Joint Laboratory
for Petascale Computation

On distributed recovery for SPMD deterministic HPC applications

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Fault-tolerance in HPC applications

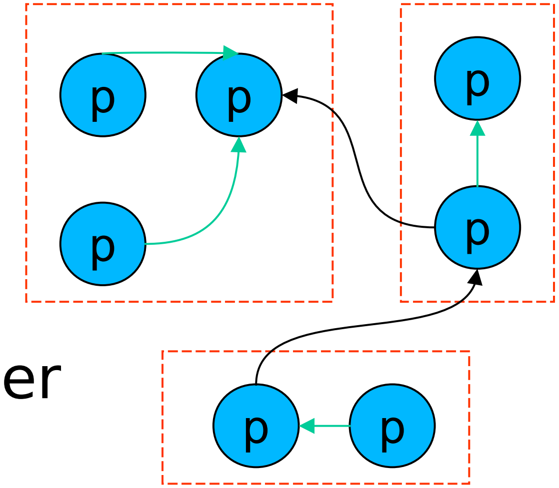
- Number of cores on one CPU and number of CPU grows
- Can expect frequent hardware failures

- Using a fault tolerance protocol is a must

- Many protocols already exist
- Hybrid protocols are the most promising

Motive for this talk: HydEE

- HydEE – a hybrid hierarchical rollback-recovery protocol for message passing applications



- Divide processes in groups (clusters)

→ Coordinated checkpointing within the cluster

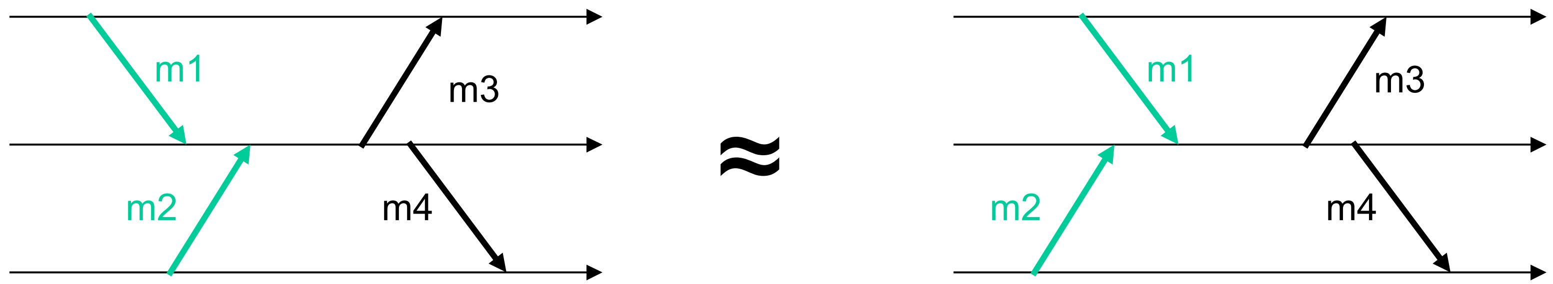
→ Message logging between clusters

  – Sender-side logging

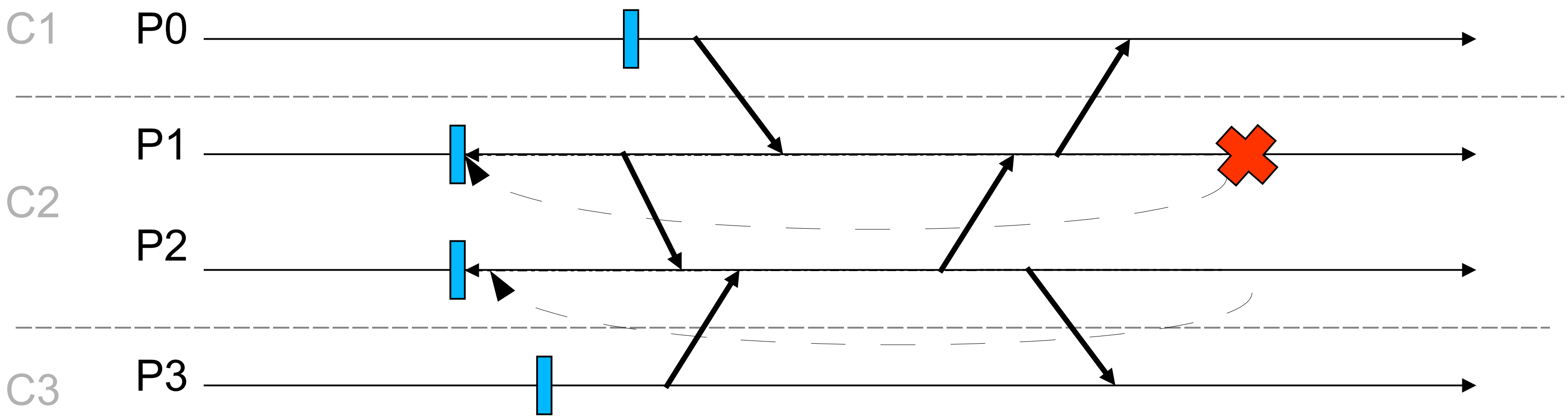
- Assumption: send-deterministic applications

