Smith College
Computer Science

CSC352

Week #7 — Spring 2017
Introduction to MPI

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Introduction to MPI

D. Thiebaut

Inspiration Reference

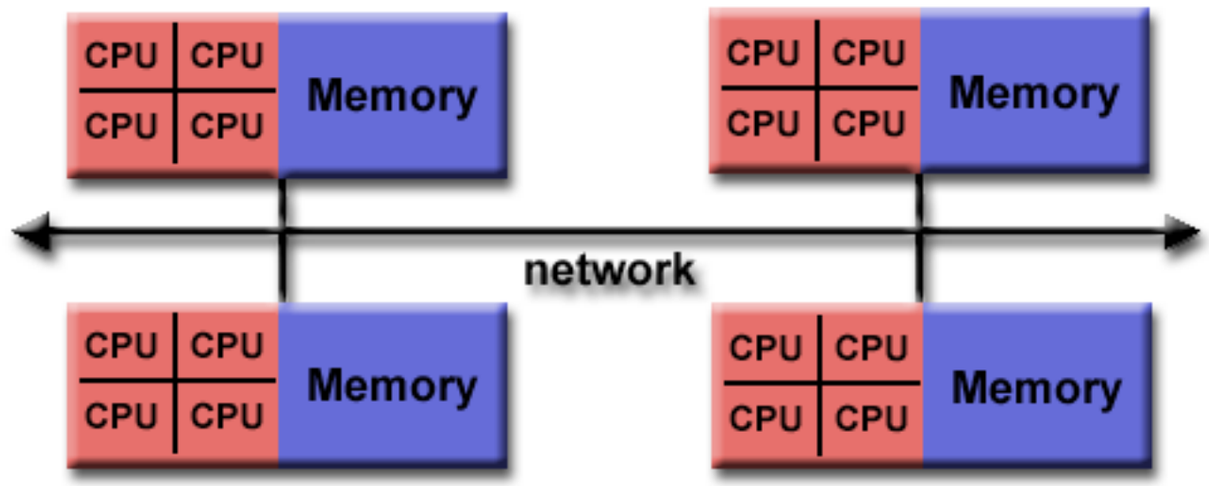
- MPI by Blaise Barney, Lawrence Livermore National Lab https://computing.llnl.gov/tutorials/mpi

Some Background

- REVIEW: Flynn's taxonomy of computer architecture (1966): old, and faded, but everybody seems to know it!
  - SISD (uniprocessor)
  - SIMD (GPU)
  - MISD (rare)
  - MIMD (everything else!)

MIMD

- Multi-core, Many-core, Distributed systems, Clusters are all **MIMD**
  - **SPMD**: Single Process/Multiple Data:
    ==> **MPI**



  - **MPMD**: Multiple Programs/Multiple Data:

MPI: *Message Passing Interface*

- MPI is a *specification*. Not a library
- MPI libraries implement the specification
- *Processes* communicate with each other:
  - Synchronization (barriers)
  - Data exchange
- MPI is **large** (125 functions)
- MPI is **small** (6 functions)

Old but Vibrant!

- **Top500**: Great majority uses MPI
- From the Top500 Q&A:

Q: Where can I get the software to generate performance results for the Top500?

A: There is software available that has been optimized and many people use to generate the Top500 performance results. This benchmark attempts to measure the best performance of a machine in solving a system of equations. The problem size and software can be chosen to produce the best performance. A copy of that software can be downloaded from:

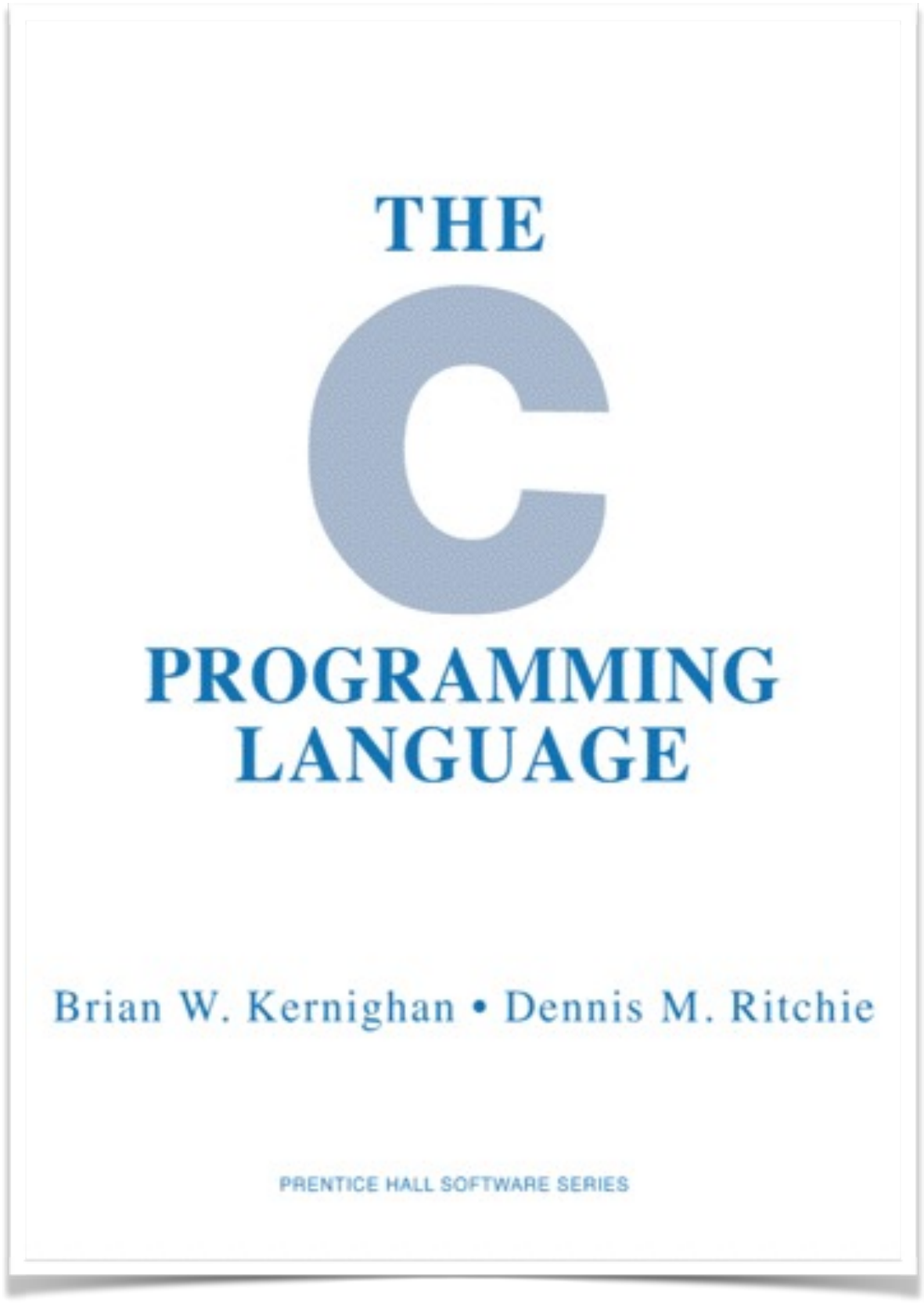
http://www.netlib.org/benchmark/hpl/

In order to run this you will need MPI and an optimized version of the BLAS. For MPI you can see: http://www-unix.mcs.anl.gov/mpi/mpich/download.html and for the BLAS see: http://www.netlib.org/atlas/ .

