CS 5220: MPI Continued

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Logistics

- HW 2 is up, due Mar 11 (overlap).
- HW 3 will go out start of next week.

Previously on Parallel Programming

Can write a lot of MPI code with 6 operations we've seen:

- `MPI_Init`
- `MPI_Finalize`
- `MPI_Comm_size`
- `MPI_Comm_rank`
- `MPI_Send`
- `MPI_Recv`

... but there are sometimes better ways. Decide on communication style using simple performance models.

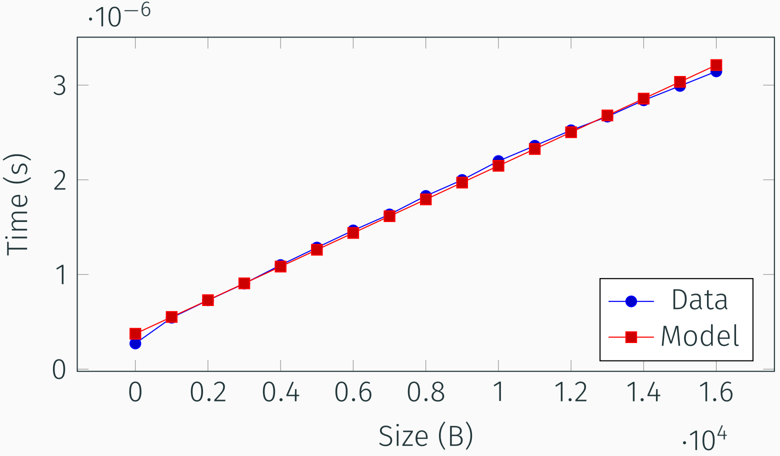
Communication performance

- Basic info: *latency* and *bandwidth*
- Simplest model: $t_{\mathrm{comm}} = \alpha + \beta M$
- More realistic: distinguish CPU overhead from "gap" ($\sim$ inverse bw)
- Different networks have different parameters
- Can tell a lot via a simple ping-pong experiment

Intel MPI on totient

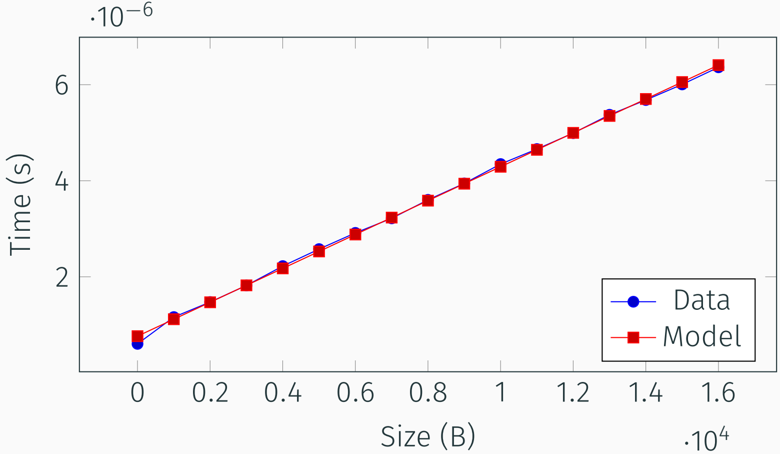
- Two six-core chips per nodes, eight nodes
- Heterogeneous network:
    - Crossbar switch between cores (?)
    - Bus between chips
    - Gigabit ethernet between nodes
- Default process layout (16 process example)
    - Processes 0-5 on first chip, first node
    - Processes 6-11 on second chip, first node
    - Processes 12-17 on first chip, second node
    - Processes 18-23 on second chip, second node
- Test ping-pong from 0 to 1, 11, and 23.

