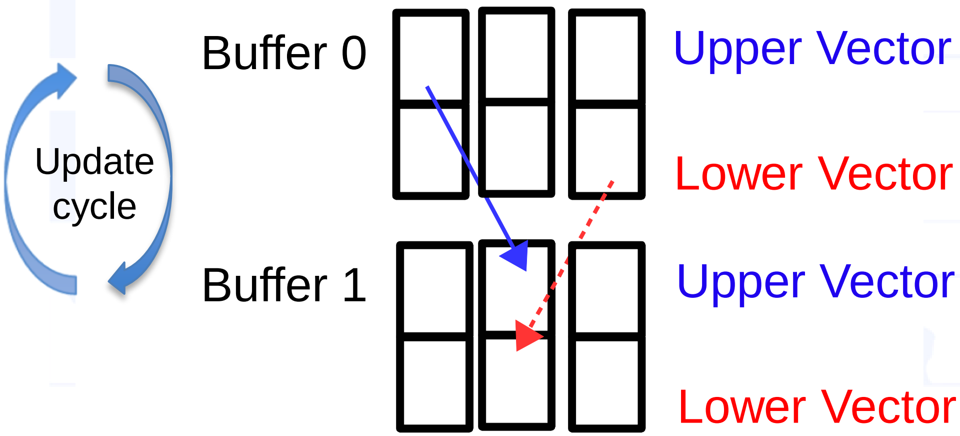
Example: Stencil applications



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

Stencil application proxy

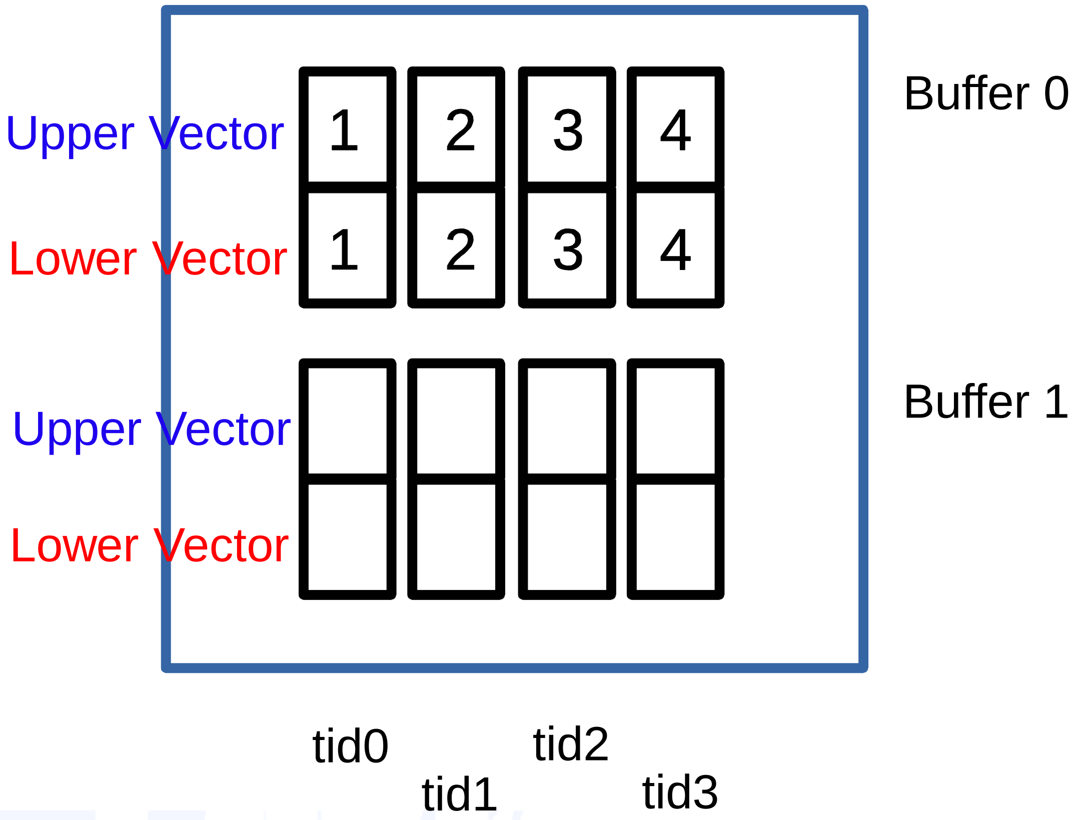


Update step:
- Update upper part
- Update lower part

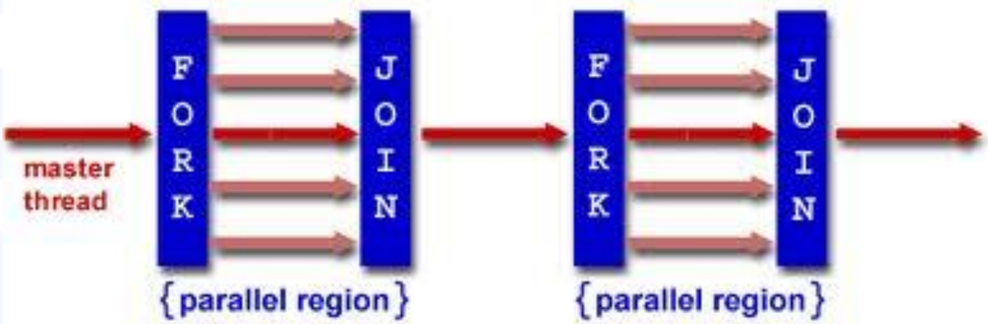
- 2 buffers per element
  - Buffer 0
  - Buffer 1
- 2 vectors per buffer
  - Upper vector
  - Lower vector
- Data dependencies
  - Left element
  - Right element

Stencil application proxy

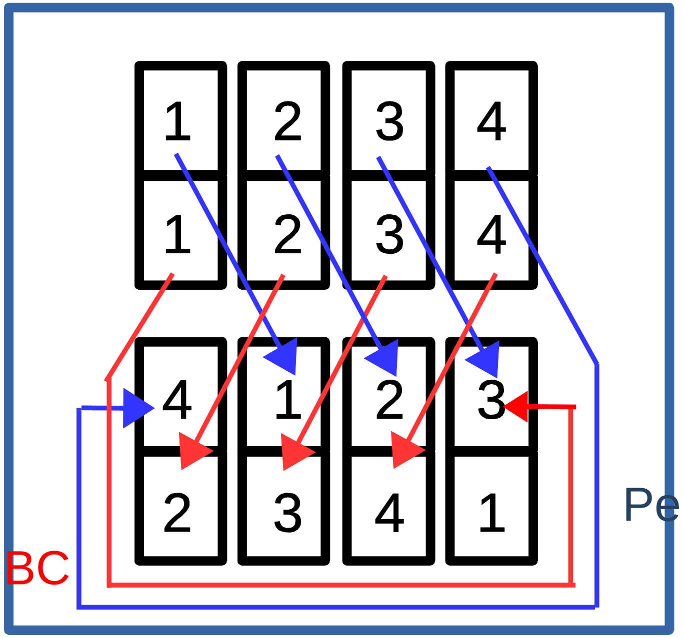
- Nthread omp threads
- static domain decomposition / assignment
- Two buffers per thread
- Two vectors per buffer
- Vector length: nvector