Advantages of MPI

- Supported in many languages (Mostly C, but not just C)
- Supports *heterogeous* computer systems

- Provides access to advanced parallel systems
- Portable (install it on your Mac or Windows PC!)



C Tutorial

(See separate set of slides)

Hello world!
(version 1)

```
// minimalist hello
// world program
// D. Thiebaut
#include <mpi.h>
#include <stdio.h>

int main( int argc, char *argv[] ) {
   MPI_Init( &argc, &argv );
   printf( "Hello world!\n" );
   MPI_Finalize();
   return 0;
}
```

Compile & Run

```
[15:33:05] ~/mpi/352$: mpicc -o hello1 hello1.c
[15:33:41] ~/mpi/352$: mpirun -np 1 ./hello1
Hello world!
[15:33:48] ~/mpi/352$: mpirun -np 2 ./hello1
Hello world!
Hello world!
[15:33:53] ~/mpi/352$: mpirun -np 4 ./hello1
Hello world!
Hello world!
Hello world!
Hello world!
[15:33:57] ~/mpi/352$:
```

Hello World!

(Version 2: more interesting)

```
#include <stdio.h>
#include <mpi.h>

int main(int argc, char *argv[]) {
  int numprocs, rank, namelen;
  char processor_name[MPI_MAX_PROCESSOR_NAME];

  MPI_Init(&argc, &argv);
  MPI_Comm_size(MPI_COMM_WORLD, &numprocs);
  MPI_Comm_rank(MPI_COMM_WORLD, &rank);
  MPI_Get_processor_name(processor_name, &namelen);

  printf("Process %d on %s out of %d\n", rank,
         processor_name, numprocs);

  MPI_Finalize();
}
```

Compile & Run

```
[15:41:51] ~/mpi/352$: mpicc -o hello2 hello2.c
[15:42:00] ~/mpi/352$: mpirun -np 2 ./hello2
Process 0 on MacDom2.local out of 2
Process 1 on MacDom2.local out of 2
```

Misc. Notes

- MPI functions return values, either an error code or `MPI_SUCCESS`
- An error **causes all processes to stop**
- Two important MPI functions:
  - **`MPI_Comm_size`**: # of processes enrolled
  - **`MPI_Comm_rank`**: rank of this process

Exercise

- Create your first MPI *Hello World!* Program on Aurora (or your own laptop if you have installed MPI on it) compile it, and run it (more details in class on which machine to use)

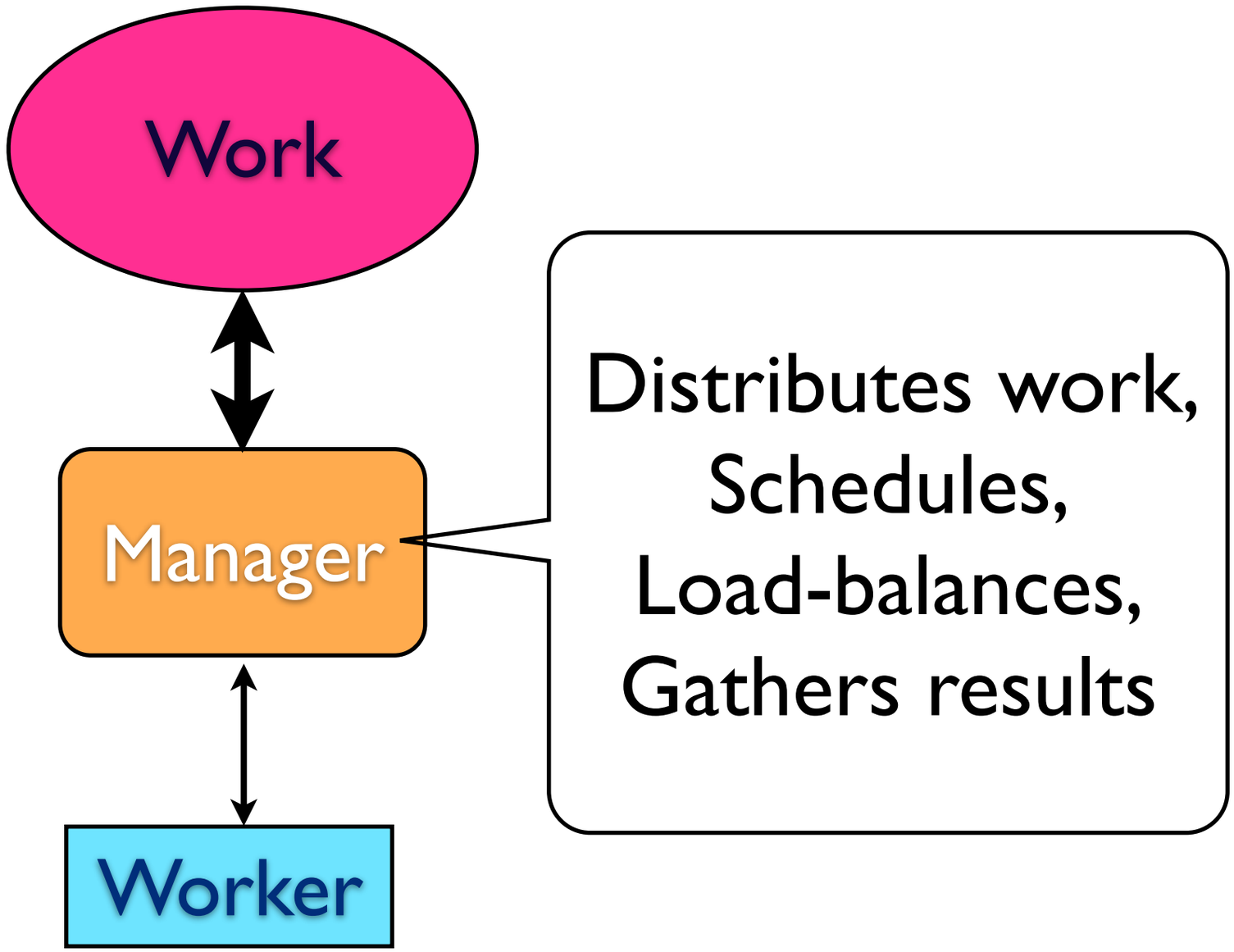
Computing Pi

(serial version in C)