Send-determinism

- In any correct execution:
  - Same messages are always sent in the same order
  - The reception order has no impact on the execution



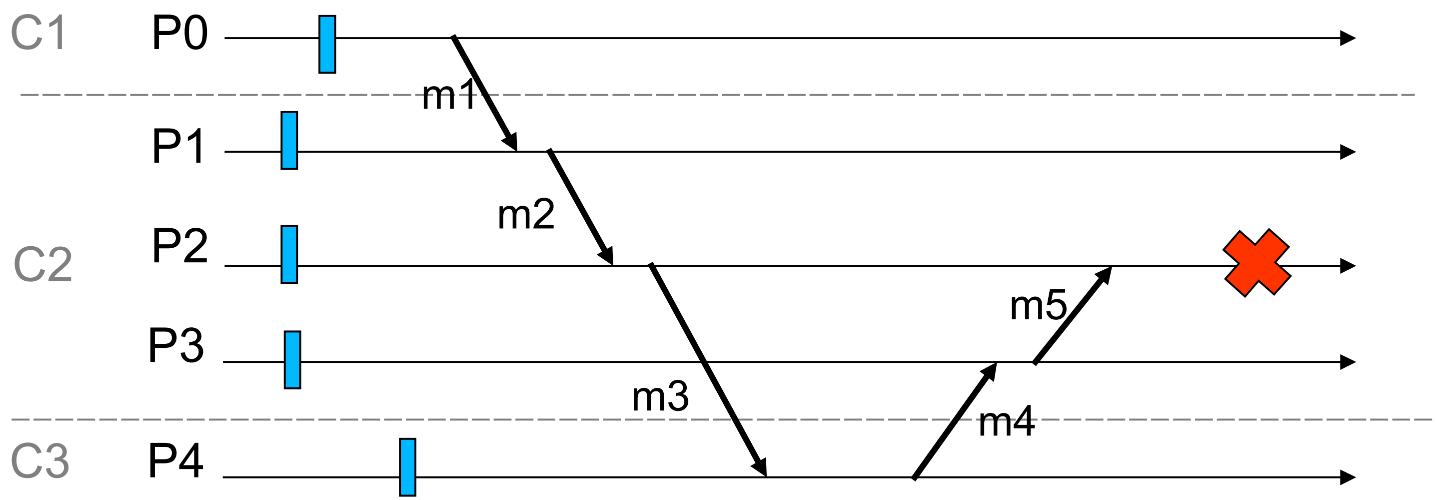
HydEE: Treating failures



1. All processes inside C2 rollback to the last checkpoint
2. Others resend logged messages to processes in C2

HydEE: Recovery issues

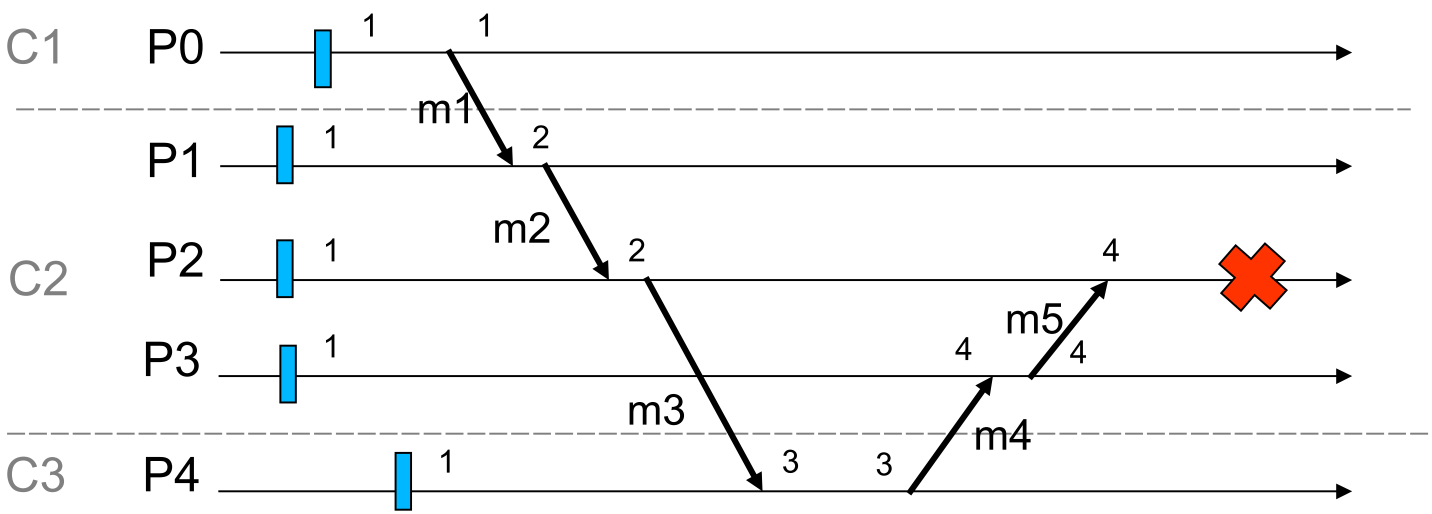
- Causal dependency between messages



