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/RPH2333

INTERTWinE - Programming Model INTERoperability ToWards Exascale

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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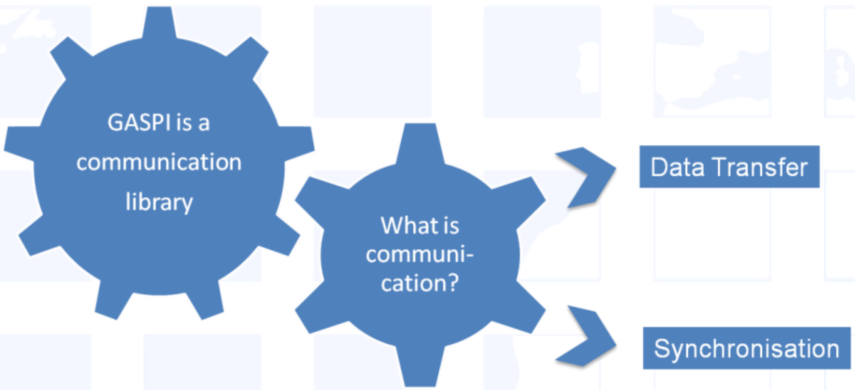
GASPI at a Glance



Nuts and Bolts for Communication Engines

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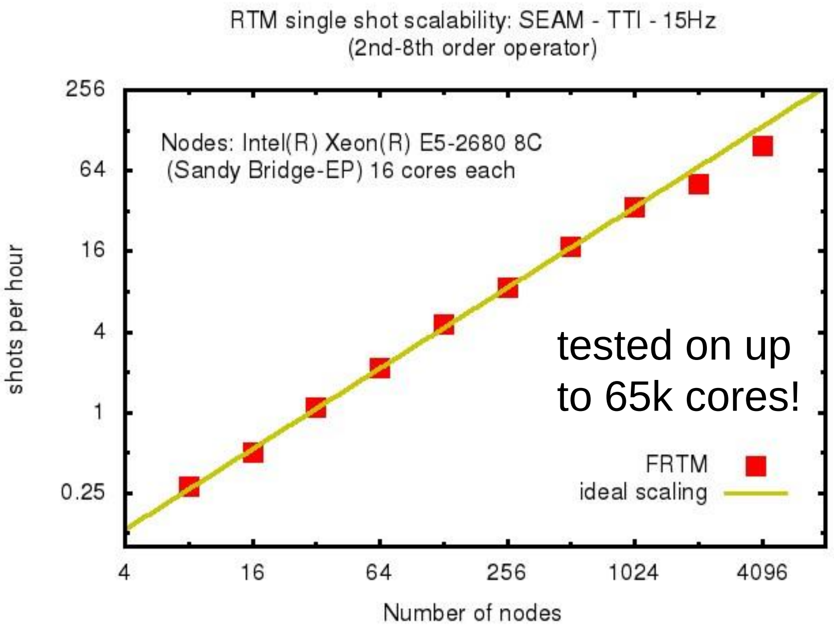
GASPI at a Glance

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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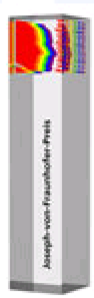
GASPI History

- **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“.

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GASPI
Standardization Forum

Founding
Members

KTH VETENSKAP OCH KONST

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T · · Systems · · ·

Fraunhofer ITWM

DLR

ZIH
Zentrum für Informationsdienste und Hochleistungsrechnen

ECMWF

Fraunhofer SCAI

Regionales RechenZentrum Erlangen
Der IT-Dienstleister der FAU

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GASPI in European Exascale Projects

EXA2CT

EXascale Algorithms and Advanced Computational Techniques

EPiGRAM

Exascale ProGRAmming Models

INTERTWinE

Programming-model design and implementation for the Exascale

Inria
INVENTORS FOR THE DIGITAL WORLD

epcc

MANCHESTER 1824
The University of Manchester

KTH VETENSKAP OCH KONST

BSC
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

DLR

Fraunhofer ITWM

T - -Systems- - -

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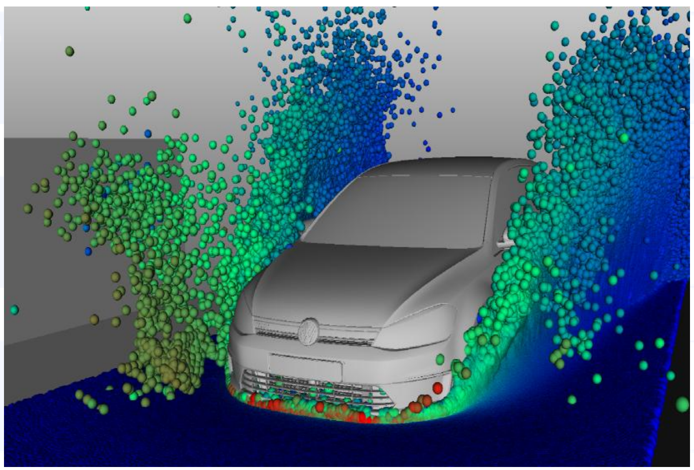
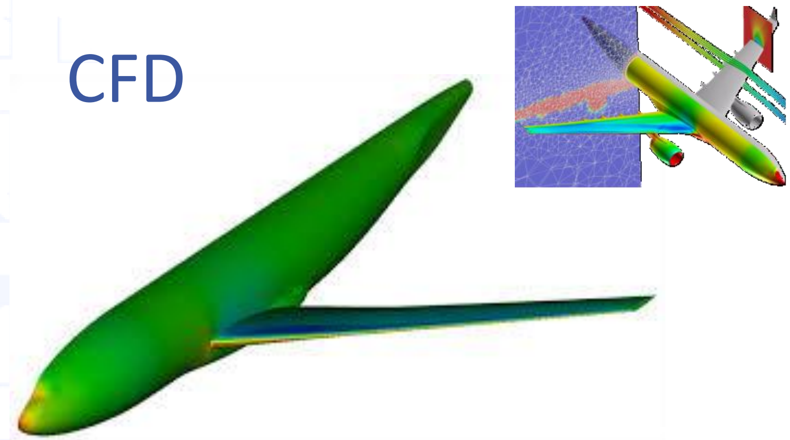
Some GASPI Applications

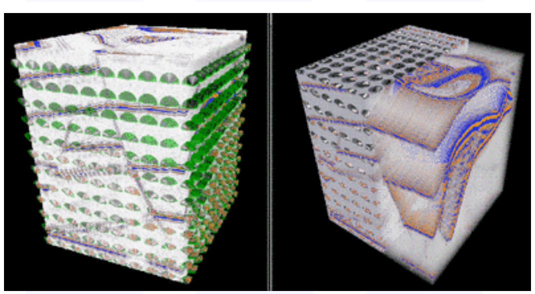
Visualization



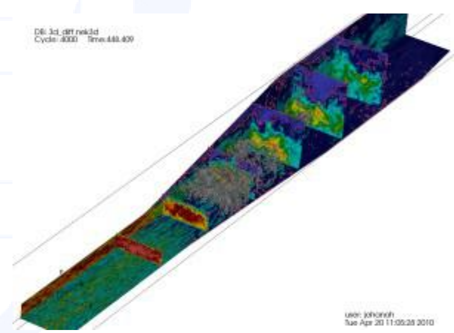
CFD

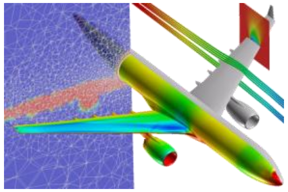


Seismic Imaging & Algorithms

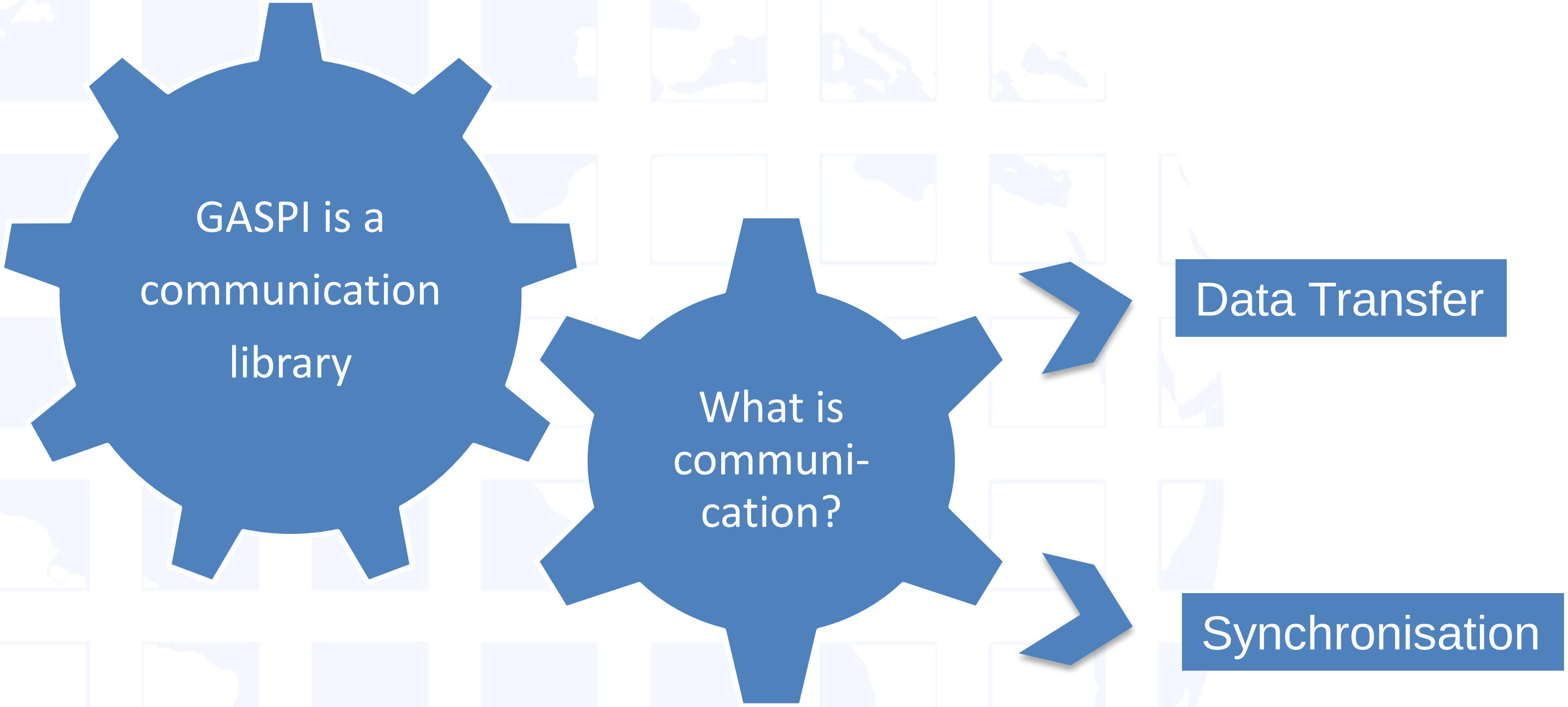


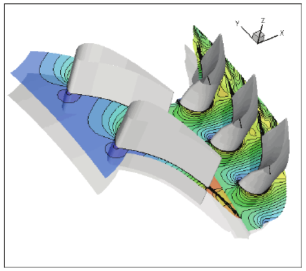
Machine Learning
Big Data
Iterative Solvers





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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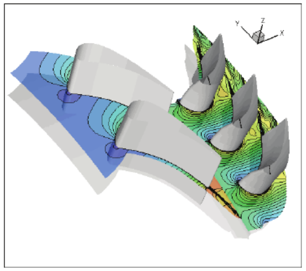
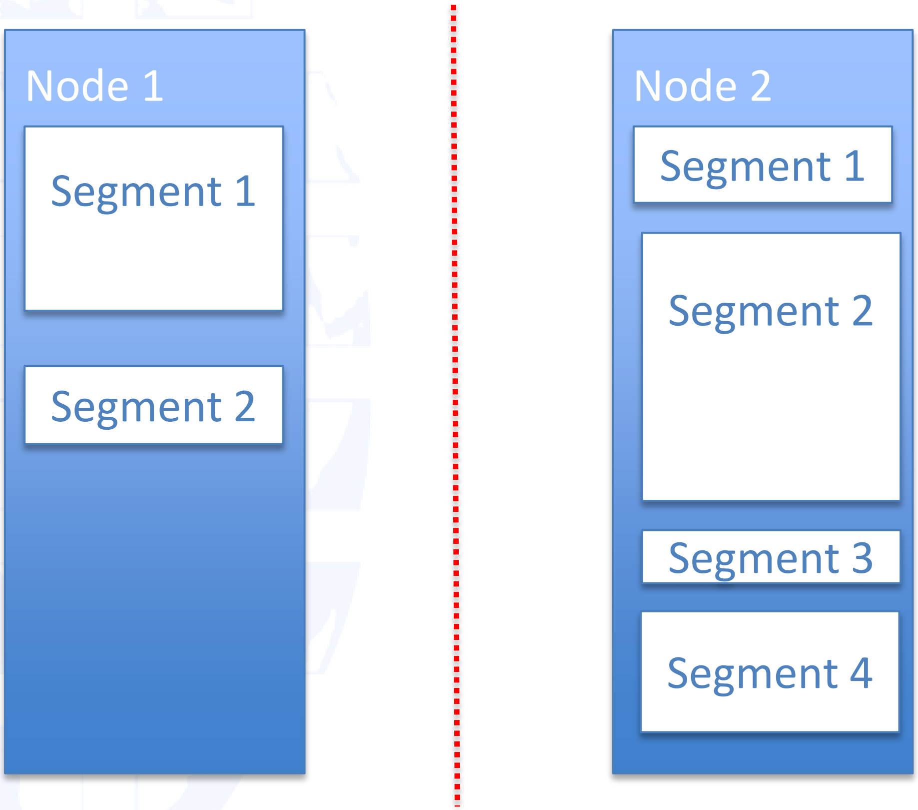


Concepts: Segments

- 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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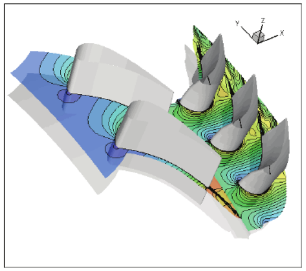
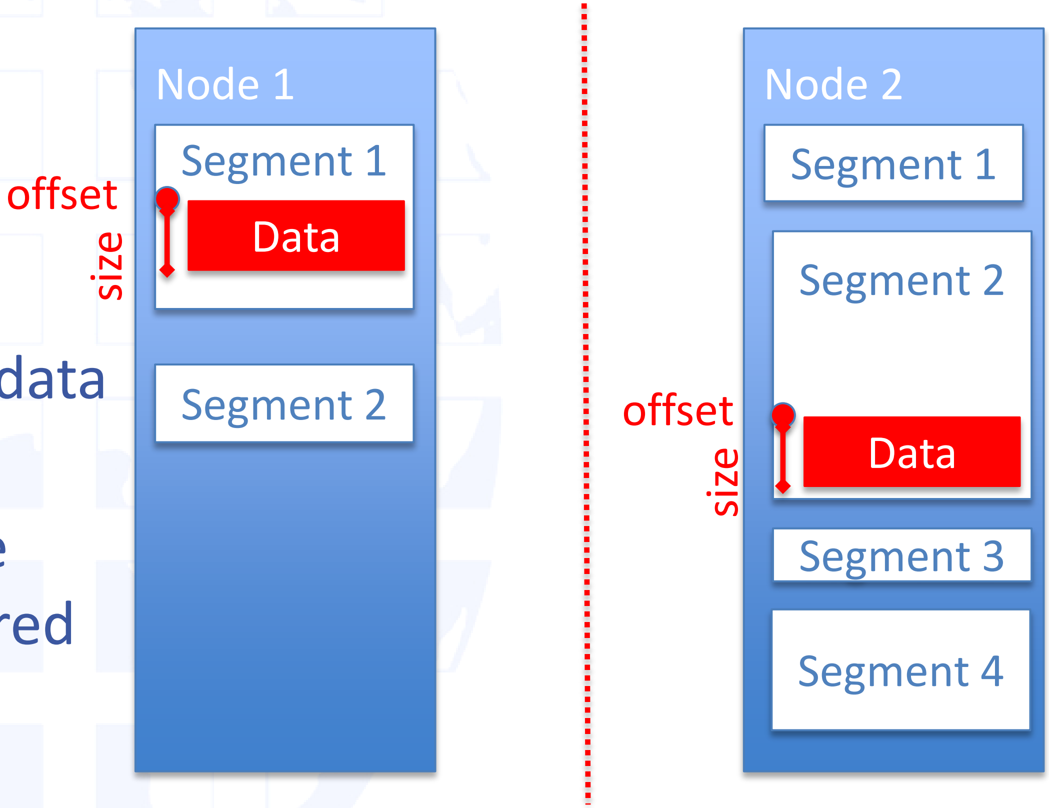