Fork-Join model



Iteration 1



Upper half: move to the right

Lower half: move to the left

Periodic BC

Periodic BC

barrier

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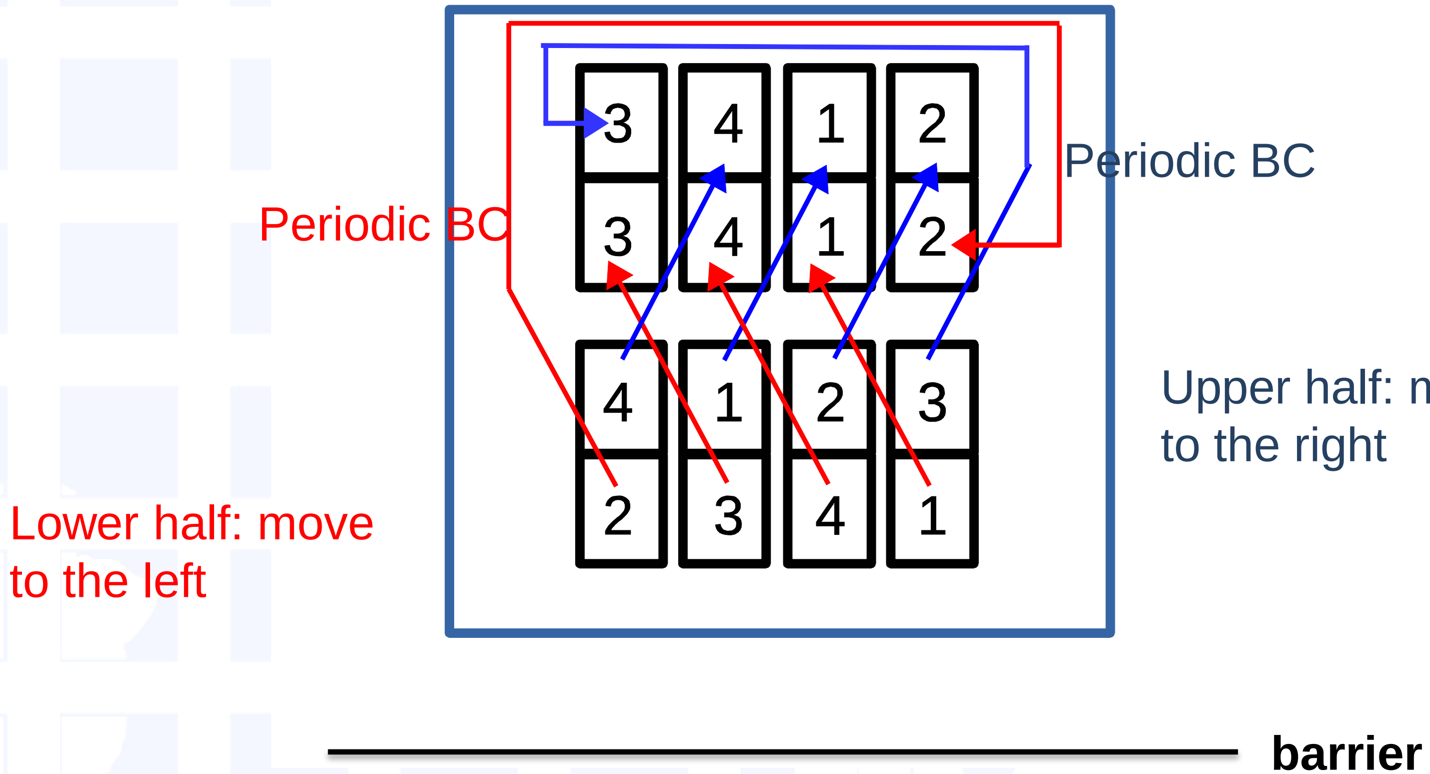
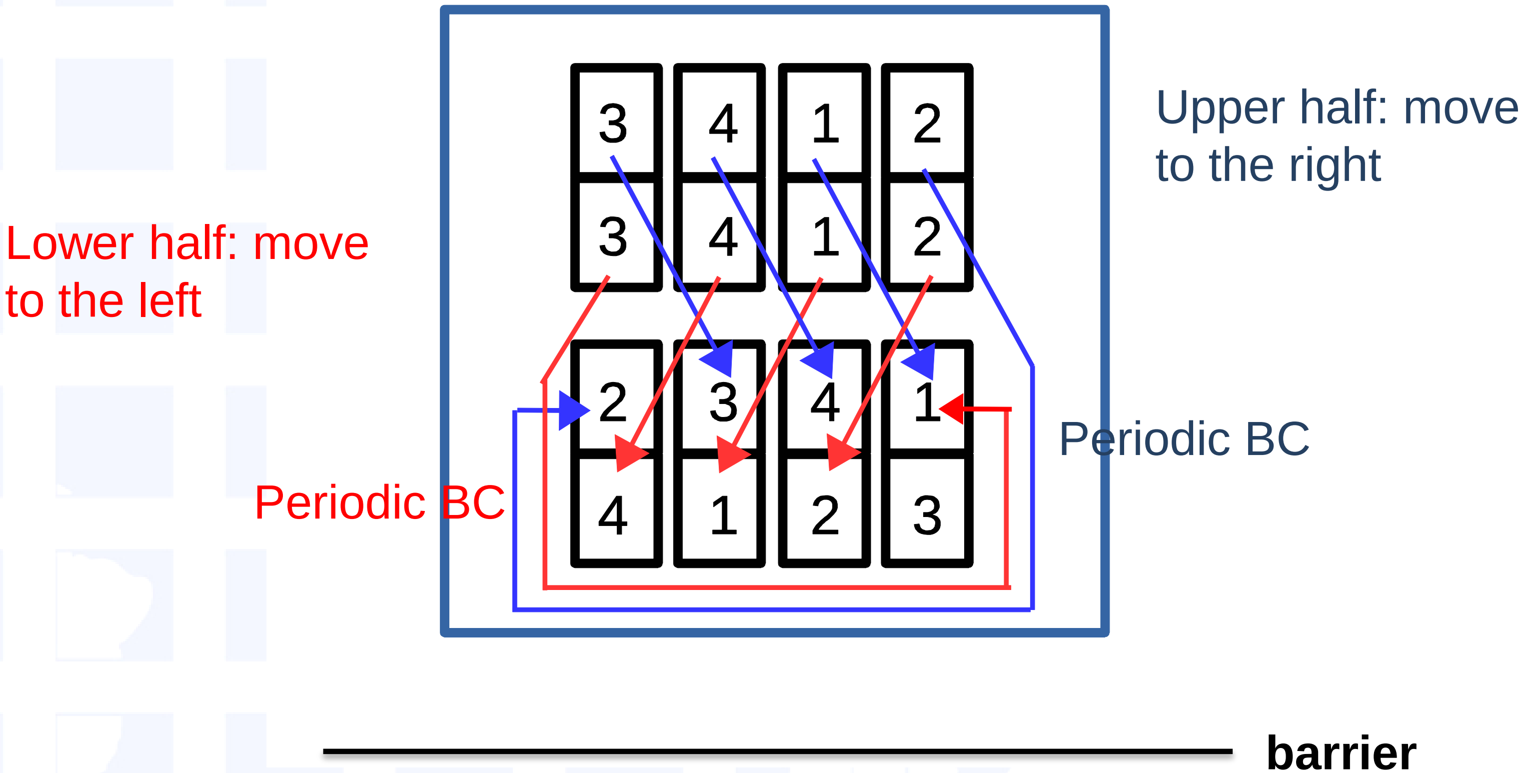
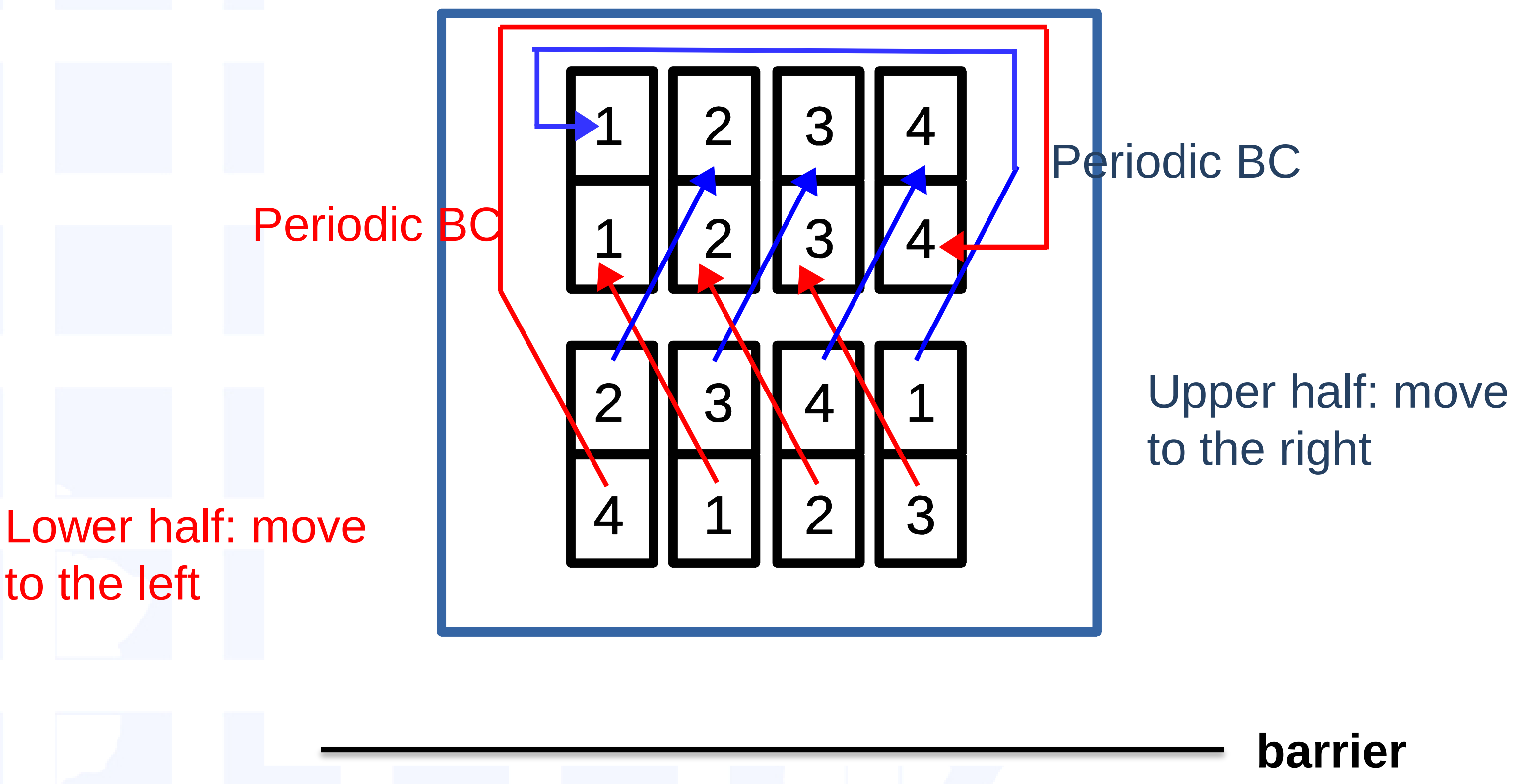
Iteration 2



Iteration 3


Upper half: move to the right
Lower half: move to the left
3 4 1 2
3 4 1 2
2 3 4 1
4 1 2 3
Periodic BC
Periodic BC
barrier

Iteration 4


Periodic BC
1
2
3
4
1
2
3
4
2
3
4
1
4
1
2
3
Periodic BC
Upper half: move to the right
Lower half: move to the left
barrier

- Nelem many iterations:
  - Initial configuration recovered

  -> Easy to check

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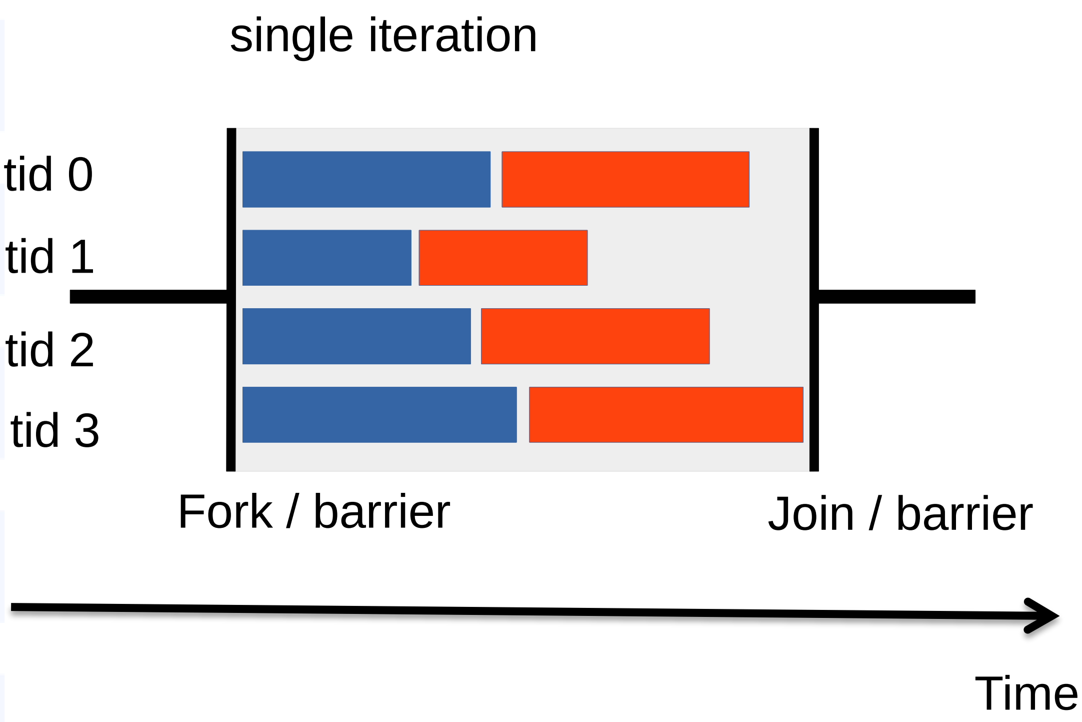
Temporal evolution



