ReMPI

Scalable MPI Record + Replay

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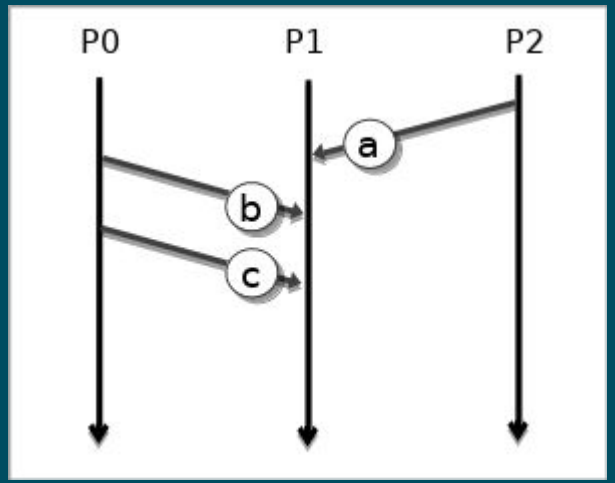
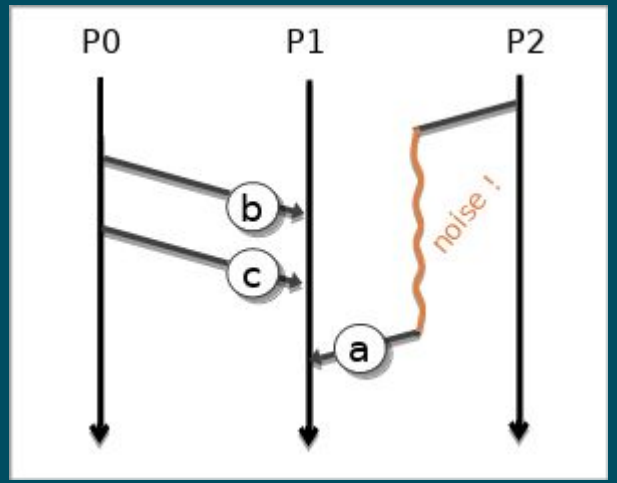
MPI Non-Determinism

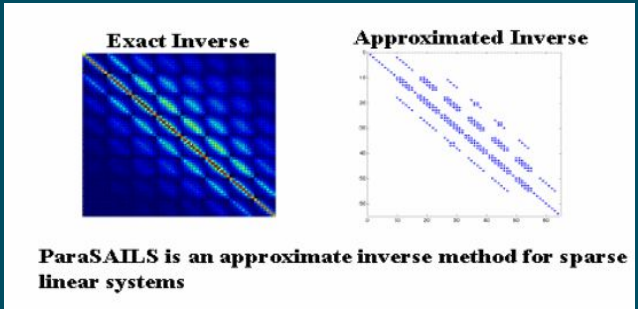
- MPI: Message Passing Interface
- Messages usually sent over a network
- Orderings may be random and could change program behavior





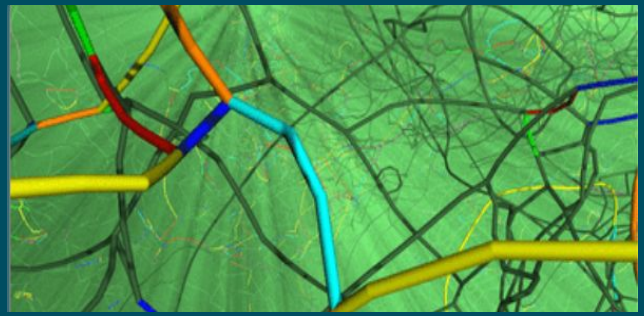
Examples

Diablo with Hypre



- Hang after many hours
- 1 in 30 runs hang
- 2 months debugging only to give up

ParaDis



- Crash between iteration 100 and 200
- Gave up debugging

Causes of MPI Non-Determinism

MPI_ANY_SOURCE

- Receives from any sender
- Can allow different orderings

```
1 MPI_Irecv(..., MPI_ANY_SOURCE, ...);
2 while (true) {
3   MPI_Test(flag);
4   if (flag) {
5     // computations...
6     MPI_Irecv(..., MPI_ANY_SOURCE, ...);
7   }
8 }
```

