Efficient MPI Support for Advanced Hybrid Programming Models

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Threaded/Hybrid MPI Programming

- Hybrid Programming gains importance
  - Reduce surface-to-volume (less comm.)
  - Will be necessary at Peta- and Exascale!
- MPI supports hybrid programming
  - Offers thread levels:
    - single, serial, funneled, multiple
  - Thread_multiple becomes more common
    - E.g., codes using OpenMP tasks

MPI Messaging Details

- MPI_Probe to receive messages of unknown size
  - MPI_Probe(…, status)
  - size = get_count(status)*size_of(datatype)
  - buffer = malloc(size)
  - MPI_Recv(buffer, …)
- MPI_Probe peeks in matching queue
  - Does not change it → stateful object

Multithreaded MPI Messaging

- Two threads, A and B perform probe, malloc, receive sequence
  - $A_P \rightarrow A_M \rightarrow A_R \rightarrow B_P \rightarrow B_M \rightarrow B_R$
- Possible ordering
  - $A_P \rightarrow B_P \rightarrow B_M \rightarrow B_R \rightarrow A_M \rightarrow A_R$
  - Wrong matching!
  - Thread A's message was "stolen" by B
  - Access to queue needs mutual exclusion ☹

“Obvious” Solution 1

- Separate threads with “channels”
  - Needs t*p threads or communicators
    - Not scalable
  - Threads cannot “share” messages
    - Not flexible for load-balancing (master/worker)
  - Problems with libraries
    - Each needs t*p tags or communicators
- This solution is impractical!

“Obvious” Solution 2

- Lock each P,M,R sequence
  - Unnecessary synchronization
  - This sequence might be slow (malloc)
    - Only one thread can perform it
  - Observation:
    - E.g., (tag,src)=(4,5) and (5,5) do not “conflict”

Solution 3 – 2d Locking

- Lock each (src,tag) pair
  - Requires 2d lock matrix
    - Should be sparse!

```
lock (src, tag)
P,M,R (e.g., irecv)
unlock(src,tag)
```

  - Wildcards (ANY_SRC, ANY_TAG) acquire locks for whole row/column or matrix
  - Minimizes lock overhead

Solution 3 is incorrect ☹

- Can lead to deadlocks
  - A correct MPI code (threads A+B):

```
A:                              A:
  send(..., 1, 1, comm)           probe/recv(0, 2, comm)
  recv(..., 1, 1, comm)         B:
  send(..., 1, 2, comm)           probe/recv(0,ANY_TAG,comm)
  ...                             send(..., 0, 1, comm)
```

  - Thread A enters locks (0,2), B is waiting forever (deadlock)

Updated Solution 3

- Obvious fix: don't block, poll ☹
  - Only needed if code uses wildcards
  - Several variants:

Scenario	any_src	any_tag	Specific	Strategy
1	-	-	x	simple 2d, blocking
2	-	x	-	simple 1d, blocking
3	-	x	x	2d lock, polling
4	x	-	-	simple 1d, blocking
5	x	-	x	2d lock, polling
6	x	x	-	2d lock, polling
7	x	x	x	2d lock, polling

Solution 4 - Matching Outside MPI

- Helper thread calls MPI_Probe
  - Receives all incoming messages
  - Full matching logic on top of that
    - Replicating MPI logic (thread safe)
- Allows blocking on MPI calls
  - High overhead though