Approximate α-β parameters (on chip)



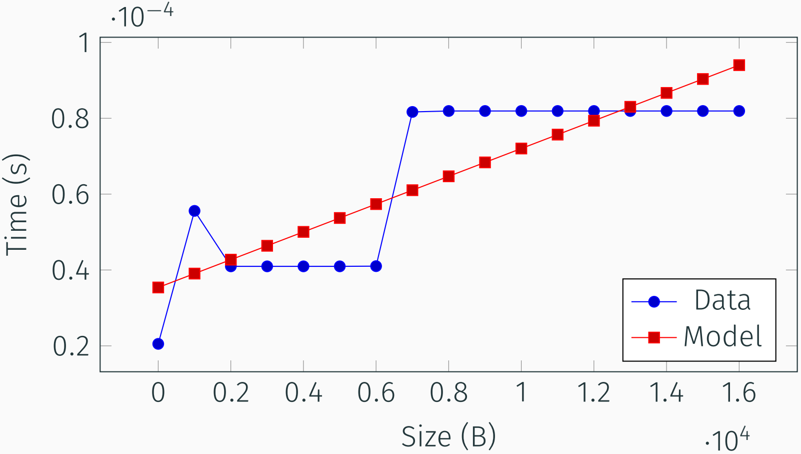
$\alpha \approx$ `3.74e-07`, $\beta \approx$ `1.77e-10`

Approximate α-β parameters (cross-chip)



$\alpha \approx$ `7.63e-07`, $\beta \approx$ `3.53e-10`

Approximate α-β parameters (cross-node)



$\alpha \approx$ `3.54e-05`, $\beta \approx$ `3.66e-09`

Moral

Not all links are created equal!

- Might handle with mixed paradigm
  - OpenMP on node, MPI across
  - Have to worry about thread-safety of MPI calls
- Can handle purely within MPI
- Can ignore the issue completely?

For today, we’ll take the last approach.

Reminder: basic send and recv

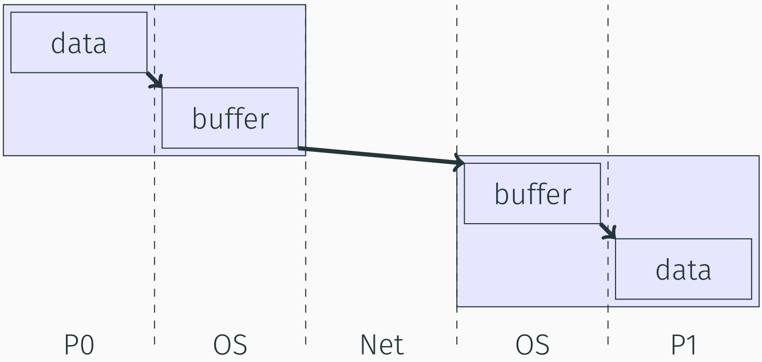
```
MPI_Send(buf, count, datatype,
         dest, tag, comm);

MPI_Recv(buf, count, datatype,
         source, tag, comm, status);
```

`MPI_Send` and `MPI_Recv` are *blocking*

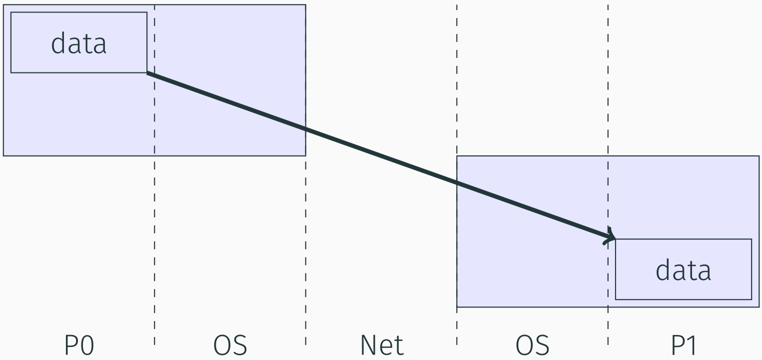
- Send does not return until data is in system
- Recv does not return until data is ready

Blocking and buffering



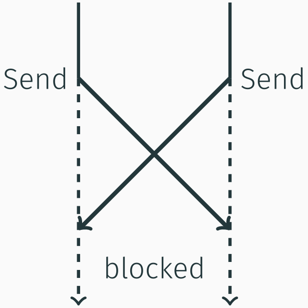
Block until data “in system” — maybe in a buffer?