MPI_Testsome/MPI_Waitsome MPI_Testany/MPI_Waitany

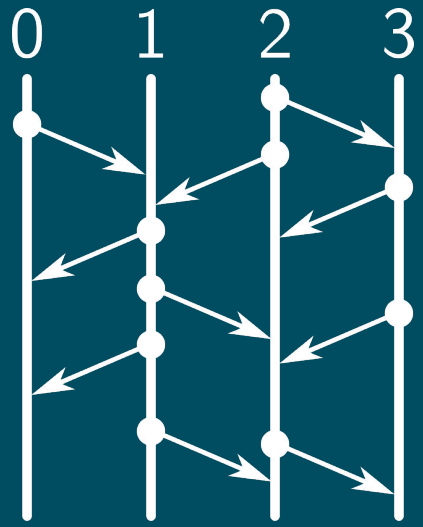
- Progress from any queued receive
- Can allow different orderings

```
 1 MPI_Irecv(..., north_rank, ..., reqs[0]);
 2 MPI_Irecv(..., south_rank, ..., reqs[1]);
 3 MPI_Irecv(..., west_rank, ..., reqs[2]);
 4 MPI_Irecv(..., east_rank, ..., reqs[3]);
 5 while (true) {
 6   MPI_Testsome(..., &reqs, &count, ..., &status);
 7   if (count > 0) {
 8     // computations...
 9     for (...) MPI_Irecv(..., status[i].MPI_SOURCE, ...);
10   }
11 }
```

MPI Record + Replay - Naive Approach

For each process record each **Send**, **Receive**, **Test**, and **Wait**

- Function type
- ID of Sender
- ID of Receiver
- Unique message ID
- Result of test
- Result of wait



Scales poorly - 24 hours of a Monte-Carlo simulation used **10GB per node**!

ReMPI

Version 1.1.0

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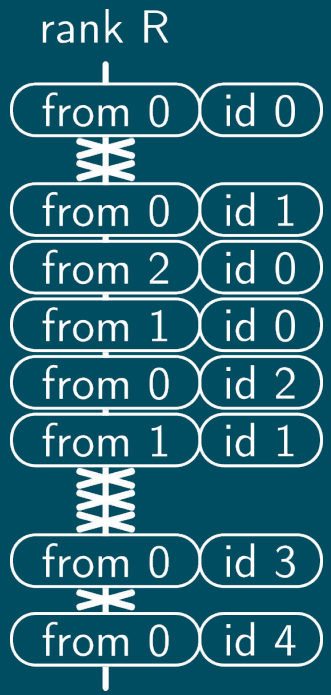
ReMPI Design Goals