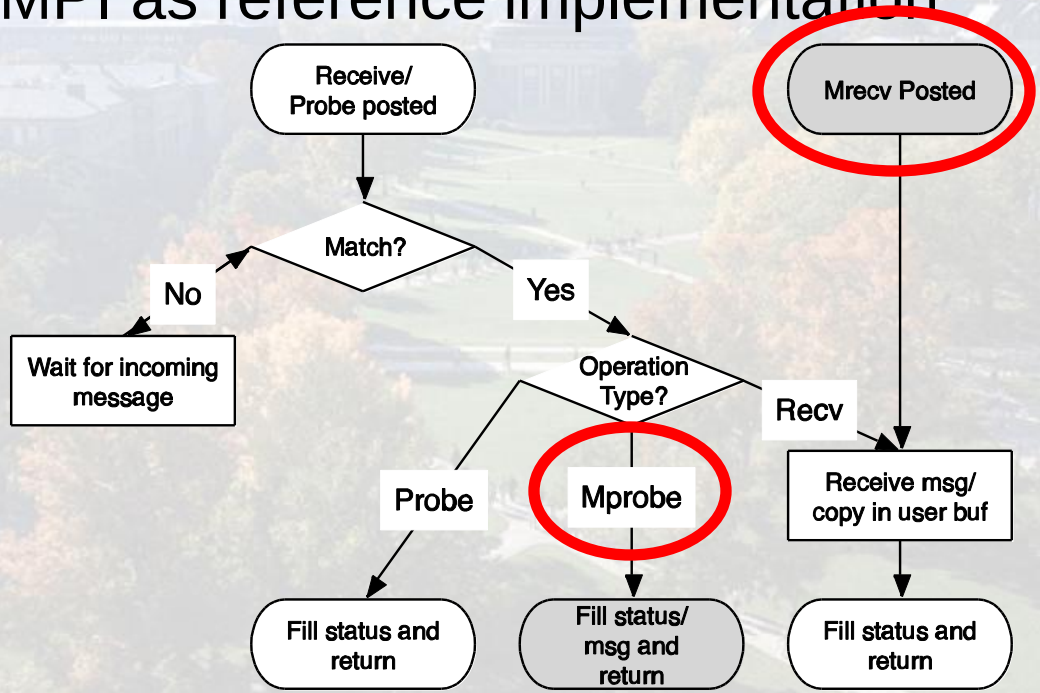
Fixing the MPI Standard?

- Avoid state in the library
  - Return handle, remove message from queue

```
MPI_Message msg; MPI_Status status;
/* Match a message */
MPI_Mprobe(MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD,
                          &msg, &status);
/* Allocate memory to receive the message */
int count; MPI_get_count(&status, MPI_BYTE, &count);
char* buffer = malloc(count);
/* Receive this message. */
MPI_Mrecv(buffer, count, MPI_BYTE, &msg, MPI_STATUS_IGNORE);
```