Concepts: Segments



Application has to manage data transfer completely:

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

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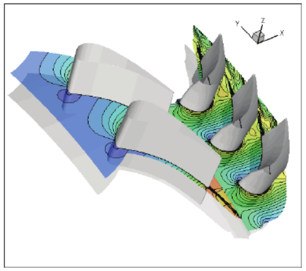
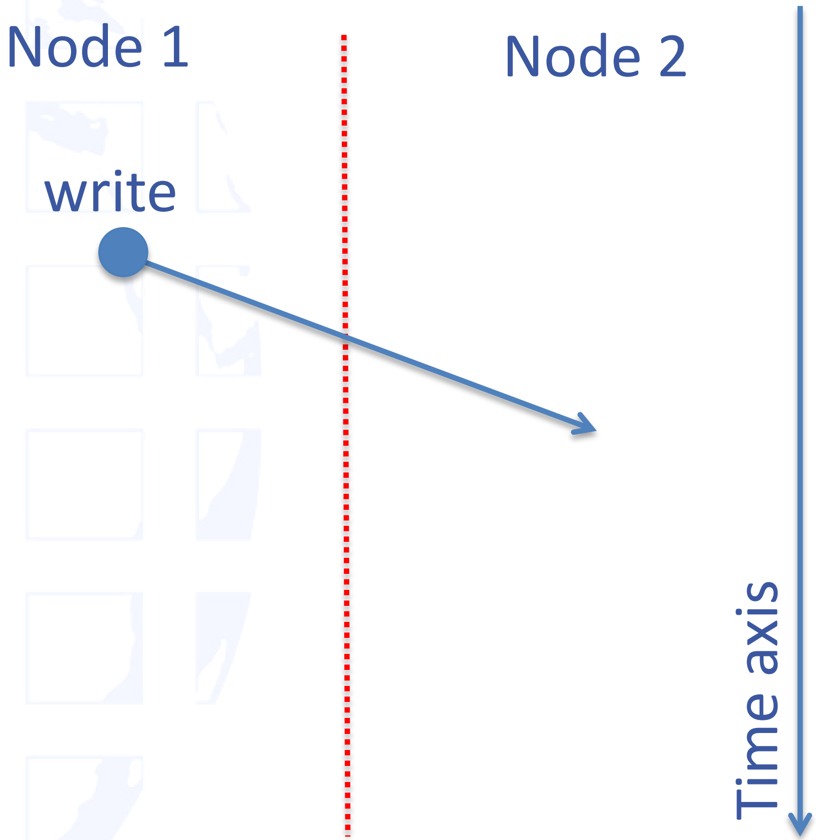


Concepts: one-sided Communication

- 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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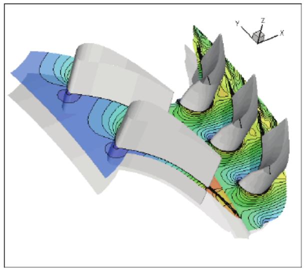
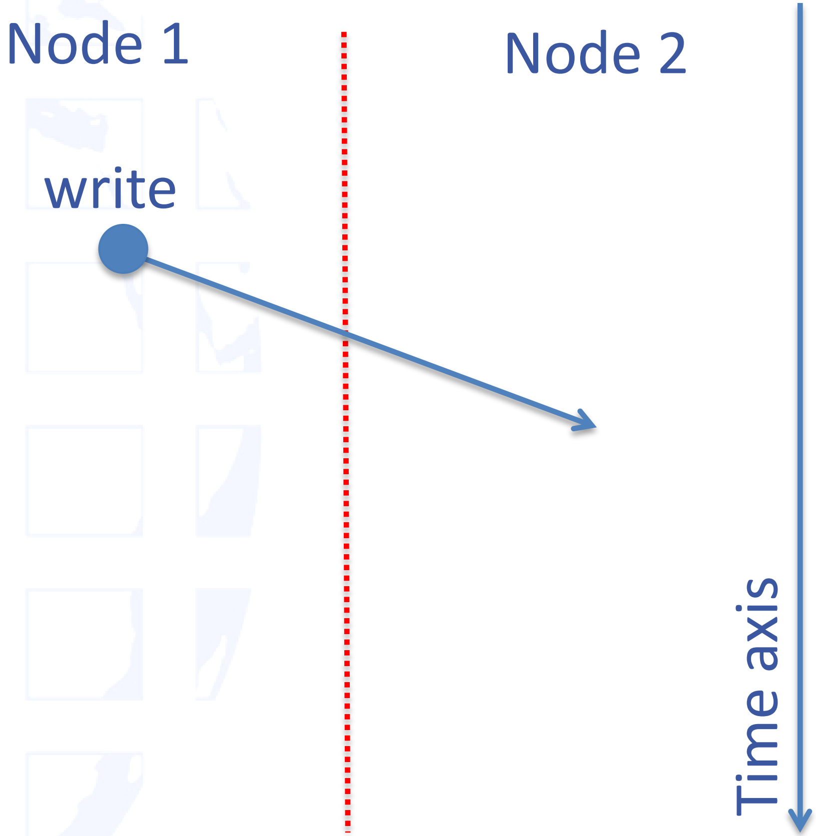


Concepts: one-sided Communication

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



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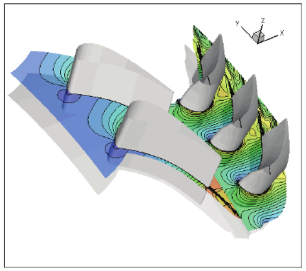
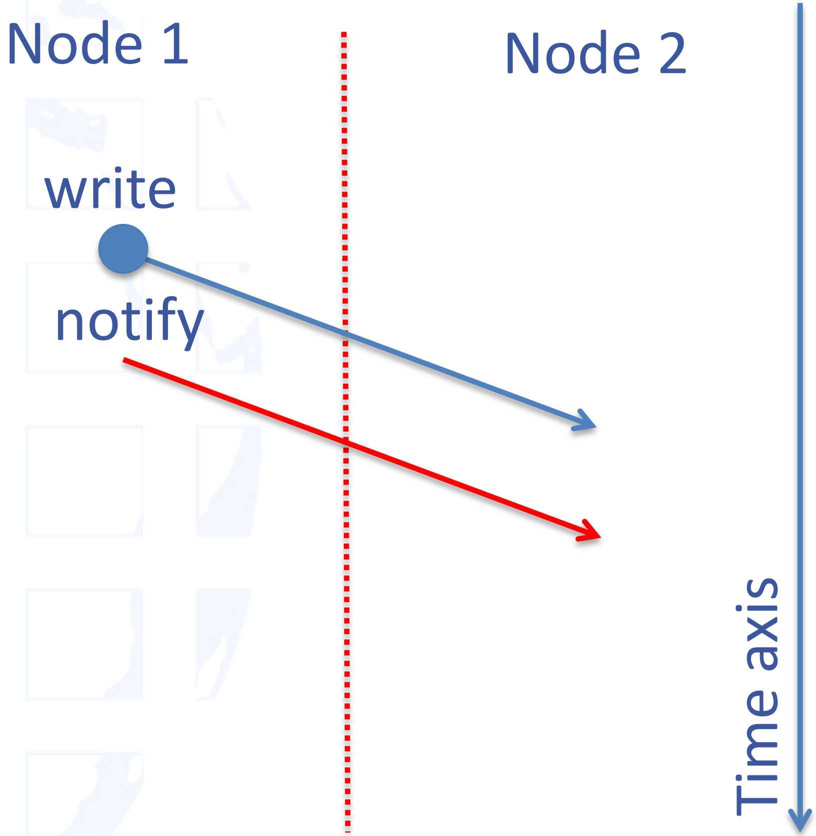


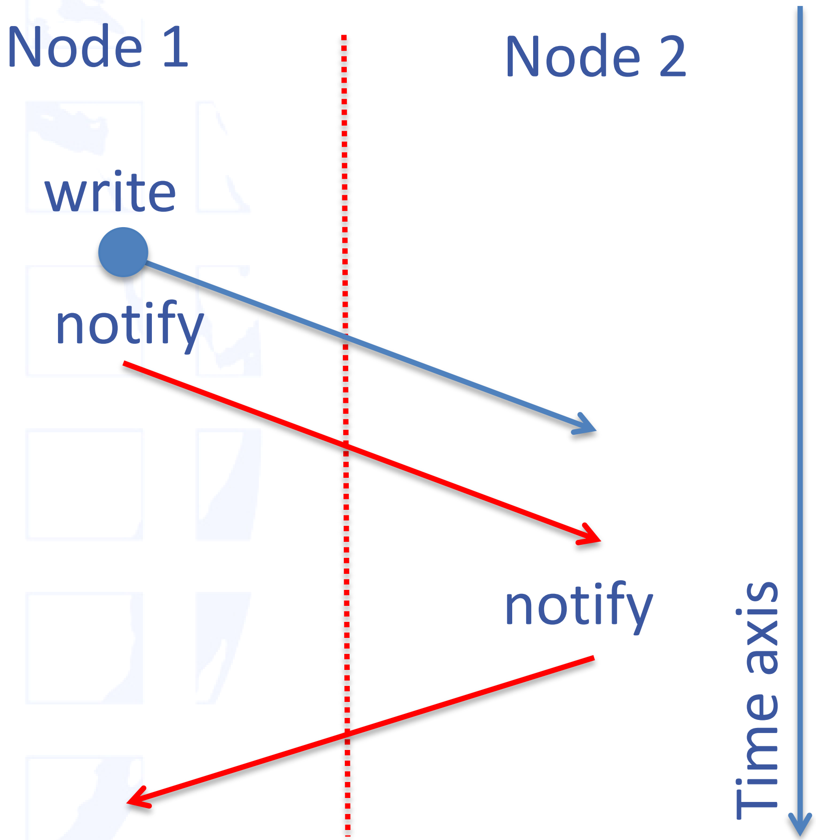
Concepts: Synchronisation with Notifications

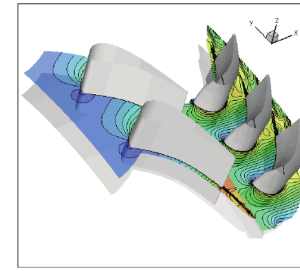
- Node 2 has not participated, it does not know that communication has started
- It has to be notified.



Concepts: Synchronisation with Notifications

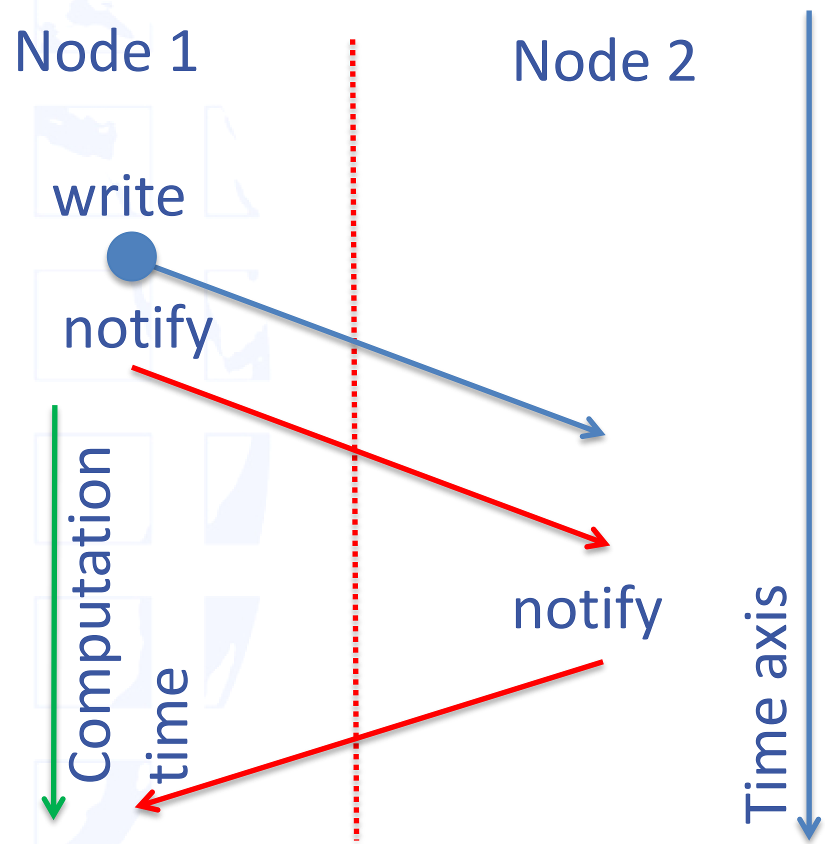
- Node 2 has not participated, it does not know that communication has started
- It has to be notified for data movement completion.
- Node 1 does not know if the write has finished.
- If it needs to know, it also has to be notified





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



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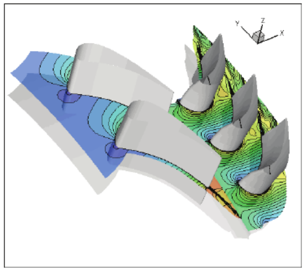
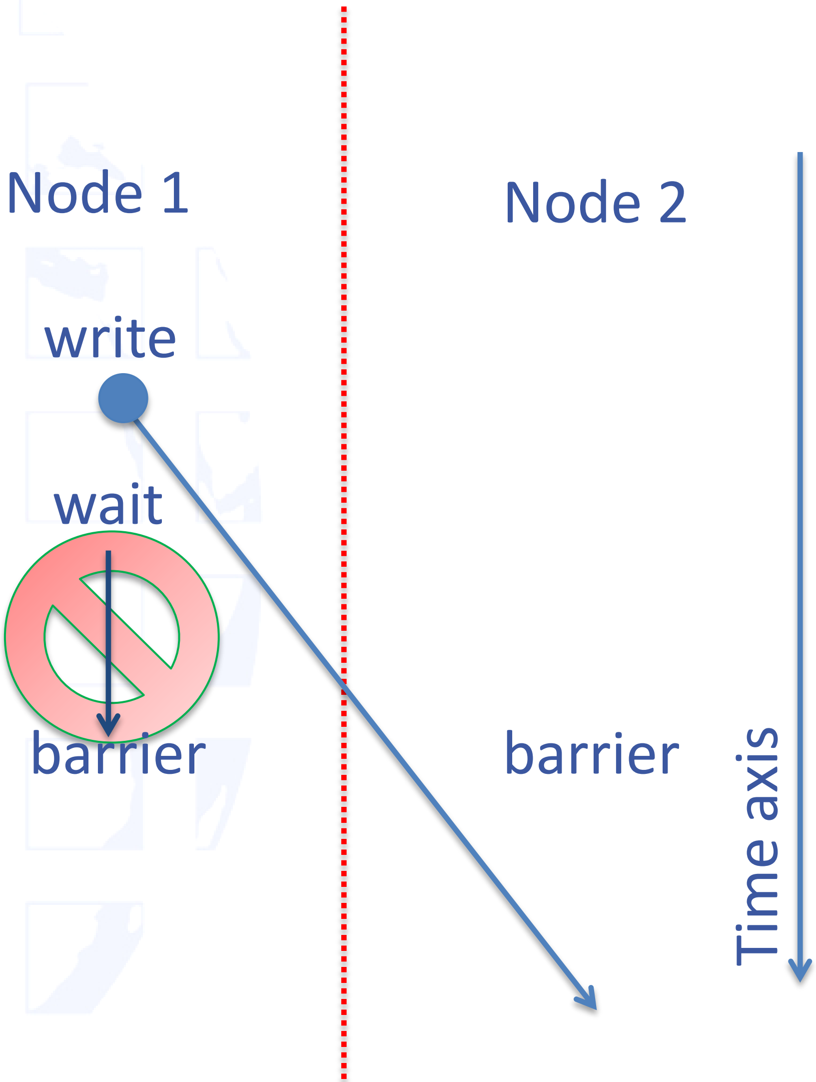


Concepts: Warning!

