Lecture 9: MPI continued

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Logistics

- Matrix multiply is done! Still have to run.
- Small HW 2 will be up before lecture on Thursday, due next Tuesday.
- Project 2 will be posted next Tuesday.
- Email me if interested in Sandia recruiting
- Also email me if interested in MEng projects.

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.

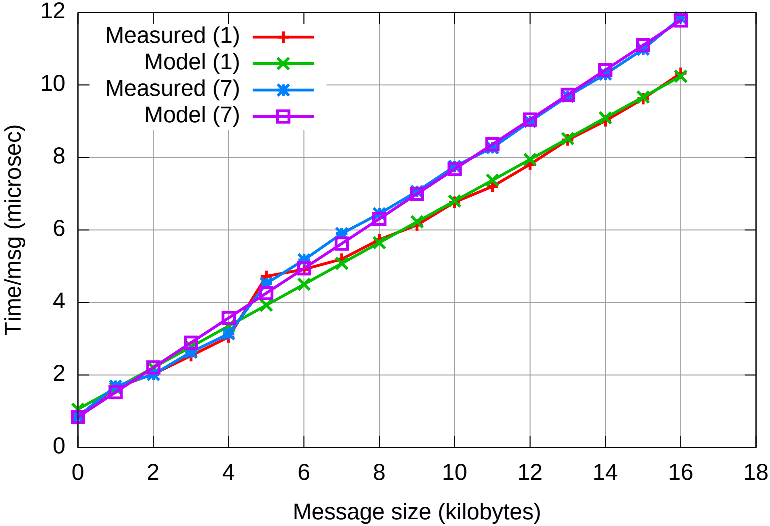
Communication performance

- 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

OpenMPI on crocus

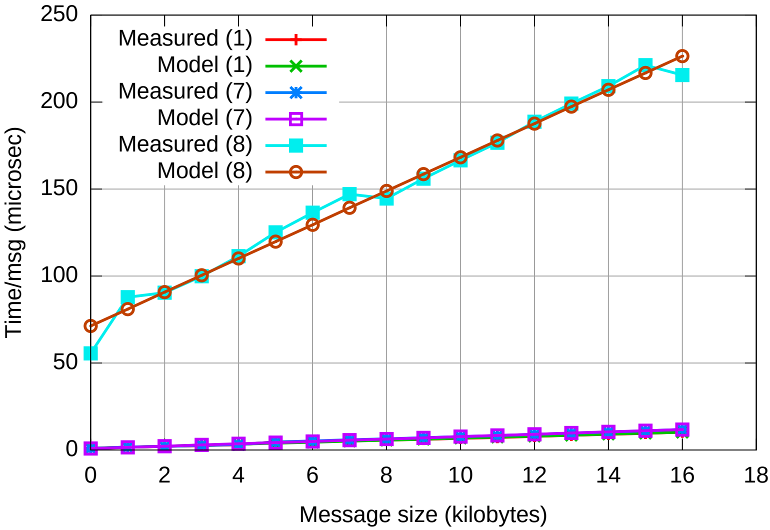
- Two quad-core chips per nodes, five nodes
- Heterogeneous network:
  - Crossbar switch between cores (?)
  - Bus between chips
  - Gigabit ehternet between nodes
- Default process layout (16 process example)
  - Processes 0-3 on first chip, first node
  - Processes 4-7 on second chip, first node
  - Processes 8-11 on first chip, second node
  - Processes 12-15 on second chip, second node
- Test ping-pong from 0 to 1, 7, and 8.

Approximate α-β parameters (on node)



$$\alpha_1 \approx 1.0 \times 10^{-6}, \beta_1 \approx 5.7 \times 10^{-10}$$
$$\alpha_2 \approx 8.4 \times 10^{-7}, \beta_2 \approx 6.8 \times 10^{-10}$$