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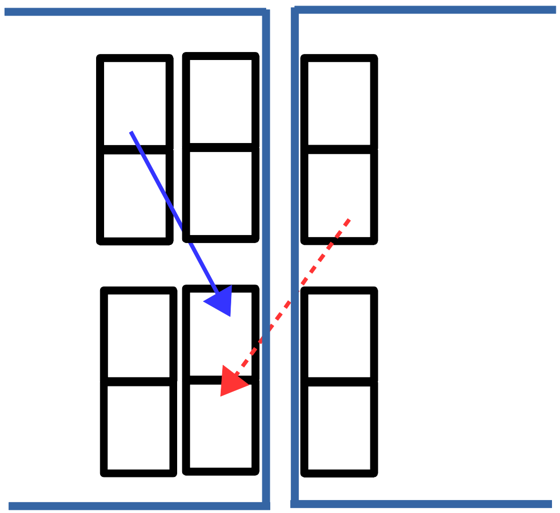
MORE THAN ONE PROCESS …

Elementary update



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

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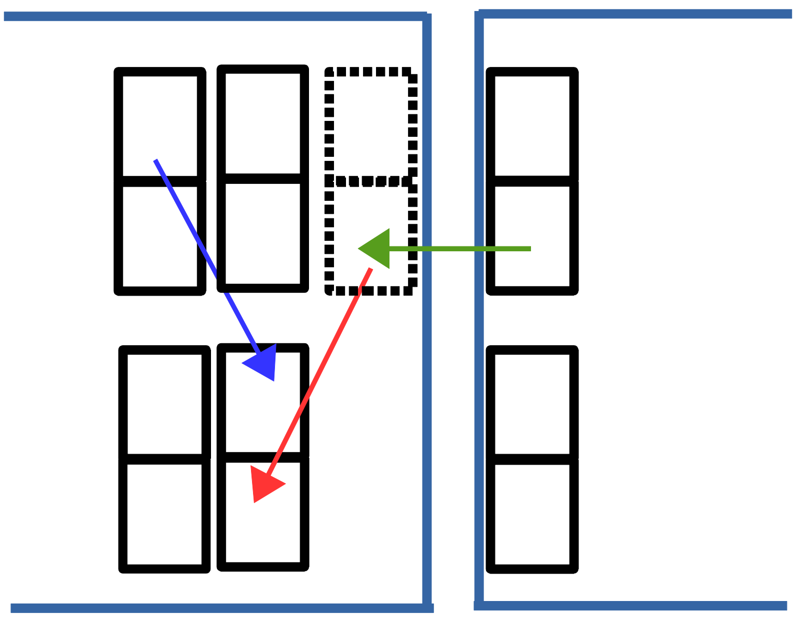
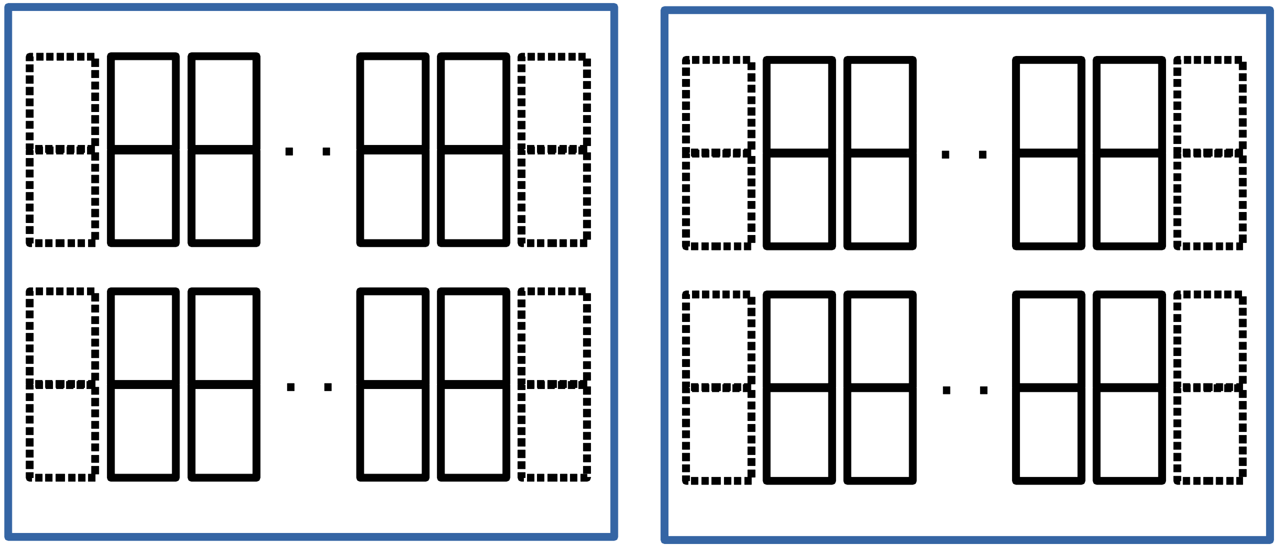
Boundary / Halo domains





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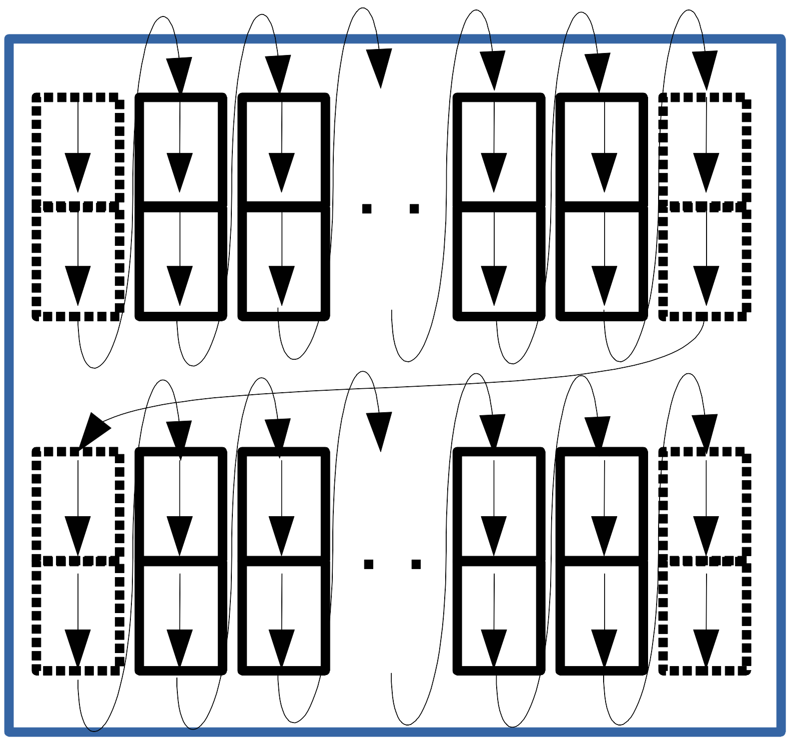
Memory layout



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Separate communication / computation phases

BULK SYNCHRONOUS

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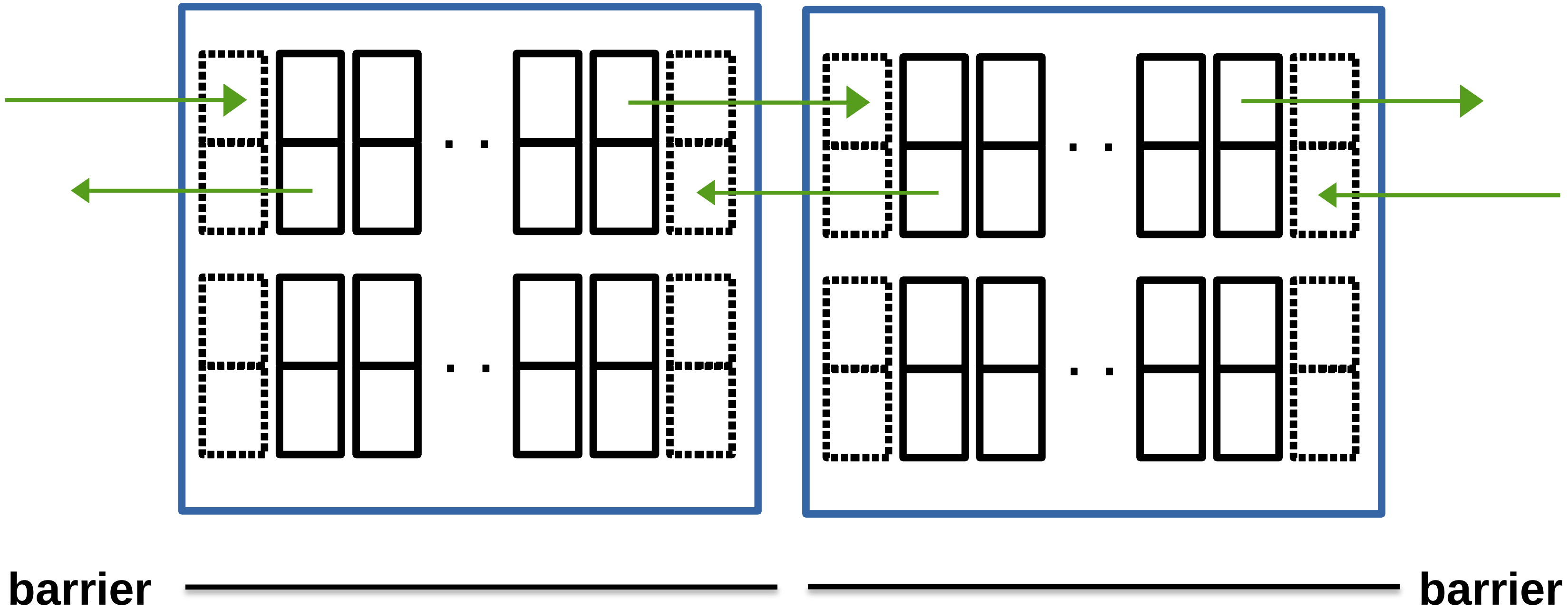
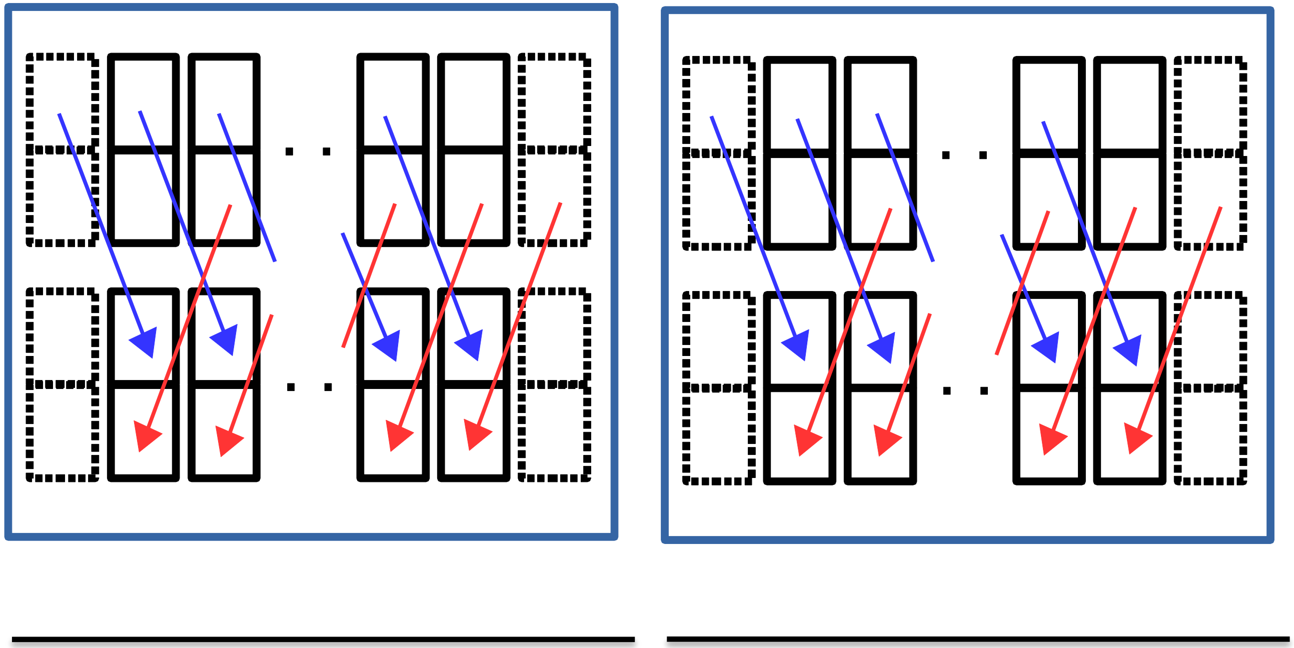
Communication phase