1. Correct MPI record + replay
2. Low runtime overhead
3. Memory and file size efficiency
4. Easy to use

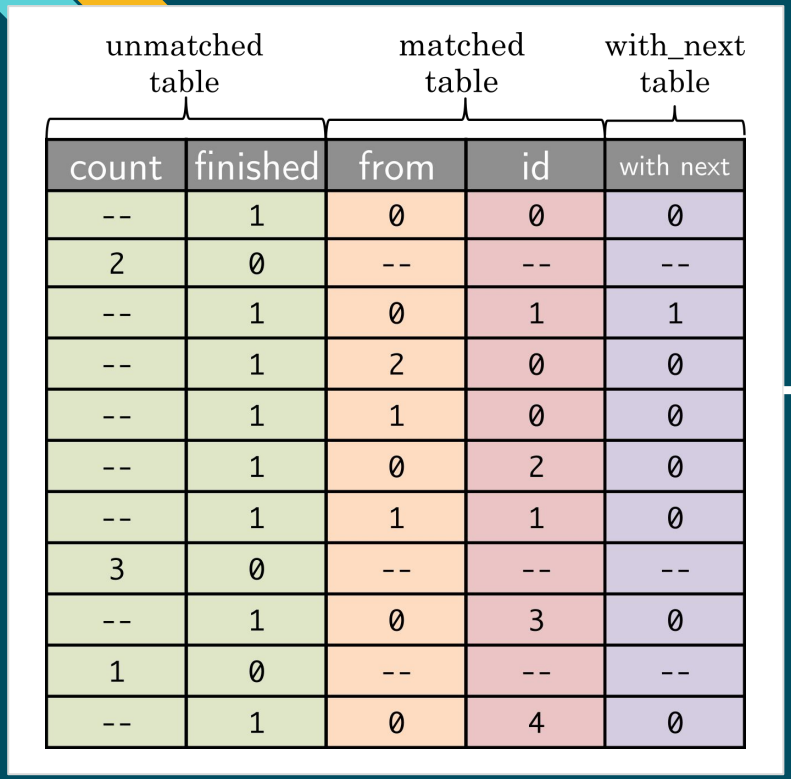
What ReMPI Captures

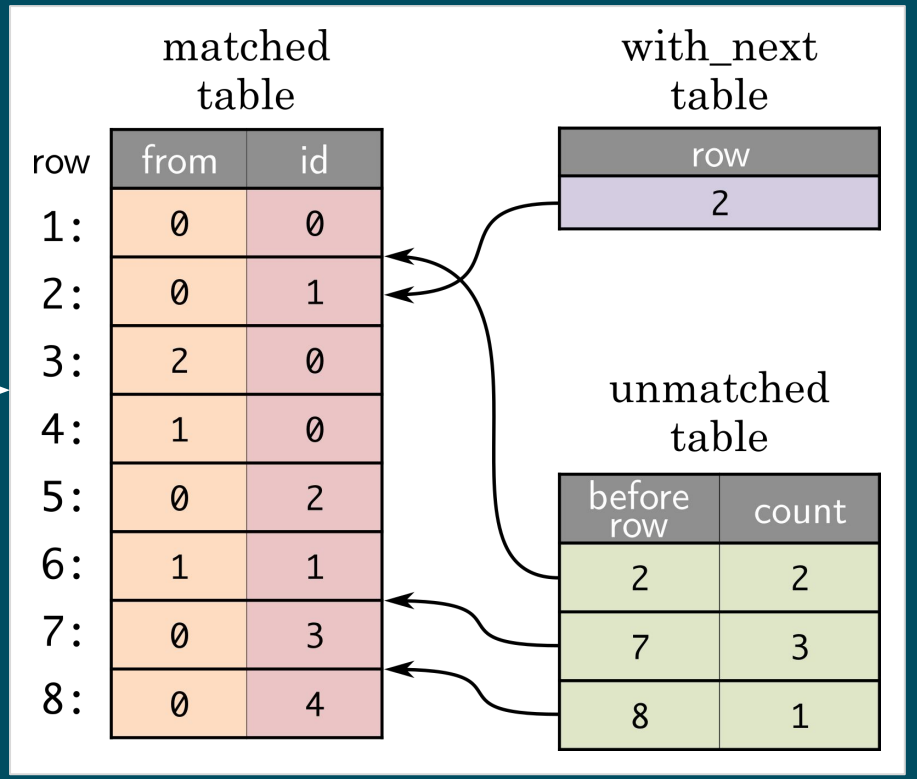
- Function type
- ID of Sender
- ID of Receiver
- Unique message ID
- Result of test
- Result of wait



unmatched table		matched table		with_next table
count	finished	from	id	with next
--	1	0	0	0
2	0	--	--	--
--	1	0	1	1
--	1	2	0	0
--	1	1	0	0
--	1	0	2	0
--	1	1	1	0
3	0	--	--	--
--	1	0	3	0
1	0	--	--	--
--	1	0	4	0