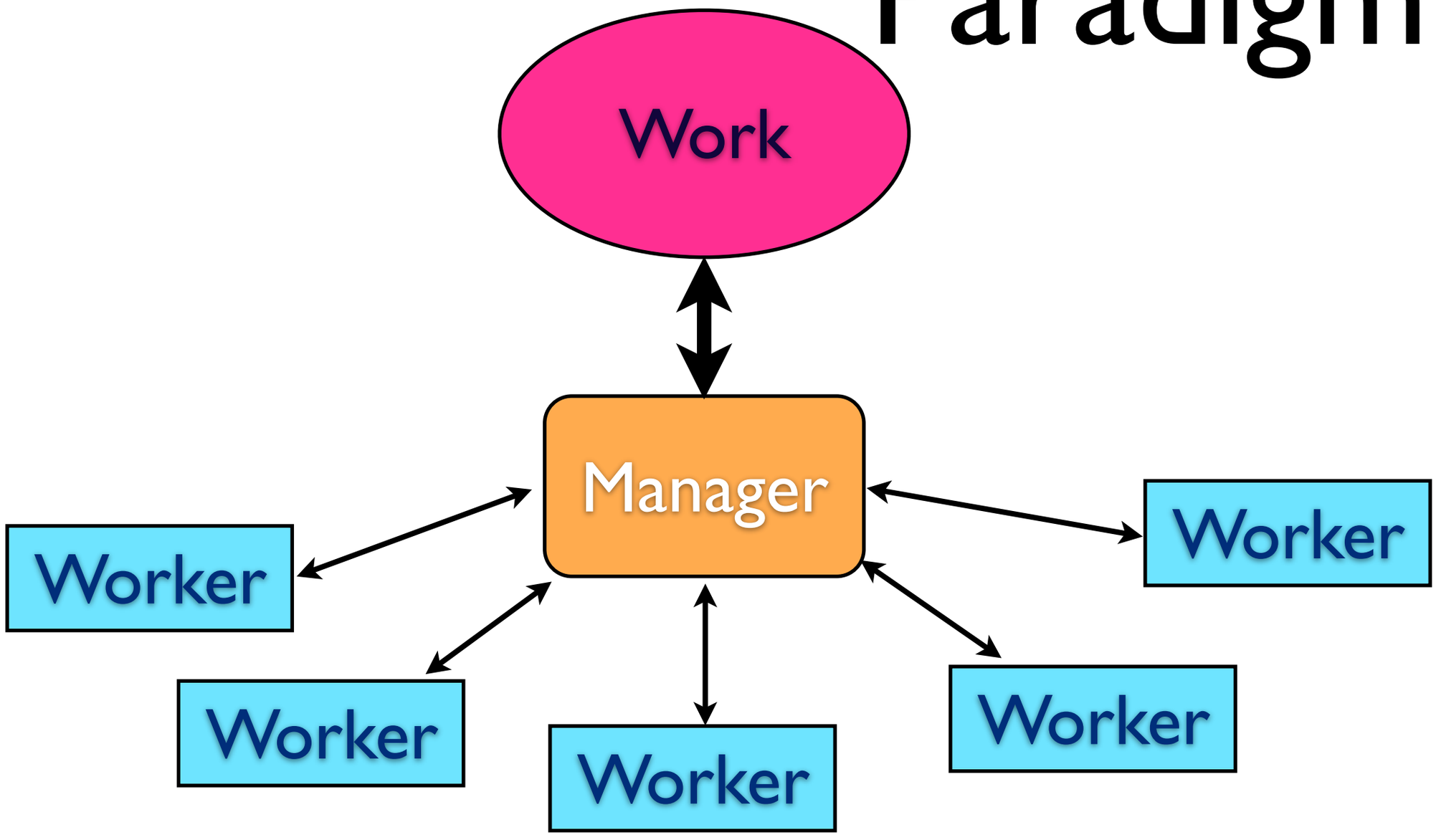
```
// pi.c
#include <stdlib.h>
#include <stdio.h>

double f( double x ) { return 4.0 / ( 1 + x*x ); }

int main( int argc, char *argv[] ) {
    int N, i;
    double deltaX, sum;

    if ( argc < 2 ) {
        printf( "Syntax %s N\n", argv[0] );
        exit(1);
    }

    N = atoi( argv[1] );
    sum = 0;
    deltaX = 1.0/N;

    for ( i = 0; i < N; i++ )
        sum += f( i * deltaX );

    printf( "%d iterations: Pi = %1.6f\n", N, sum*deltaX );
}
```

```
cc -o pi pi.c
./pi 100000
100000 iterations: Pi = 3.141603
```

Manager/Worker Paradigm



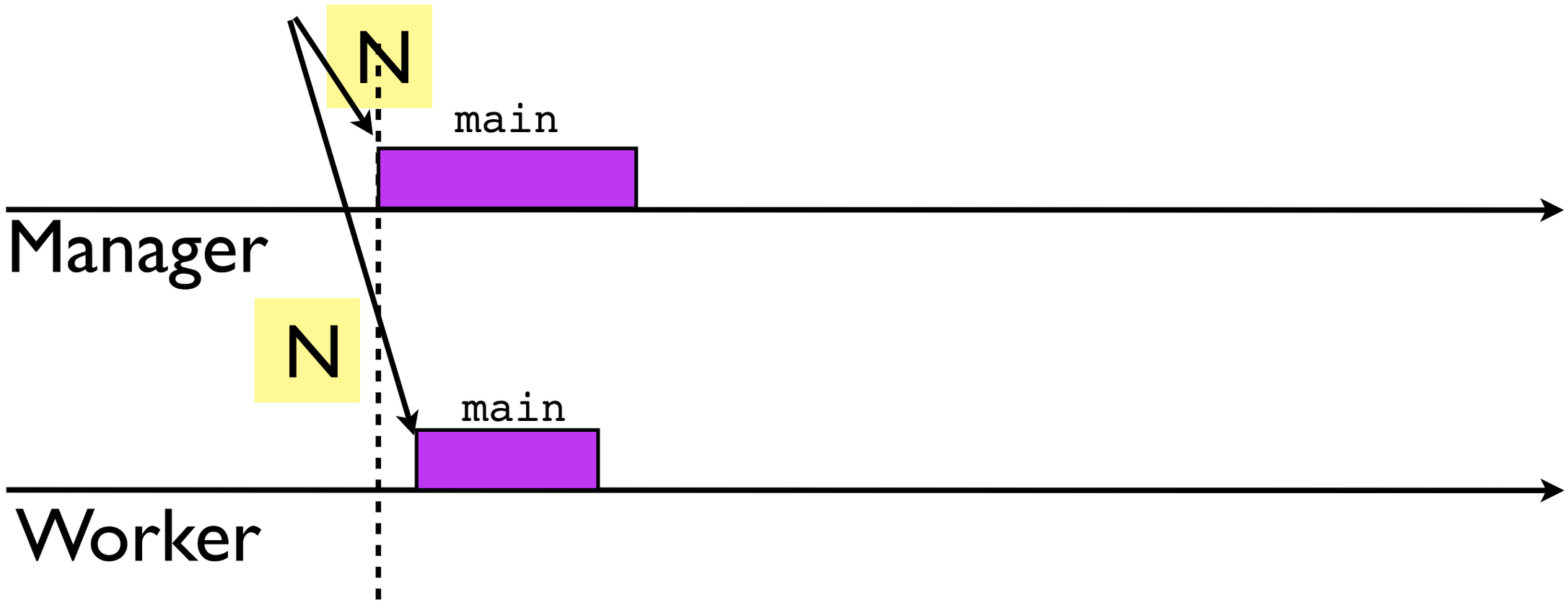
Manager/Worker Paradigm



Computing Pi
(Parallel version in MPI)