- 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



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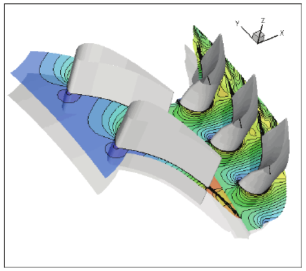
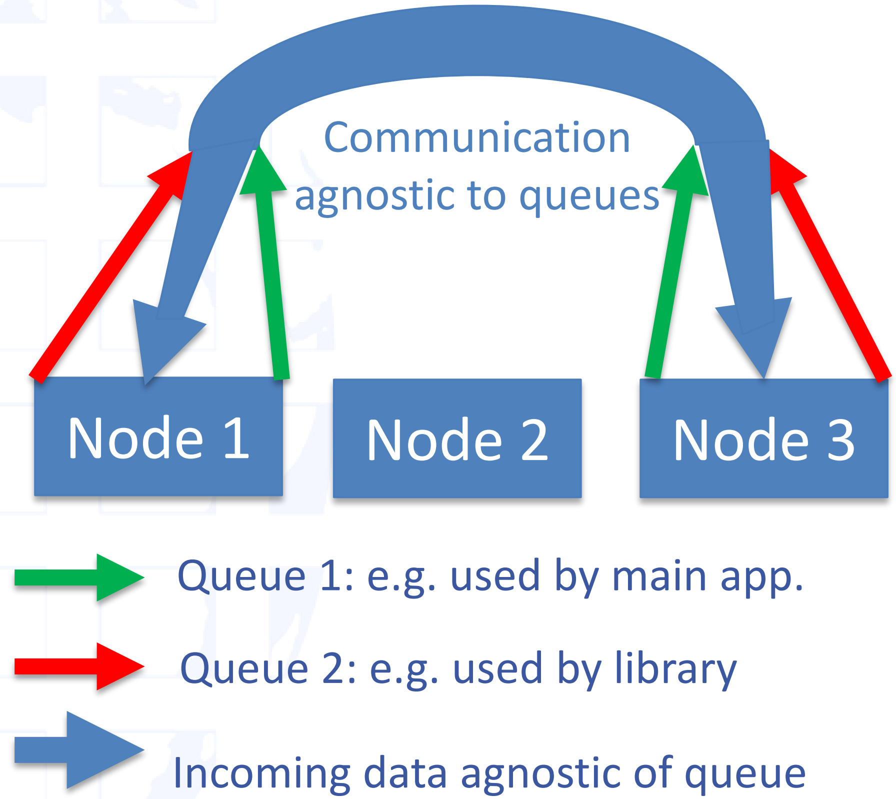


Concepts: Communication Queues

- Communication requests are posted to queues
- Queues are a local concept!
- Used to separate concerns between different parts of the applications
- Queues are used in order to establish the synchronization context.



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

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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 time
    - not necessarily an error
    - the procedure has to be invoked subsequently in order to fully complete the designated operation
  - GASPI_QUEUE_FULL
    - Request could not be posted to queue. End of queue has been reached, change queue or wait
  - GASPI_ERROR
    - designated operation failed -> check error vector
- Advice: Always check return value !

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success_or_die.h

```
#ifndef SUCCESS_OR_DIE_H
#define SUCCESS_OR_DIE_H

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

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

#endif
```

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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

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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
```

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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) );

  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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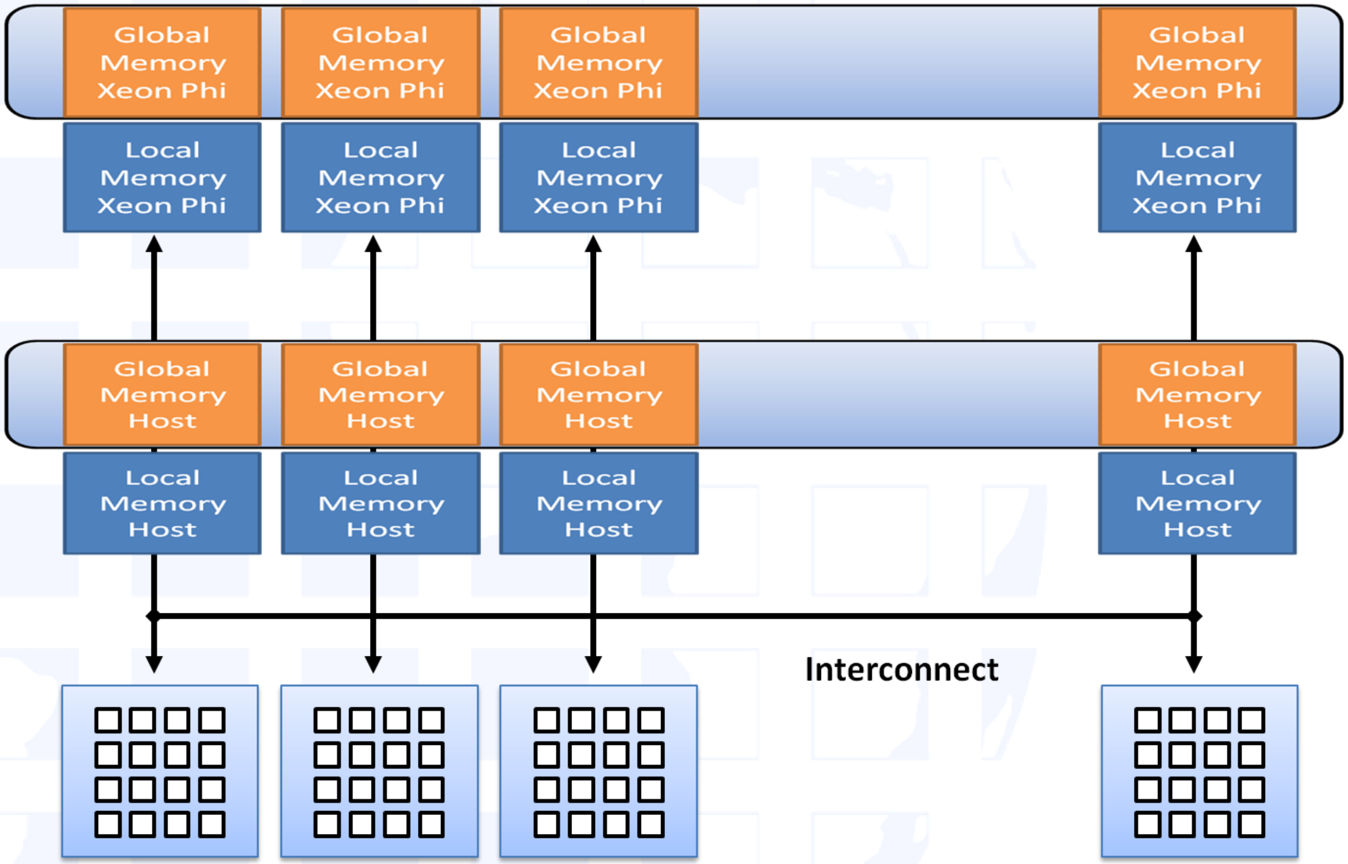
Segments



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Segments

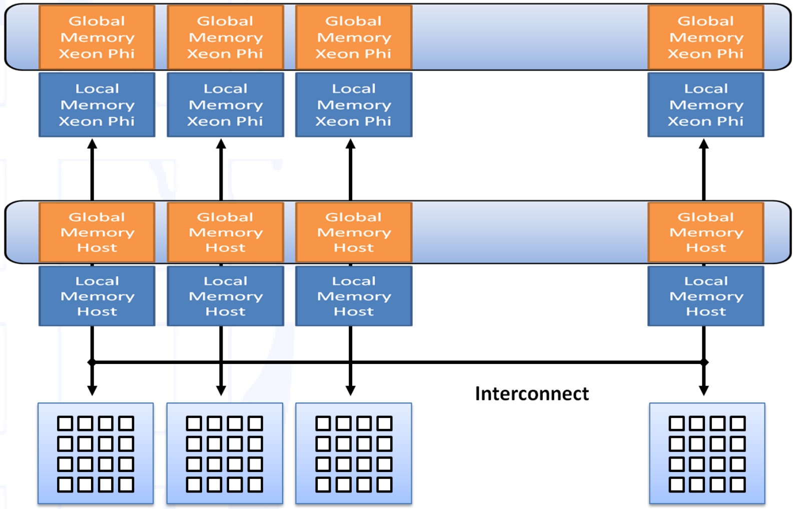
- Software abstraction of hardware memory hierarchy
  - NUMA
  - GPU
  - Xeon Phi
- One partition of the PGAS
- Contiguous block of virtual memory
  - no pre-defined memory model
  - memory management up to the application
- Locally / remotely accessible
  - local access by ordinary memory operations
  - 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

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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)
```

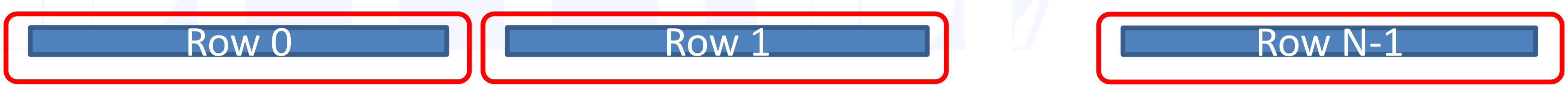
- Maximum number of segments
- Defines range of allowed segment IDs [0,segment_max - 1)

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

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

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One-sided Communication

GASPI One-sided Communication

- gaspi_write

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

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

GASPI One-sided Communication

- gaspi_read

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

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

GASPI One-sided Communication

- gaspi_wait

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

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

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
  - Asynchronous execution, thin abstraction of HW queues.

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 (qwait)
- Return value GASPI_QUEUE_FULL indicates full queue.

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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);
}
```

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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

GASPI Notification Mechanism

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

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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

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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;
 }
}
```

Global Address Space Programming Interface GASPI

Hardware Optimized

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_list
  - Several subsequent read from the same rank.
- gaspi_read_notify
  - read + subsequent gaspi_notify, unordered with respect to „other“ writes.

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
  – Unordered relative to other communication (!)

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
  – Unordered relative to other communication (!)

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

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GASPI extended one-sided

- gaspi_read_notify

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

  - „gaspi_read with subsequent gaspi_notify“
  - Unordered relative to other communication (!)

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Communication – Hands on

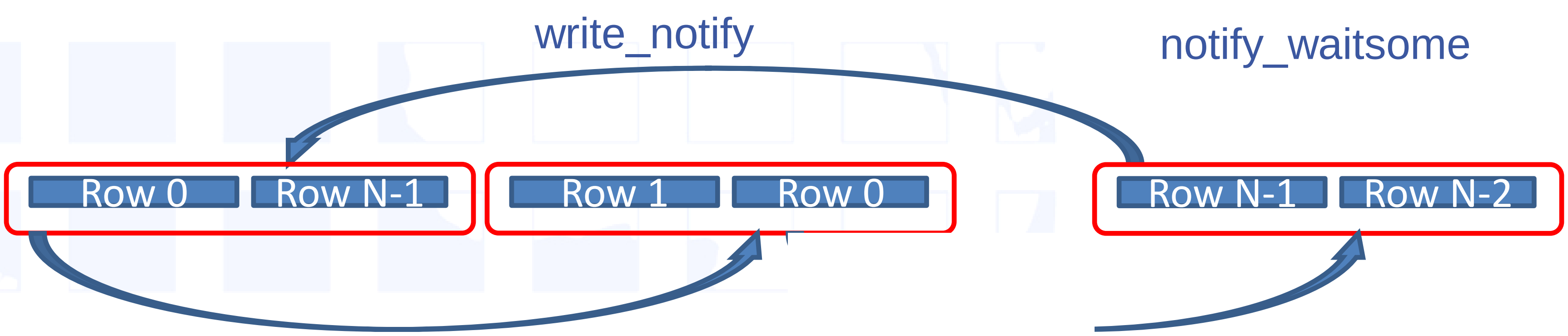
- Take your GASPI program which stores a NxM matrix in a distributed way and extend it by communication for rows

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 ); }
```

```
/* 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)
{ 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;}
```

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Ping-Pong

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Ping-Ping – Hands-On

- message_rate.c
  - Wait for incoming notifications (and reset them)
- message_ping_pong.c
  - Acknowledge incoming bulk of notifications.
- message_ping_ping.c
  - Directly return all incoming notifications
- fairness_between_queues.c
  - Fairness between queues
- using_GASPI_TEST.c
  - Multithreaded testing for incoming notifications

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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

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Collective Functions

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

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GASPI Collective Function

- gaspi_barrier

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

- gaspi_allreduce

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

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Passive communication

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Passive Communication Functions (I)

- 2 sided semantics send/recv
  - gaspi_passive_send

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

    - time based blocking

Passive Communication Functions (II)

– Gaspi_passive receive

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

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

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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 *) ((char*)_vptr + sizeof(packet));
      return_offset(t->rank, t->len, t->offset)
    }
return NULL;
```

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Fault Tolerance

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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;
}
```

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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 nProc_MPI, iProc_MPI;
gaspi_rank_t iProc, nProc;

MPI_Init(&argc, &argv);
MPI_Comm_rank (MPI_COMM_WORLD, &iProc_MPI);
MPI_Comm_size (MPI_COMM_WORLD, &nProc_MPI);

SUCCESS_OR_DIE (gaspi_proc_ini(GASPI_BLOCK));
SUCCESS_OR_DIE (gaspi_proc_rank (&iProc));
SUCCESS_OR_DIE (gaspi_proc_num (&nProc));

ASSERT(iProc == iProc_MPI);
ASSERT(nProc == nProc_MPI);

…
```

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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

```
// allgatherV
 SUCCESS_OR_DIE (gaspi_segment_create ( segment_id
               , vlen * sizeof(int), GASPI_GROUP_ALL, GASPI_BLOCK
               , GASPI_ALLOC_DEFAULT));

  gaspi_pointer_t _ptr = NULL;
  SUCCESS_OR_DIE (gaspi_segment_ptr (segment_id, &_ptr));
  int *array = (int *) _ptr;
  init_array(array, offset, size, iProc, nProc);

  MPI_Allgatherv(&array[offset[iProc]], size[iProc], MPI_INT
                 , array, size, offset, MPI_INT, MPI_COMM_WORLD);
```

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
Gaspi_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();
```

Global
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Interoperability - Hands on

- Implement allgatherV
- Local array size M_SZ*2^(rank)

```
// init MPI/GASPI
int const B_SZ = 2;
int const M_SZ = 2048;

int *offset = malloc(nProc * sizeof(int));
ASSERT(offset != NULL);

int  *size = malloc(nProc * sizeof(int));
ASSERT(size != NULL);

int vlen = 0;
int i, k = 1;