m5 can be received by mistake before m2

HydEE: Recovery issues

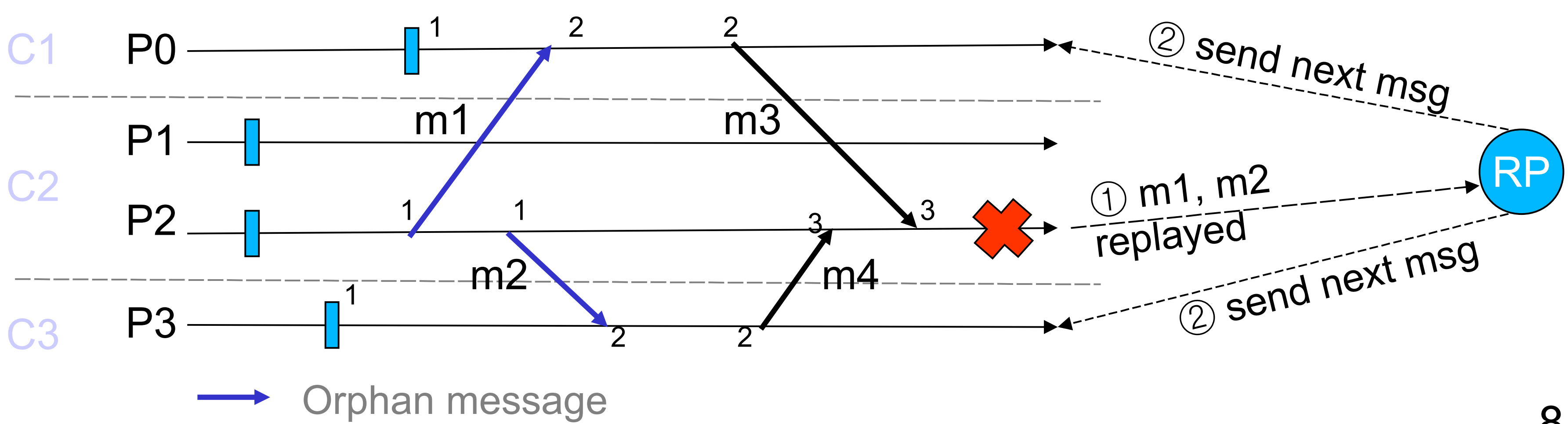
- Causal dependency between messages



  – Use phases to express dependency
    - Update my phase when intra-cluster message received
    - Update and increment when message comes from another cluster
- Guaranty of replay of orphan messages
  – Send-determinism guarantees that the same message will be replayed by the rolled back process