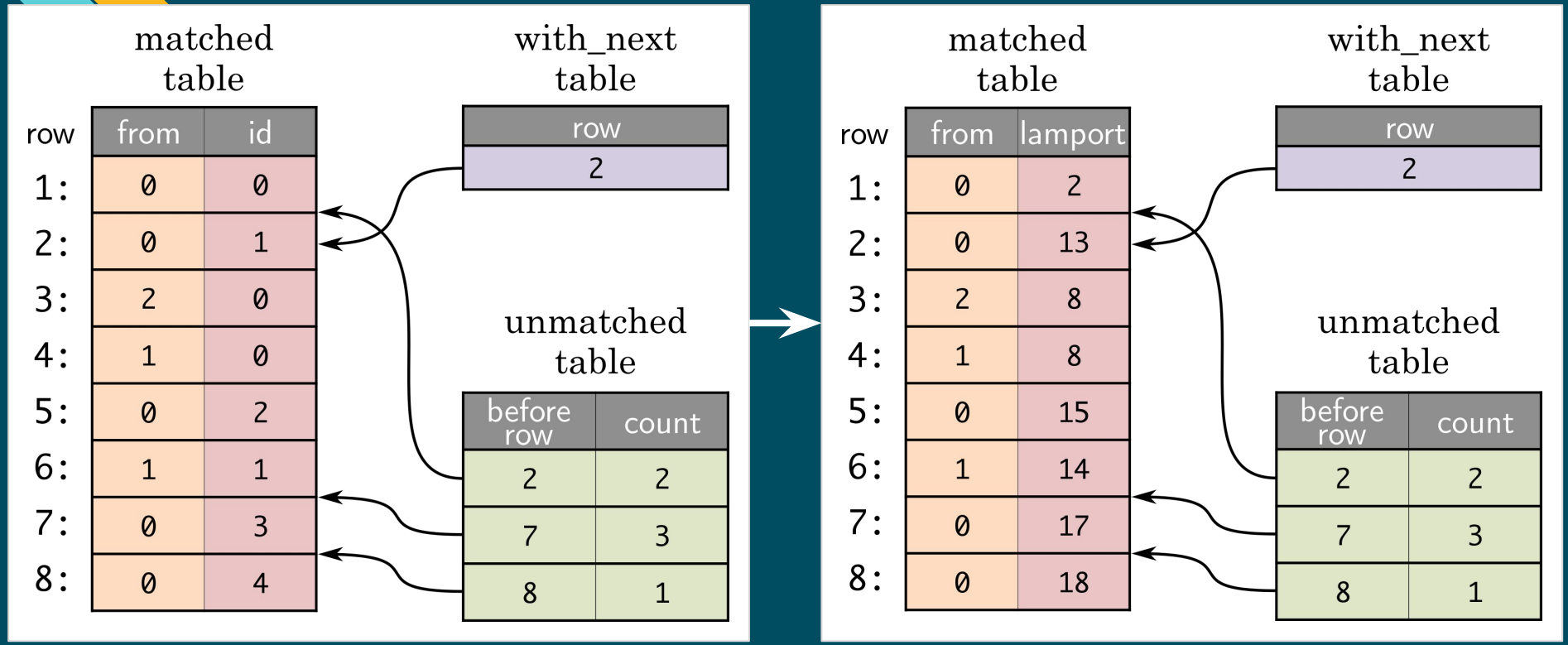
Redundancy Elimination





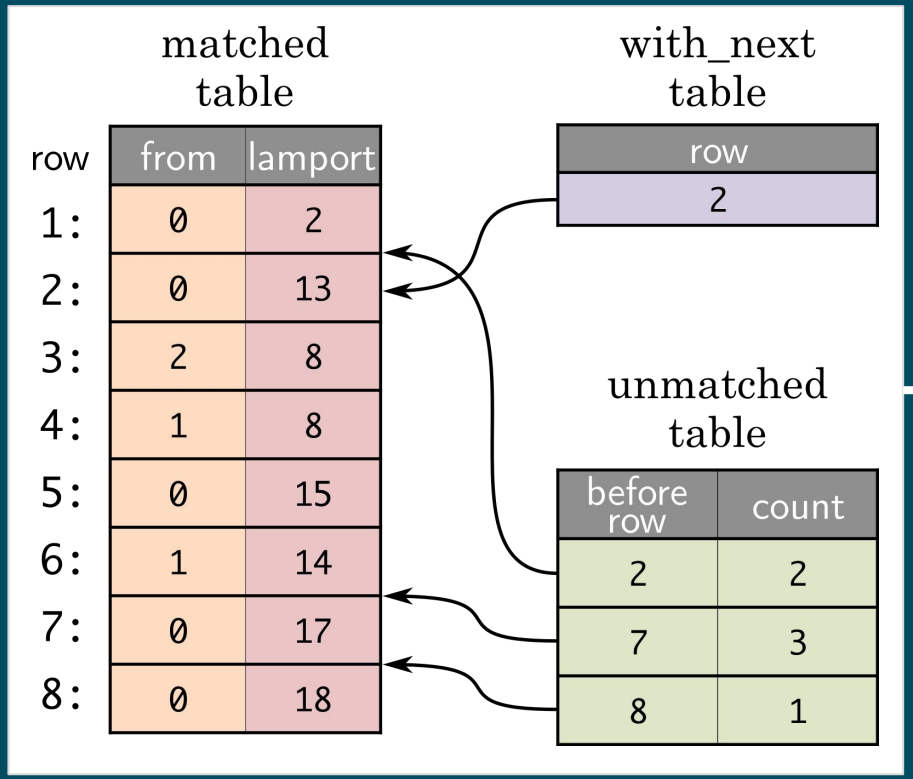
55 values → 23 values

Lamport Clocks



23 values → 23 values

Clock Delta Compression (CDC)



