Performance Analysis of Parallel Applications Using LTTng & Trace Compass

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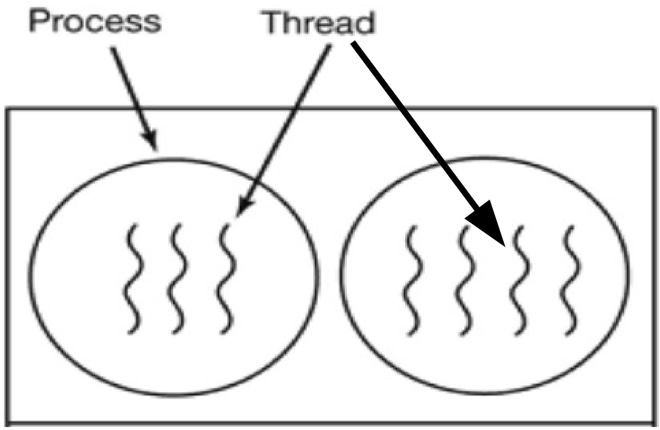
What is MPI?

- Message Passing Interface (MPI)
  - Industry-wide standard protocol for passing messages between parallel processors.
  - MPI is for communication among processes with separate address spaces.
  - Interprocess communication consists of
    - Synchronization
    - Movement of data from one process’s address space to another’s.

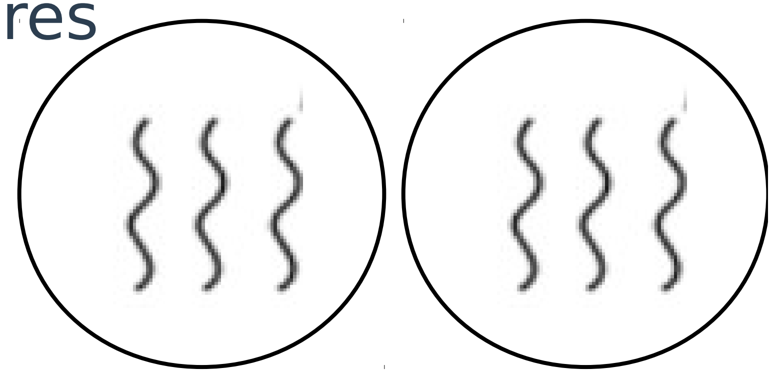
MPI vs Threads

- Thread parallelism provides a shared memory model within a process.
  - Pthread: an execution model allows a program to control multiple different overlapping flows of work.
  - OpenMP: looplevel parallelism, created and managed by the compiler, based on user directives.
- MPI describes parallelism between processes (with separate address spaces).
    - MPICH, OpenMPI



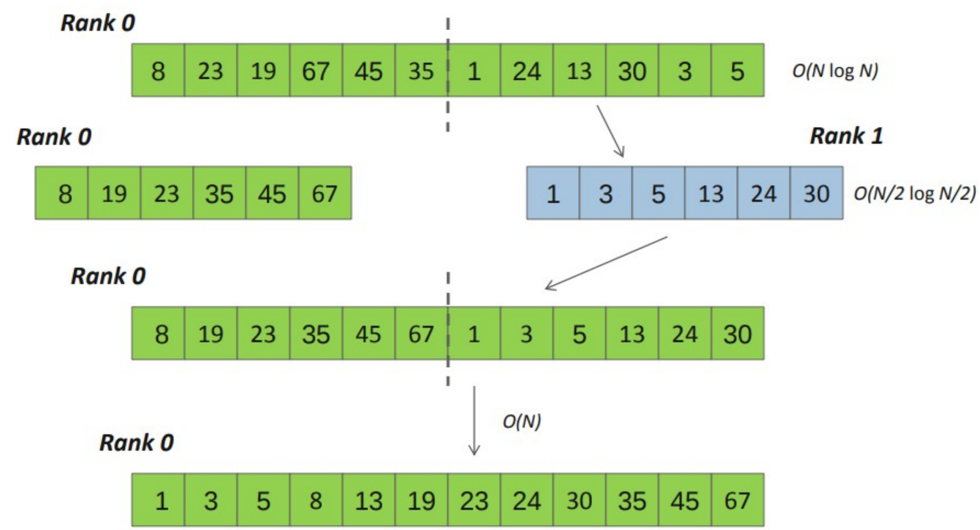
MPI + Threads

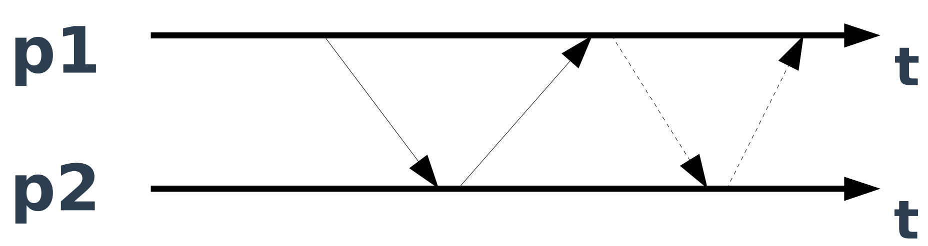
- **MPI-only:**
  - Single thread of execution
    - System resources do not scale at the same rate as processing cores
- **MPI+threads:**
  - Multiple threads executing simultaneously
    - Allows sharing of system resources



Parallel Sort Using MPI

- #include <mpi.h>
- #include <stdio.h>
- int main(int argc, char ** argv)
- {
- int rank, a[1000], b[500];
- MPI_Init(&argc, &argv);
- MPI_Comm_rank(MPI_COMM_WORLD, &rank);
- if (rank == 0) {
  - MPI_Send(&a[500], 500, MPI_INT, 1, 0, MPI_COMM_WORLD);
  - sort(a, 500);
  - MPI_Recv(b, 500, MPI_INT, 1, 0, MPI_COMM_WORLD,
  - MPI_STATUS_IGNORE);
  - /* Serial: Merge array b and sorted part of array a */
- }
- else if (rank == 1) {
  - MPI_Recv(b, 500, MPI_INT, 0, 0, MPI_COMM_WORLD,
  - MPI_STATUS_IGNORE);
  - sort(b, 500);
  - MPI_Send(b, 500, MPI_INT, 0, 0, MPI_COMM_WORLD);
- }
- MPI_Finalize(); return 0;
- }





MPI Performance Analysis

- **Debugging can be difficult!**
  - In a serial program, you can find slow functions (by profiling, tracing, etc.) and optimize them.
- **Investigating of all participating processes**
  - In MPI, if MPI_Recv() takes a lot of time in one process, we should look at other processes, as well as the problematic function/process.
    - What happens on other processes, when this process/function is slow?
  - The synchronization among the processes can be a concern and should be debugged.

MPI Performance Analysis (contd)

- **Network performance is important:**
  - Latency: The time from when a Send is initiated until the first byte is received by a Receive.
  - Bandwidth: The rate at which a sender is able to send data to a receiver.
- **Profilers:**
  - Aggregate statistics at run time
    - Amount of time spent in MPI functions, number of messages sent, etc.
- **Tracers**
  - Collect events from different parts of the execution.

PMPI: MPI Profiling

- **PMPI refers to the MPI standard profiling interface.**
  - Profiling layer of MPI
  - Implemented via additional API in MPI library
  - Different name: PMPI_Init()
    - Same functionality as MPI_Init()
- **Each standard MPI function can be called with an MPI_ or PMPI_ prefix.**
  - MPI_Send() or PMPI_Send().
- **This allows one to write functions with the MPI_ prefix that call the equivalent PMPI_ function.**

```
Int MPI_Init(…)
{
trace_entry();
  PMPI_Init(…);
trace_exit();
}
```

PMPI: MPI Profiling (contd)

- **User may choose subset of MPI routines to be profiled**
  - Useful for building performance analysis tools
  - LD_PRELOAD or dynamic linking
- **Tools**
  - Vampir: Timeline of MPI traffic (Etnus, Inc.)
  - Paradyn: Performance analysis (U. Wisconsin)
  - mpiP: J. Vetter (LLNL)
  - ScalaTrace: F. Mueller et al. (NCSU)
  - Paraver
  - Jumpshot
  - LTTng & Trace Compass ?