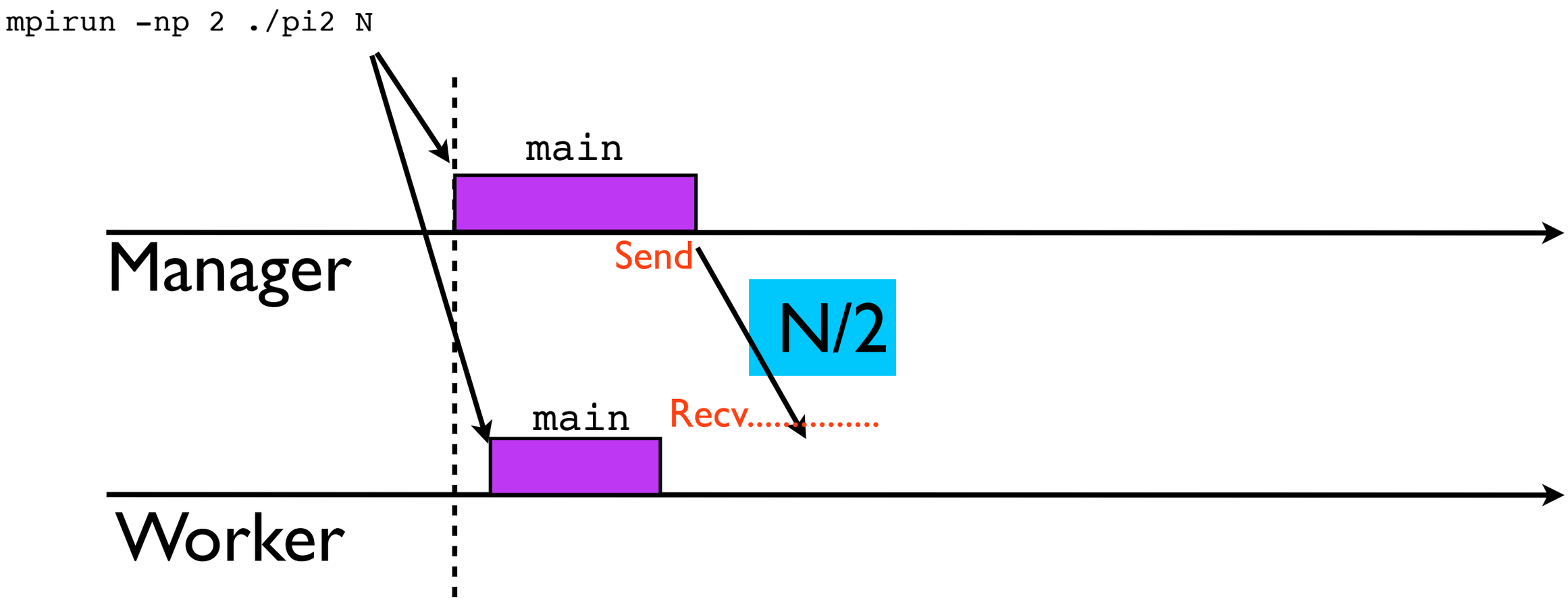
- Manager/Worker setup

```
mpirun -np 2 ./pi2 N
```



Computing Pi
(Parallel version in MPI)

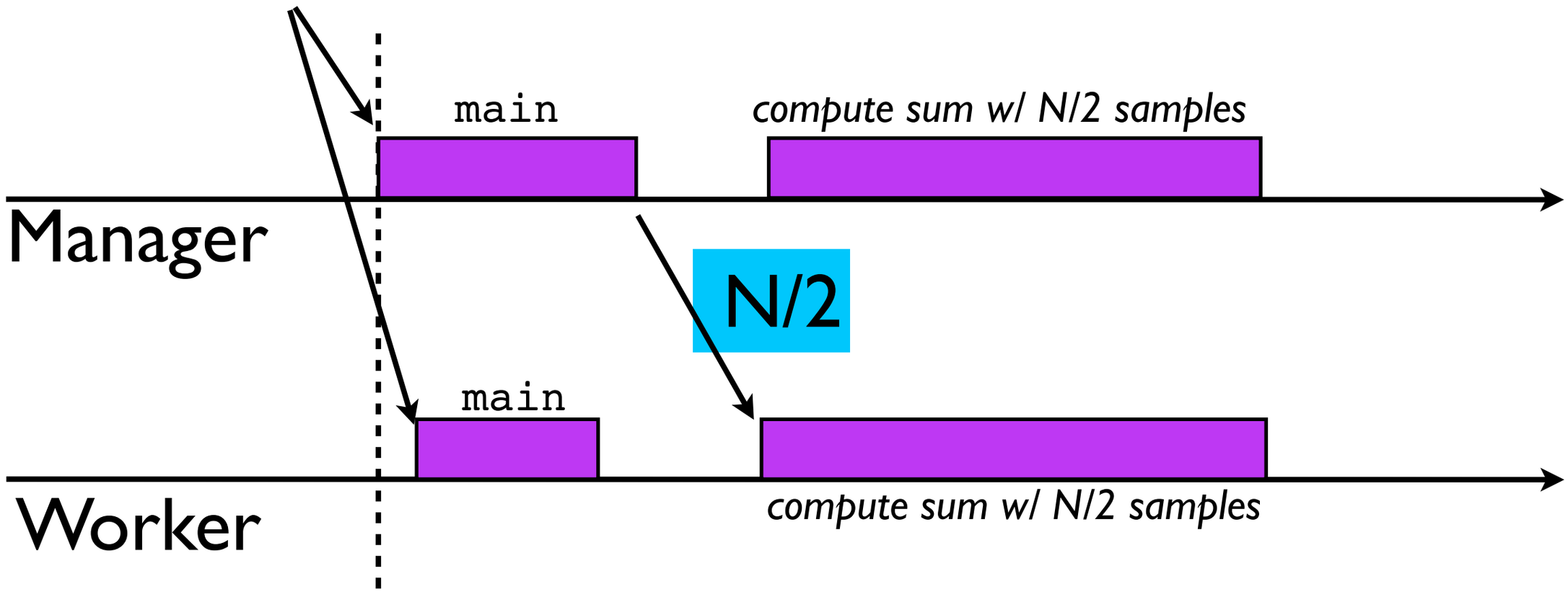
- Manager/Worker setup



Computing Pi
(Parallel version in MPI)