row	delay
2	+2
3	+1
6	−1

row
2

before row	count
2	2
7	3
8	1

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23 values → 13 values

Linear Predictive Encoding

row	delay
2	+2
3	+1
6	−1

row
2

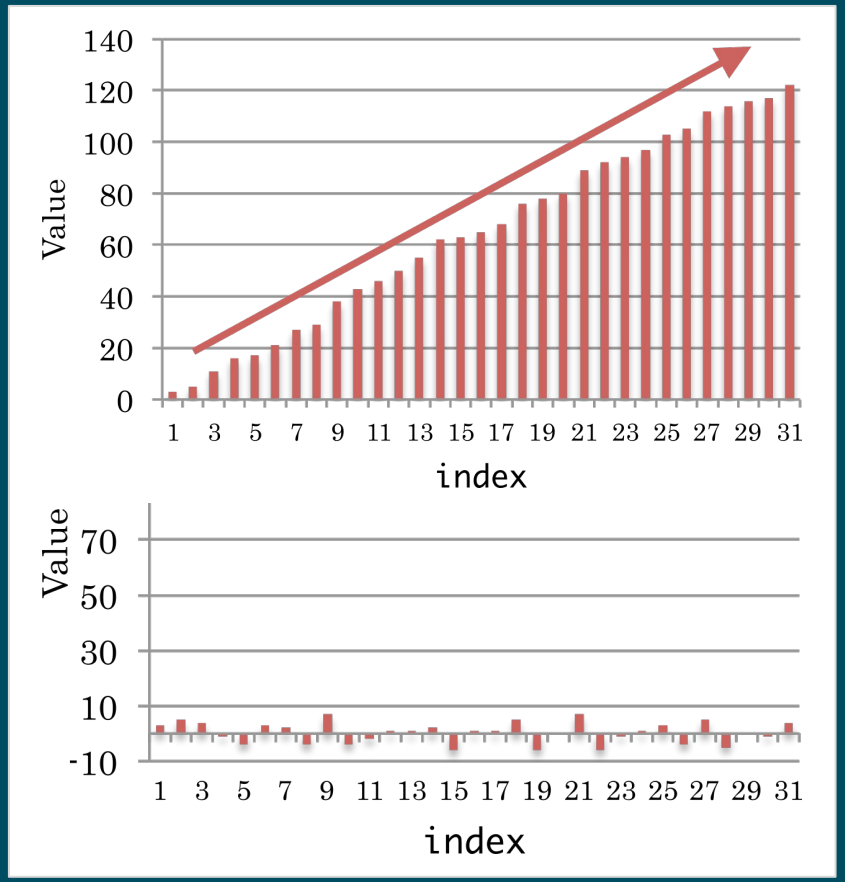
before row	count
2	2
7	3
8	1

delta p.	delay
+2	+2
+1	+1
+2	−1

delta predict.
+2

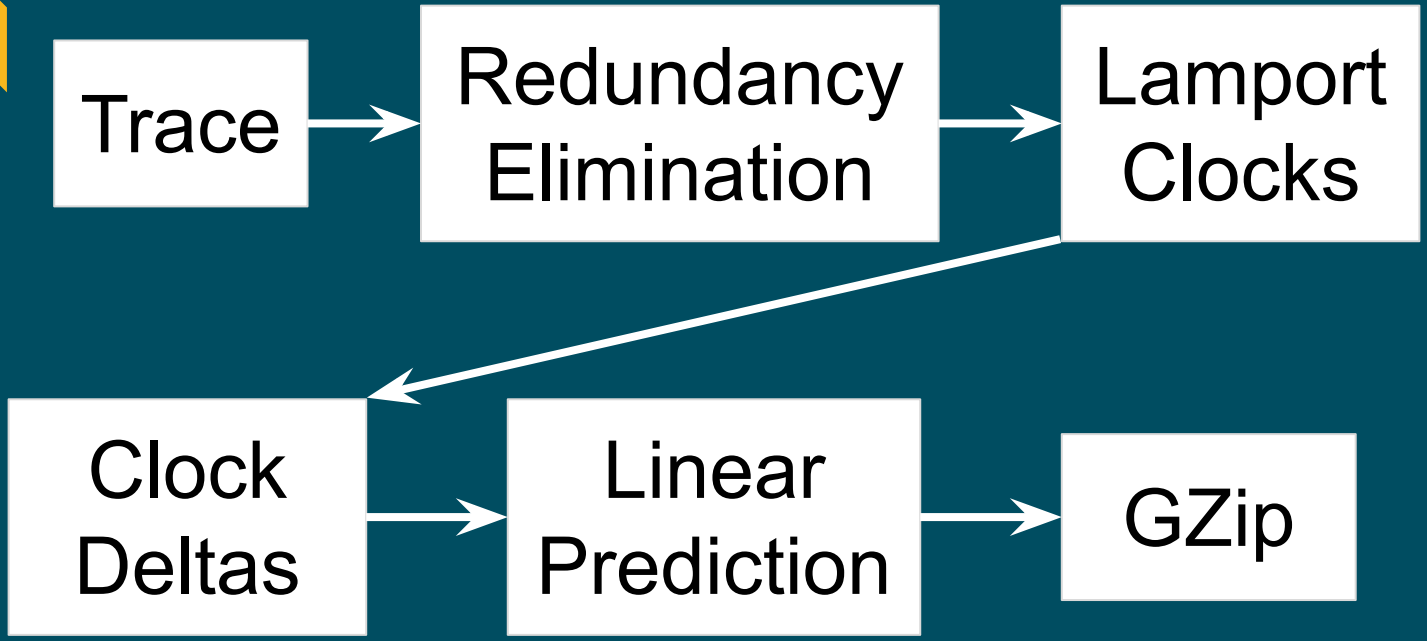
before delta	count
+2	2
+5	3
−4	1

13 values



http://fpanalysistools.org/

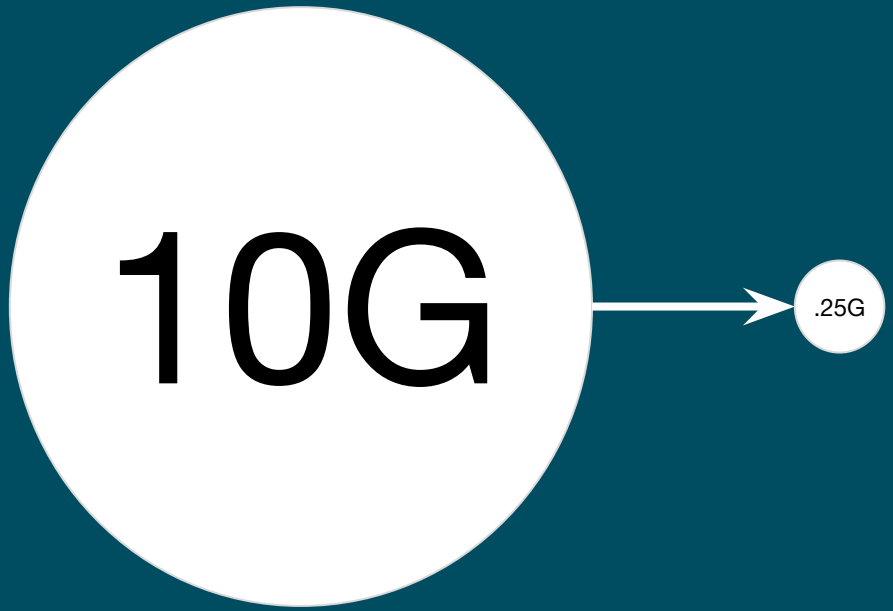
Total Pipeline



13 values

Effectiveness

40x Compression



20 %
Overhead
vs. Naive

Examples

Exercise 1 - Look at the code

```
Module-ReMPI $ cd exercise-1
```

Let’s look at the simple example MPI application

`example.c`

```
exercise-1 $ vim example.c
```

or

```
exercise-1 $ pygmentize example.c | cat -n
```

or whatever...

Exercise 1 - Look at the code

example.c

```
 9 int main(int argc, char *argv[]) {
10-20   [...]
21   for (dest = 0; dest < size; dest++) {
22
23     // each process takes a turn being the receiver
24     if (my_rank == dest) {
25       fprintf(stderr, "----\n");
26       for (i = 0; i < size-1; i++) {
27         MPI_Recv(&buf, 1, MPI_INT, MPI_ANY_SOURCE, 0, MPI_COMM_WORLD, &status);
28         fprintf(stderr, "Rank %d: MPI_Recv from Rank %d\n",
29                 my_rank, status.MPI_SOURCE);
30       }
31
32     // all other processes send
33     } else {
34       // random sleep to induce random behavior
35       usleep(rand() % 10 * 10000);
36
37       MPI_Send(&buf, 1, MPI_INT, dest, 0, MPI_COMM_WORLD);