MPI Tracing with LTTng

```
MPI_Send(…)
{
  Tracepoint (mpi,mpi_send_entry,…)
  PMPI_Send(…)
  Tracepoint (mpi,mpi_send_exit,…)
}
```

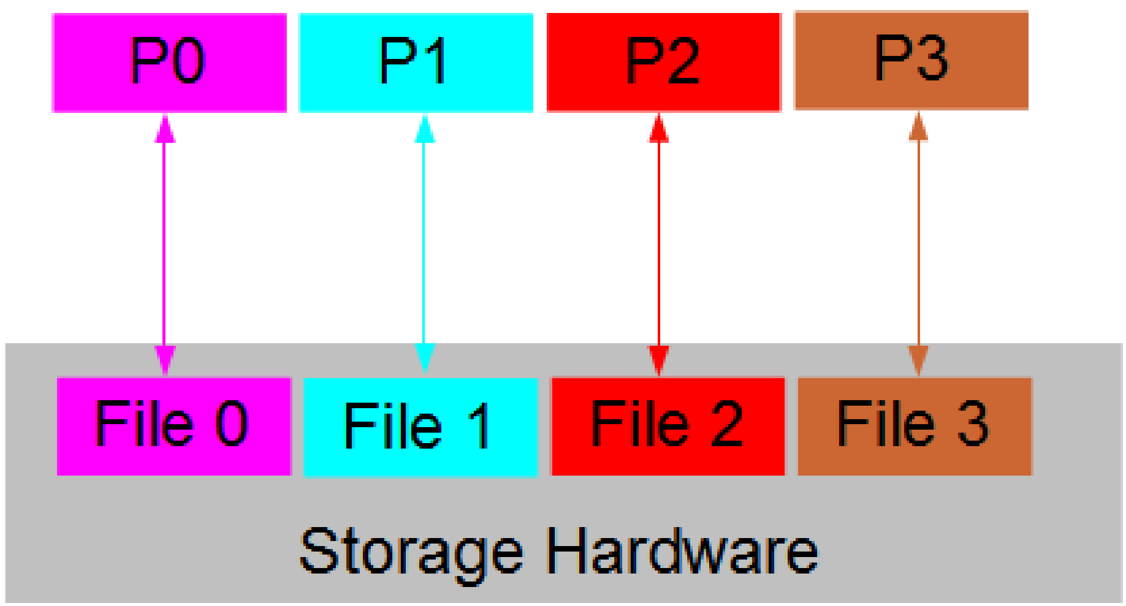
- **Compile and LD_Preload it**
  - LD_Preload is to intercept methods
  - Load this before all of other libraries

LTTng-UST Tracepoints

- **MPI (50 methods)**
  - **Environment Management Functions** (MPI_Init, MPI_Finalize MPI_Abort, etc.)
  - **Point to Point Communication Functions** (MPI_Send, MPI_Recv, MPI_Isend,MPI_Irecv, MPI_Ssend, MPI_Wait*, etc.)
  - **Collective Communication Functions** (MPI_Barrier, MPI_Bcast, MPI_Scatter, MPI_Gather, MPI_Allgather, MPI_Reduce, MPI_Allreduce,
  - **MPI-IO Functions** (MPI_File_open, MPI_File_read, MPI_File_write, MPI_File_close, etc.)
  - **HDF5 (20 methods)**
    - Hierarchical Data Format functions
  - **Pthread (20 methods)**
  - Thread management function
    - Thread create, join, etc.
  - Locks
    - Spin locks,Mutex, R/W locks

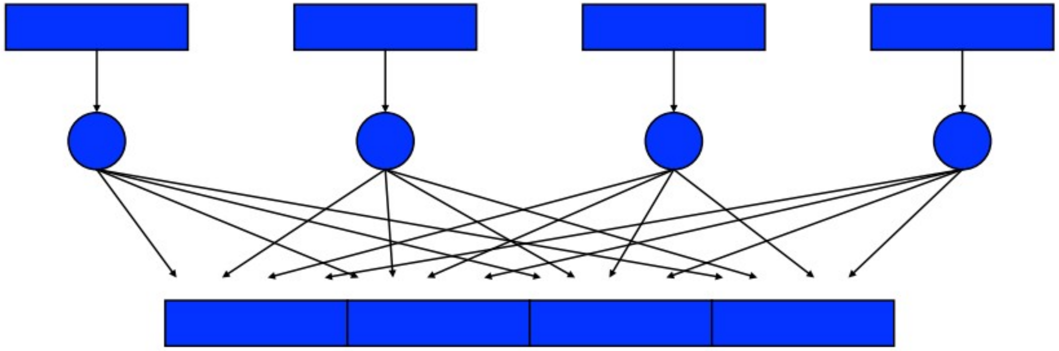
Parallel I/O Styles

- **Independent Parallel I/O**
  - Parallelism but lots of small files to handle
  - With or without MPI



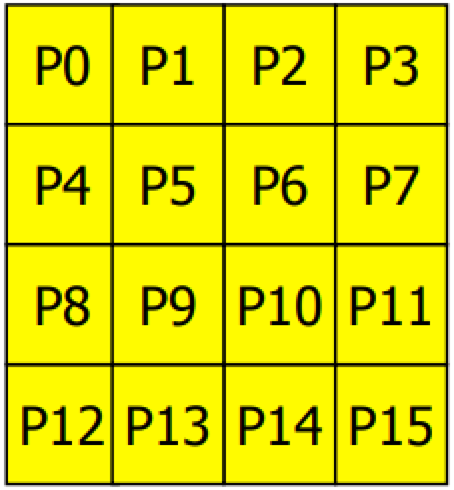
Parallel I/O Styles (contd)

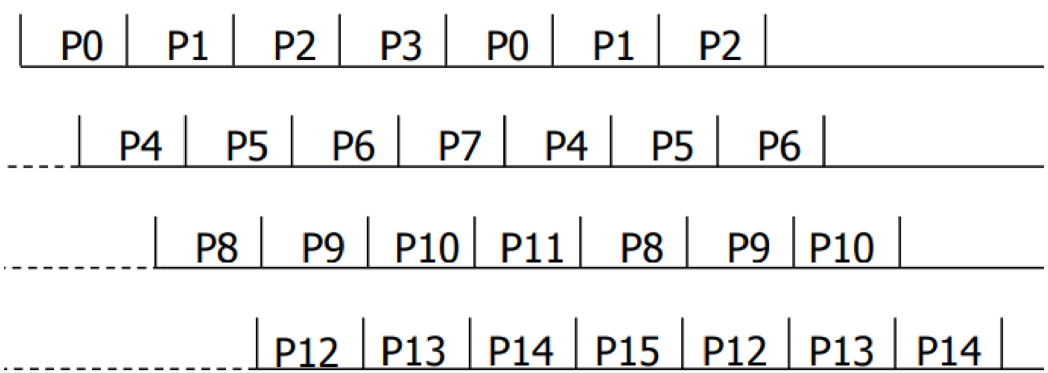
- **Cooperative Parallel I/O**
  - Parallelism
  - Only with MPI!