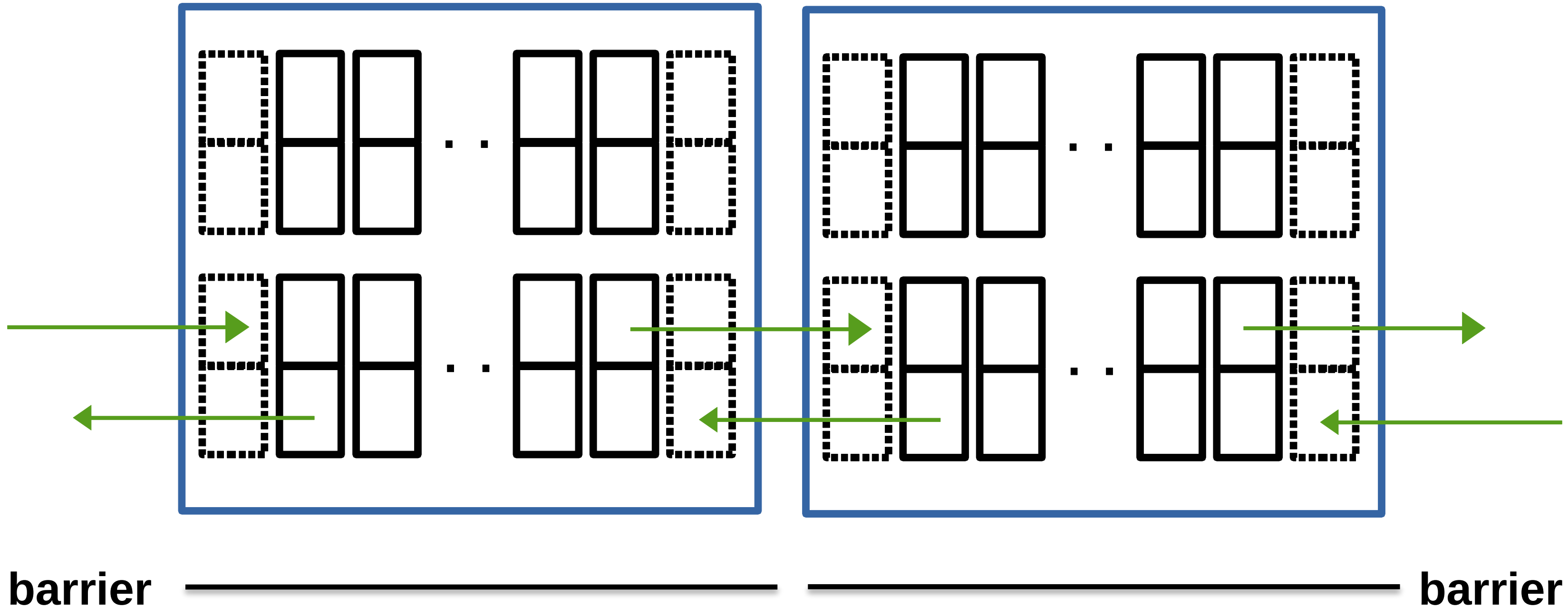


Computation phase



barrier barrier

Communication phase



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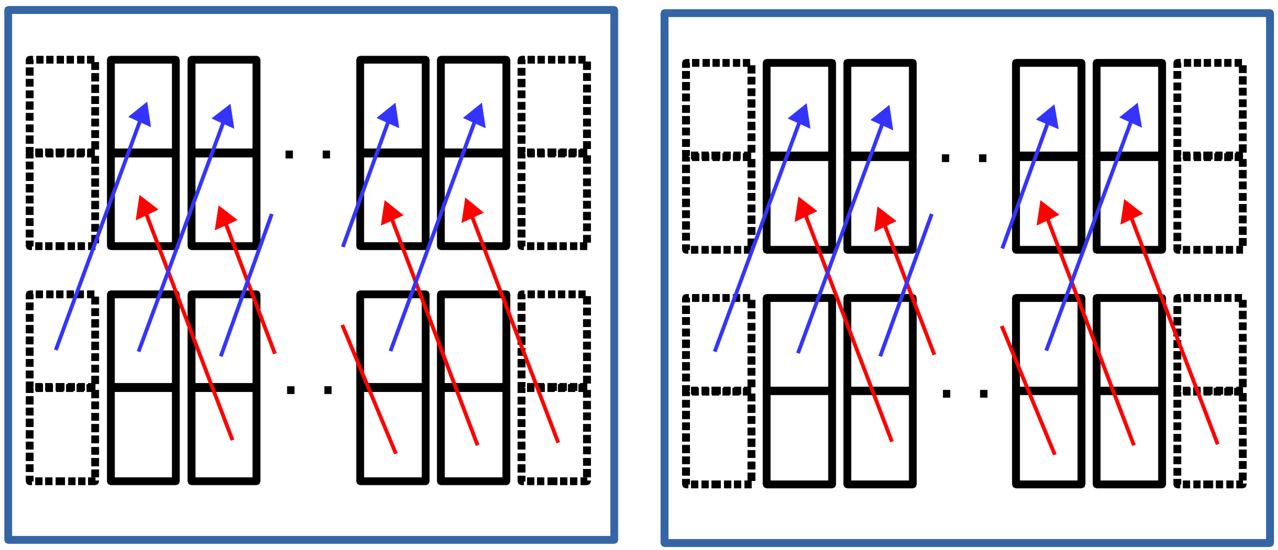
Computation phase



barrier barrier

Hands-on

- Implement the bulk-synchronous algorithm
  - use left_right_double_buffer_funneled.c as template

The GASPI Ring Exchange

- GASPI – left_right_double_buffer_funneled.c

```
 if (tid == 0) {
 // issue write
 write_notify_and_cycle
  ( .. , LEFT(iProc, nProc),., right_data_available[buffer_id], 1 + i);
 // issue write
 write_notify_and_cycle
  ( .., RIGHT(iProc, nProc),., 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;
```

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Basic ingredients

EXCURSION: EFFICIENT PARALLEL EXECUTION

Efficient parallel execution

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

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Efficient parallel execution

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

SCALABILITY

Scalability S

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

Measure for the additional benefit generated by employing additional resources

Scalability S

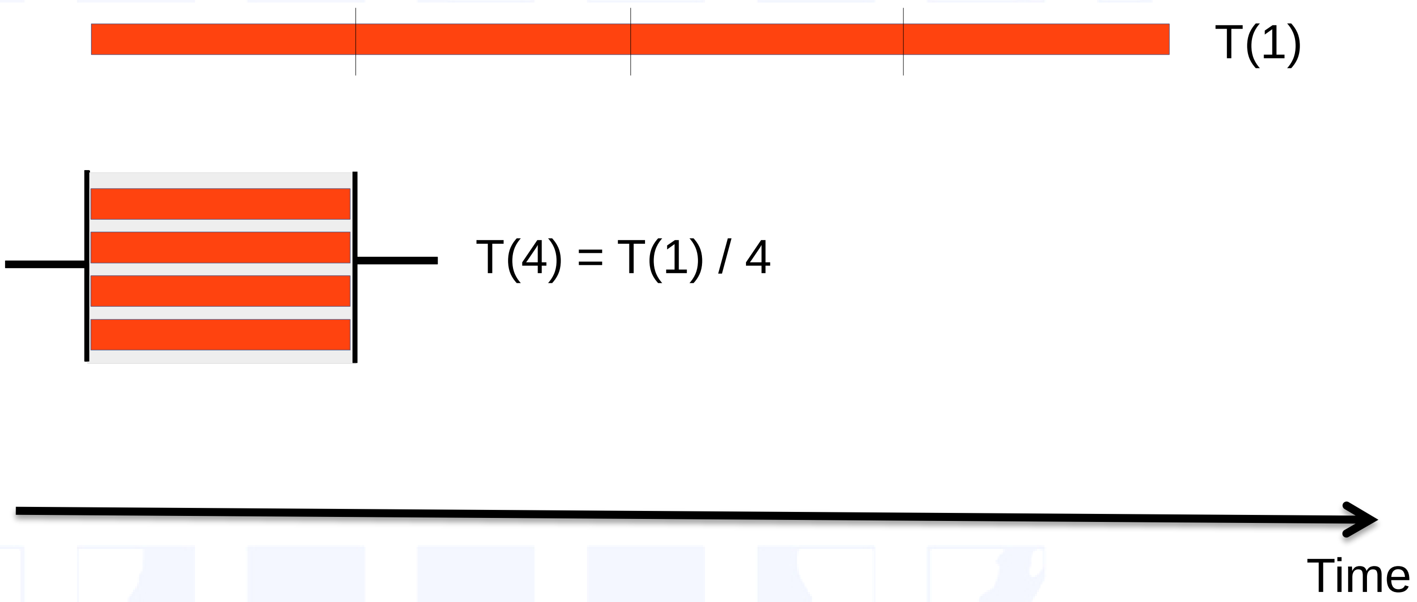
- Optimal: linear scalability, i.e.