- Manager/Worker setup

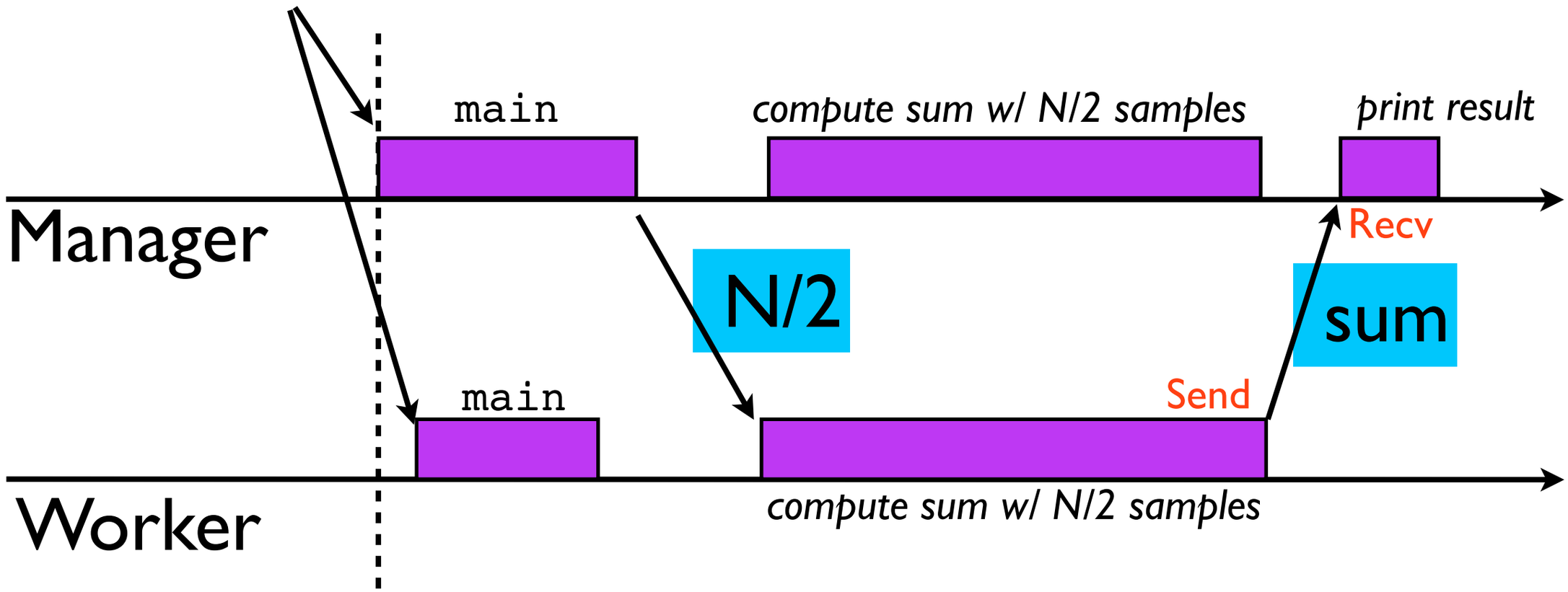
```
mpirun -np 2 ./pi2 N
```



Computing Pi
(Parallel version in MPI)

- Manager/Worker setup

```
mpirun -np 2 ./pi2 N
```



Computing Pi
(Parallel version in MPI)
Main Function

```
int main(int argc, char *argv[]) {
  int N, myId, noProcs, nameLen, i;
  char procName[MPI_MAX_PROCESSOR_NAME];

  if ( argc<2 ) {
    printf( "Syntax: mpirun -np 2 pi2 N\n" );
    return 1;
  }
  N = atoi( argv[1] );

  //--- start MPI ---
  MPI_Init( &argc, &argv );
  MPI_Comm_rank( MPI_COMM_WORLD, &myId );
  MPI_Comm_size( MPI_COMM_WORLD, &noProcs );
  MPI_Get_processor_name( procName, &nameLen );
  printf( "Process %d of %d started on %s. N = %d\n",
          myId, noProcs, procName, N );
 //--- farm out the work: 1 manager, several workers ---
  if ( myId == MANAGER )
    doManager( N );
  else
    doWorker( );

  //--- close up MPI ---
  MPI_Finalize();
  return 0;
}
```

Computing Pi

(Parallel version in MPI)
Manager Function

```
//===  M A N A G E R  ===
void doManager( int n ) {
  double sum0 = 0, sum1;
  double deltaX = 1.0/n;
  int i;
  MPI_Status status;

  //--- first send n to worker ---
  MPI_Send( &n, 1, MPI_INT, WORKER, 0, MPI_COMM_WORLD );

  //--- perform 1st half of the work ---
  for ( i=0; i< n/2; i++ )
    sum0 += f( i * deltaX );

  //--- wait for other half from worker ---
  MPI_Recv( &sum1, 1, MPI_DOUBLE, MPI_ANY_SOURCE, 0, MPI_COMM_WORLD, &status );

  //--- output result ---
  printf( "%d iterations: Pi = %1.6f\n", n, ( sum0 + sum1 )*deltaX );
}
```

Computing Pi

(Parallel version in MPI)
Worker Function

```
//===  W O R K E R  ===
void doWorker( ) {
  int i, n;
  MPI_Status status;
  double sum = 0, deltaX;

  //--- get n from manager ---
  MPI_Recv( &n, 1, MPI_INT, MPI_ANY_SOURCE, 0, MPI_COMM_WORLD, &status );

  //--- do (second) half of the work ---
  deltaX = 1.0/n;

  for ( i=n/2; i< n; i++ )
    sum += f( i * deltaX );

  //-- send result to manager ---
  MPI_Send( &sum, 1, MPI_DOUBLE, MANAGER, 0, MPI_COMM_WORLD );
}
```

MPI_Send

```
MPI_Send(&work,                 // buffer
         1,                     // number of items
         MPI_INT,               // type of items
         rank,                  // Id of receiver
         tag,                   // message tag (must match)
         MPI_COMM_WORLD);       // the communicator's group
```

https://computing.llnl.gov/tutorials/mpi/#Derived_Data_Types

```
MPI_CHAR
MPI_SHORT
MPI_INT
MPI_LONG
MPI_UNSIGNED
MPI_FLOAT
MPI_DOUBLE
```

MPI_Recv

```
MPI_Recv(&result,              // buffer
         1,                    // # items
         MPI_DOUBLE,           // item type
         MPI_ANY_SOURCE,       // receive from any sender
         MPI_ANY_TAG,          // any tag
         MPI_COMM_WORLD,       // default communicator
         &status);             // info about the received
                               // message
```

In C, status is a structure that contains three fields named MPI_SOURCE, MPI_TAG, and MPI_ERROR; the structure may contain additional fields. Thus, status.MPI_SOURCE, status.MPI_TAG and status.MPI_ERROR contain the source, tag, and error code, respectively, of the received message.

http://www.mpi-forum.org/docs/mpi-11-html/node35.html#Node35

Status Structure

```
int recvd_tag, recvd_from;
int recvd_count;
MPI_Status status;

MPI_Recv(..., ..., ..., &status );

Recvd_tag = status.MPI_TAG;
Recvd_from= status.MPI_SOURCE;
MPI_Get_count( &status,
               datatypeOfbuffer,
               &recvd_count );
```

Compile and Run

```
(on beowulf or hadoop0)
mpicc -o pi2b pi2b.c
mpirun -np 2 ./pi2b 1000000
Process 0 of 2 started on MacDom2.local. N = 1000000
Process 1 of 2 started on MacDom2.local. N = 1000000
1000000 iterations: Pi = 3.141594
```