Parallel I/O Example

- **Distributed Array Access**
  - Large array distributed among n processes
  - Each square represents a sub-array in the memory of a single process



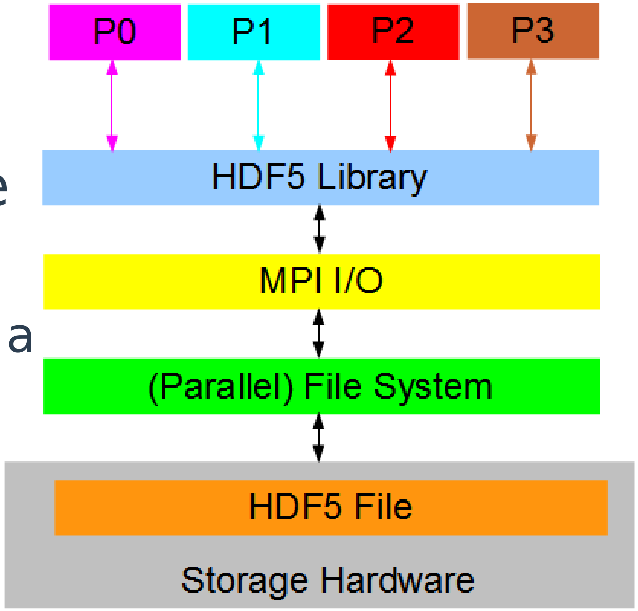


Parallel I/O in MPI

- **MPI has replacement functions for POSIX I/O**
- **Why not use POSIX?**
  - Single file (instead of one file / process)
  - Parallel performance
- **Multiple types of I/O in MPI**
  - Some are not possible without MPI
  -

HDF5

- **A high level open-source parallel I/O library**
  - Interface between the app and the parallel MPI-IO.
  - Encapsulates the MPI-IO library, optimize and add more features to build a high level parallel I/O library.
  - The users only need to apply this knowledge in their parallel program.
    - Save the development and optimization time for a parallel I/O application.
  - Is been used to manage large and complex data collections in several companies like NASA, etc.



LTTng-UST Tracepoints for Parallel I/O

- **Different I/O levels**
  - **HDF5**
    - Hierarchical Data Format functions (h5x_create,h5x_write,h5x_close, etc.)
  - **MPI**
    - **MPI-IO Functions** (MPI_File_open, MPI_File_read, MPI_File_write, MPI_File_close, etc.)
  - **File system**

Trace Compass Views

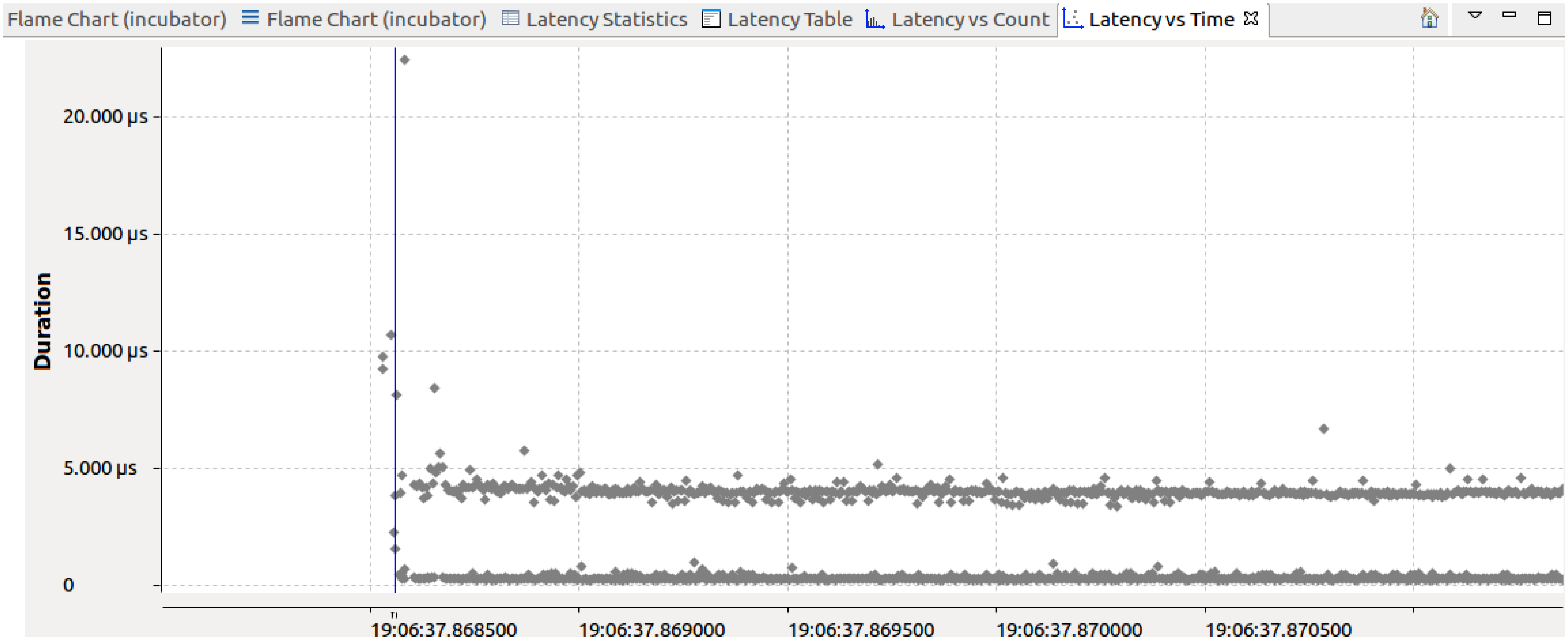
- **Profiling**
  - Amount of time spent in MPI functions,
  - Number of messages sent, the IO of each process and the whole system,
  - Different latency values, etc.
- **Multilevel Call Stack**
  - MPI--> Pthread--> Kernel
  - HDF5 --> MPI-IO → POSIX --> Kernel

Trace Compass Views (contd)

Properties | Tasks | State System Explorer | Flame Chart (incubator) | Flame Chart (incubator) | Latency Statistics | Latency Table

Start Time	End Time	Duration	Name	Content
19:06:37.659 787 533	19:06:37.868 526 185	208,738,652	mpi:mpi_init	threadID=22822
19:06:37.895 679 755	19:06:37.929 753 468	34,073,713	mpi:mpi_finalize	threadID=22823
19:06:37.895 690 377	19:06:37.928 175 500	32,485,123	mpi:mpi_finalize	threadID=22822
19:06:37.881 234 161	19:06:37.895 181 373	13,947,212	mpi:mpi_recv	threadID=22823
19:06:37.859 748 690	19:06:37.868 526 097	8,777,407	mpi:mpi_init	threadID=22823
19:06:37.871 962 773	19:06:37.879 105 641	7,142,868	mpi:mpi_recv	threadID=22823
19:06:37.879 475 363	19:06:37.880 407 771	932,408	mpi:mpi_recv	threadID=22823
19:06:37.868 582 007	19:06:37.868 604 736	22,729	mpi:mpi_recv	threadID=22823
19:06:37.881 081 572	19:06:37.881 101 757	20,185	mpi:mpi_recv	threadID=22823
19:06:37.895 184 923	19:06:37.895 200 562	15,639	mpi:mpi_recv	threadID=22823
19:06:37.879 106 690	19:06:37.879 118 195	11,505	mpi:mpi_recv	threadID=22823
19:06:37.880 482 090	19:06:37.880 493 170	11,080	mpi:mpi_recv	threadID=22823
19:06:37.868 548 444	19:06:37.868 559 284	10,840	mpi:mpi_recv	threadID=22823
19:06:37.871 731 183	19:06:37.871 741 800	10,617	mpi:mpi_recv	threadID=22823
19:06:37.895 177 570	19:06:37.895 188 040	10,470	mpi:mpi_recv	threadID=22822
19:06:37.868 529 249	19:06:37.868 539 169	9,920	mpi:mpi_barrier	threadID=22822
19:06:37.880 409 030	19:06:37.880 418 818	9,788	mpi:mpi_recv	threadID=22823
19:06:37.868 529 275	19:06:37.868 538 648	9,373	mpi:mpi_barrier	threadID=22823
19:06:37.871 698 536	19:06:37.871 707 673	9,137	mpi:mpi_recv	threadID=22823