38     }
39
40     // wait for all messages to be delivered
41     MPI_Barrier(MPI_COMM_WORLD);
42   }
```

Exercise 1 - `./step-01.sh`

```
exercise-1 $ mpicc example.c
```

Compile the example

- ReMPI is not involved with compilation

Exercise 1 - `./step-02.sh`

Run the example many times without ReMPI.

Convince yourself it changes from run to run.

```
 exercise-1 $ mpirun -n 4 ./a.out
----
Rank 0: MPI_Recv from Rank 3
Rank 0: MPI_Recv from Rank 1
Rank 0: MPI_Recv from Rank 2
----
Rank 1: MPI_Recv from Rank 2
Rank 1: MPI_Recv from Rank 3
Rank 1: MPI_Recv from Rank 0
----
Rank 2: MPI_Recv from Rank 3
Rank 2: MPI_Recv from Rank 0
Rank 2: MPI_Recv from Rank 1
----
Rank 3: MPI_Recv from Rank 2
Rank 3: MPI_Recv from Rank 0
Rank 3: MPI_Recv from Rank 1
```

Exercise 1 - `./step-03.sh`

Run ReMPI record manually

```
 exercise-1 $ REMPI_MODE=0 \
> LD_PRELOAD=/usr/local/lib/librempi.so \
> mpirun -n 4 ./a.out
REMPI::eaec2a97ea3c:  0:  ========== ReMPI Configuration ==========
REMPI::eaec2a97ea3c:  0:        REMPI_MODE:  0
REMPI::eaec2a97ea3c:  0:         REMPI_DIR:  .
REMPI::eaec2a97ea3c:  0:      REMPI_ENCODE:  0
REMPI::eaec2a97ea3c:  0:        REMPI_GZIP:  0
REMPI::eaec2a97ea3c:  0:     REMPI_TEST_ID:  0
REMPI::eaec2a97ea3c:  0:         REMPI_MAX:  131072
REMPI::eaec2a97ea3c:  0:  ========================================
[...]
REMPI::eaec2a97ea3c:  0:  Global validation code: 1732970486
```

- Uses LD_PRELOAD and PMPI
- Options are with environment variables
- Works with any MPI library