Blocking and buffering



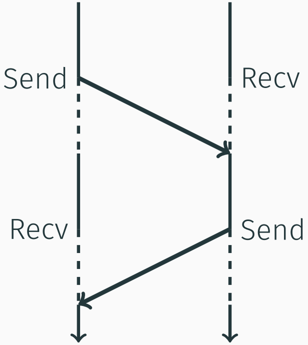
Alternative: don't copy, block until done.

Problem 1: Potential deadlock



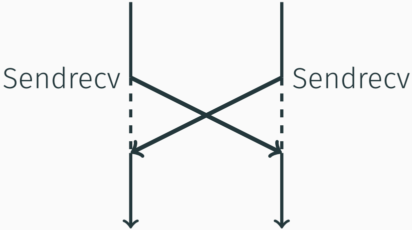
Both processors wait to finish send before they can receive!
May not happen if lots of buffering on both sides.

Solution 1: Alternating order



Could alternate who sends and who receives.

Solution 2: Combined send/recv



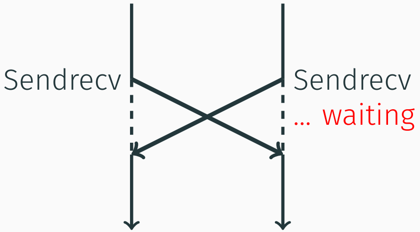
Common operations deserve explicit support!

Combined sendrecv

```
MPI_Sendrecv(sendbuf, sendcount, sendtype,
             dest, sendtag,
             recvbuf, recvcount, recvtype,
             source, recvtag,
             comm, status);
```

Blocking operation, combines send and recv to avoid deadlock.

Problem 2: Communication overhead

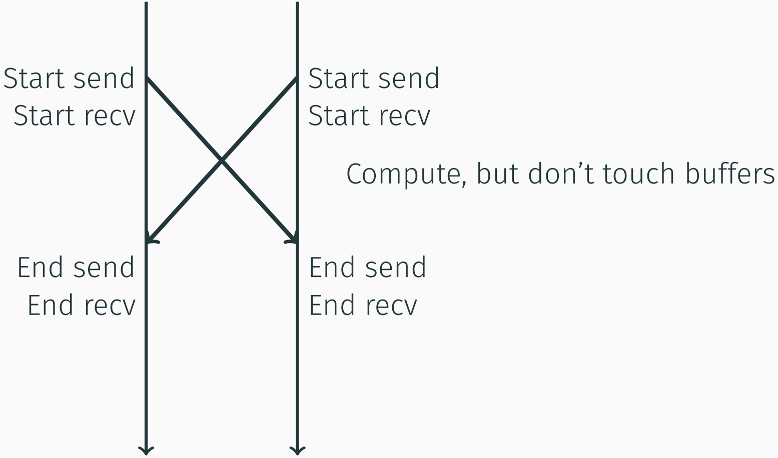


Partial solution: nonblocking communication

Blocking vs non-blocking communication

- `MPI_Send` and `MPI_Recv` are *blocking*
    - Send does not return until data is in system
    - Recv does not return until data is ready
    - Cons: possible deadlock, time wasted waiting
- Why blocking?
    - Overwrite buffer during send $\implies$ evil!
    - Read buffer before data ready $\implies$ evil!
- Alternative: *nonblocking* communication
    - Split into distinct initiation/completion phases
    - Initiate send/recv and promise not to touch buffer
    - Check later for operation completion

Overlap communication and computation



Nonblocking operations

Initiate message:

```
MPI_Isend(start, count, datatype, dest
          tag, comm, request);
MPI_Irecv(start, count, datatype, dest
          tag, comm, request);
```

Wait for message completion:

```
MPI_Wait(request, status);
```

Test for message completion:

```
MPI_Test(request, status);
```

Multiple outstanding requests

Sometimes useful to have multiple outstanding messages:

```
MPI_Waitall(count, requests, statuses);
MPI_Waitany(count, requests, index, status);
MPI_Waitsome(count, requests, indices, statuses);
```

Multiple versions of test as well.