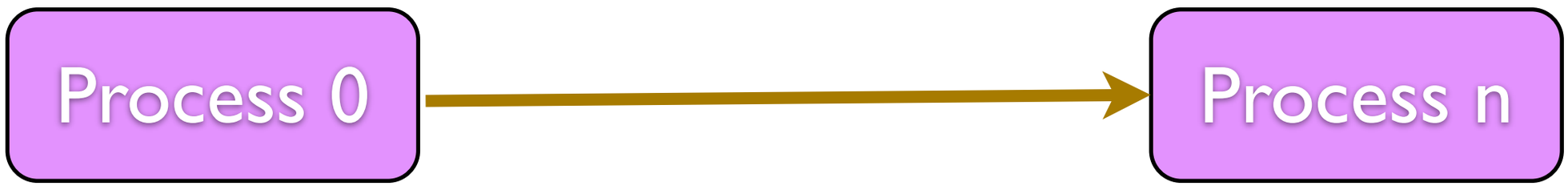
Definition MPI_COMM_WORLD

- MPI_COMM_WORLD is a *Communicator*
- It contains ALL processes
- A communicator determines the scope and the "communication universe" in which a point-to-point or collective operation is to operate.
- It's the *universe* for most MPI programs

Communication

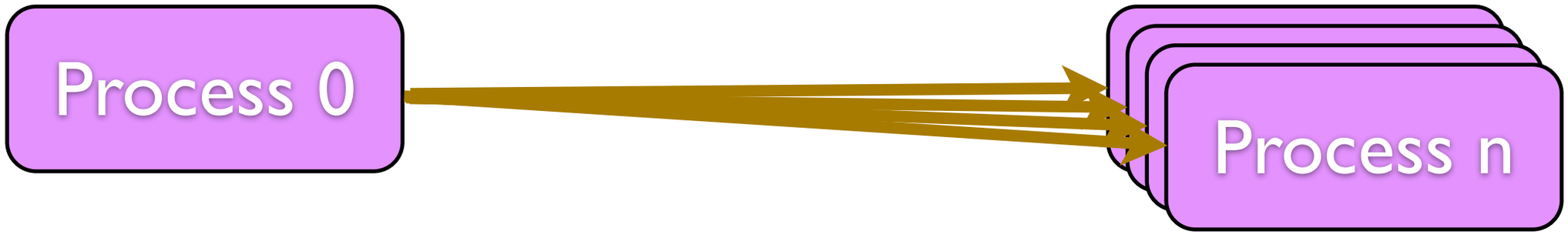
```
MPI_Send(__,__,__,n,__,__)
```

```
MPI_Recv(__,__,__,0,__,__,__)
```



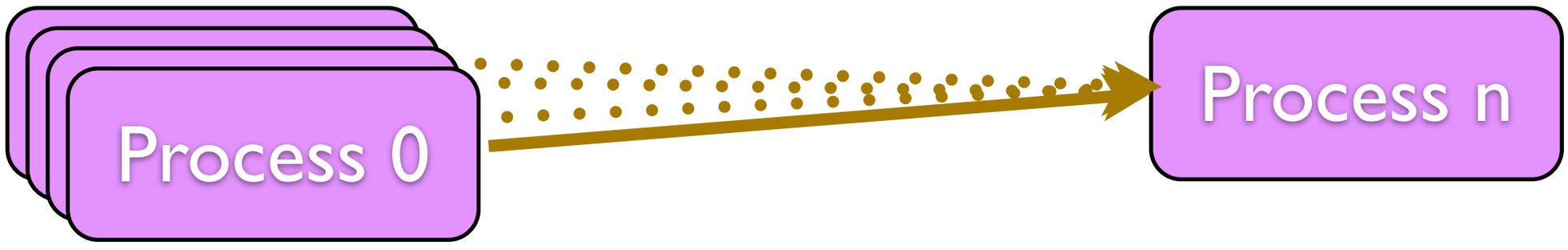

```
MPI_Bcast(__,__,__,__,__)
```

```
MPI_Recv(__,__,__,0,__,__,__)
```




```
MPI_Send(__,__,__,n,__,__)
```

```
MPI_Recv(__,__,__,
         MPI_ANY_SOURCE,__,__,__)
```



Exercise

- Create your own version of the pi program (type it!) and run it with np=2
  - On your laptop
  - On aurora

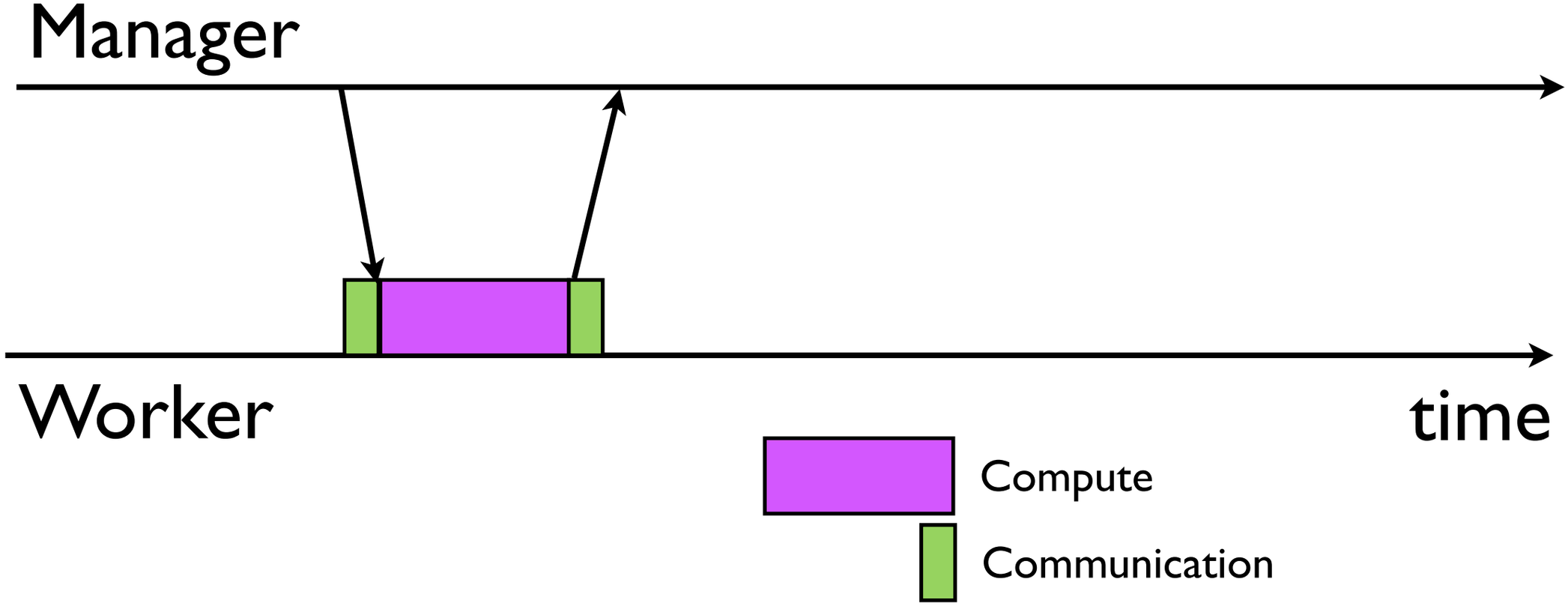
Exercise

- Create your own version of the pi program (type it!) and run it with *np*=10
  - On your laptop
  - On aurora