Trace Compass Views (contd)

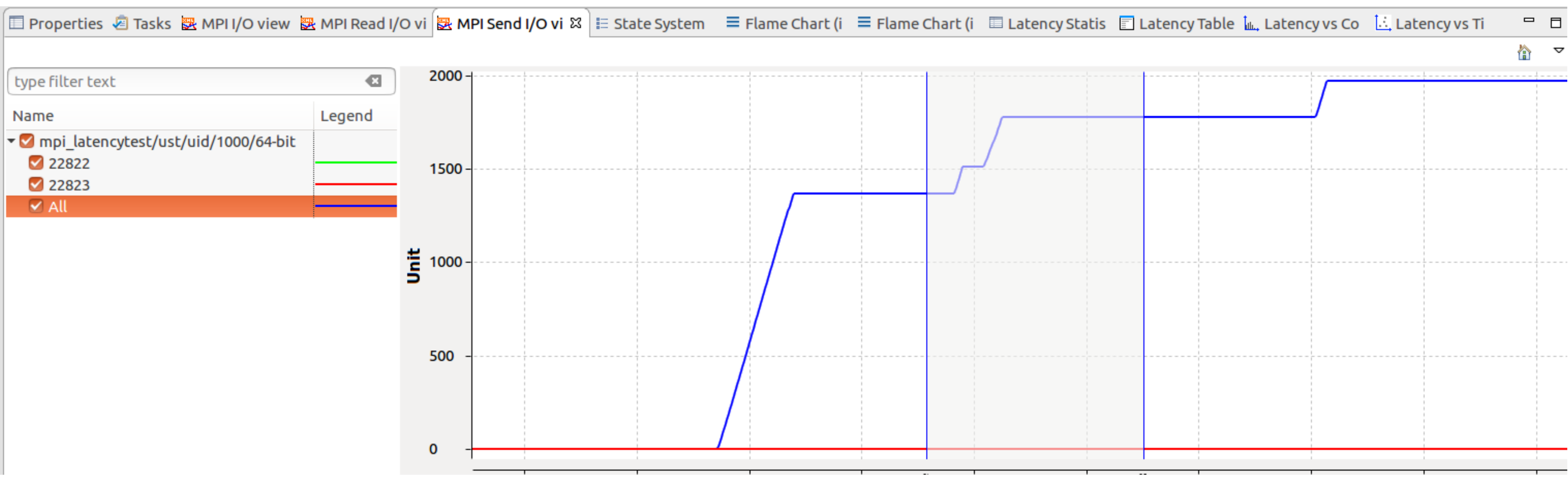


Trace Compass Views (contd)

Properties | Tasks | State System Explorer | Flame Chart (incubator) | Flame Chart (incubator) | Latency Statistics

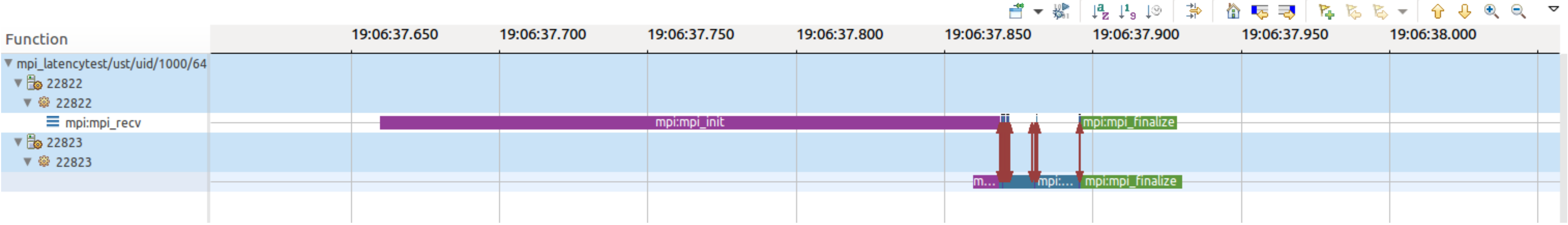
Level	Minimu	Maximum	Average	Standard Deviation	Count	Total
Total	244 ns	208.739 ms	77.791 µs	3.392 ms	4006	311.631 ms
mpi:mpi_send	244 ns	4.883 µs	310 ns	224 ns	2000	620.009 µs
mpi:mpi_recv	378 ns	13.947 ms	13.458 µs	350.853 µs	2000	26.917 ms
mpi:mpi_barrier	9.373 µs	9.920 µs	9.646 µs	---	2	19.293 µs
mpi:mpi_init	8.777 ms	208.739 ms	108.758 ms	---	2	217.516 ms
mpi:mpi_finalize	32.485 ms	34.074 ms	33.279 ms	---	2	66.559 ms

Trace Compass Views (contd)

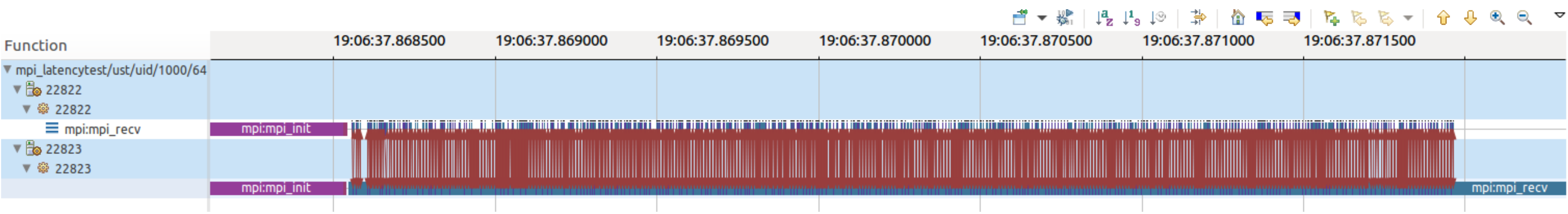


Trace Compass Views (contd)

Case 1: ping-pong



Trace Compass Views (contd)



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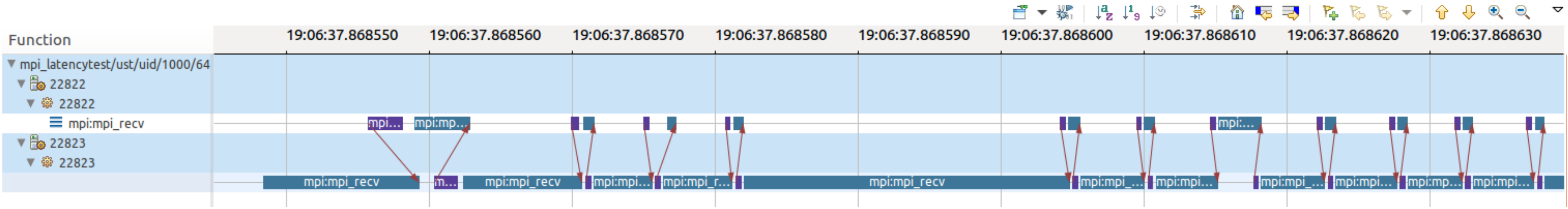