HydEE: Recovery process

- A separate recovery process to orchestrate the recovery
- It ensures causal order: no message is sent until there are orphan messages in lower phase
- It has the info about
  - The phase to which process rolls back
  - Phases of all logged messages to be replayed
  - Number of orphan messages in each phase



Motivation and goal

- Recovery process can slow down the recovery
  - Process has to wait for the permit from RP to resend the next logged message
- The faster the network the more is impact of the centralized recovery

Actually:

- Restarted process can immediately access logged messages
- It can figure out what messages not to replay
- If it could figure out causal order by itself recovery would finish faster

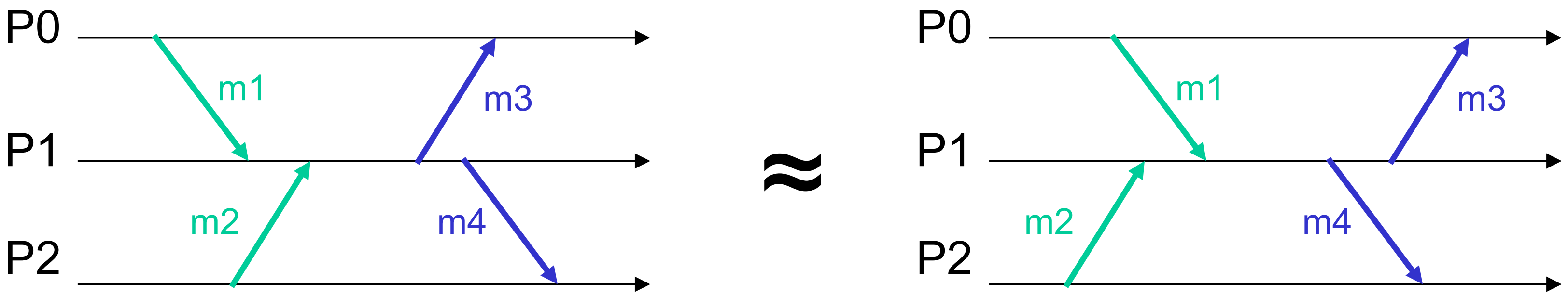
Distributed recovery

Assumption about determinism

- Relax the constraints of send-determinism
- One communication consists of : sender, receiver, message content

SPMD-determinism - in any correct execution the set of communications is the same

- Typical property of SPMD applications



Distributed recovery: concept

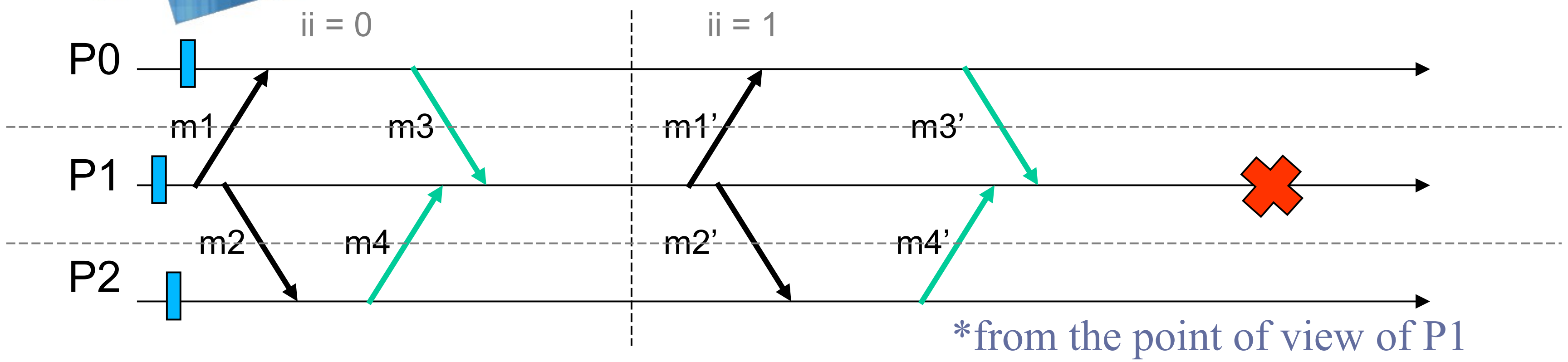
- Restarted process gets all the logs and info about orphan messages
- It decides autonomously whether
  - to receive next message from the log
    - which message it should be then?
  - to receive next message from another restarted process
  - the next message to send is an orphan message so no need to resend
- Phases don't work anymore