Approximate α-β parameters (cross-node)



$$\alpha_3 \approx 7.1 \times 10^{-5},\ \beta_3 \approx 9.7 \times 10^{-9}$$

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

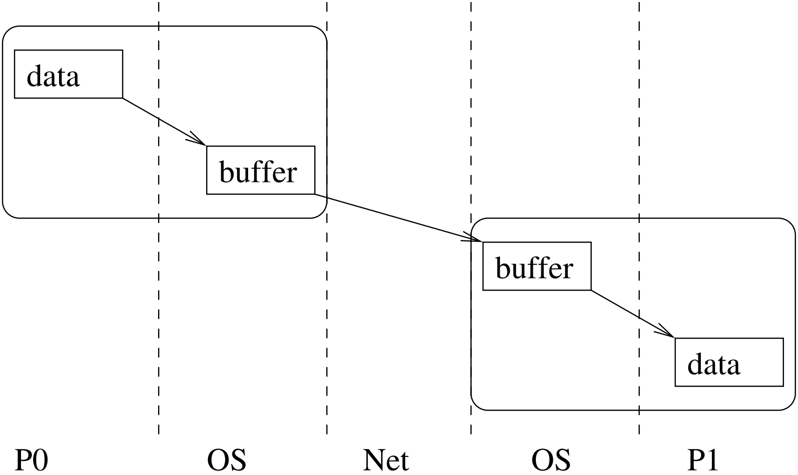
```
MPI_Send(buf, count, datatype,
         dest, tag, comm);

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

`MPI_Send` and `MPI_Recv` are *blocking*

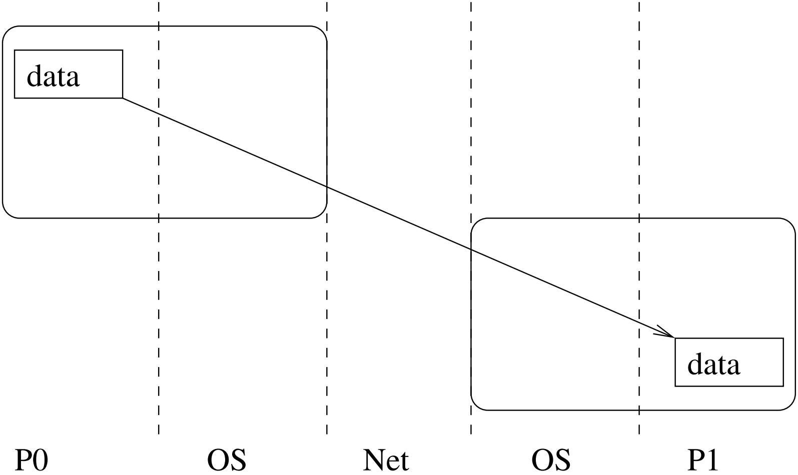
- Send does not return until data is in system
- Recv does not return until data is ready

Blocking and buffering



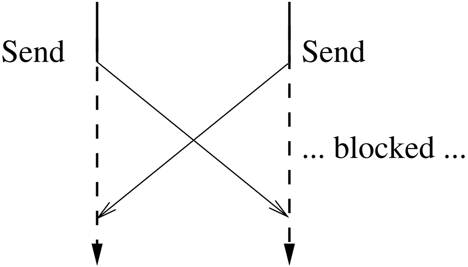
Block until data “in system” — maybe in a buffer?

Blocking and buffering



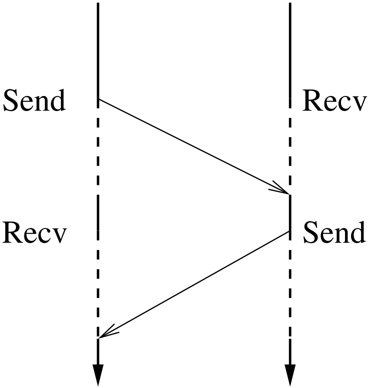
Alternative: don't copy, block until done.

Problem 1: Potential deadlock



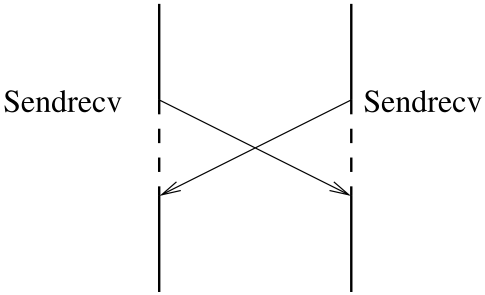