for (i = 0; i < nProc; ++i)
  {
    offset[i]   = vlen;
    size[i]     = M_SZ * k;
    vlen       += size[i];
    k          *= B_SZ;
  }
```

Interoperability - Hands on - II

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
4. Use GASPI segment allocated memory as a communication buffer in the MPI allgatherV operation

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The GASPI programming model

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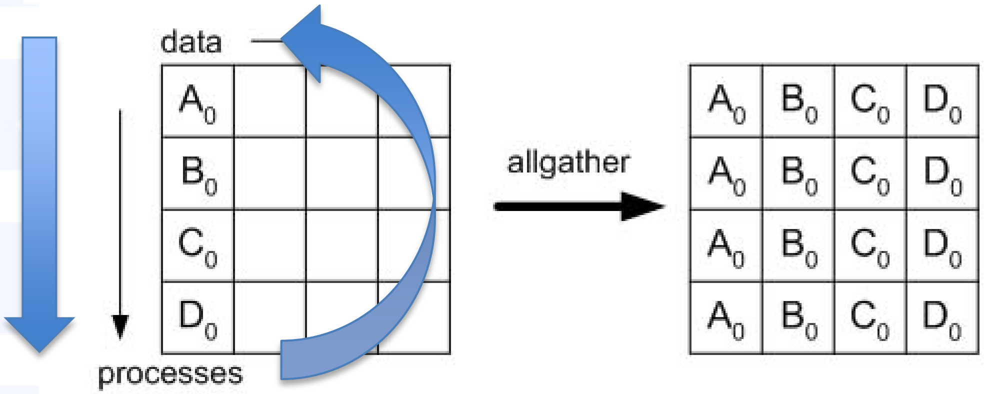
Asynchronous execution
with maximal overlap of communication and computation

THINK PERFORMANCE

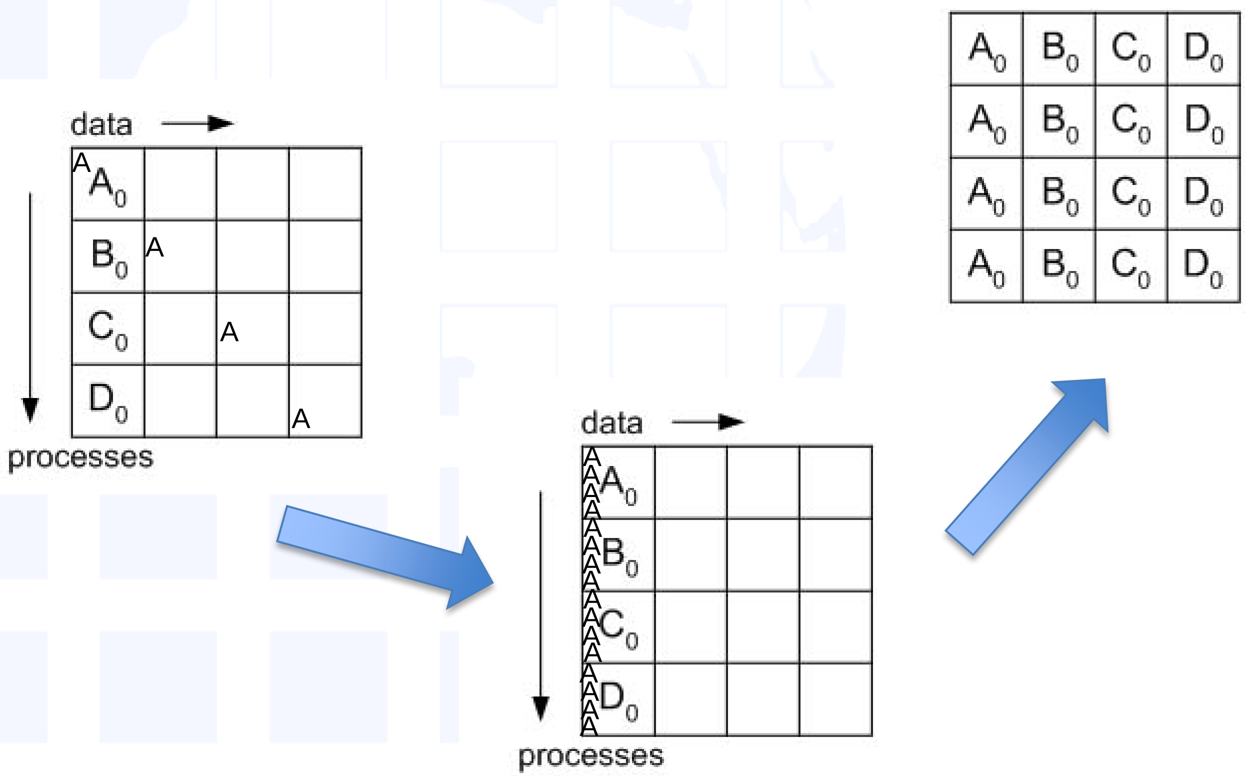
Example: allgatherV

- Complete the ‚folklore‘ round-robin algorithm



Example: allgatherV

- Complete the ‚pipelined‘ algorithm, (allscatter + broadcast)



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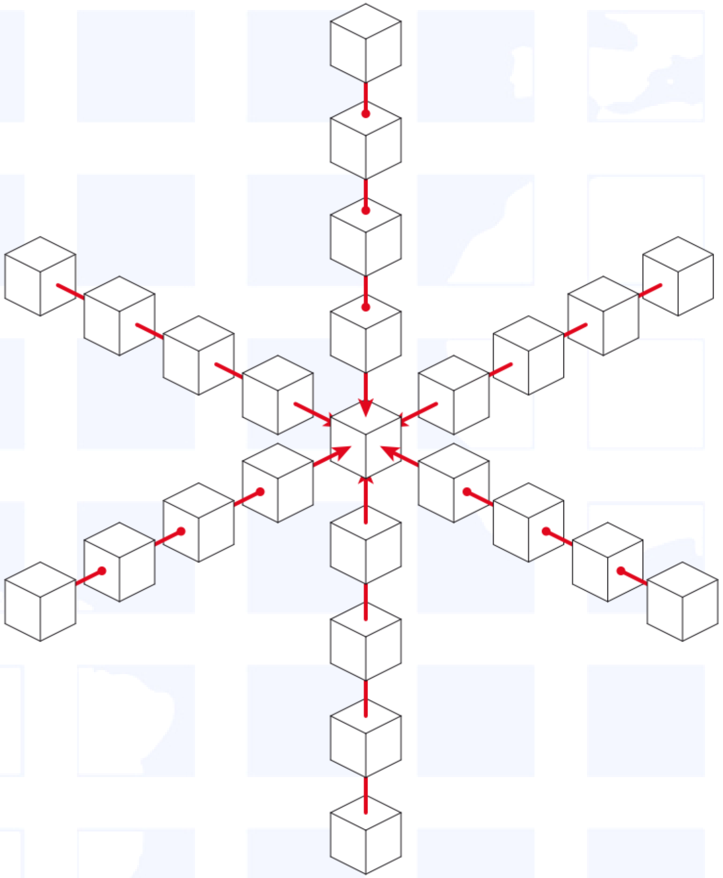
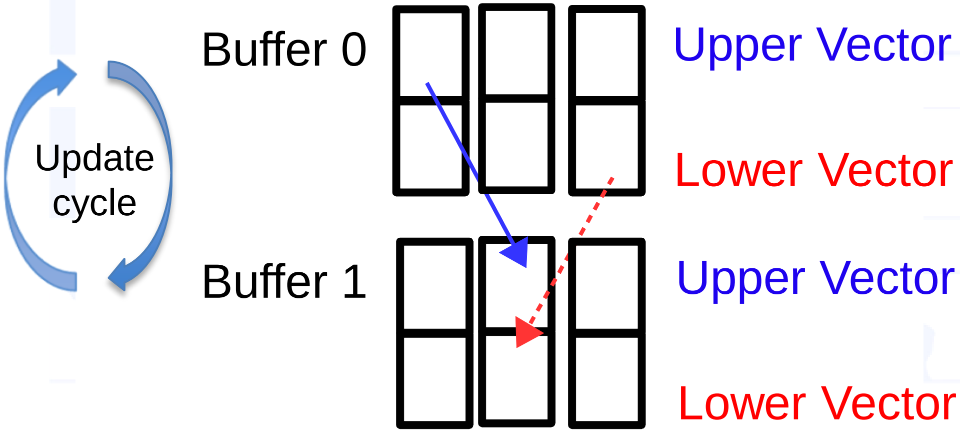
Example: Stencil applications



- 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

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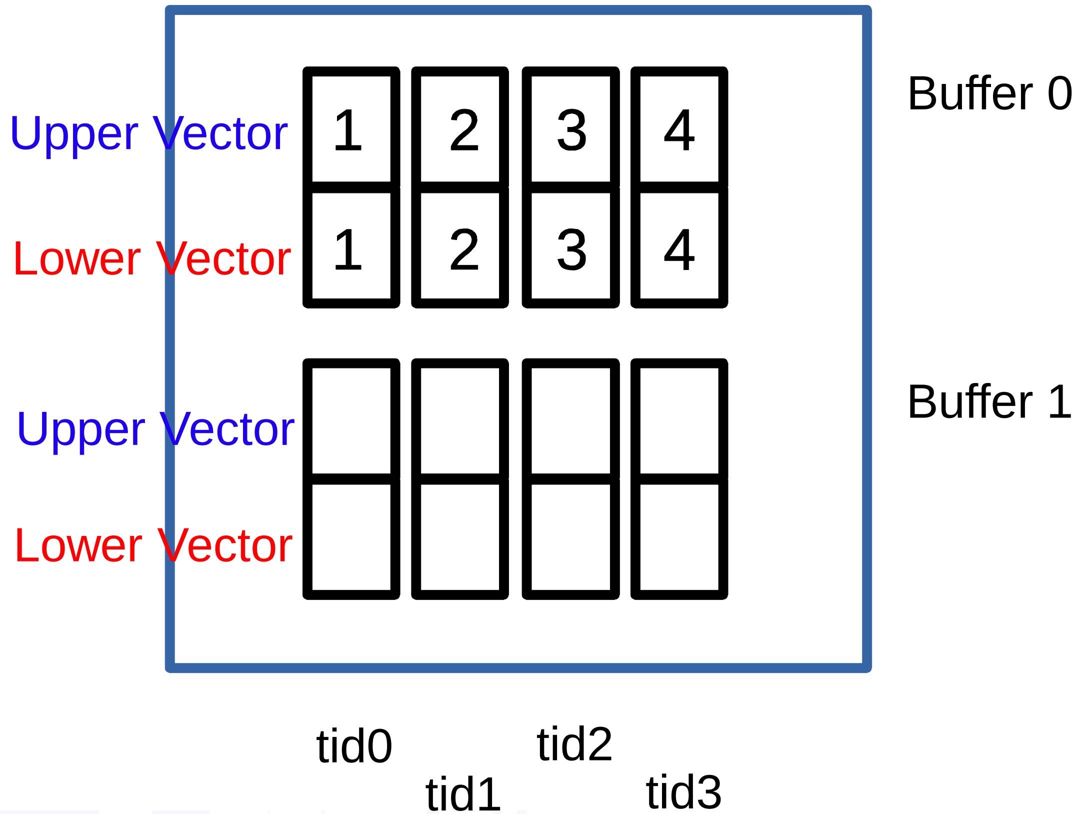
Stencil application proxy

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



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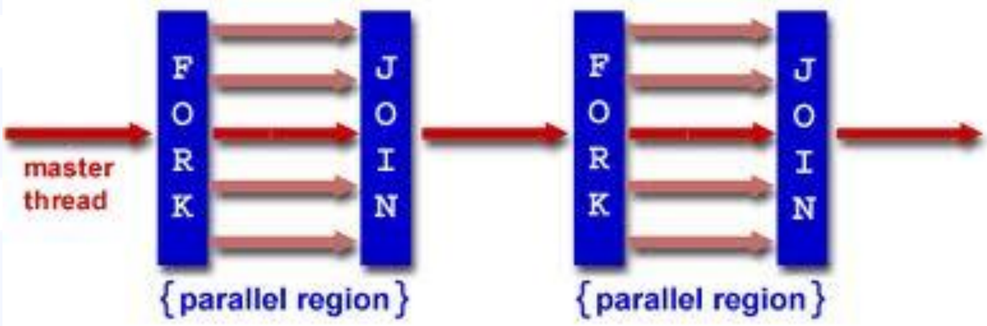
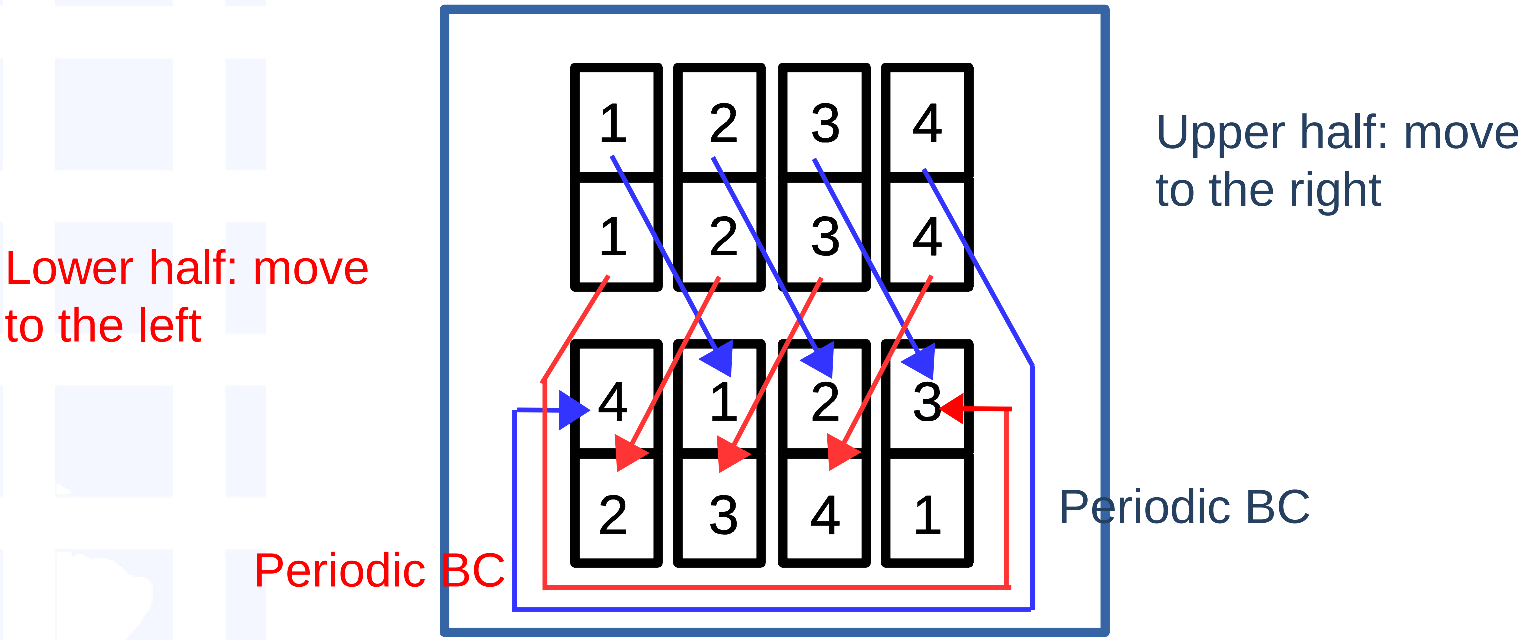
Fork-Join model

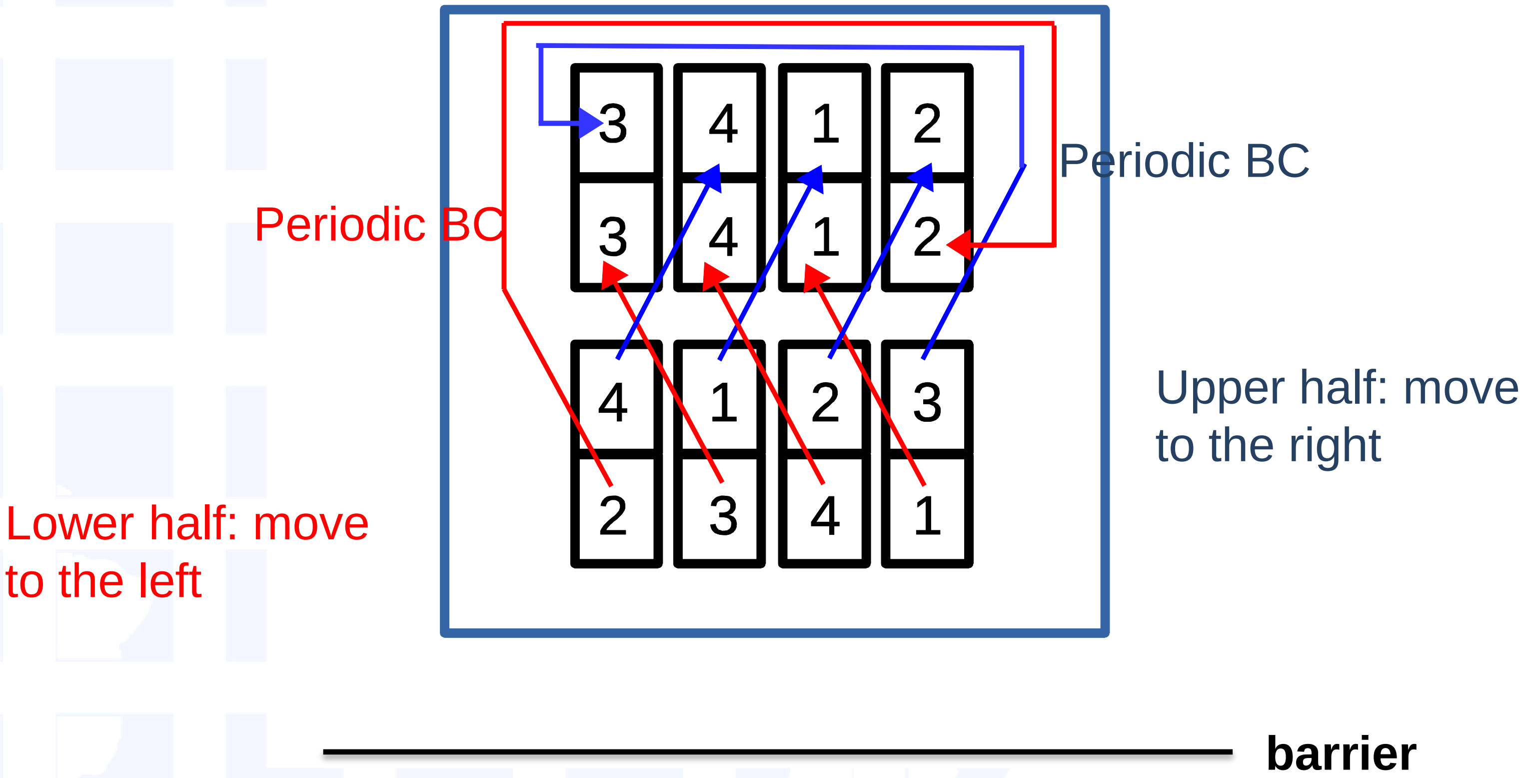


Iteration 1

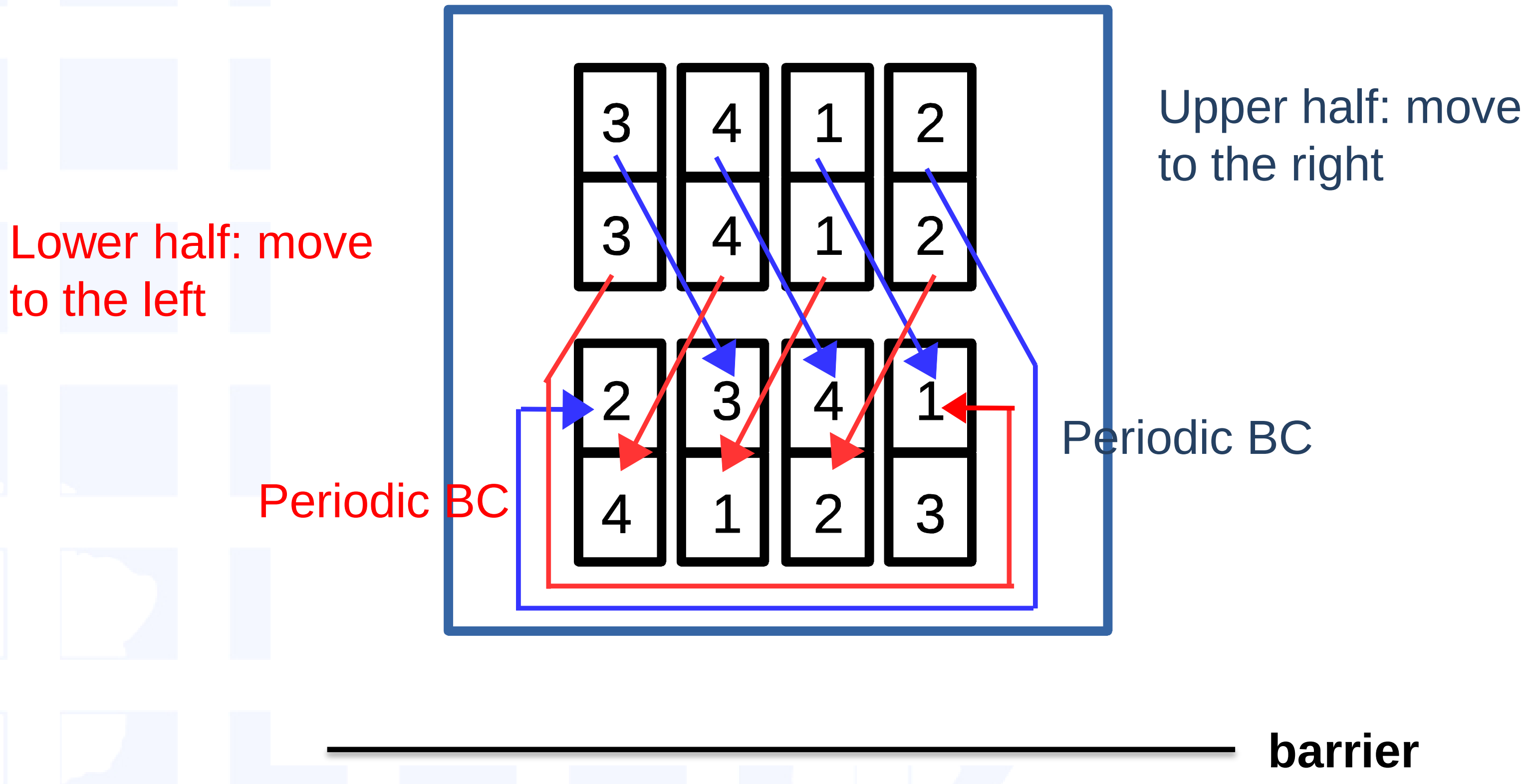


barrier

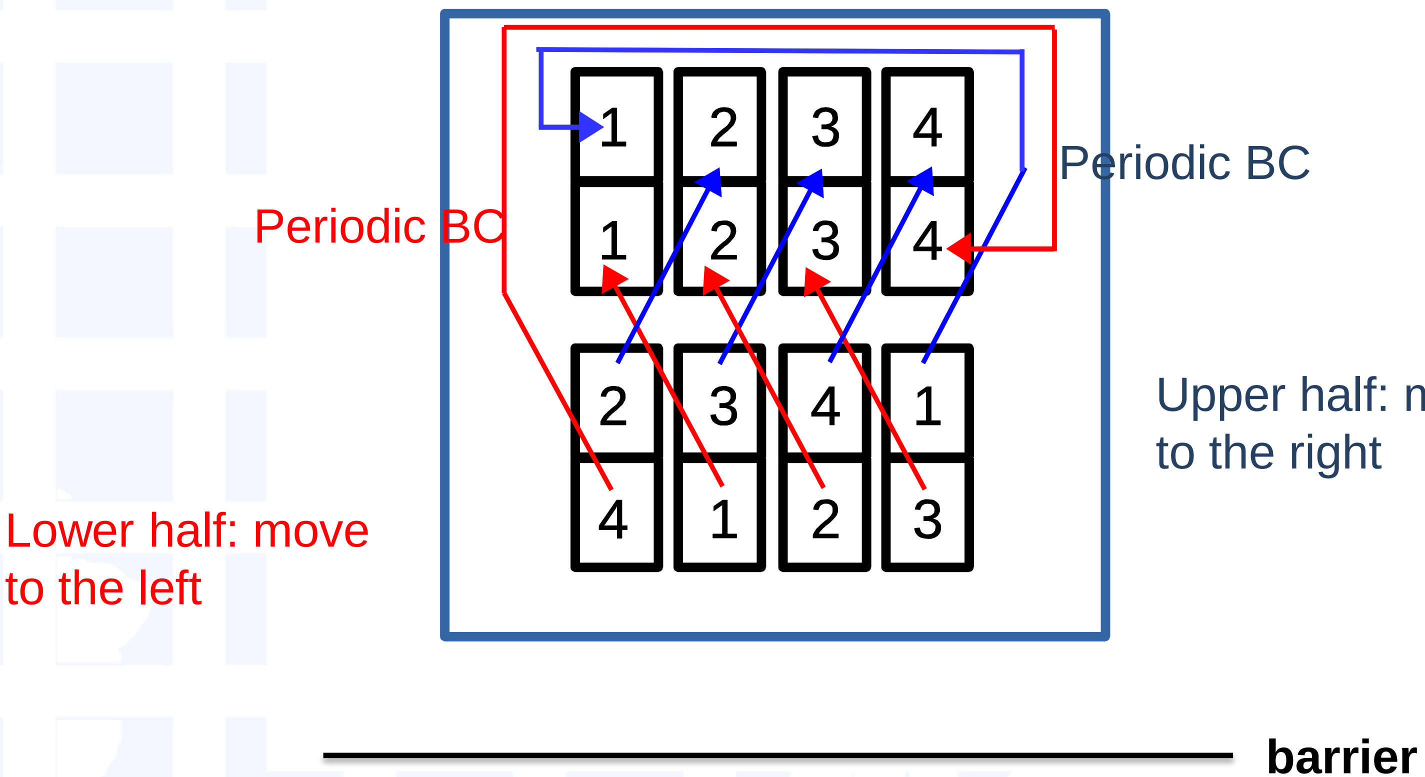