Implementation

- Open MPI as reference implementation



- Low-level matching (e.g., MX) will need FW support

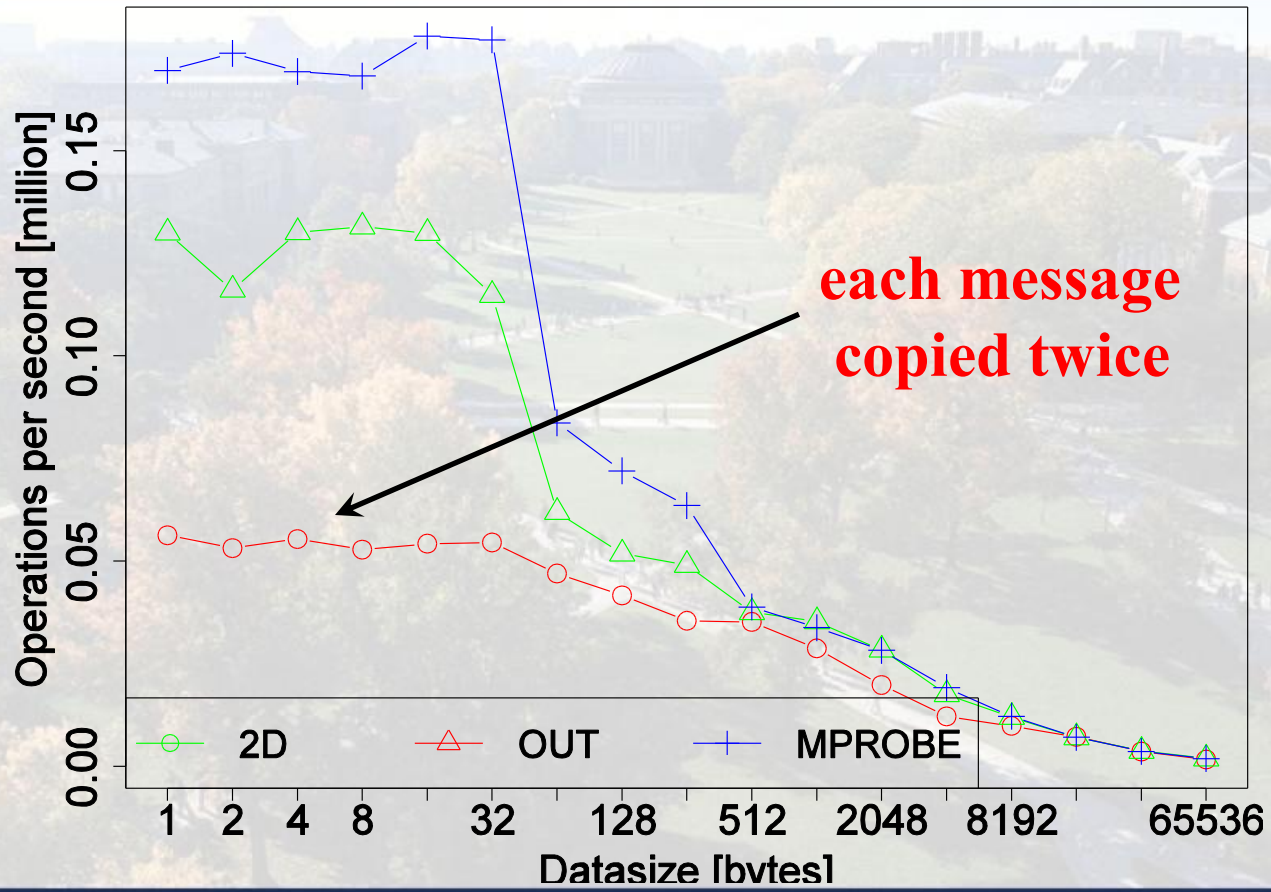
Test System

- Sif at Indiana University
  - Eight core 1.86 GHz Xeon
  - Myrinet 10G (MX)
  - Open MPI rev. 22973 + mprobe patch
    - `--enable-mpi-thread-multiple`
    - Using MPI_THREAD_MULTIPLE with TCP BTL