Need a mechanism to help the process make the decision

Localizing the problem(1)

- Main source of confusion: message reception
- Assume that channels are FIFO
  - won't confuse messages in case of named reception
- Anonymous receptions (MPI_ANY_SOURCE) create problems

Localizing the problem(2)




```
for( int  ii = 0; ii < num_iter; ii++ ) {

   for( int i = 0; i < nproc; i++) {
     if( i  != myrank )
          mpi_send( buf1, count, MPI_INTEGER,
                        i, tag0, MPI_COMM_WORLD );
   }

   for( int i = 0; i < nproc - 1; i++) {
        mpi_recv( buf2[i], count, MPI_INTEGER,
                        MPI_ANY_SOURCE, tag0,
                        MPI_COMM_WORLD, &rreq );
   }
mpi_barrier( MPI_COMM_WORLD );
}
```

After rollback P1 receives logs with:

m3, m3' // from P0

m4, m4'   // from P2

can receive by mistake e.g. m3 and m3'

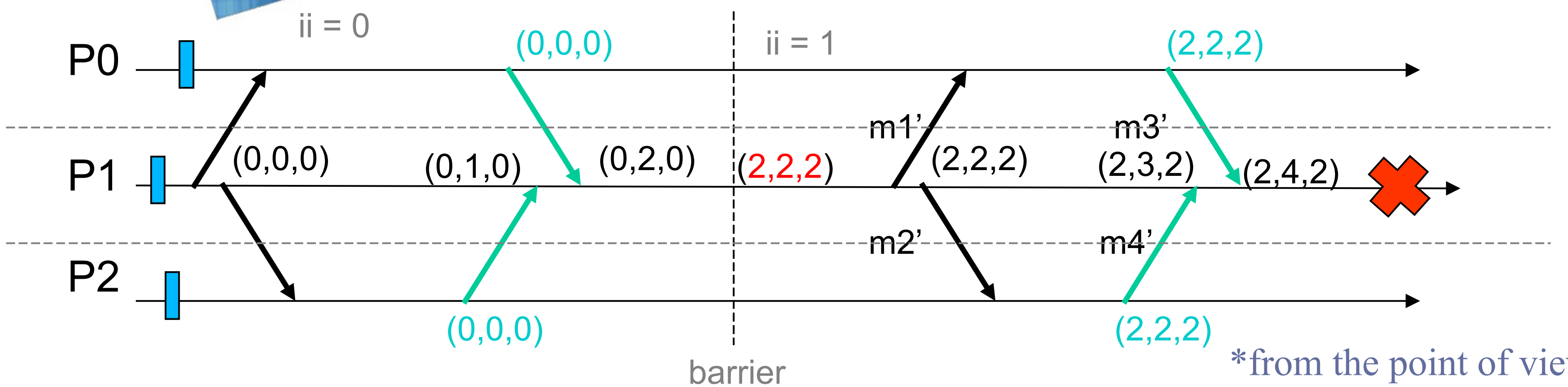
Possible approaches

Goal: express causal dependency between anonymous receptions in one process

- Two approaches:

1. Count my anonymous receptions and propagate to all processes
2. Define communication *sections* that would separate anonymous receptions
   a) Adding directives #SECTION_START and #SECTION_END
      - want to avoid this
   b) Automatic runtime detection of sections

Counting number of anonymous receptions



*from the point of view of P1

- Count my own anonymous receptions
- Keep a vector of counters of all the other processes
- Append own copy of vector to each sent message
- Update own copy with each message reception