Iteration 2


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

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

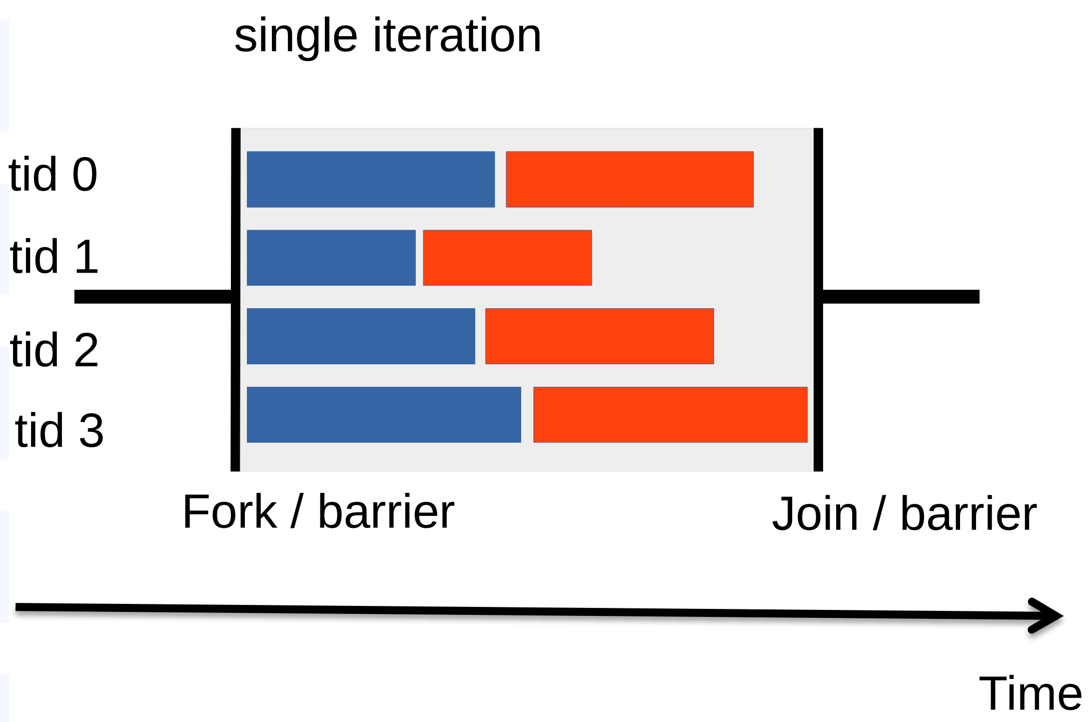
Iteration 4


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

- Nelem many iterations:
  - Initial configuration recovered

  -> Easy to check

Temporal evolution



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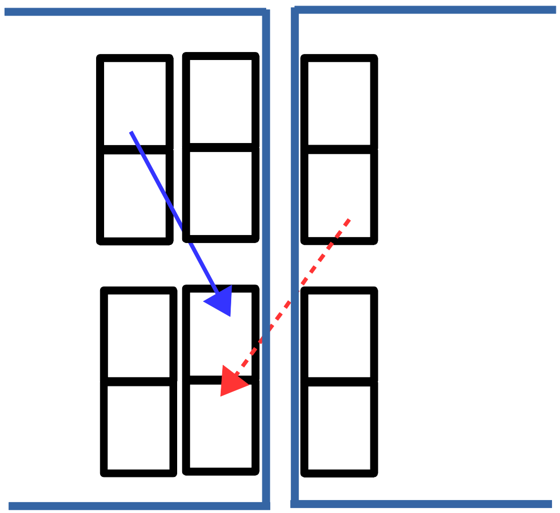
MORE THAN ONE PROCESS …

Elementary update



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

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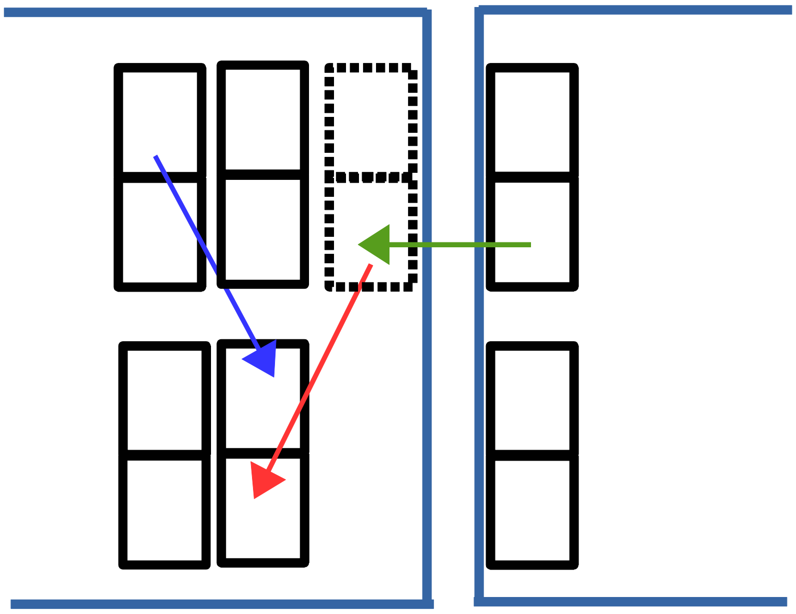
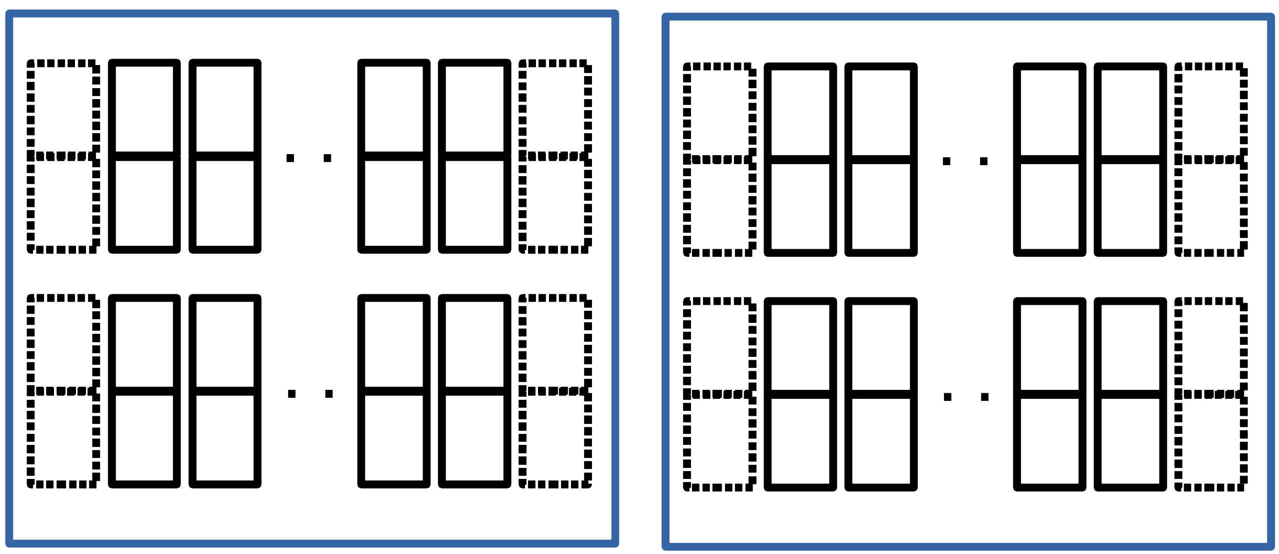
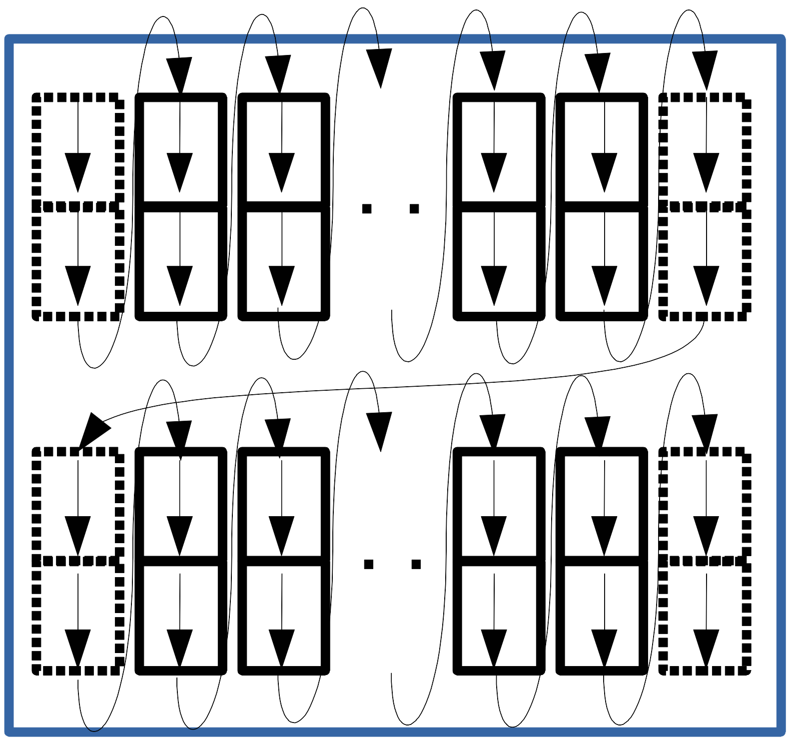
Boundary / Halo domains





Memory layout



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Separate communication / computation phases

BULK SYNCHRONOUS

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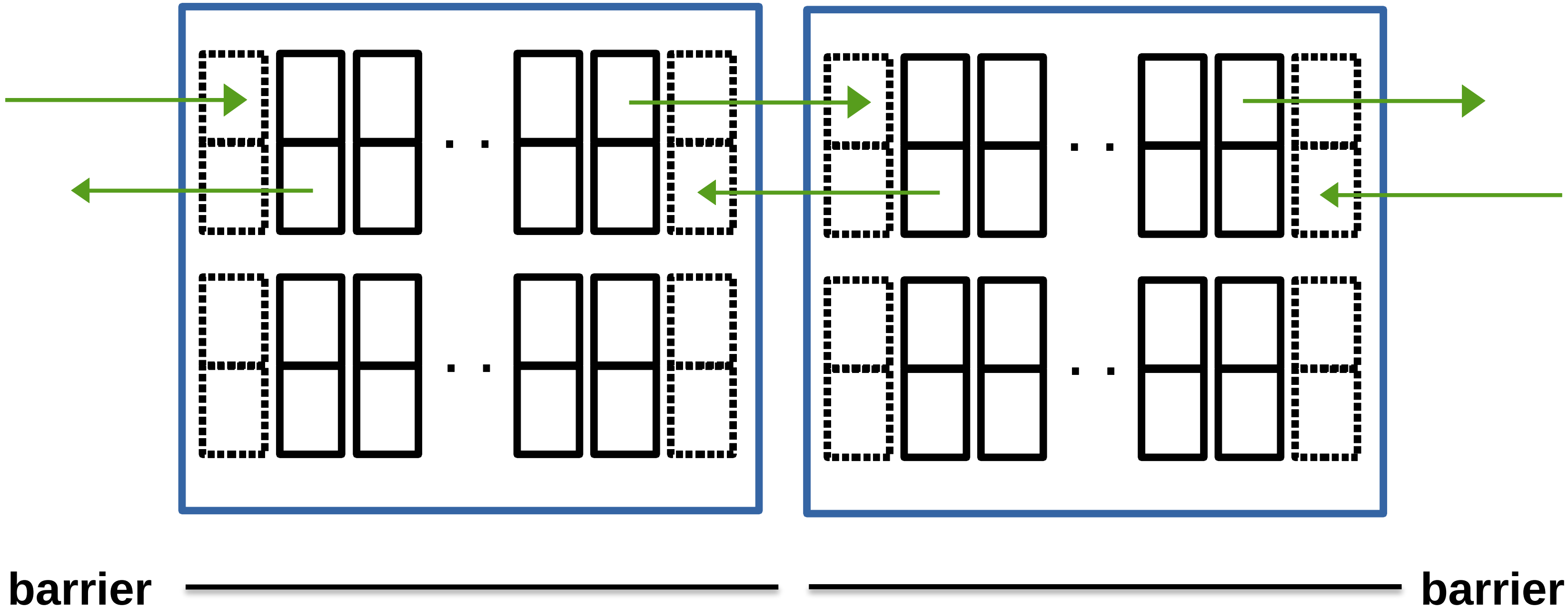
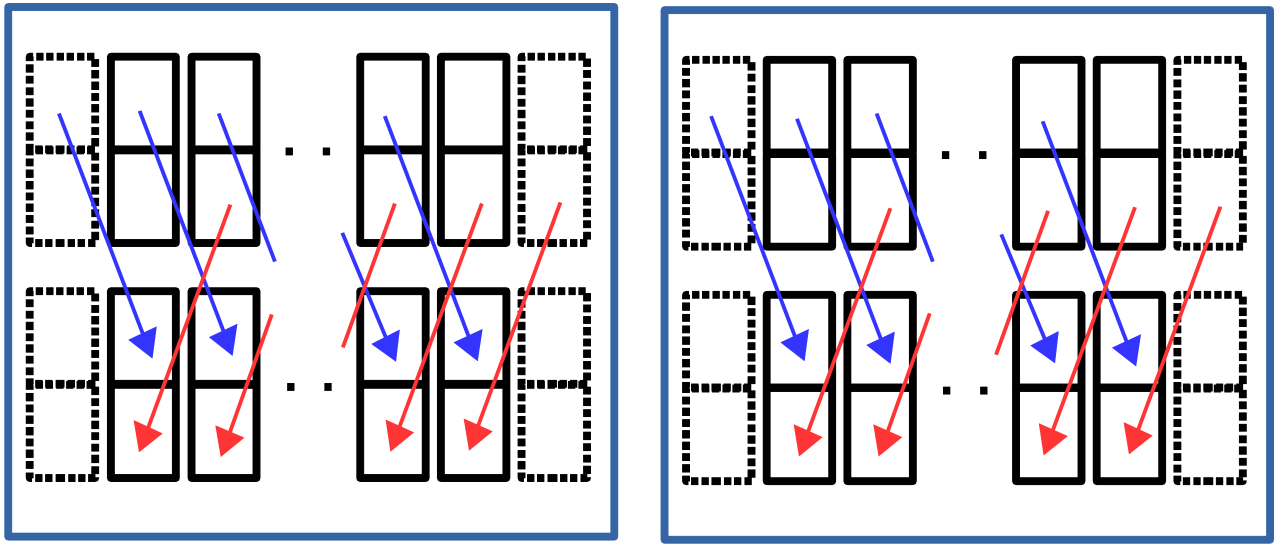
Communication phase



barrier barrier

Computation phase



barrier ——— ——— barrier

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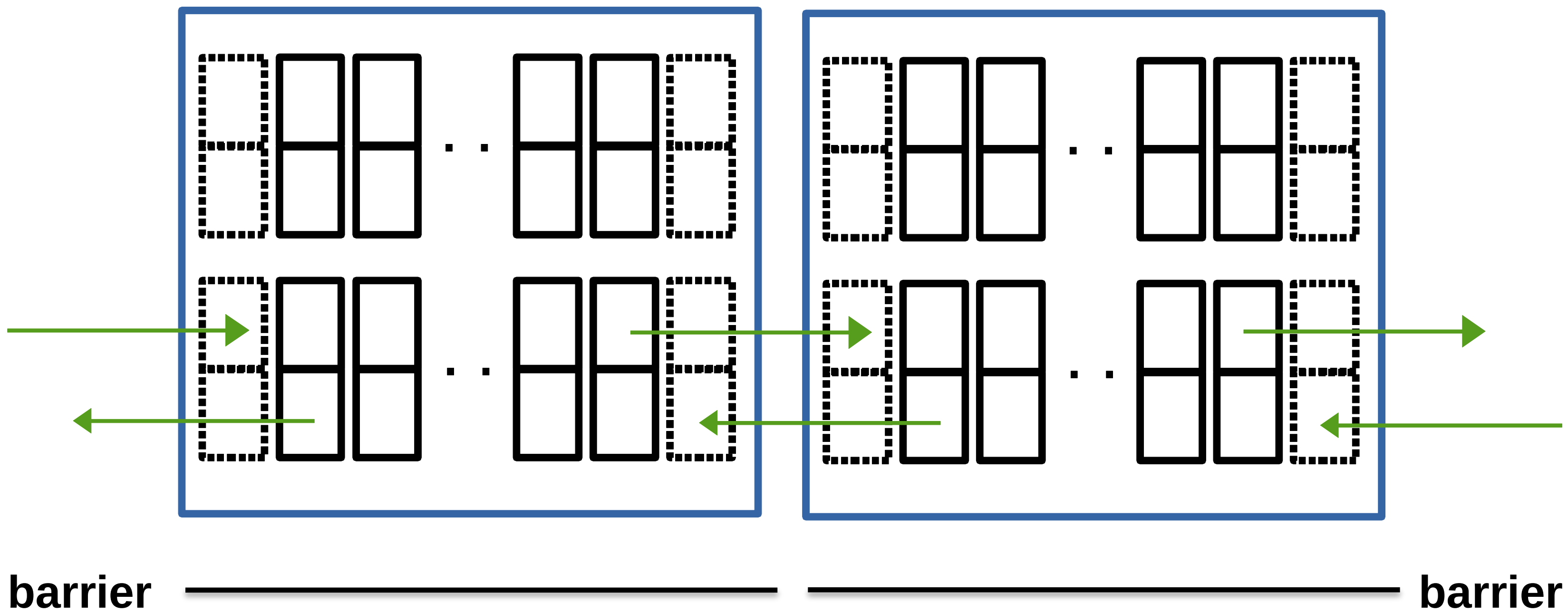
Communication phase



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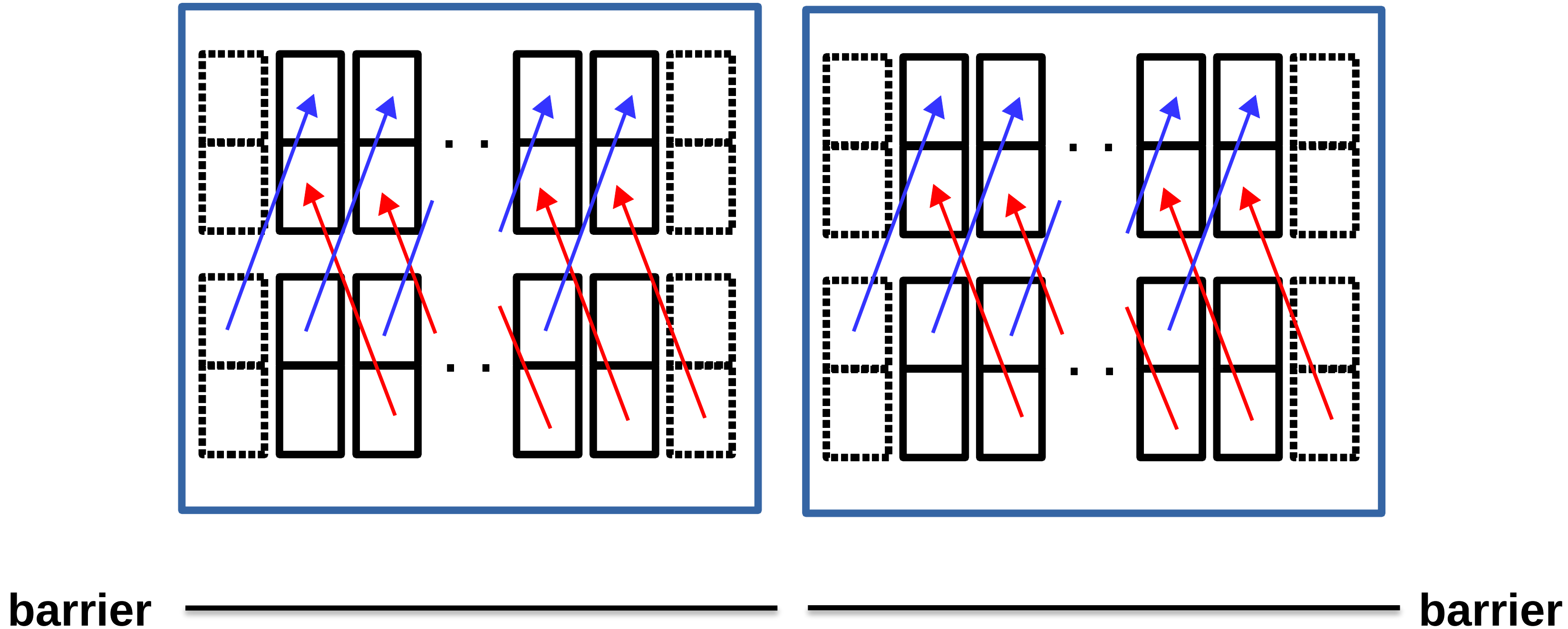
Computation phase



Hands-on

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

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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;
```