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

  -> doubling the resources implies doubling the generated benefit

Implications for parallelization

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

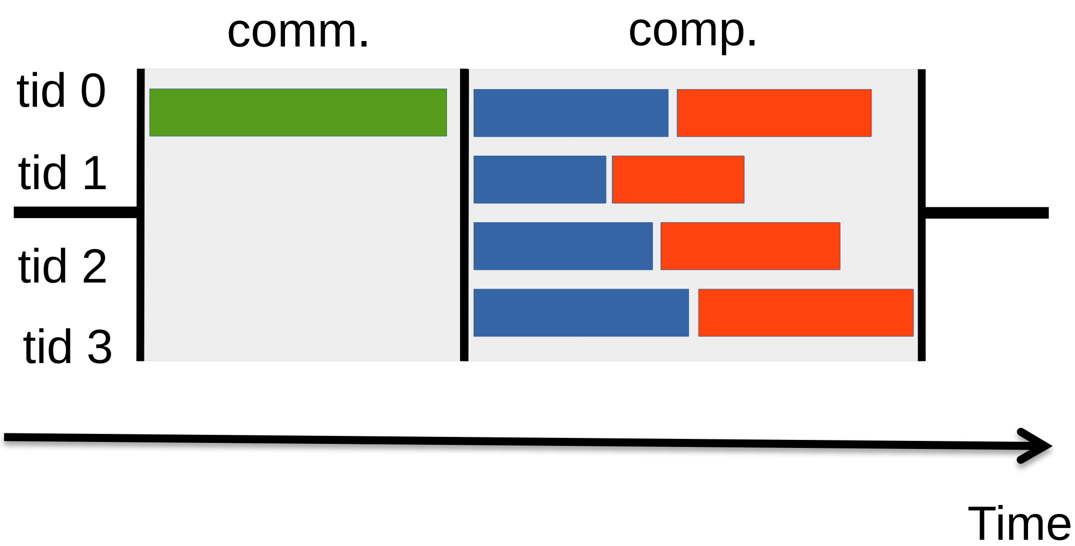


Implications for parallelization

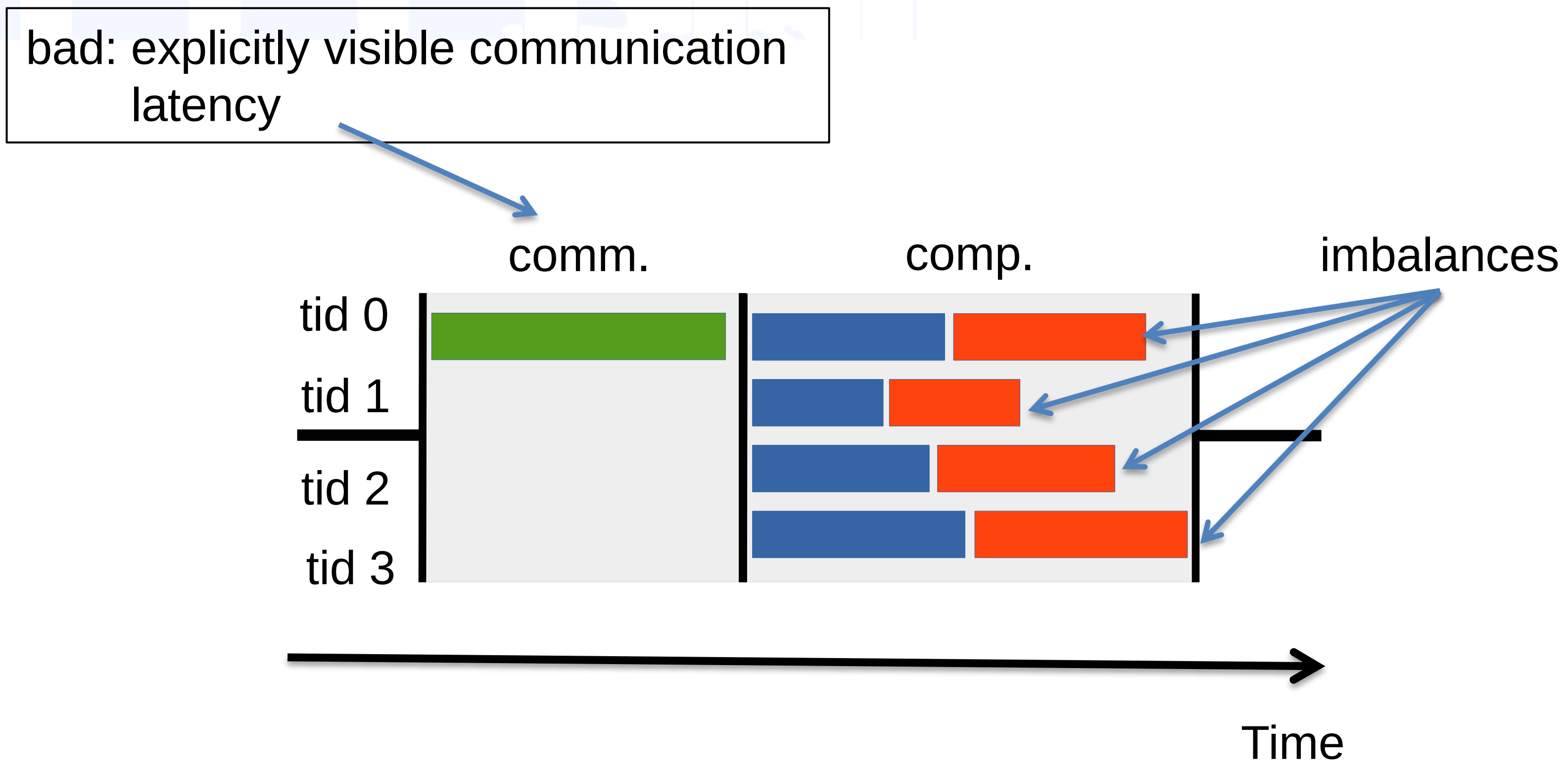
- $T(N_{proc}) := \mathrm{T}(1)/N_{proc}$
- T(1) is pure computation time, i.e.
  - communication latencies need to be completely hidden by the parallel implementation
  - Optimal load balancing is required
    - No synchronization points
      (Potential aggregation of imbalances, imbalances are per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