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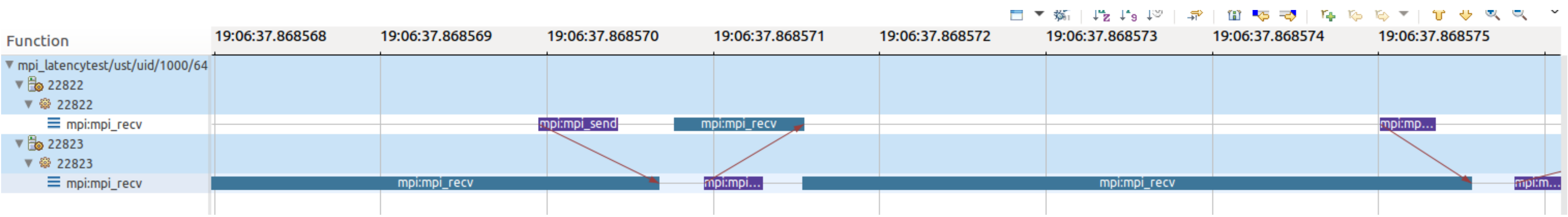
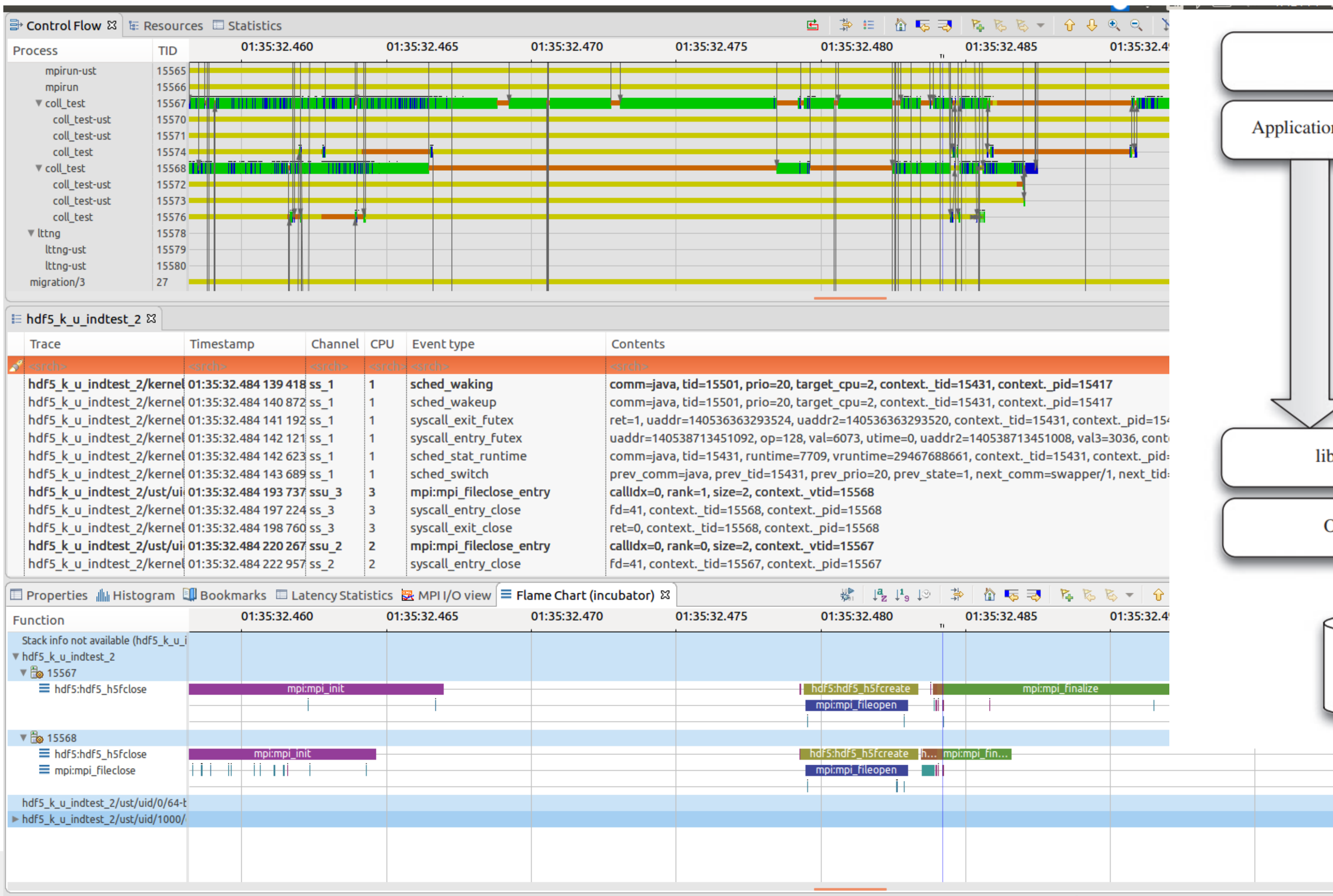
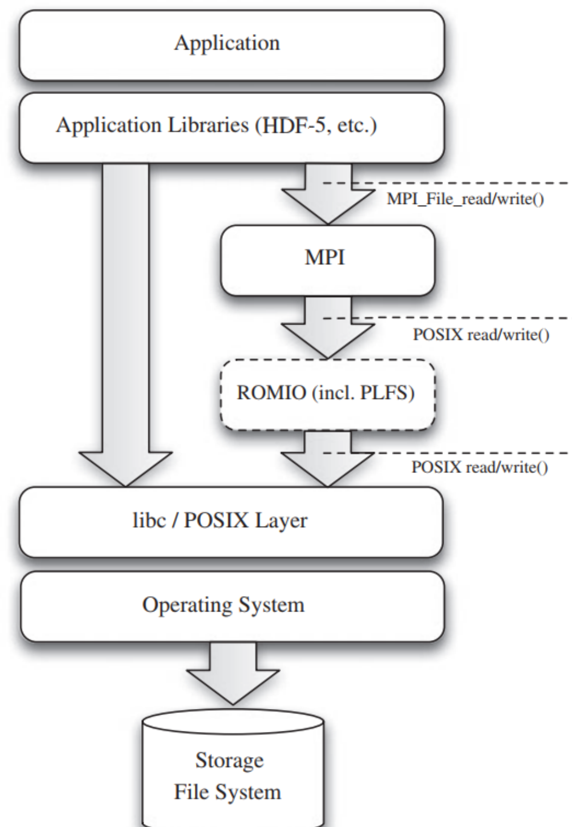


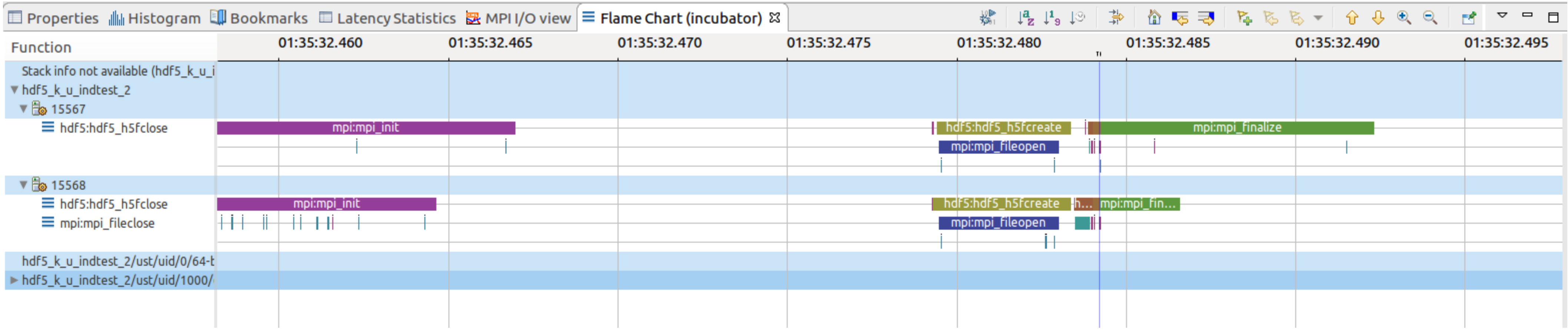
Trace Compass Views (contd)