Scheduling/ Load-Balancing

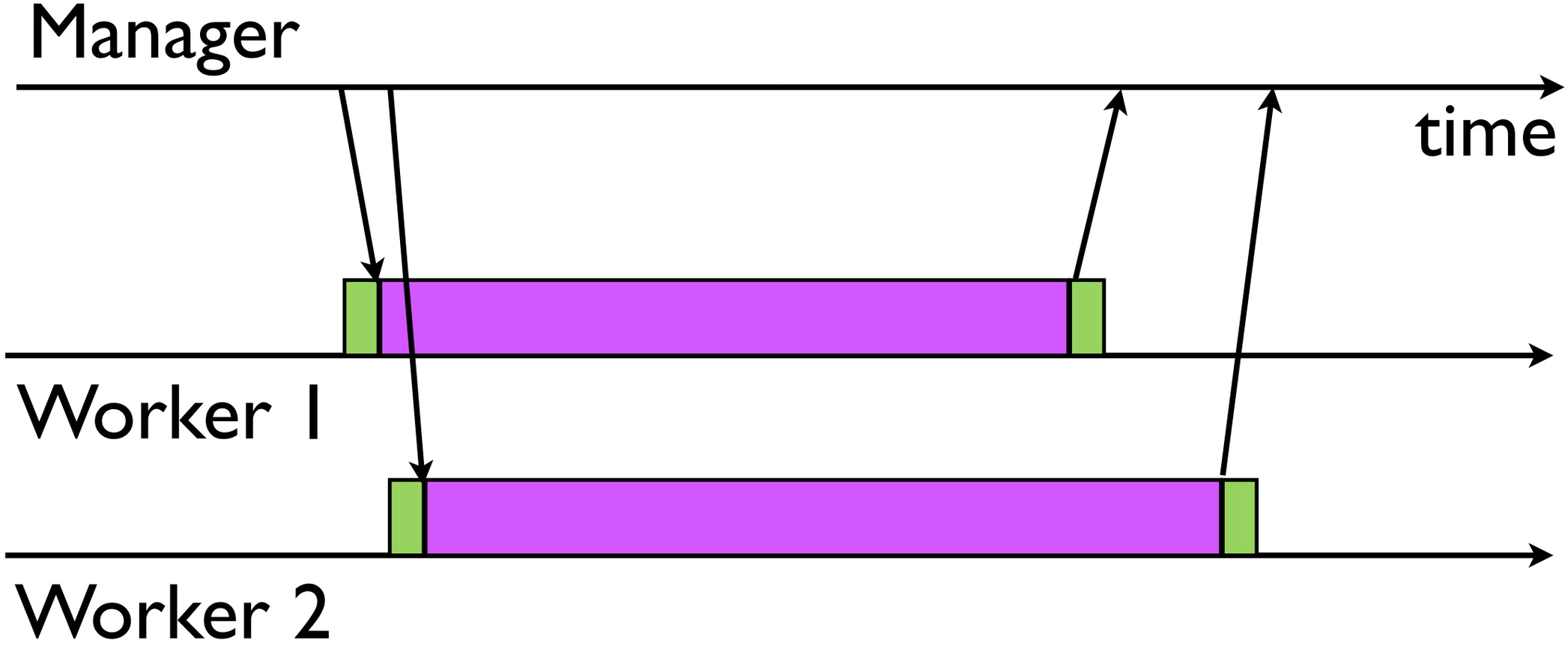
- Similar concepts
- Goal: Maximize performance by transferring tasks from busy to idle processors
- How: Determine parallel tasks + assign tasks to processors