Exercise 1 - `./step-04.sh`

Run ReMPI record conveniently

```
 exercise-1 $ rempi record mpirun -n 4 ./a.out
REMPI::eaec2a97ea3c:  0:  ========== ReMPI Configuration ==========
REMPI::eaec2a97ea3c:  0:        REMPI_MODE:  0
REMPI::eaec2a97ea3c:  0:         REMPI_DIR:  .
REMPI::eaec2a97ea3c:  0:      REMPI_ENCODE:  0
REMPI::eaec2a97ea3c:  0:        REMPI_GZIP:  0
REMPI::eaec2a97ea3c:  0:     REMPI_TEST_ID:  0
REMPI::eaec2a97ea3c:  0:         REMPI_MAX:  131072
REMPI::eaec2a97ea3c:  0:  ========================================
[...]
REMPI::eaec2a97ea3c:  0:  Global validation code: 1732970486
```

- Convenience script “rempi”
- Sets LD_PRELOAD and REMPI_MODE
- Running many times still has different results

Exercise 1

See the recorded traces

```
 exercise-1 $ ls -l *.rempi
-rw-r--r-- 1 rempi sudo 296 Nov  6 07:19 rank_0.rempi
-rw-r--r-- 1 rempi sudo 296 Nov  6 07:19 rank_1.rempi
-rw-r--r-- 1 rempi sudo 296 Nov  6 07:19 rank_2.rempi
-rw-r--r-- 1 rempi sudo 296 Nov  6 07:19 rank_3.rempi
```

- Traces are put into the current directory by default
- Each process (i.e. rank) makes its own trace
- Binary files - small in size

Exercise 1 - `./step-05.sh`

Run ReMPI replay manually

```
 exercise-1 $ REMPI_MODE=1 \
> LD_PRELOAD=/usr/local/lib/librempi.so \
> mpirun -n 4 ./a.out
REMPI::eaec2a97ea3c:  0:  ========== ReMPI Configuration ==========
REMPI::eaec2a97ea3c:  0:        REMPI_MODE:  1
REMPI::eaec2a97ea3c:  0:         REMPI_DIR:  .
REMPI::eaec2a97ea3c:  0:      REMPI_ENCODE:  0
REMPI::eaec2a97ea3c:  0:        REMPI_GZIP:  0
REMPI::eaec2a97ea3c:  0:     REMPI_TEST_ID:  0
REMPI::eaec2a97ea3c:  0:         REMPI_MAX:  131072
REMPI::eaec2a97ea3c:  0:  ========================================
[...]
REMPI::eaec2a97ea3c:  0:  Global validation code: 1732970486
```

- Only difference: REMPI_MODE=1
- Running many times gives *the same result!*

Exercise 1 - `./step-06.sh`

Run ReMPI replay conveniently

```
 exercise-1 $ rempi replay mpirun -n 4 ./a.out
REMPI::eaec2a97ea3c:  0:  ========== ReMPI Configuration ==========
REMPI::eaec2a97ea3c:  0:        REMPI_MODE:  1
REMPI::eaec2a97ea3c:  0:         REMPI_DIR:  .
REMPI::eaec2a97ea3c:  0:      REMPI_ENCODE:  0
REMPI::eaec2a97ea3c:  0:        REMPI_GZIP:  0
REMPI::eaec2a97ea3c:  0:     REMPI_TEST_ID:  0
REMPI::eaec2a97ea3c:  0:         REMPI_MAX:  131072
REMPI::eaec2a97ea3c:  0:  ========================================
[...]
REMPI::eaec2a97ea3c:  0:  Global validation code: 1732970486
```

- Convenience script “rempi” again
- Sets LD_PRELOAD and REMPI_MODE

Exercise 1 - `./step-07.sh`

Try replay with different process count

```
 exercise-1 $ rempi replay mpirun -n 5 ./a.out
[...]
REMPI: ** ERROR **:eaec2a97ea3c:  4:  Record file open failed: ./rank_4.rempi
(rempi_encoder.cpp:open_record_file:226)
a.out: rempi_err.cpp:95: void rempi_assert(int): Assertion `b' failed.
Rank 0: MPI_Recv from Rank 1
Rank 0: MPI_Recv from Rank 2
Rank 0: MPI_Recv from Rank 3
REMPI:ALERT:eaec2a97ea3c:  0:  MPI_Recv/Irecv should not be called according to record: 2
(MPI_Recv/Irecv: 1, Matching function: 2, Probing function: 3)
(rempi_recorder.cpp:replay_irecv:370)
a.out: rempi_err.cpp:95: void rempi_assert(int): Assertion `b' failed.

[...]
```

Fails fast and hard when used wrong

Exercise 1 - `./step-08.sh`

Try replay with different process count

```
 exercise-1 $ rempi replay mpirun -n 3 ./a.out
[...]
REMPI:ALERT:eaec2a97ea3c:  0:  A matching function should not be called according to
record: 1
  (MPI_Recv/Irecv: 1, Matching function: 2, Probing function: 3)
(rempi_recorder.cpp:replay_mf_input:945)
a.out: rempi_err.cpp:95: void rempi_assert(int): Assertion `b' failed.

[...]
```