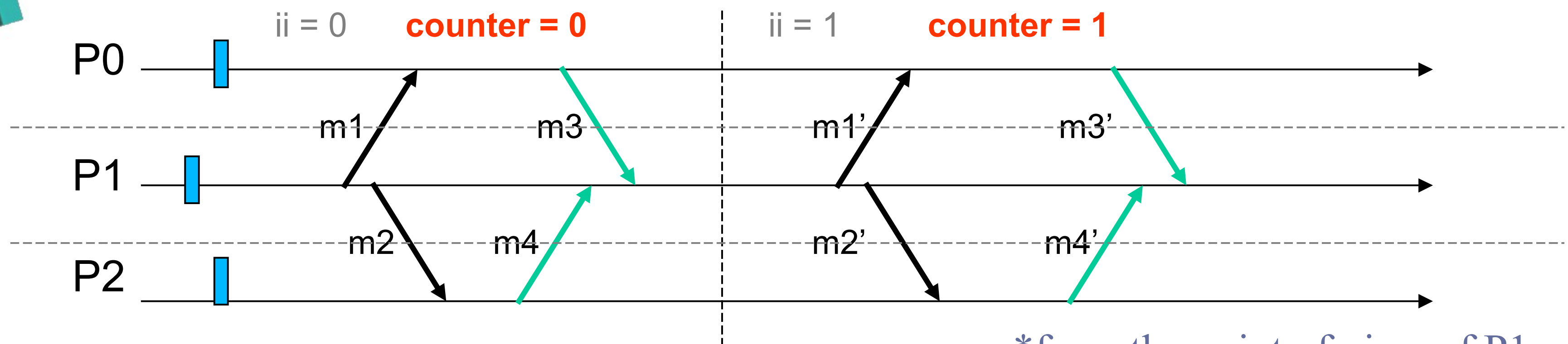
After rollback:

- Choose msg with the corresponding counter ≤ my current counter
- Works but not scalable ☹

Communication sections (1)

- Section confines matching (by tag) send and recv
- Counter for sections
  - increment upon crossing the border between two sections
  - append to each sent message
- Counter of sent message should match my current counter
- Different counters for different messages tags

Communication sections(2)



*from the point of view of P1

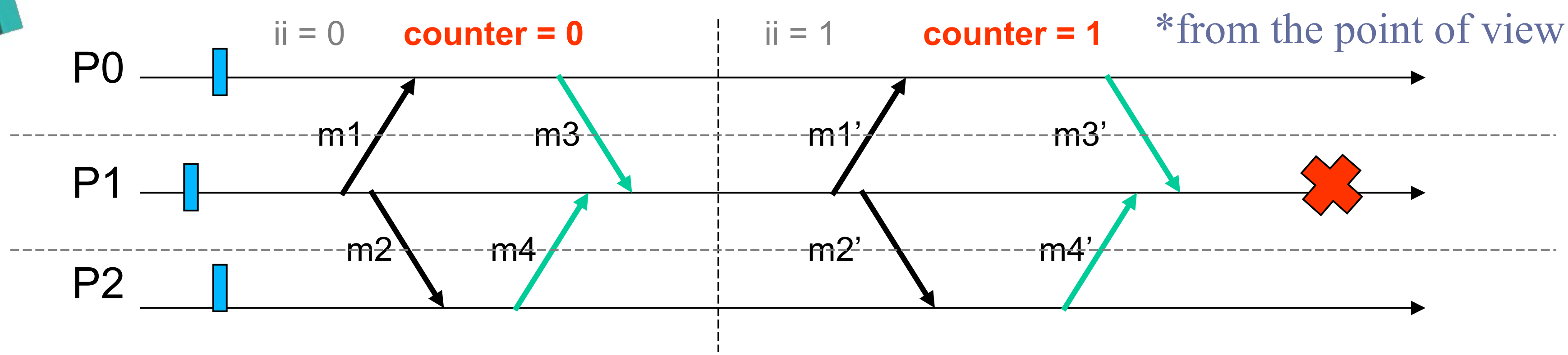
```
for( int  ii = 0; ii < num_iter; ii++ ) {

   for( int i = 0; i < nproc; i++) {
      if( i  != myrank )
        mpi_send( buf1, count, MPI_INTEGER,
                       i, tag0, MPI_COMM_WORLD );
   }

   for( int i = 0; i < nproc - 1; i++) {
       mpi_recv( buf2[i], count, MPI_INTEGER,
                       MPI_ANY_SOURCE, tag0,
                       MPI_COMM_WORLD, &rreq);
   }
mpi_barrier( MPI_COMM_WORLD );
}
```