END OF EXCURSION

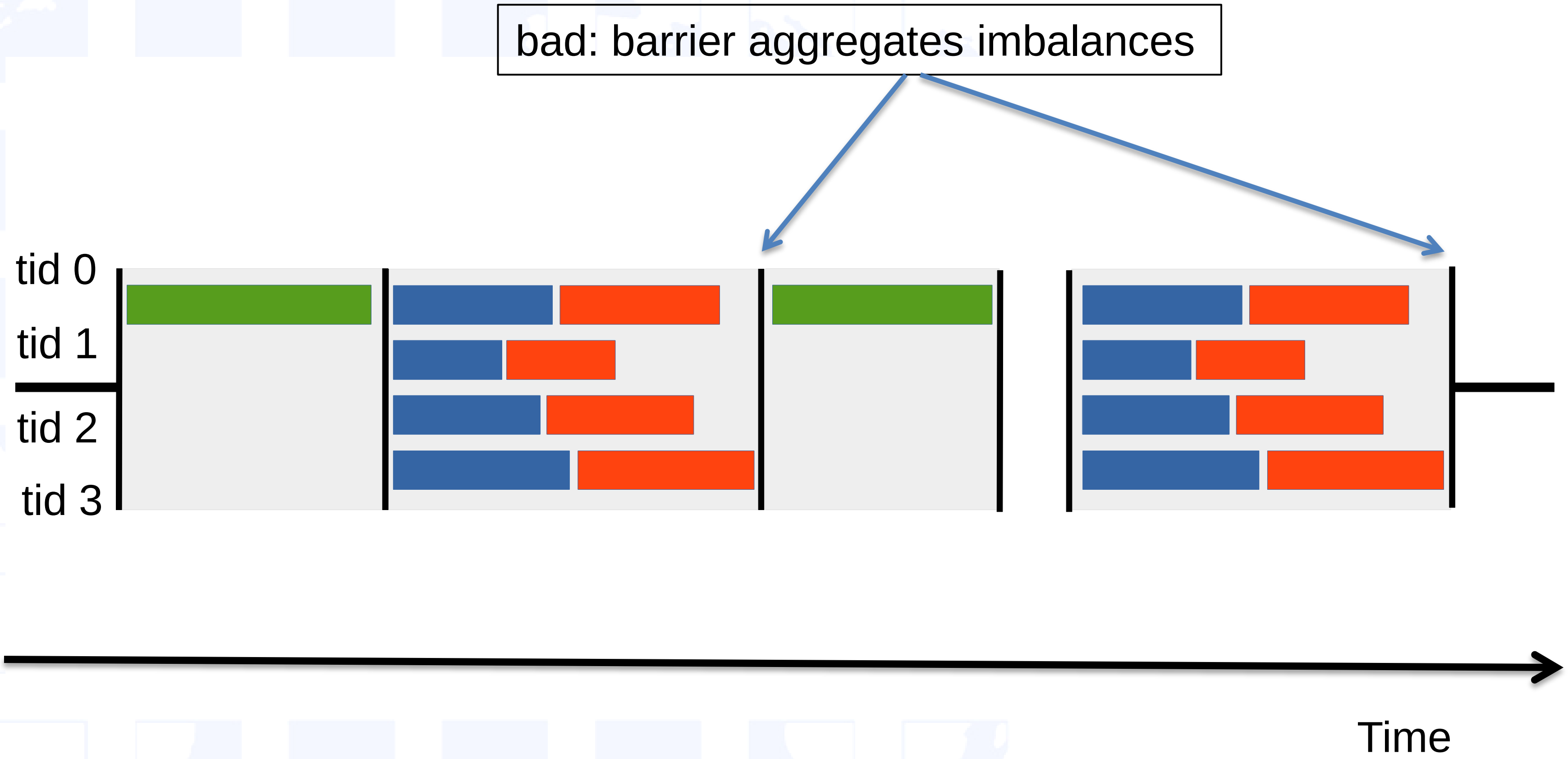
Temporal evolution: one iteration



Temporal evolution: one iteration



Temporal evolution: all iterations



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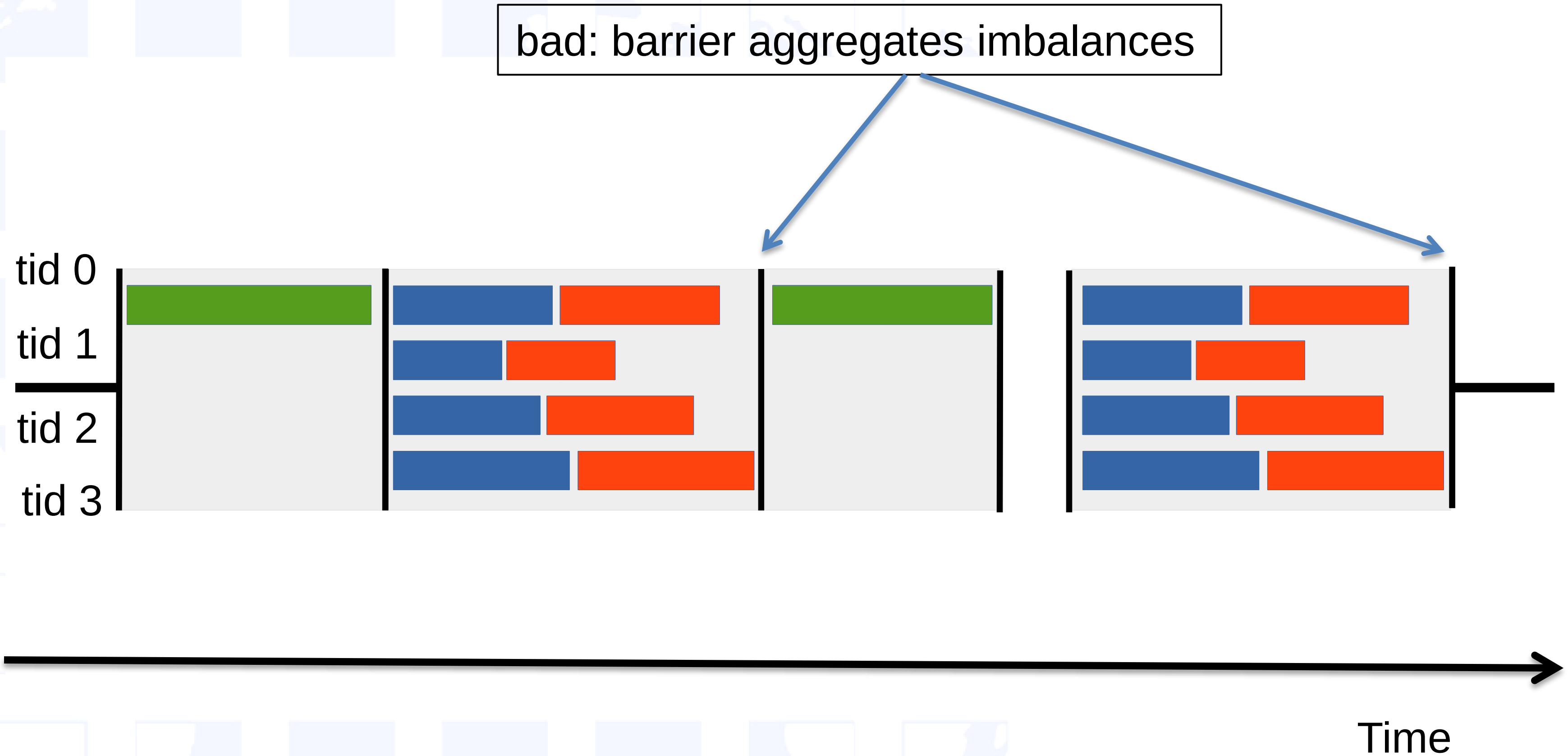
Temporal evolution: all iterations



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Hide communication behind computation

COMMUNICATION / COMPUTATION OVERLAP

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Strategy

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

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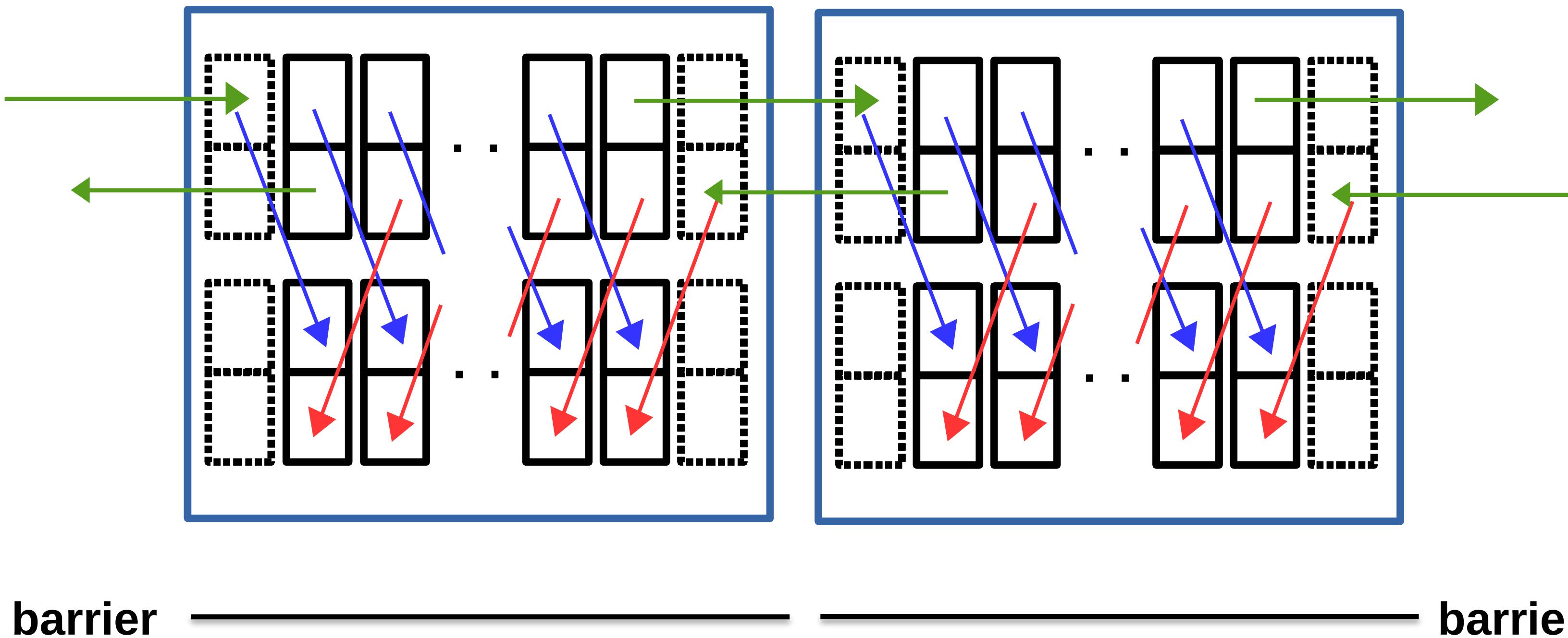
Strategy

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

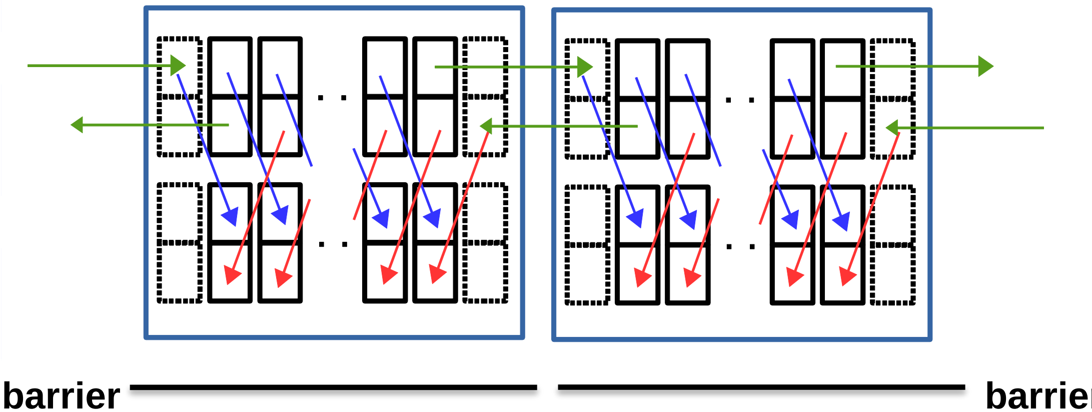
Single iteration



Single iteration: details

Left boundary element:

1. Initiate boundary data transfer to remote halo



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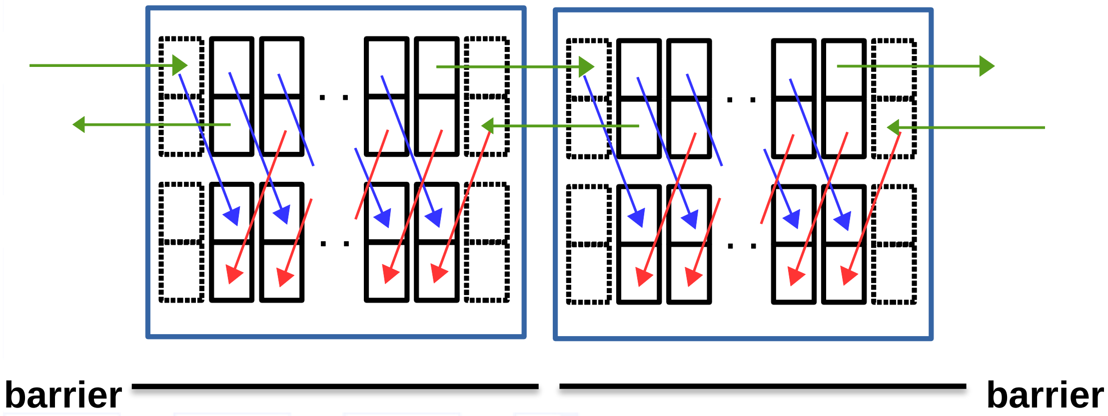
Left boundary element:

1. Initiate boundary data transfer to remote halo

2. Wait for boundary data transfer to local halo completion



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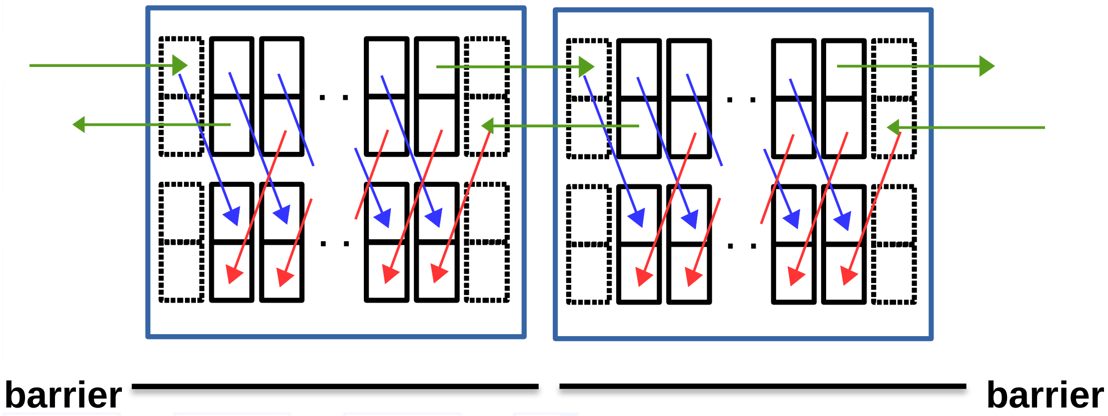
Left boundary element:

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



Global
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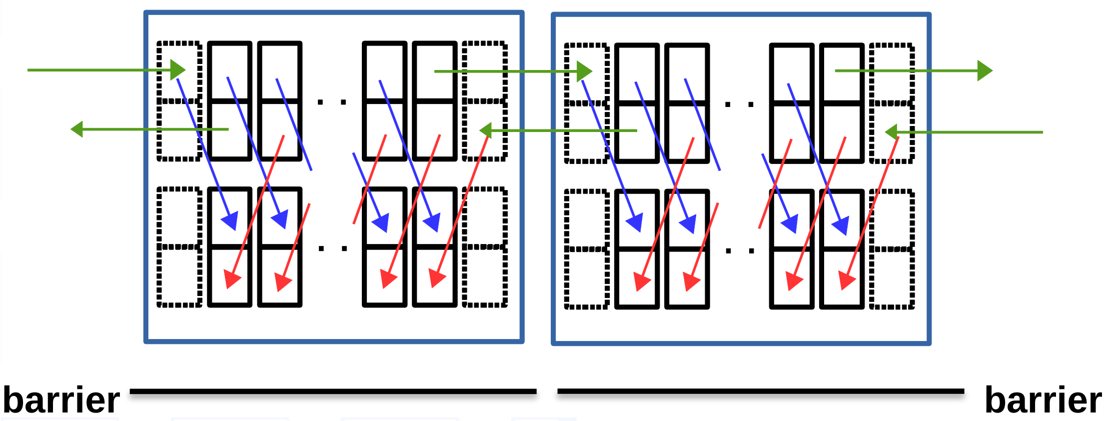
Left boundary element:

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

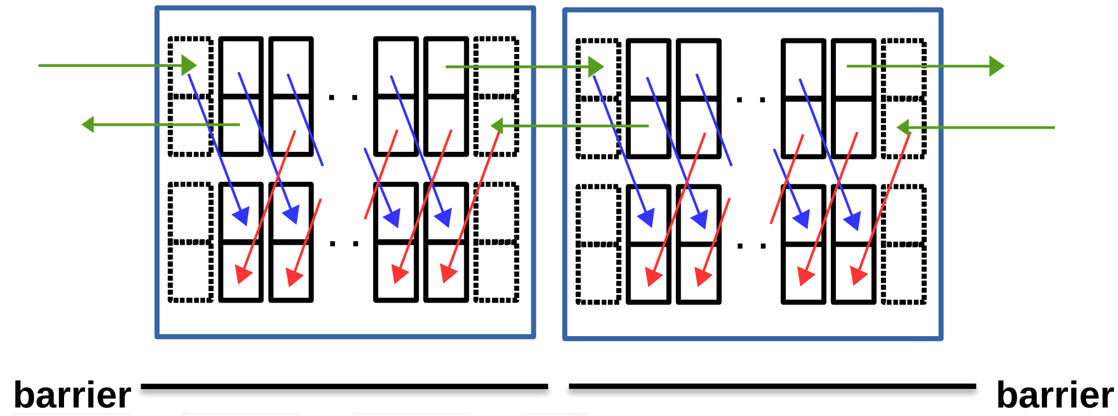
-> Right boundary element handled analogously



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!

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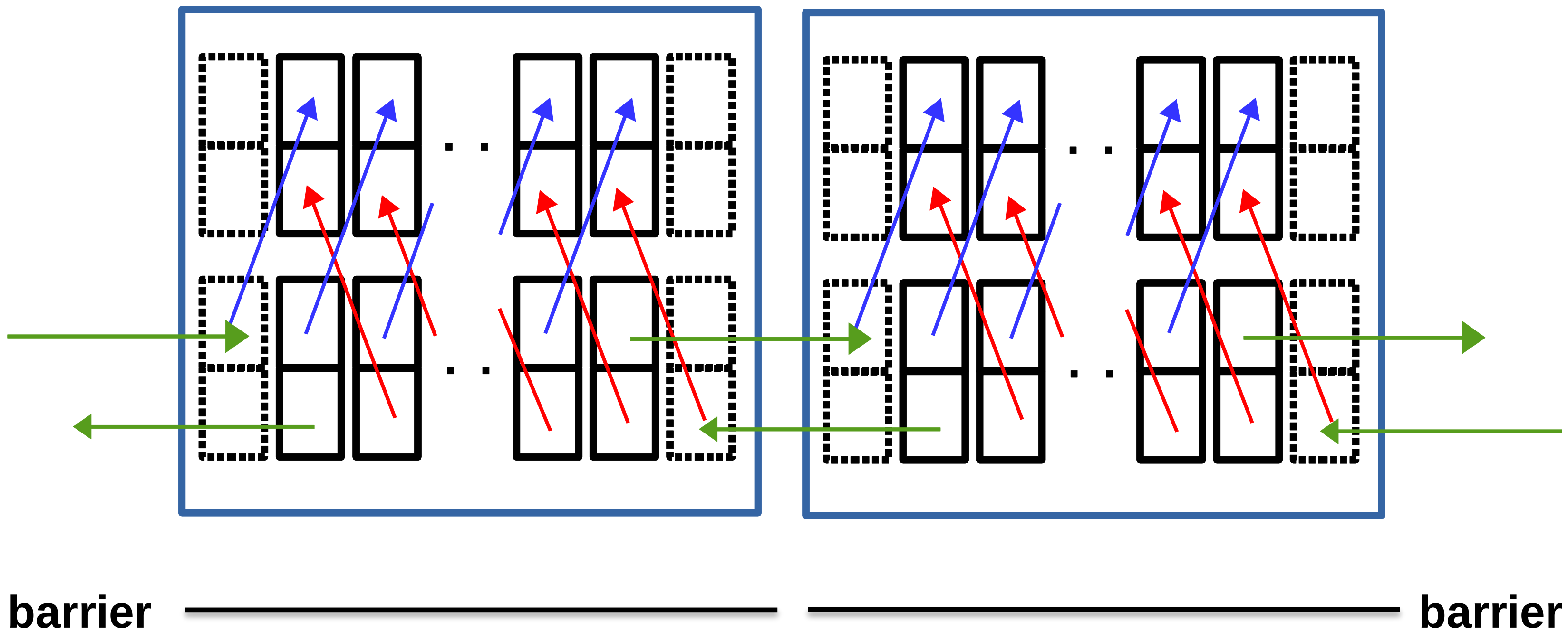
Single iteration