Other send/recv variants

Other variants of `MPI_Send`

- `MPI_Ssend` (synchronous) – do not complete until receive has begun
- `MPI_Bsend` (buffered) – user provides buffer (via `MPI_Buffer_attach`)
- `MPI_Rsend` (ready) – user guarantees receive has already been posted
- Can combine modes (e.g. `MPI_Issend`)

`MPI_Recv` receives anything.

Another approach

- Send/recv is one-to-one communication
- An alternative is one-to-many (and vice-versa):
    - *Broadcast* to distribute data from one process
    - *Reduce* to combine data from all processors
    - Operations are called by all processes in communicator

Broadcast and reduce

```
MPI_Bcast(buffer, count, datatype,
          root, comm);
MPI_Reduce(sendbuf, recvbuf, count, datatype,
           op, root, comm);
```

- `buffer` is copied from root to others
- `recvbuf` receives result only at root
- `op` $\in$ { `MPI_MAX`, `MPI_SUM`, ...}

Example: basic Monte Carlo

```
#include <stdio.h>
#include <stdlib.h>
#include <mpi.h>
int main(int argc, char** argv) {
    int nproc, myid, ntrials = atoi(argv[1]);
    MPI_Init(&argc, &argv);
    MPI_Comm_size(MPI_COMM_WORLD, &nproc);
    MPI_Comm_rank(MPI_COMM_WORLD, &my_id);
    MPI_Bcast(&ntrials, 1, MPI_INT,
              0, MPI_COMM_WORLD);
    run_trials(myid, nproc, ntrials);
    MPI_Finalize();
    return 0;
}
```

Example: basic Monte Carlo

Let `sum[0]` = $\sum_i X_i$ and `sum[1]` = $\sum_i X_i^2$.

```
void run_mc(int myid, int nproc, int ntrials) {
    double sums[2] = {0,0};
    double my_sums[2] = {0,0};
    /* ... run ntrials local experiments ... */
    MPI_Reduce(my_sums, sums, 2, MPI_DOUBLE,
               MPI_SUM, 0, MPI_COMM_WORLD);
    if (myid == 0) {
        int N = nproc*ntrials;
        double EX = sums[0]/N;
        double EX2 = sums[1]/N;
        printf("Mean: %g; err: %g\n",
               EX, sqrt((EX*EX-EX2)/N));
    }
}
```

Collective operations

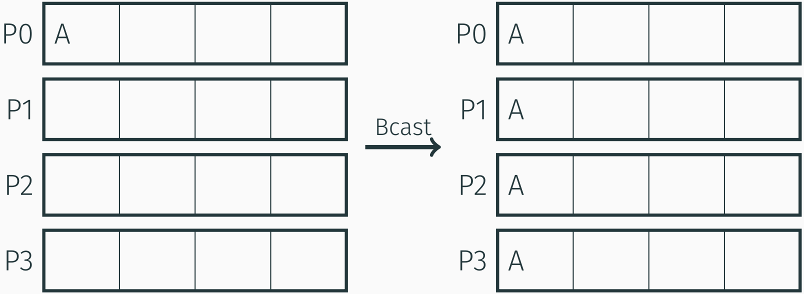
- Involve all processes in communicator
- Basic classes:
    - Synchronization (e.g. barrier)
    - Data movement (e.g. broadcast)
    - Computation (e.g. reduce)