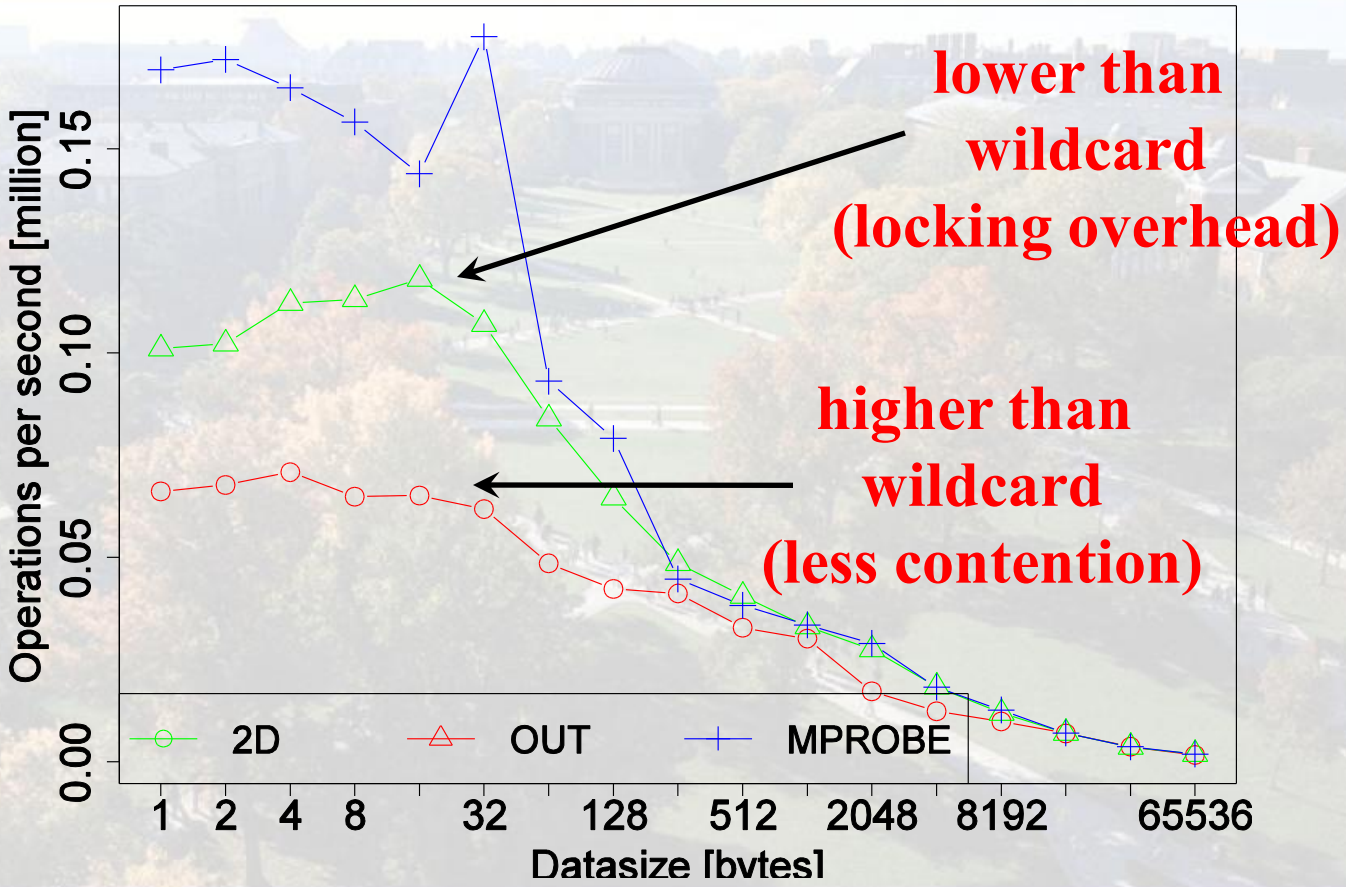
Benchmarks

- Receive Message Rate
  - MT receive (j processes send to j threads)
    - 2d locking (2D)
    - Outside MPI matching (OUT)
    - Mprobe reference (MPROBE)
- Threaded Roundtrip Time
  - Send n RTT messages between threads
  - Report average latency