Fails fast and hard when used wrong

ReMPI Options

Options are printed at the top of the output

```
REMPI::eaec2a97ea3c:  0:  ========== ReMPI Configuration ==========
REMPI::eaec2a97ea3c:  0:        REMPI_MODE:  1
REMPI::eaec2a97ea3c:  0:         REMPI_DIR:  .
REMPI::eaec2a97ea3c:  0:      REMPI_ENCODE:  0
REMPI::eaec2a97ea3c:  0:        REMPI_GZIP:  0
REMPI::eaec2a97ea3c:  0:     REMPI_TEST_ID:  0
REMPI::eaec2a97ea3c:  0:         REMPI_MAX:  131072
REMPI::eaec2a97ea3c:  0:  ========================================
[...]
```

I will show:

- REMPI_DIR
- REMPI_GZIP

Exercise 1 - `./step-09.sh`

Record to a given directory using environment variable

```
 exercise-1 $ export REMPI_DIR=./rempi-races
 exercise-1 $ rempi record mpirun -n 4 ./a.out
[...]
 exercise-1 $ ls -l ./rempi-races
total 16
-rw-r--r-- 1 rempi sudo 264 Nov  6 15:21 rank_0.rempi
-rw-r--r-- 1 rempi sudo 296 Nov  6 15:21 rank_1.rempi
-rw-r--r-- 1 rempi sudo 264 Nov  6 15:21 rank_2.rempi
-rw-r--r-- 1 rempi sudo 296 Nov  6 15:21 rank_3.rempi
```

You can set the environment variable once and work

Exercise 1 - `./step-10.sh`

Record to a given directory using argument

```
 exercise-1 $ rempi record REMPI_DIR=./rempi-races mpirun -n 4 ./a.out
[...]
 exercise-1 $ ls -l ./rempi-races
total 16
-rw-r--r-- 1 rempi sudo 264 Nov  6 15:21 rank_0.rempi
-rw-r--r-- 1 rempi sudo 296 Nov  6 15:21 rank_1.rempi
-rw-r--r-- 1 rempi sudo 264 Nov  6 15:21 rank_2.rempi
-rw-r--r-- 1 rempi sudo 296 Nov  6 15:21 rank_3.rempi
```

You can give it as an argument each time instead

Exercise 1 - `./step-11.sh`

Replay from a given directory using argument

```
 exercise-1 $ rempi replay \
> REMPI_DIR=./rempi-races \
> mpirun -n 4 ./a.out
[...]
```

If you do not have the REMPI_DIR environment variable set,
then you need to specify it at replay too.

Exercise 1 - `./step-12.sh`

Record a large run with GZip

```
 exercise-1 $ rempi record \
> REMPI_DIR=./rempi-gzip \
> REMPI_GZIP=1 \
> mpirun -n 20 ./a.out
[...]
 exercise-1 $ ls -l ./rempi-gzip
total 80
-rw-r--r-- 1 rempi sudo 174 Nov  6 16:14 rank_0.rempi
-rw-r--r-- 1 rempi sudo 164 Nov  6 16:14 rank_1.rempi
-rw-r--r-- 1 rempi sudo 175 Nov  6 16:14 rank_10.rempi
-rw-r--r-- 1 rempi sudo 175 Nov  6 16:14 rank_11.rempi
[...]
```

The compressed traces look small.

Let’s see how big without gzip

Exercise 1 - `./step-13.sh`

Record a large run without GZip for comparison

```
 exercise-1 $ rempi record \
> REMPI_DIR=./rempi-no-gzip \
> REMPI_GZIP=0 \
> mpirun -n 20 ./a.out
[...]
 exercise-1 $ ls -l ./rempi-no-gzip
total 80
-rw-r--r-- 1 rempi sudo 1832 Nov  6 16:19 rank_0.rempi
-rw-r--r-- 1 rempi sudo 1832 Nov  6 16:19 rank_1.rempi
-rw-r--r-- 1 rempi sudo 1832 Nov  6 16:19 rank_10.rempi
-rw-r--r-- 1 rempi sudo 1832 Nov  6 16:19 rank_11.rempi
[...]
```

The uncompressed traces are about 11x bigger.

Exercise 1 - `./step-14.sh`

Replay a GZip run

```
 exercise-1 $ rempi replay \
> REMPI_DIR=./rempi-gzip \
> REMPI_GZIP=1 \
> mpirun -n 20 ./a.out
[...]
```

You must specify the same REMPI_GZIP setting to replay
I suggest you set it in your environment variables

ReMPI

Thank You!

Questions?

pruners.github.io/rempi