Barrier

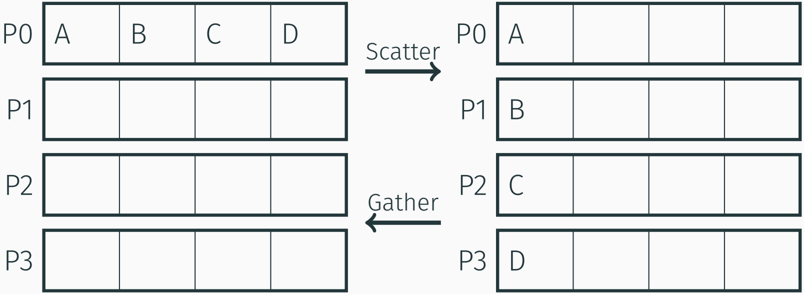
```
MPI_Barrier(comm);
```

Not much more to say. Not needed that often.

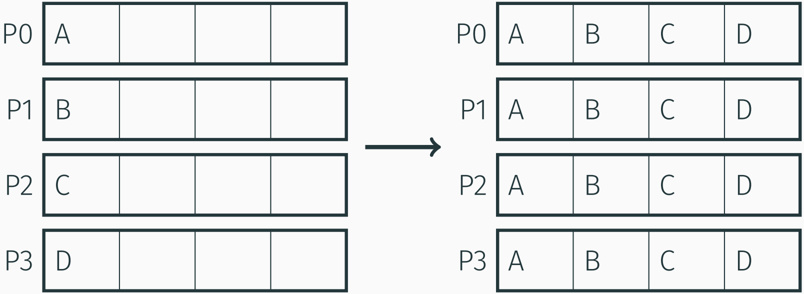
Broadcast



Scatter/gather



Allgather



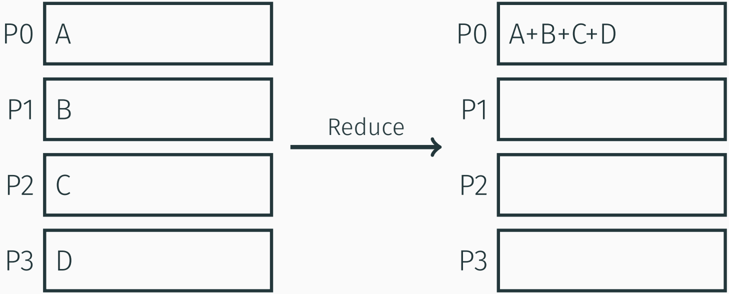
Alltoall

P0	A0	A1	A2	A3
P1	B0	B1	B2	B3
P2	C0	C1	C2	C3
P3	D0	D1	D2	D3

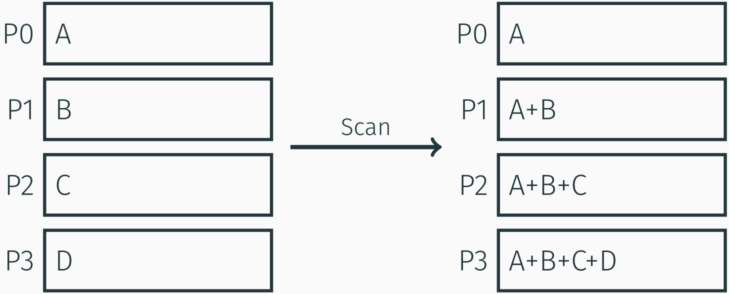
⟶

P0	A0	B0	C0	D0
P1	A1	B1	C1	D1
P2	A2	B2	C2	D2
P3	A3	B3	C3	D3

Reduce



Scan



The kitchen sink

- In addition to above, have vector variants (`v` suffix), more `All` variants (`Allreduce`), `Reduce_scatter`, ...
- MPI3 adds one-sided communication (put/get)
- MPI is *not* a small library!
- But a small number of calls goes a long way
    - `Init`/`Finalize`
    - `Get_comm_rank`, `Get_comm_size`
    - `Send`/`Recv` variants and `Wait`
    - `Allreduce`, `Allgather`, `Bcast`