communication section

Distributed recovery with sections



- After rollback P1→others: “I restart from (tag0,cnt=0)”
- Others→P1: “Here is my message log starting from cnt=0:”

  m3(tag0, cnt=0), m3’(tag0, cnt=1) // from P0

  m4(tag0, cnt=0), m4’(tag0, cnt=1) // from P2
- Others→P1: “This I received from you since cnt=0:”

  (tag0, cnt=0)->m1, (tag0, cnt=1)->m1’ // from P0

  (tag0, cnt=0)->m2, (tag0, cnt=1)->m2’ // from P2
- In the anonymous reception choose messages with matching counter

Automatic detection of sections (1)

- Define calls that can start and end a section
  - and guarantee that matching send and receive are within the same section

Can open a section:
mpi_send mpi_isend mpi_irecv

Can close a section:
mpi_recv mpi_wait(rreq) mpi_waitall(rreqs) mpi_waitany(rreqs)

- In a series of consecutive calls that can open/close the section only the first call will trigger the action

```
for( int i = 0; i < nproc; i++) {
      mpi_send( buf1, count, MPI_INTEGER,
                  i, tag0, MPI_COMM_WORLD );
  }
```

only the first mpi_send will open the section for tag0

Automatic detection of sections (2)

- List of counters for each message tag (associated section)
  - struct { int tag; int cnt; bool isOpened};
- Counter incremented when section is <u>re-opened</u>

```
for( int  ii = 0; ii < num_iter; ii++ ) {       // ii = 0, list of counters empty

   for( int i = 0; i < nproc; i++) {
       if( i  != myrank )
         mpi_send( buf1, count, MPI_INTEGER, i,  //  init cnt and open the section ( tag0, 0, true)
                        tag0, MPI_COMM_WORLD );      // attach cnt=0 to the msg
   }
   for( int i = 0; i < nproc - 1; i++) {
       mpi_recv( buf2[i], count, MPI_INTEGER,  // first recv closes the section (tag0, 0, false)
                       MPI_ANY_SOURCE, tag0,
                       MPI_COMM_WORLD, &rreq );
   }
mpi_barrier( MPI_COMM_WORLD );
}
```

Next loop by ii: increment counter upon reaching first mpi_send.

Automatic detection of sections: Asymmetric case(1)

- Sections are easy to detect if all the processes do the same (SPMD parallelism)
- If the execution is not symmetric the definition of sections collapses

```
for( int  ii = 0; ii < num_iter; ii++ ) {
  if ( myrank < nproc / 2 ) {
       for( int i = nproc / 2 ; i < nproc; i++) {
               mpi_send( buf1, count, MPI_INTEGER, i,
                             tag0, MPI_COMM_WORLD );
       }
  } else {
    for( int i = 0; i < nproc / 2; i++) {
         mpi_recv( buf2[i], count, MPI_INTEGER,
                        MPI_ANY_SOURCE, tag0,
                     MPI_COMM_WORLD, &req[i] );
    }
  }
mpi_barrier( MPI_COMM_WORLD );
}
```

**proc group1:
mpi_send will open a section but no matching mpi_recv to close it**

**proc group 2:
mpi_recv can only close a section, no matching mpi_send to open it**

Automatic detection of sections: Asymmetric case(2)

- Use synchronization calls to detect end of section?
  - it's possible to write asymmetric program without explicit synchronization (e.g. ping-pong with two tags)
- Re-define set of calls to open and close a section?
  - Two sets overlap →don't know to which set a call belongs

SYMMETRIC
Can start a section:
mpi_send
mpi_isend
mpi_irecv
Can end a section:
mpi_recv
mpi_wait(rreq)
mpi_waitall(rreqs)
mpi_waitany(rreqs)

+

ASYMMETRIC
Can start & end a section:
mpi_send
mpi_isend
mpi_recv

No solution yet

Future work

- Find a solution for automatic section detection for asymmetric case
- Come up with a completely different approach?