Case 2: Multi-level Parallel I/O





Trace Compass Views (contd)



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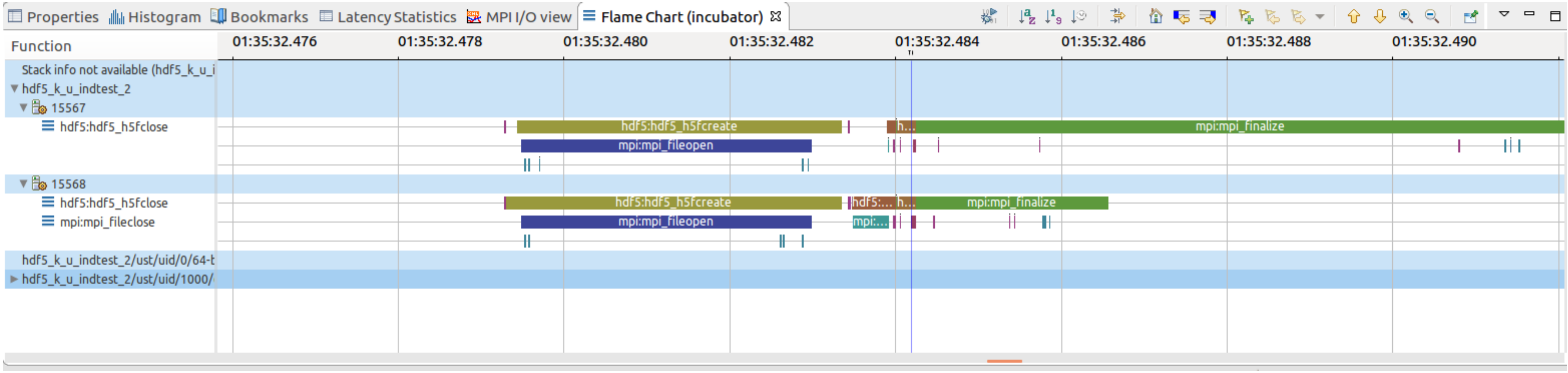

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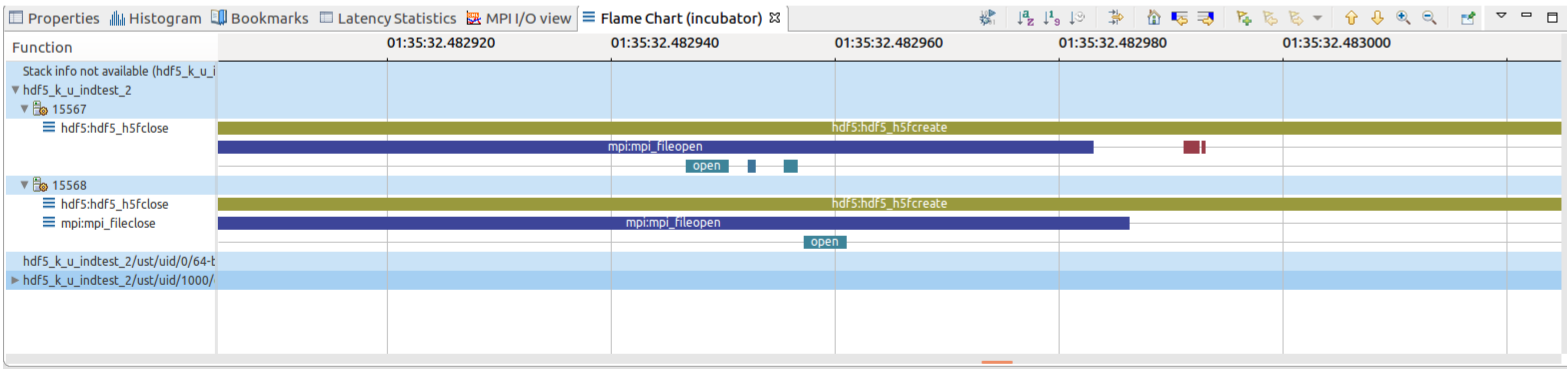

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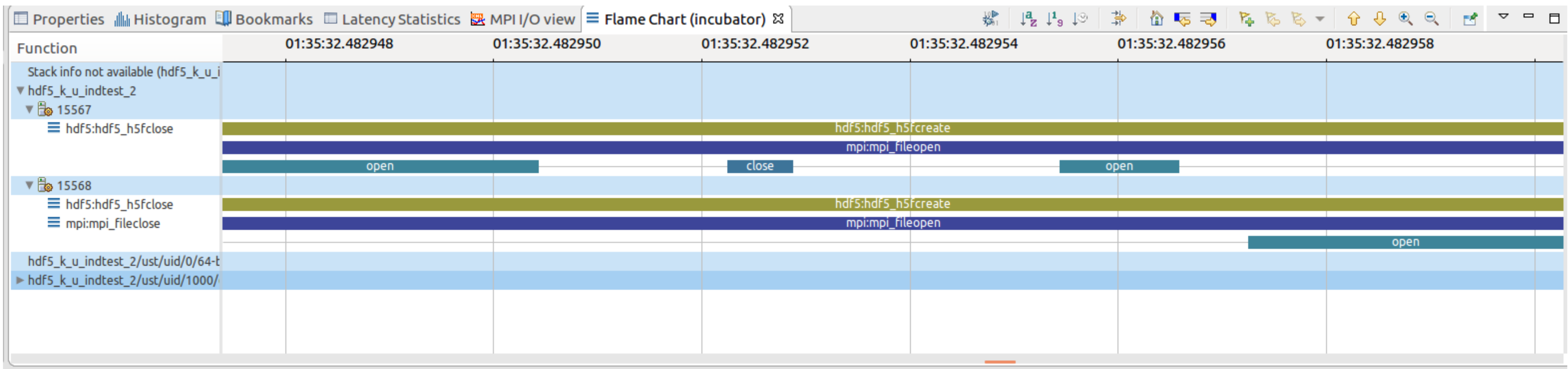

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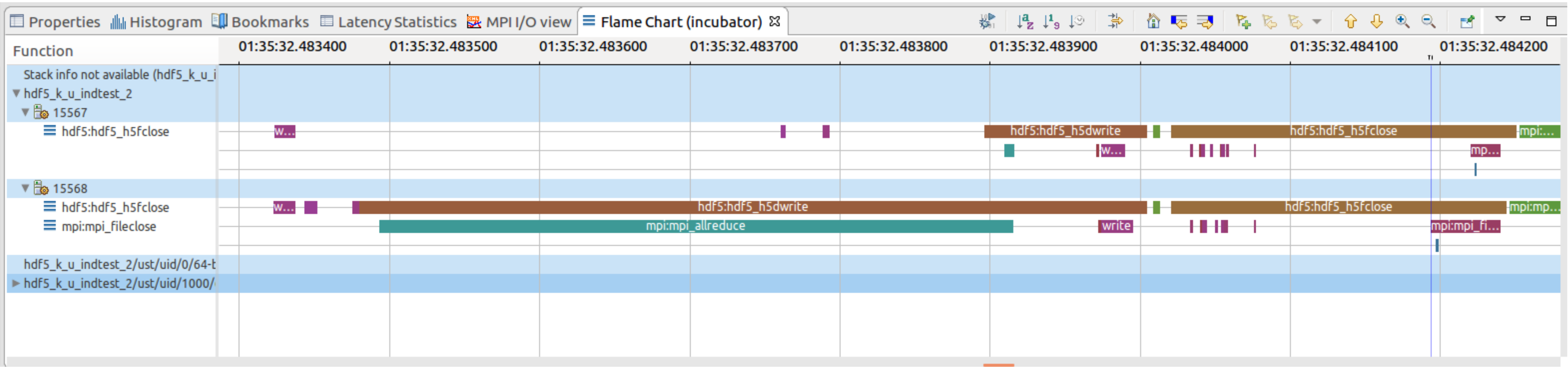