Basic ingredients

EXCURSION: EFFICIENT PARALLEL EXECUTION

Efficient parallel execution

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

Efficient parallel execution

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

SCALABILITY

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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

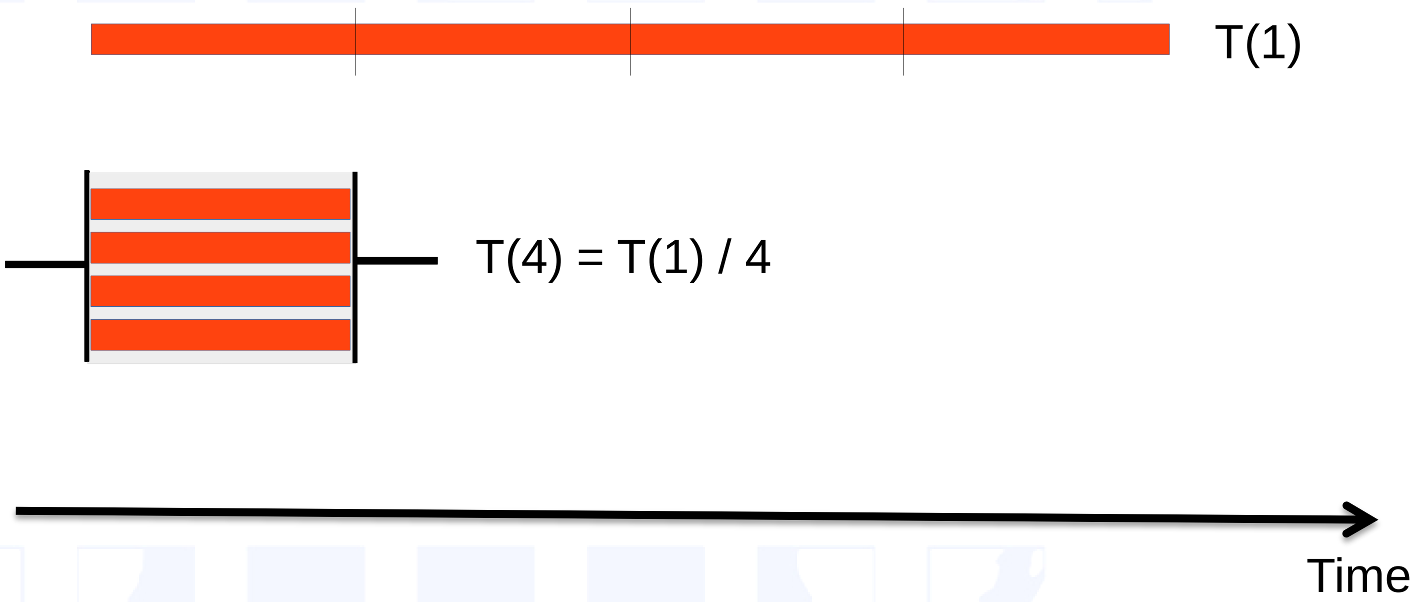
- Optimal: linear scalability, i.e.

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

  -> doubling the resources implies doubling the generated benefit

Implications for parallelization

- $T\left(N_{proc}\right) := \mathrm{T}(1)/N_{proc}$



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.)

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END OF EXCURSION

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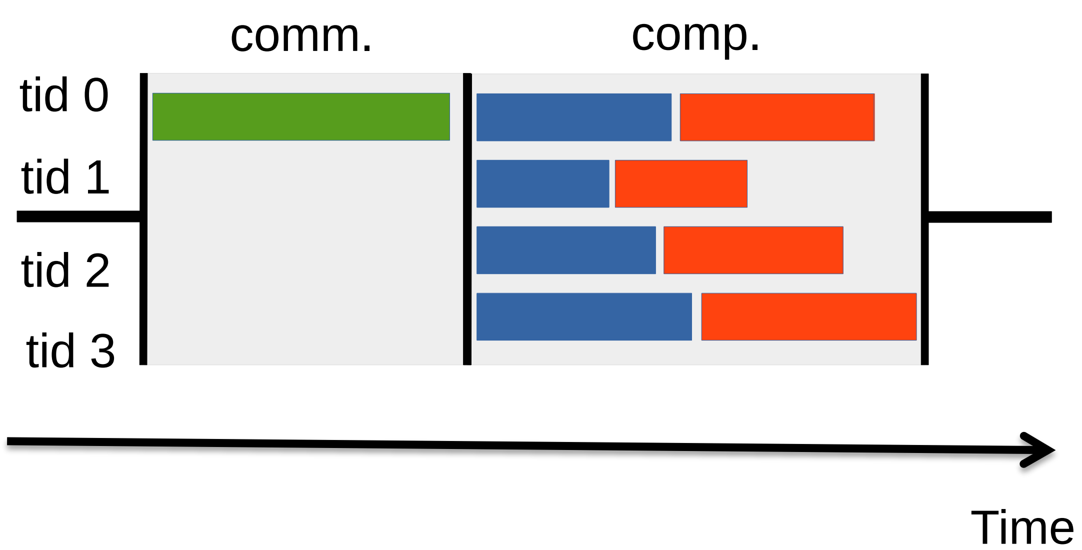
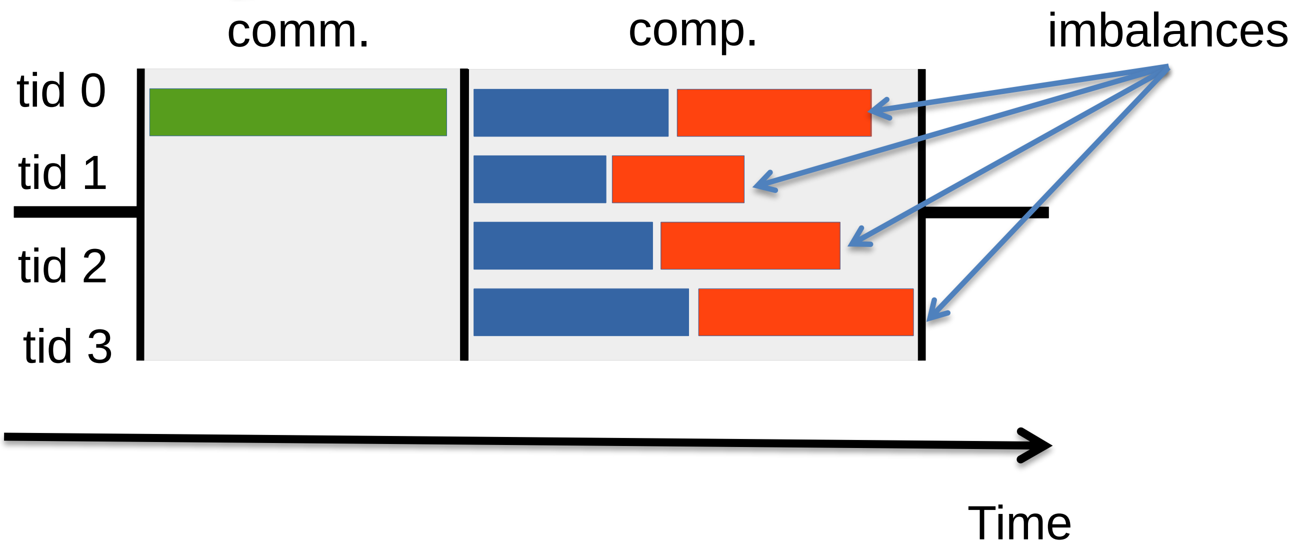
Temporal evolution: one iteration