Hands-on

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

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The GASPI Ring Exchange

- GASPI – left_right_double_buffer_multiple.c

```
if (tid == 0) {
 write_notify_and_cycle
  ( .., LEFT(iProc, nProc),. , right_data_available[buffer_id], 1 + i);
  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 {
 write_notify_and_cycle
  ( .., RIGHT(iProc, nProc),. , left_data_available[buffer_id], 1 + i);
  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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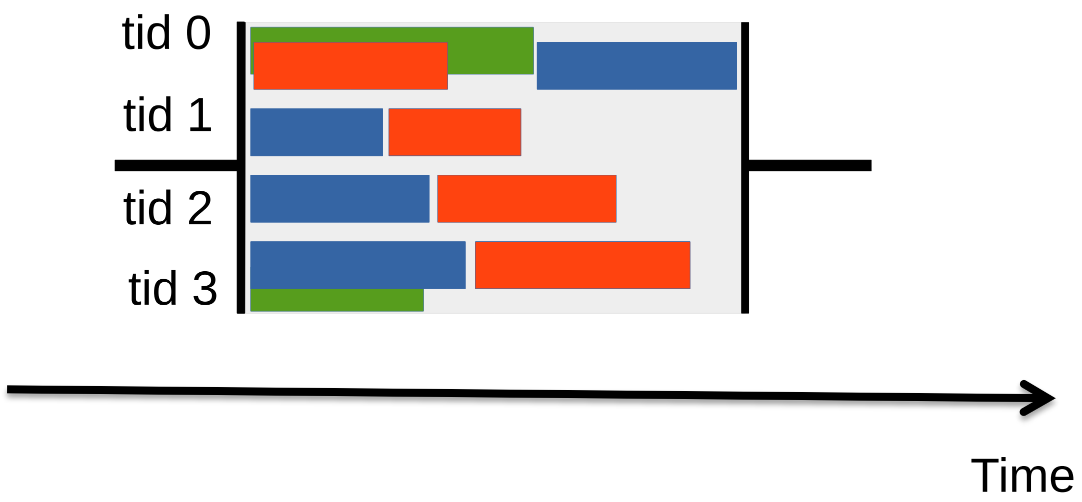
Temporal evolution



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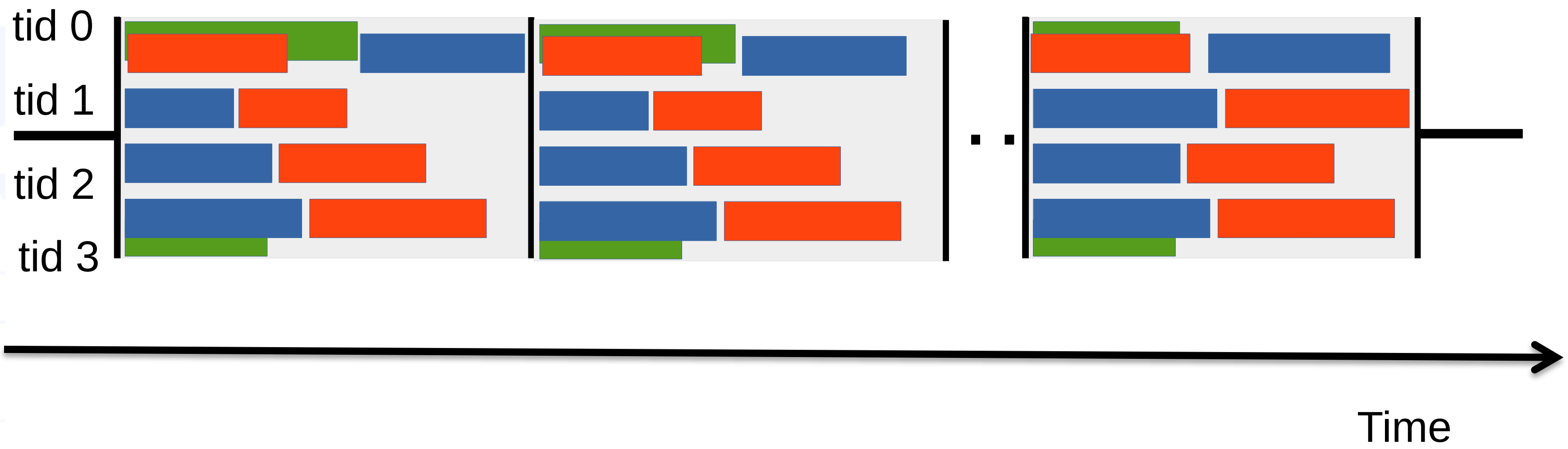
Temporal evolution



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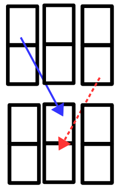
Avoid synchronization point

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

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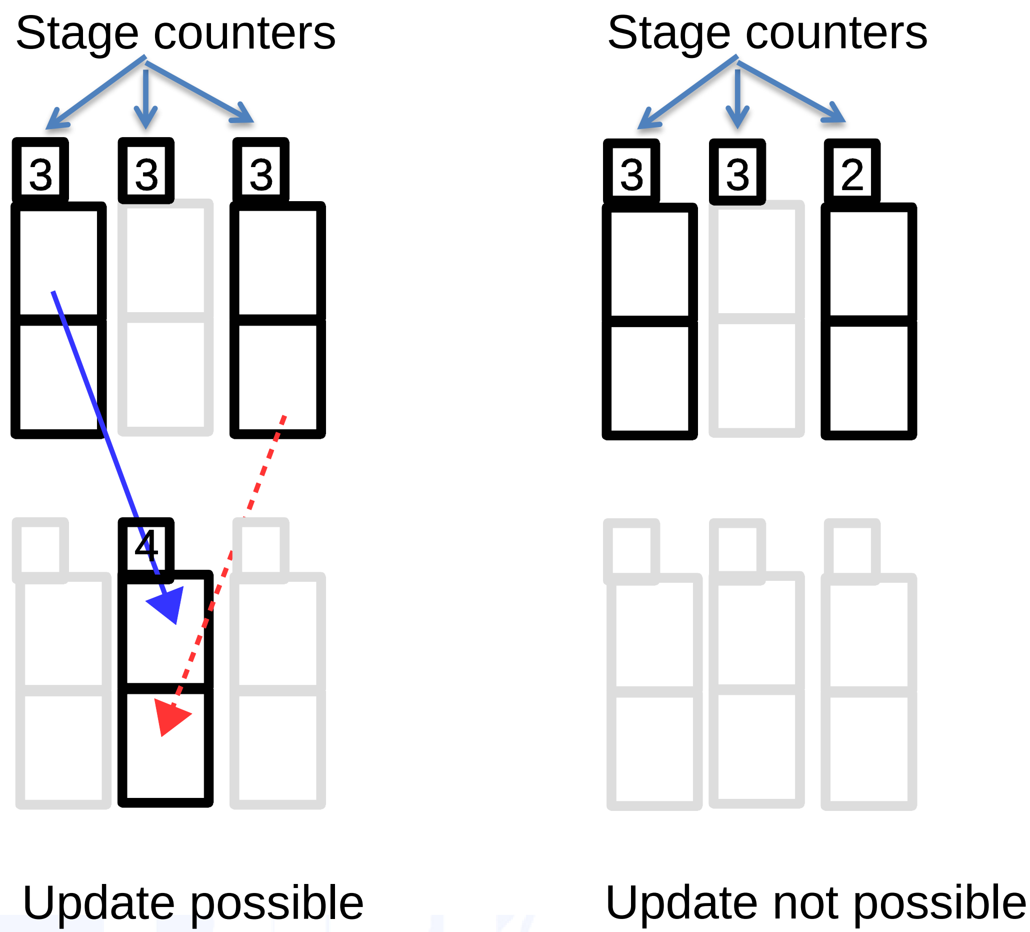
Reduce synchronicity

- 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

-> **Only local dependencies remain**



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- 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

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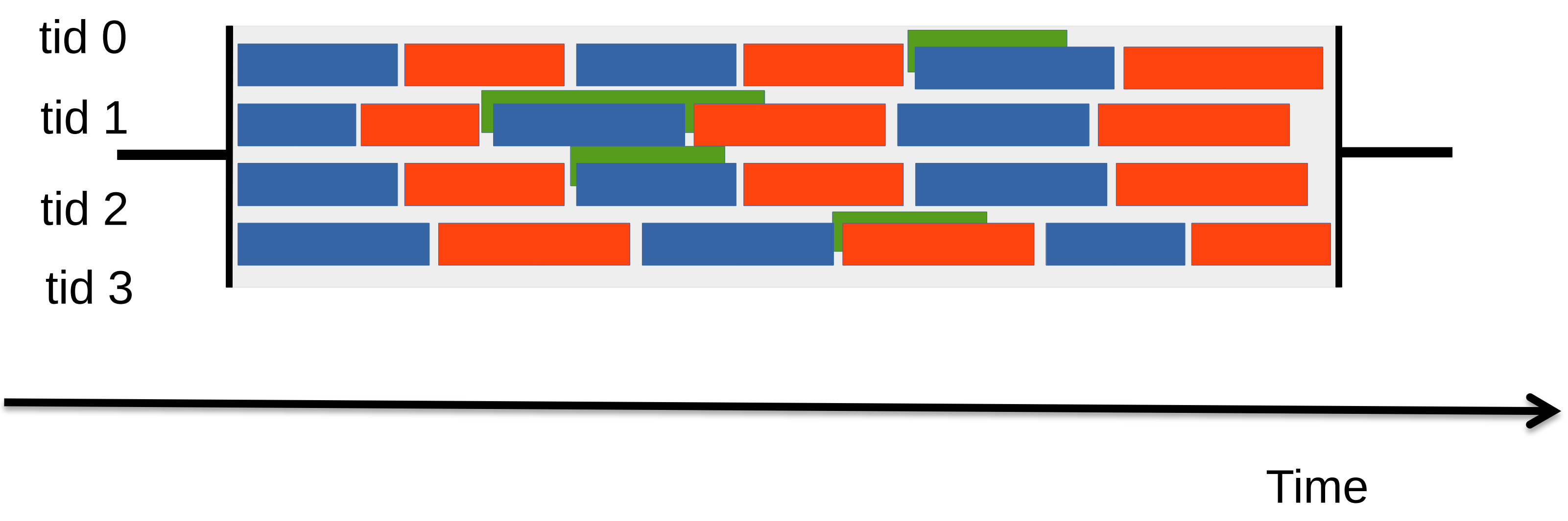
The GASPI Ring Exchange

- 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) {
     write_notify_and_cycle(..);
  } else if (sl->halo_type == RIGHT)
     write_notify_and_cycle(..);
  }
 ++sl->stage;
}
```

Temporal evolution



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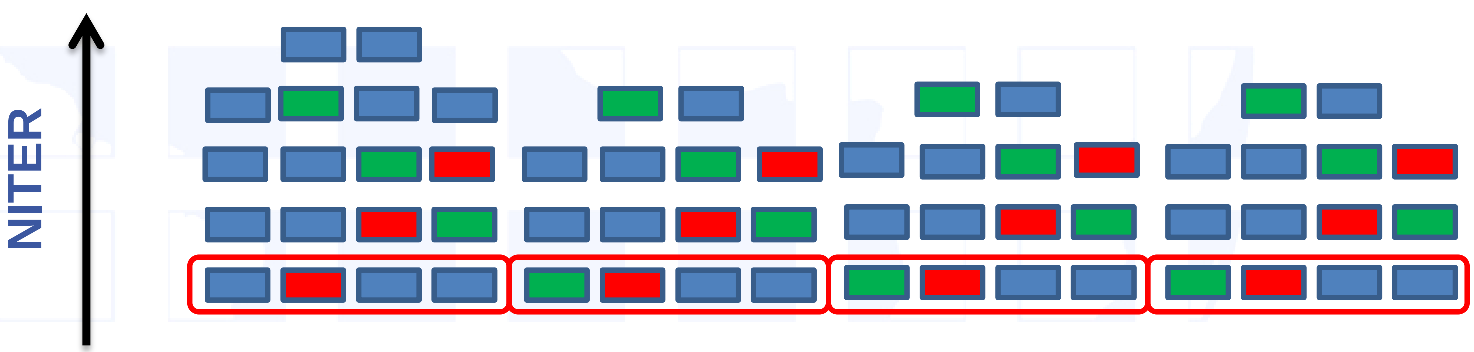
The GASPI Ring Exchange

GASPI – Dataflow

- Locally and globally asynchronous dataflow.



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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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Questions?

Thank you for your attention

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