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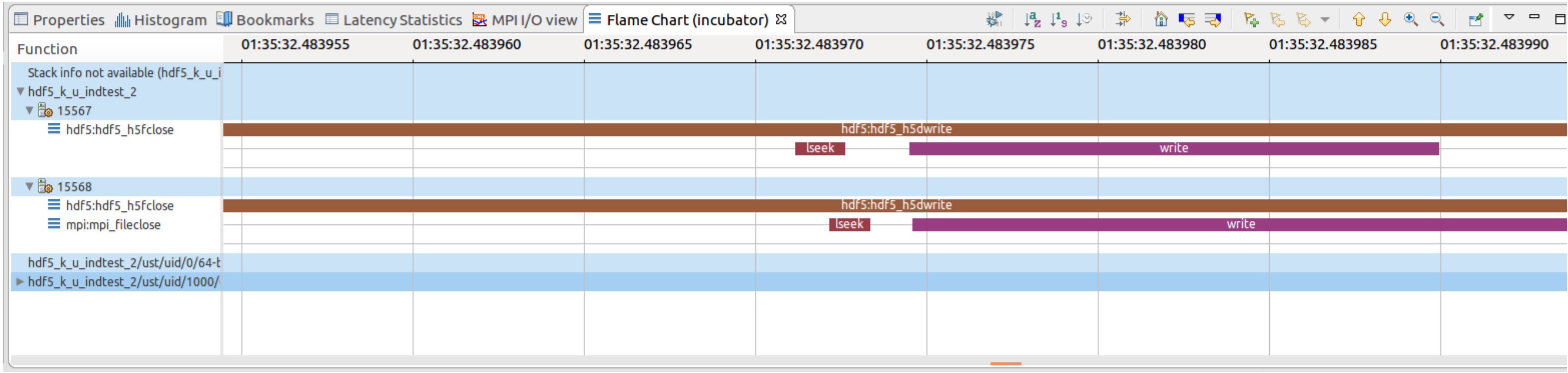

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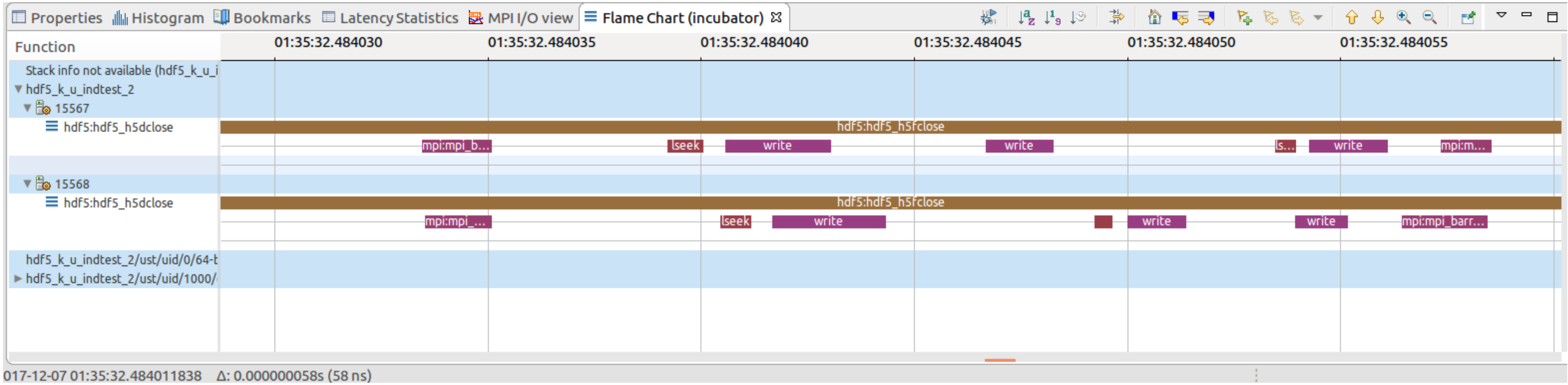

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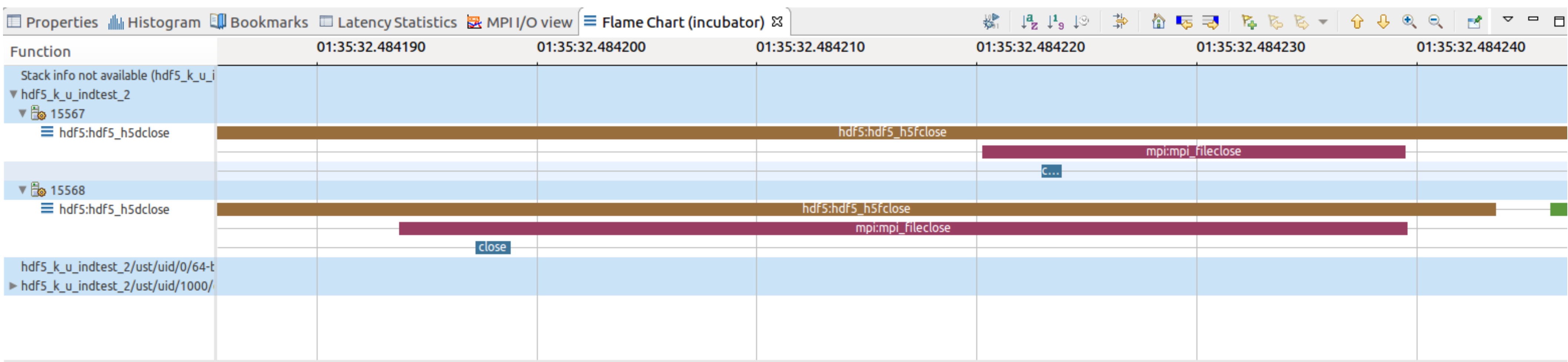
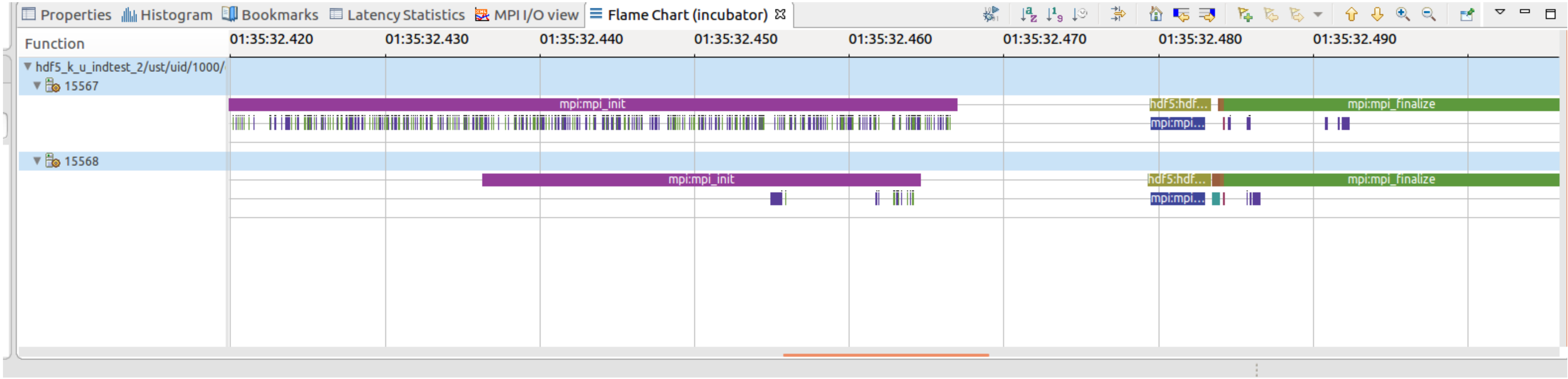