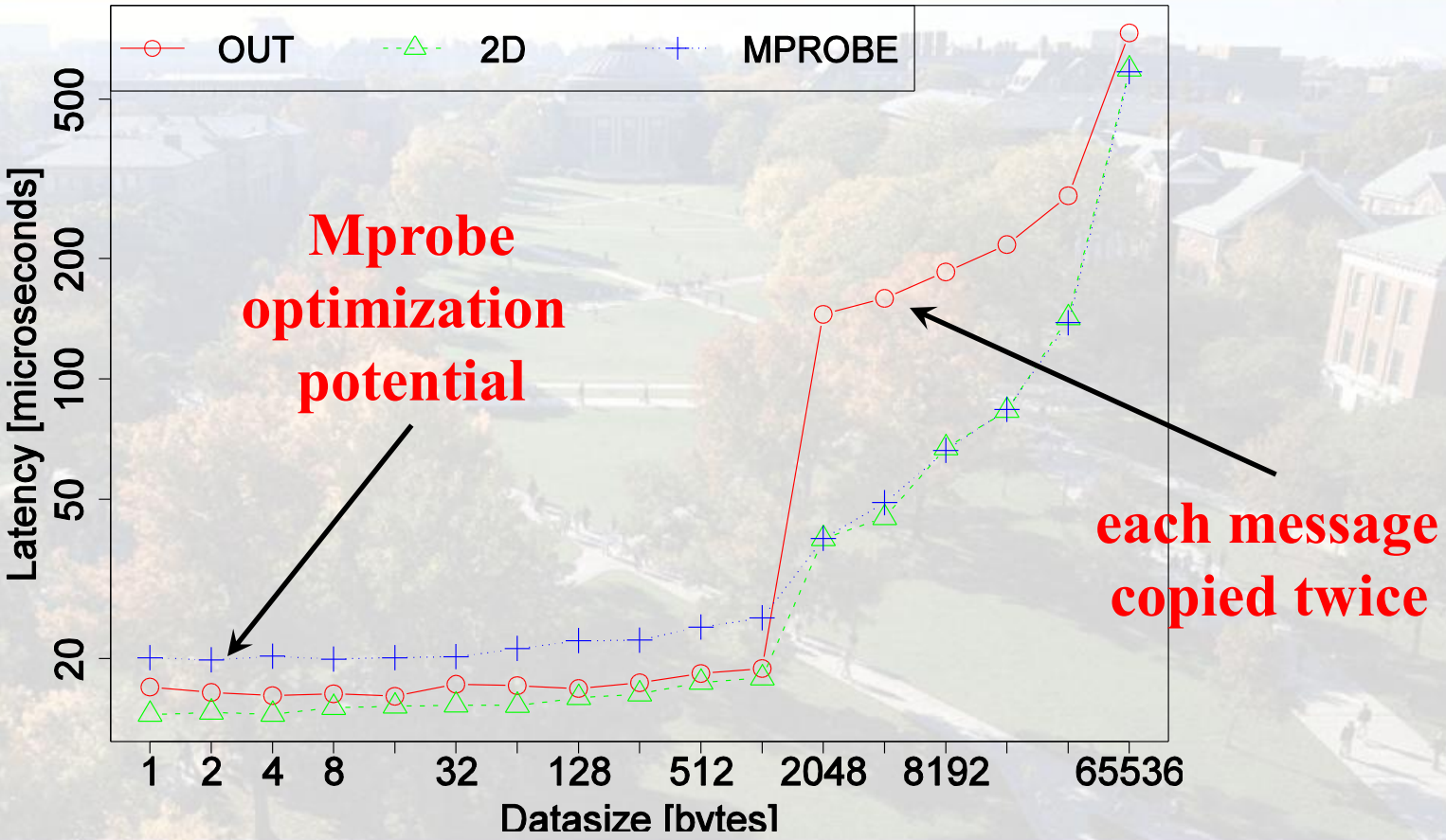
ANY_SRC, ANY_TAG Receive



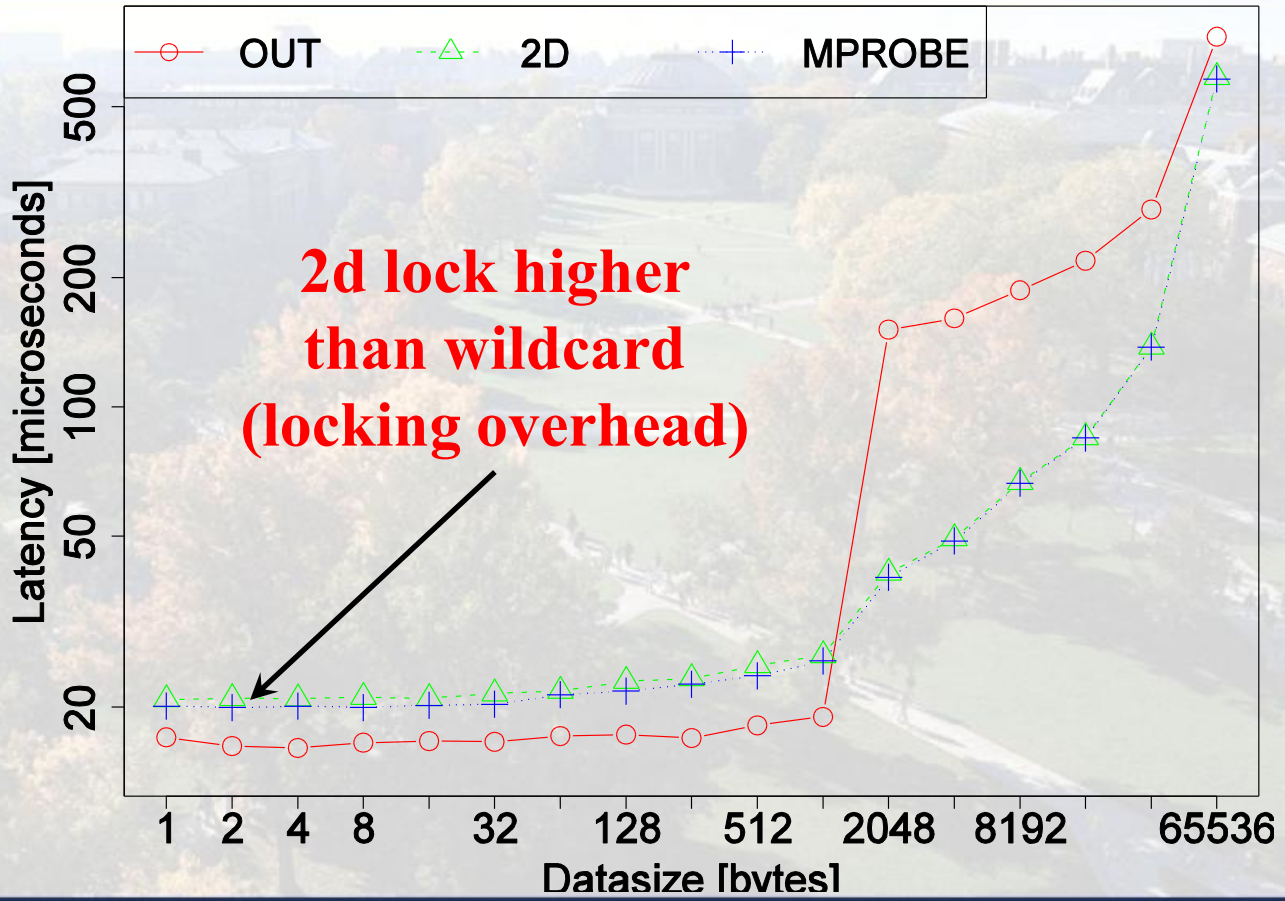
Directed Receive



ANY_SRC, ANY_TAG Latency



Directed Latency



Conclusions

- MPI_Probe is not thread-safe
  - Arguably a bug in MPI-2.2
- Obvious solutions do not help
  - Resource exhaustion
- Complex solutions are tricky
  - Too complex for average MPI user
- Change to standard to add stateless interface
  - Mprobe proposal under consideration for MPI-3
  - Encouraging initial performance results!