Both processors wait to finish send before they can receive!
May not happen if lots of buffering on both sides.

Solution 1: Alternating order



Could alternate who sends and who receives.

Solution 2: Combined send/recv



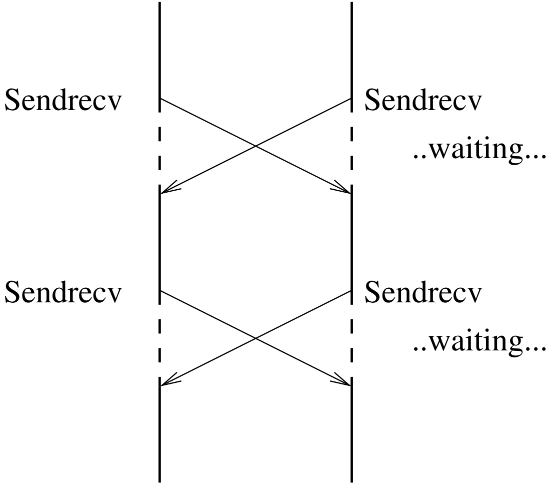
Common operations deserve explicit support!

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

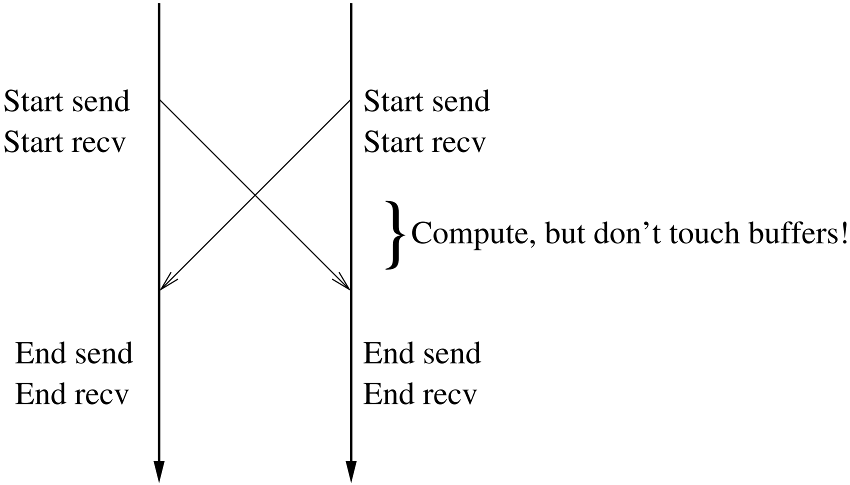


Partial solution: nonblocking communication

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_Wait(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 <mpi.h>
int main(int argc, char** argv) {
    int nproc, myid, ntrials;
    MPI_Init(&argc, &argv);
    MPI_Comm_size(MPI_COMM_WORLD, &nproc);
    MPI_Comm_rank(MPI_COMM_WORLD, &my_id);
    if (myid == 0) {
        printf("Trials per CPU:\n");