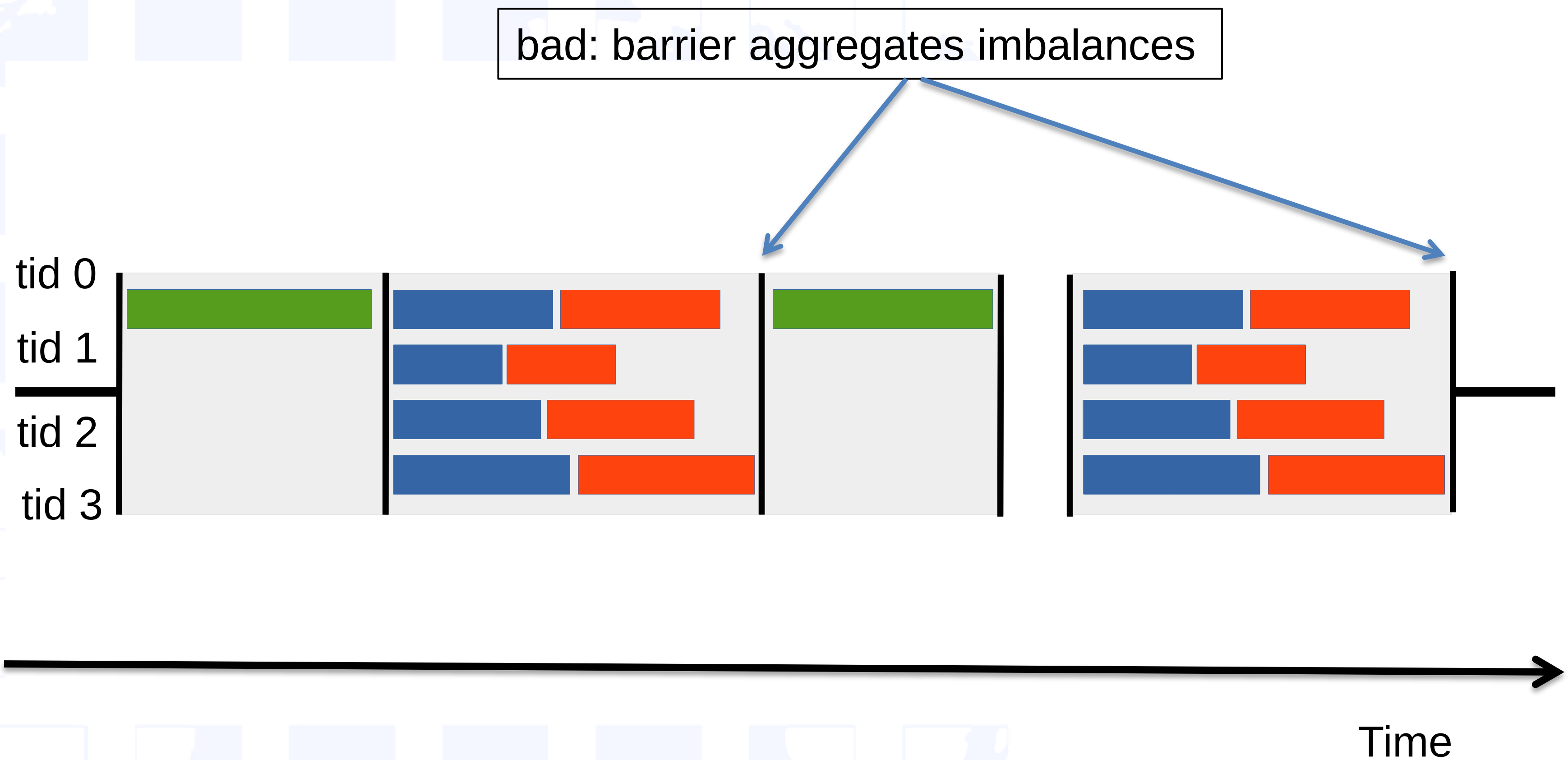


Temporal evolution: one iteration

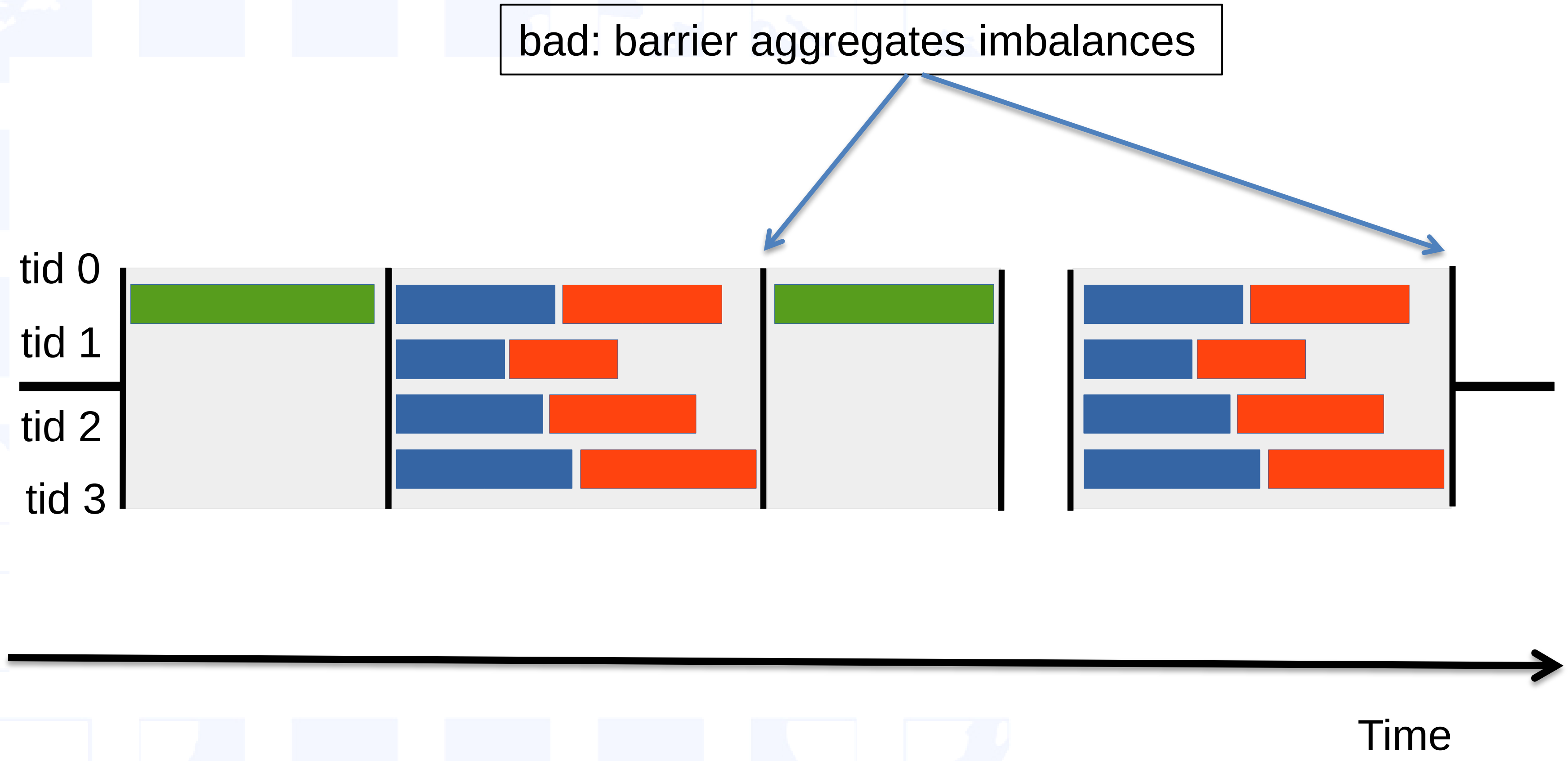
bad: explicitly visible communication latency



Temporal evolution: all iterations



Temporal evolution: all iterations



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Hide communication behind computation

COMMUNICATION / COMPUTATION OVERLAP

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

Strategy

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

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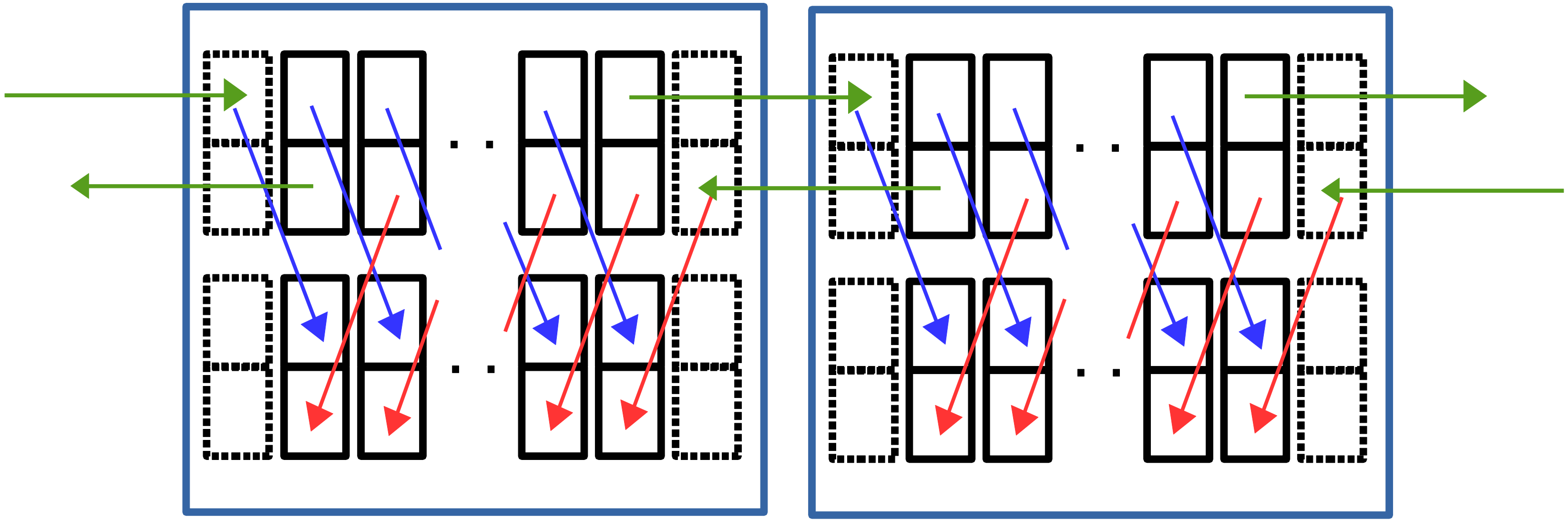
Single iteration

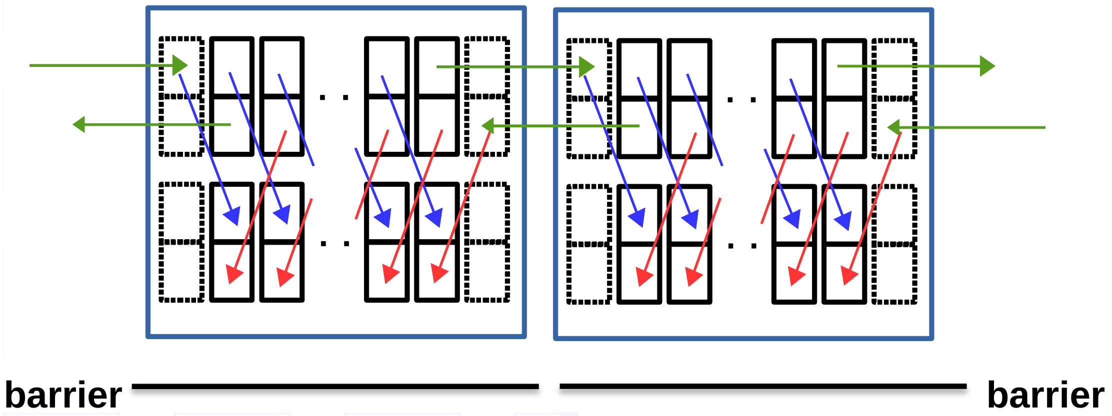


barrier —— barrier

Single iteration: details

Left boundary element:

1. Initiate boundary data transfer to remote halo



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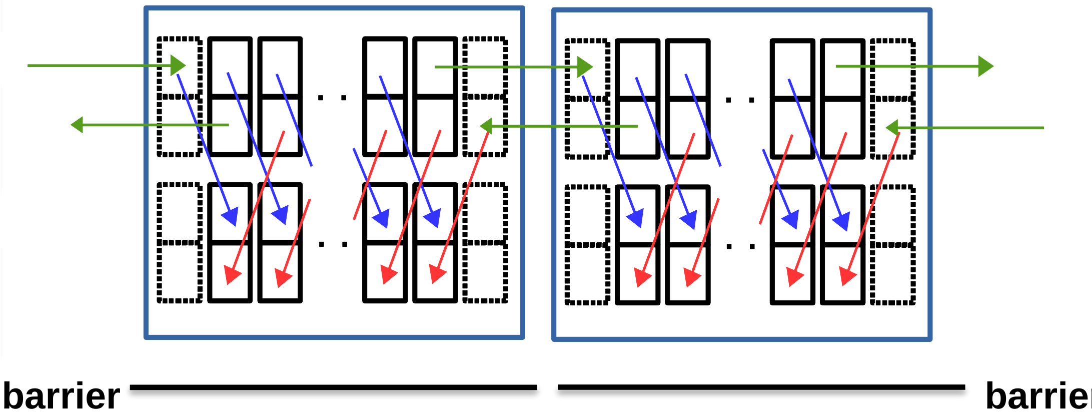
Left boundary element:

1. Initiate boundary data transfer to remote halo

2. Wait for boundary data transfer to local halo completion



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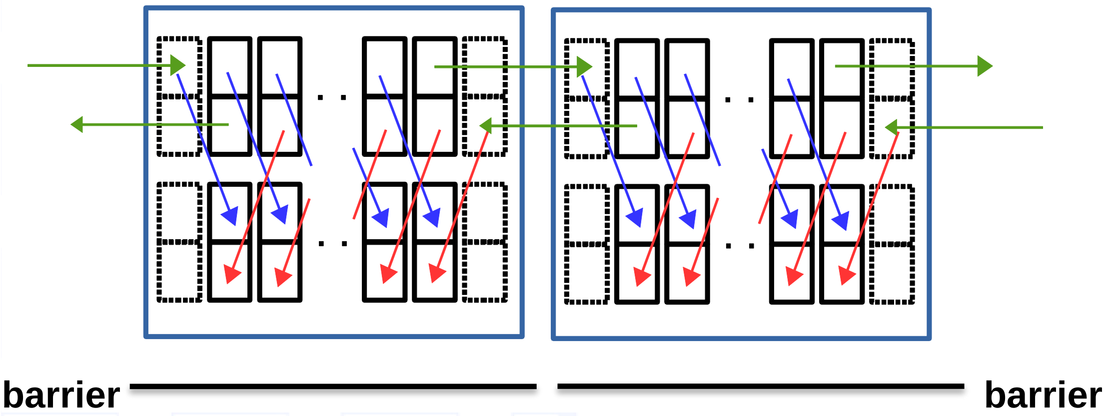
Left boundary element:

1. Initiate boundary data transfer to remote halo

2. Wait for boundary data transfer to local halo completion

3. Update vector



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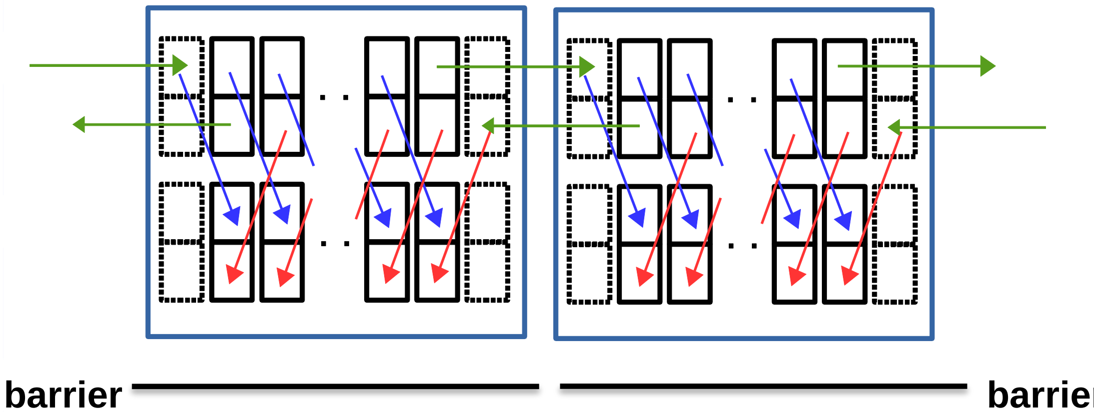
Left boundary element:

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



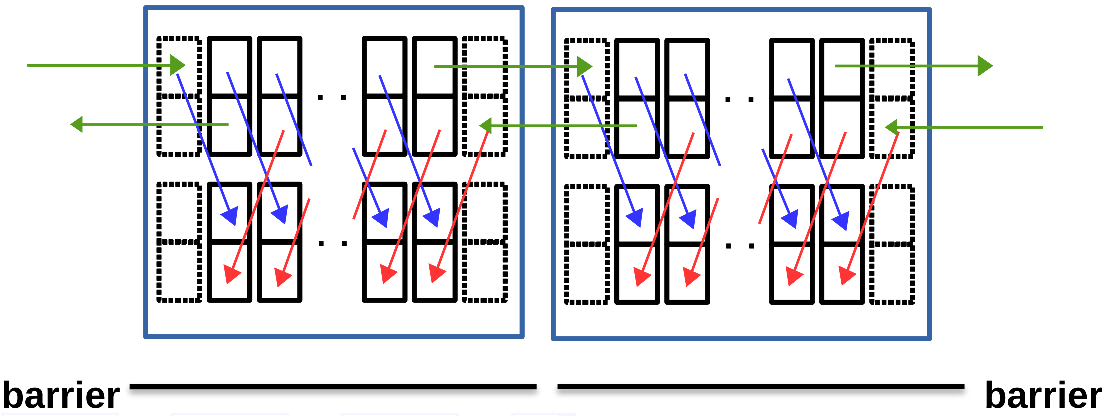
Left boundary element:

1. Initiate boundary data transfer to remote halo

2. Wait for boundary data transfer to local halo completion

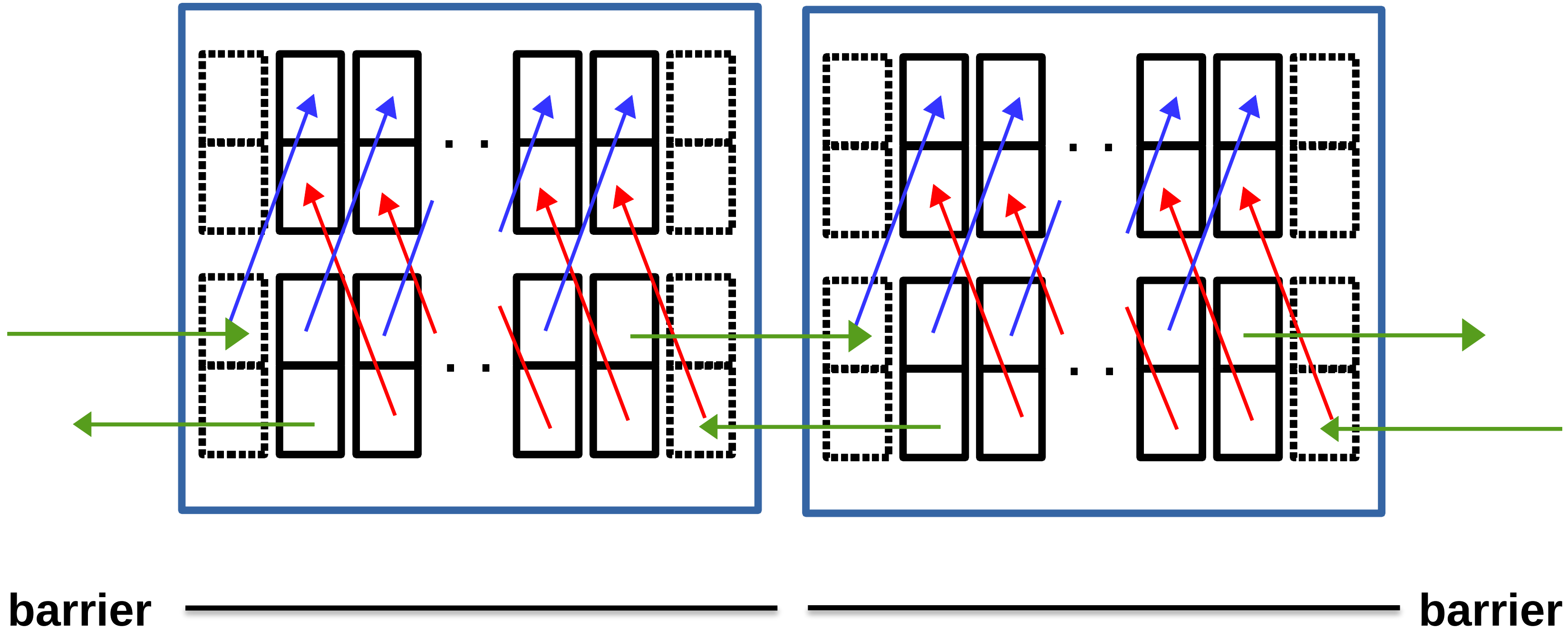
3. Update vector

-> Right boundary element handled analogously



In the meanwhile inner elements are done in parallel!

Single iteration



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Hands-on

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

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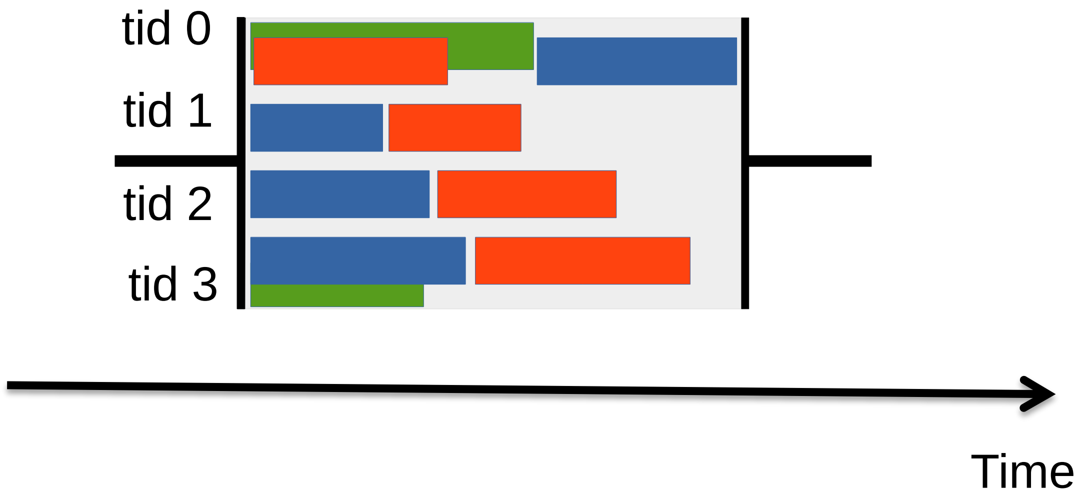
The GASPI Ring Exchange

- 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;
```

Temporal evolution



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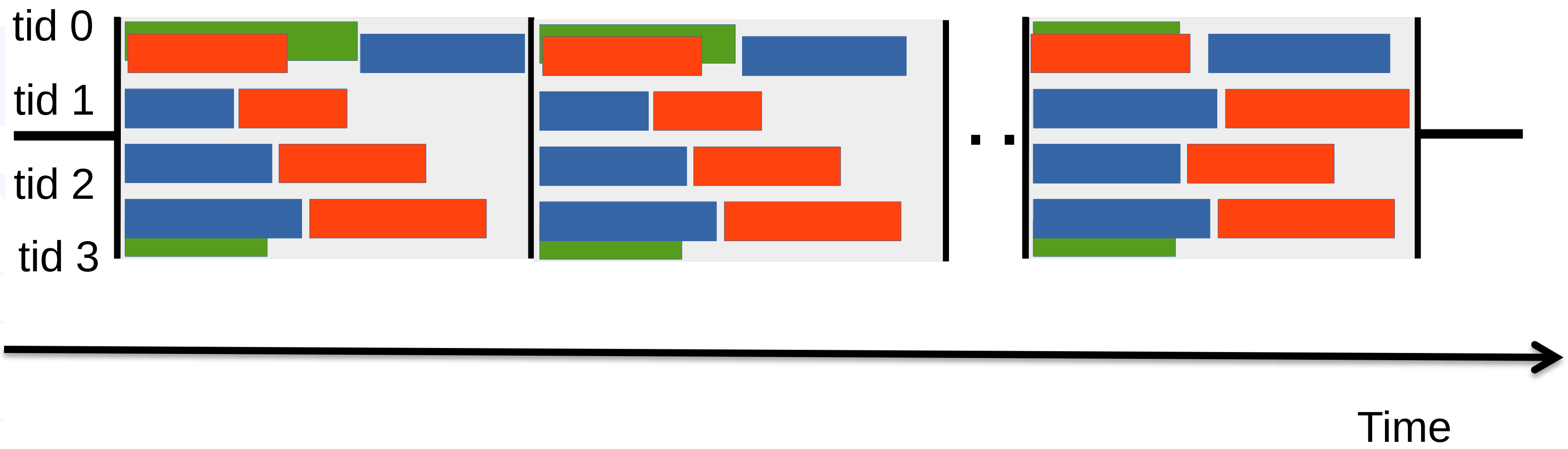
Temporal evolution



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Avoid synchronization point

DATA DEPENDENCY DRIVEN

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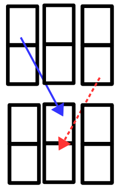
- What has been achieved?
  - Overlap of communication by computation
  - Communication latency is (partly) hidden
- What has not been achieved?
  - Fully Asynchronous execution
  - Still processwide synchronization after each iteration
    -> process wide aggregation of thread imbalances

- 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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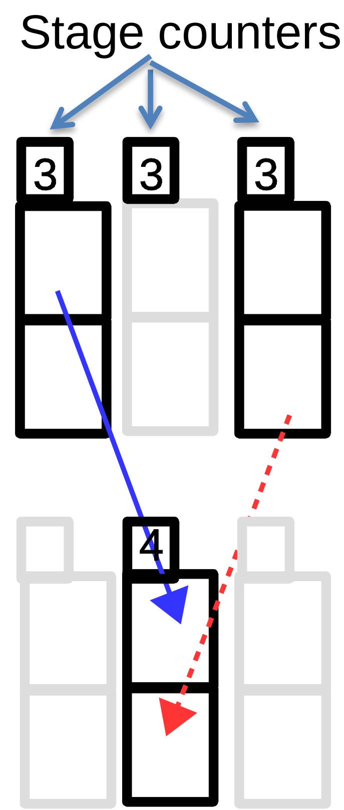
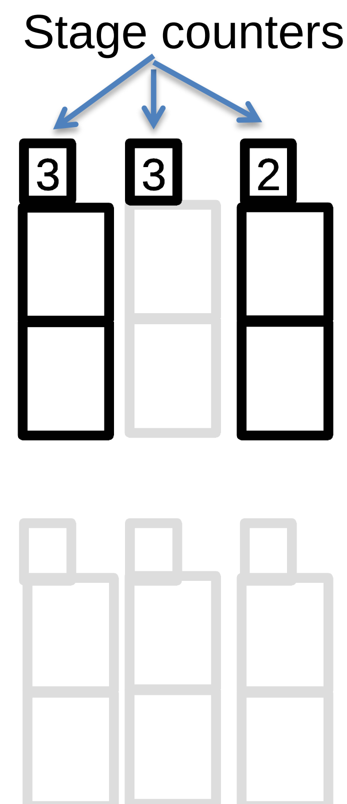
Reduce synchronicity

- 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**



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

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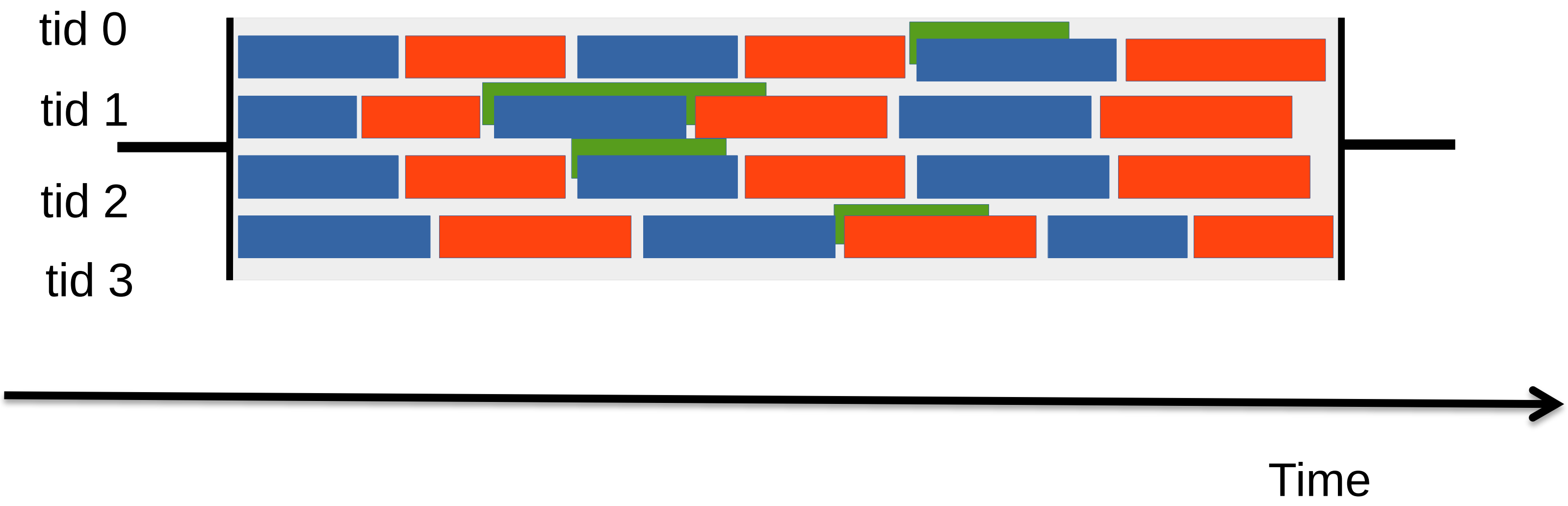
The GASPI Ring Exchange

- 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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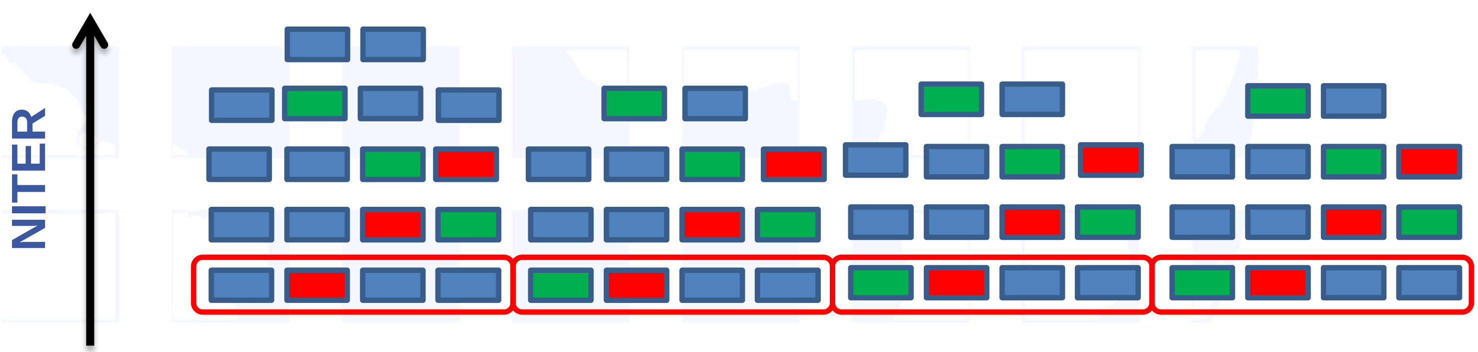
The GASPI Ring Exchange

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