Trace Compass Views (contd)

Case 3: MPI & Pthread



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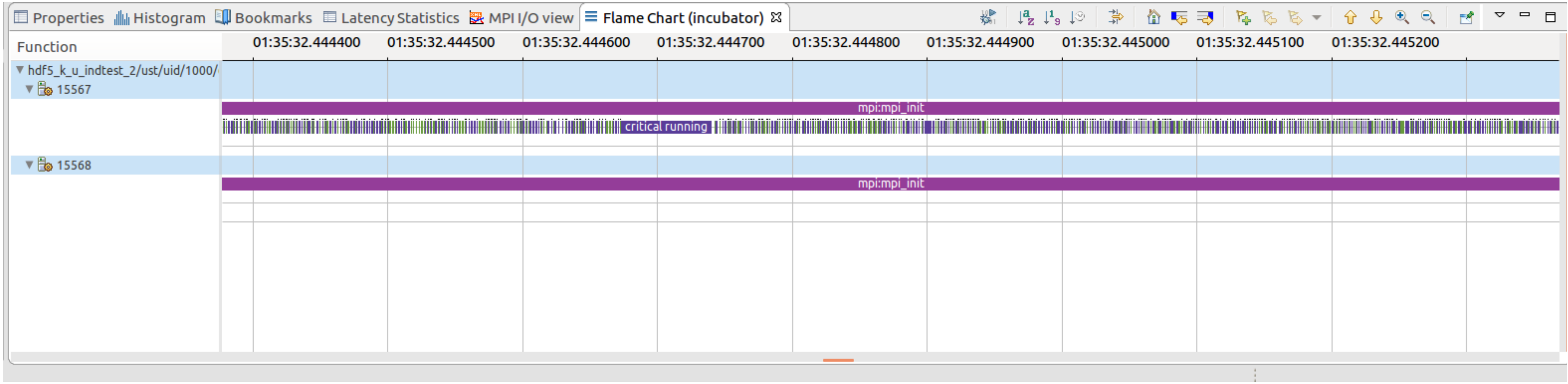

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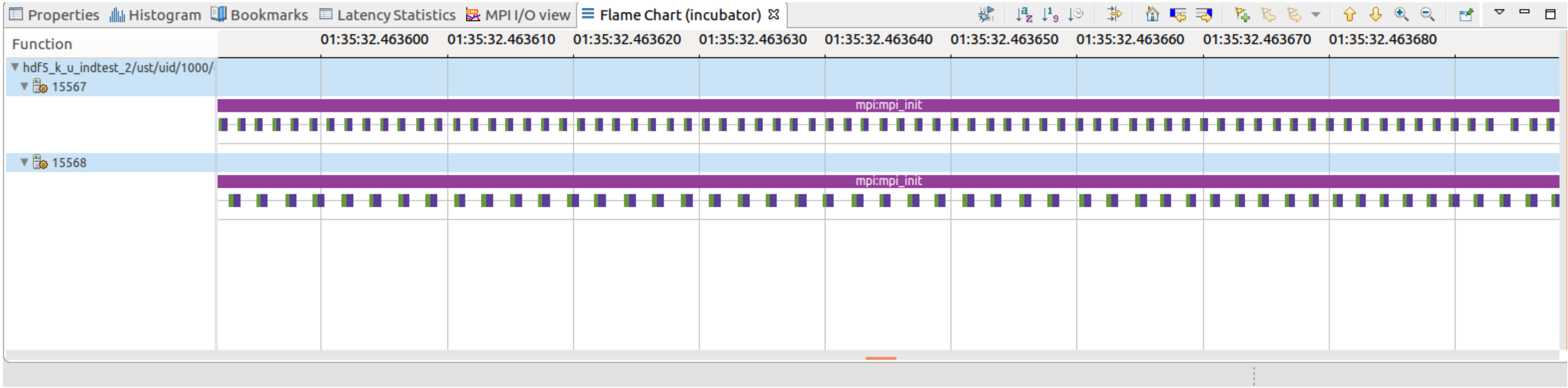

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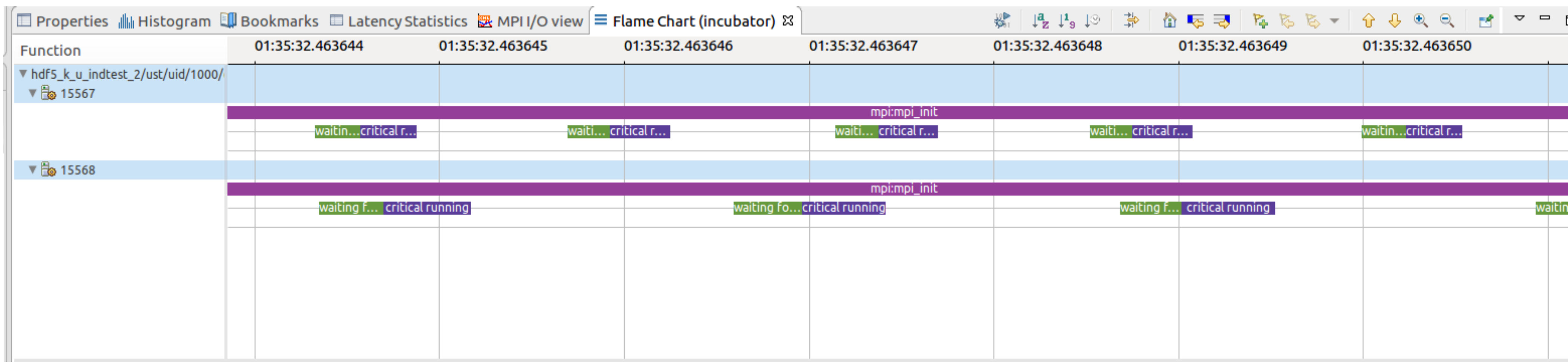

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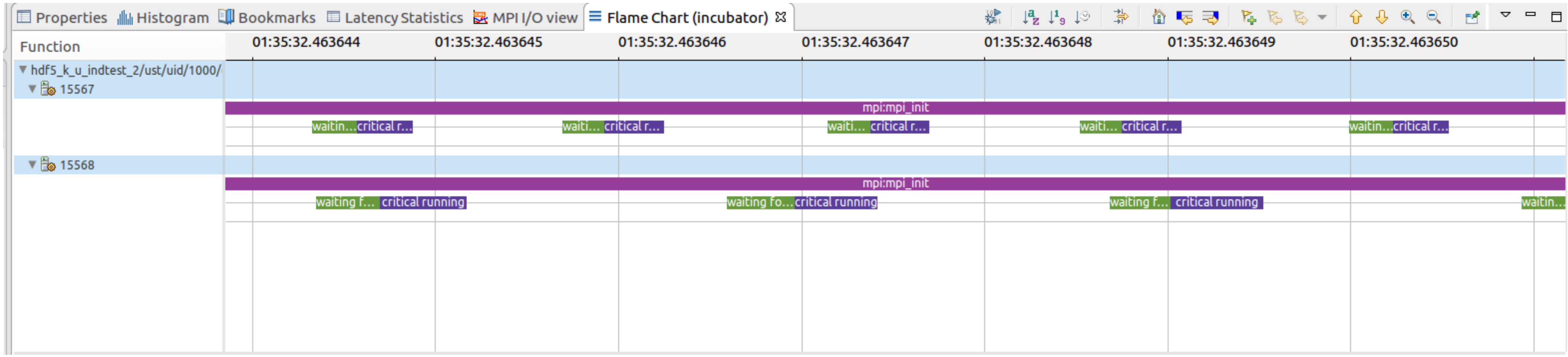

Thank you

Any Question?

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