        scanf("%d", &ntrials);
    }
    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

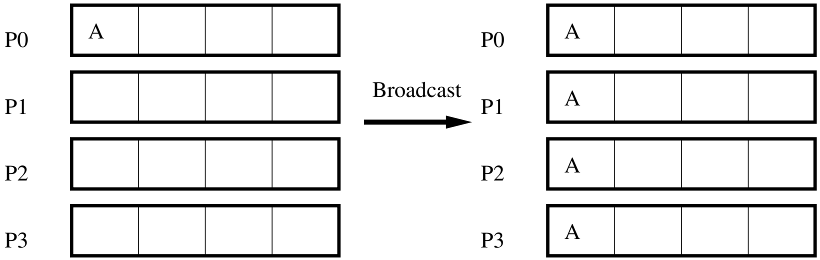
- Involve all processes in communicator
- Basic classes:
  - Synchronization (e.g. barrier)
  - Data movement (e.g. broadcast)
  - Computation (e.g. reduce)

Barrier

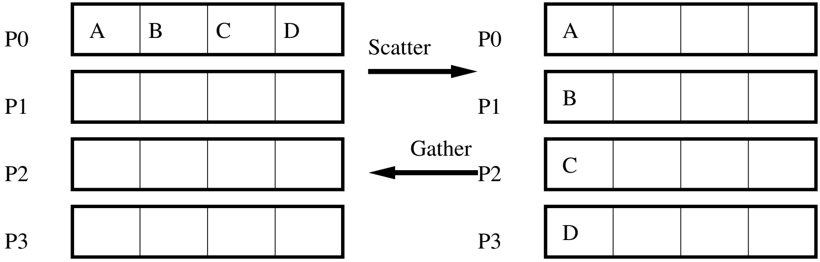
```
MPI_Barrier(comm);
```

Not much more to say. Not needed that often.

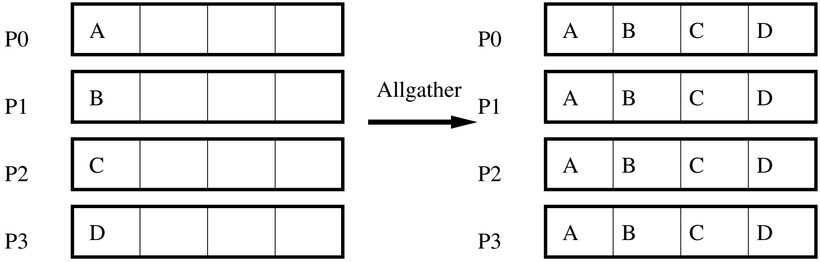
Broadcast



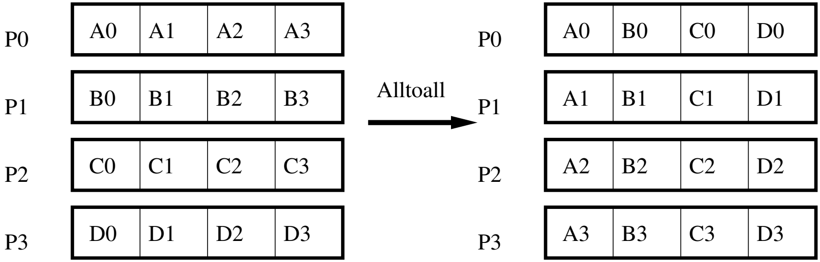
Scatter/gather



Allgather

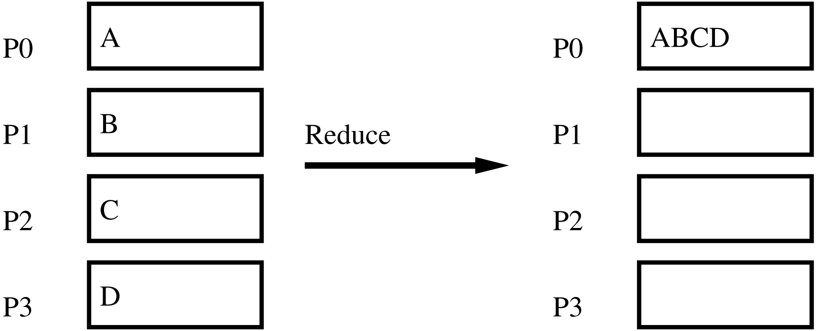


Alltoall

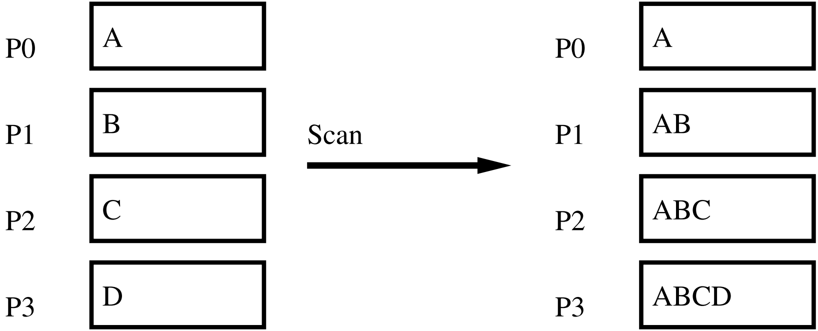


P0
A0
A1
A2
A3
P1
B0
B1
B2
B3
P2
C0
C1
C2
C3
P3
D0
D1
D2
D3
Alltoall
P0
A0
B0
C0
D0
P1
A1
B1
C1
D1
P2
A2
B2
C2
D2
P3
A3
B3
C3
D3

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`