Communication vs. Computation

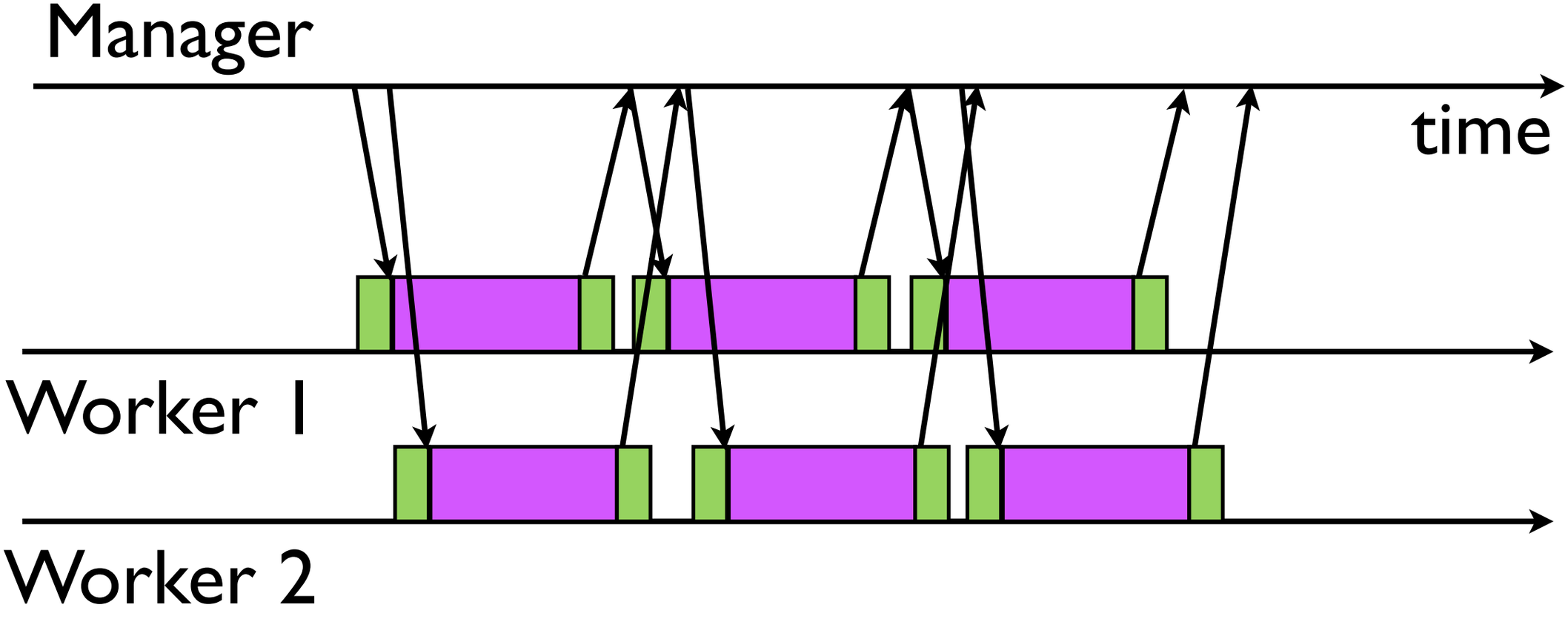


Communication vs. Computation

Coarse-grain parallelism



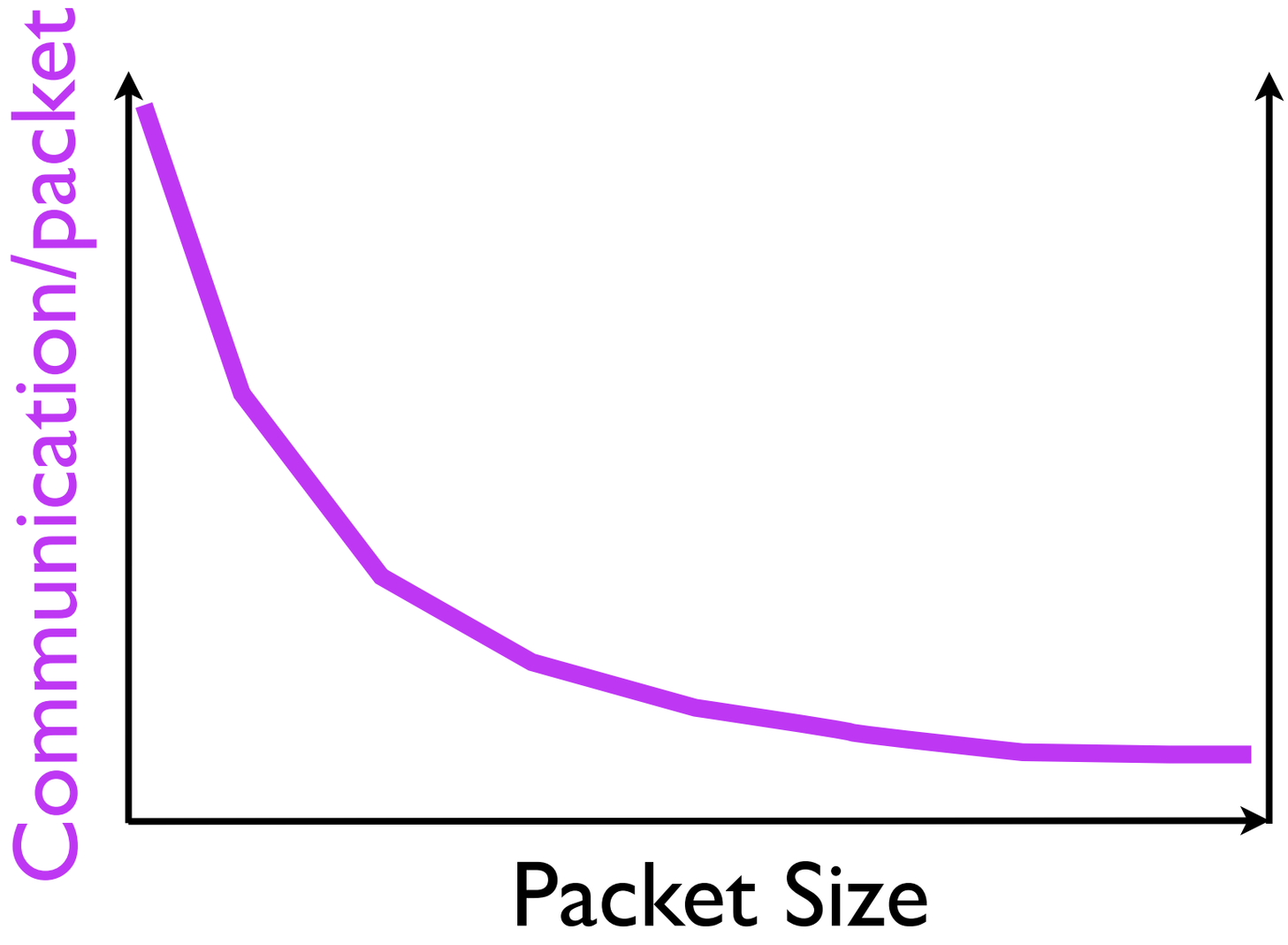
Communication vs. Computation



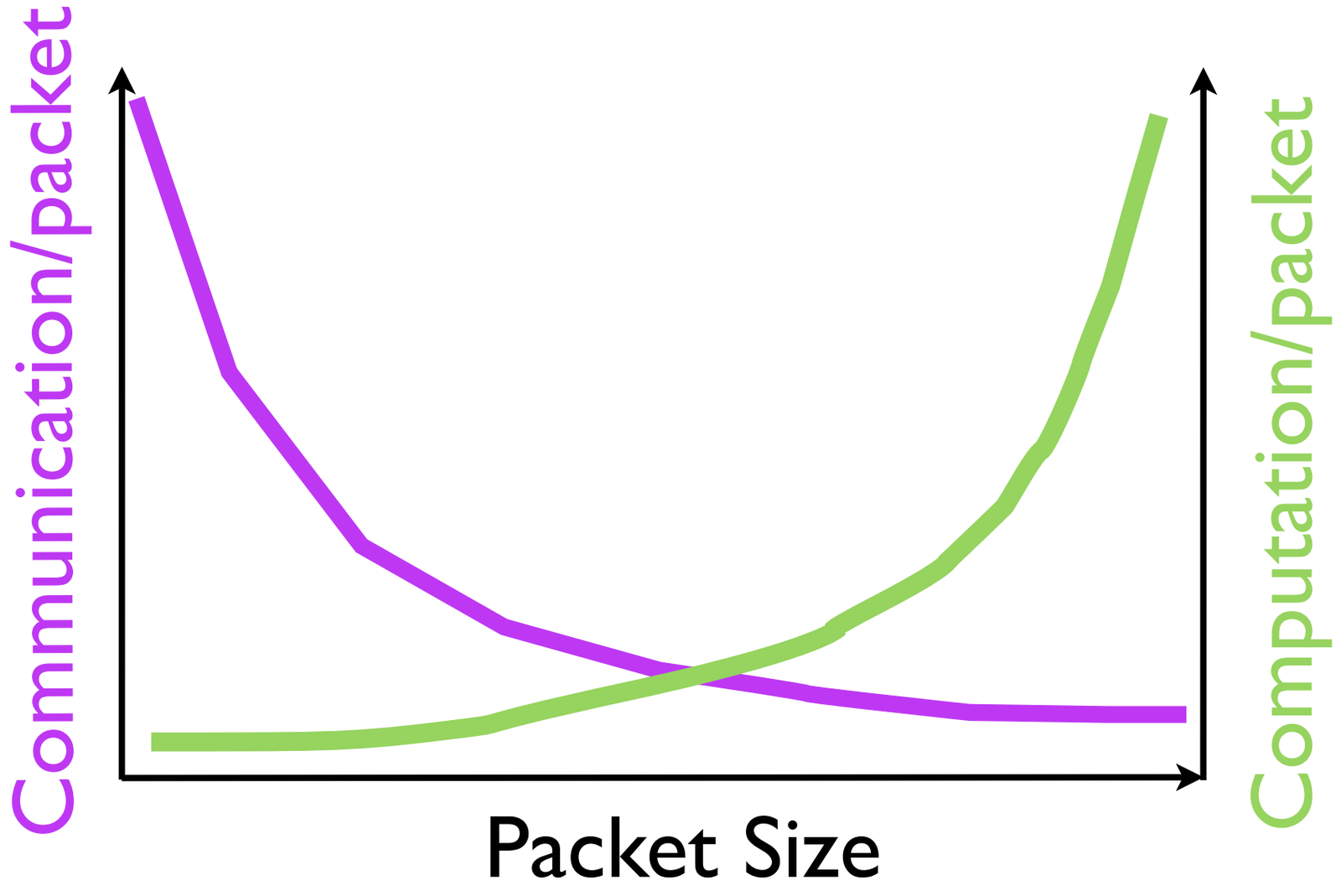
All-Important Graph: Communication vs Computation

Packet Size

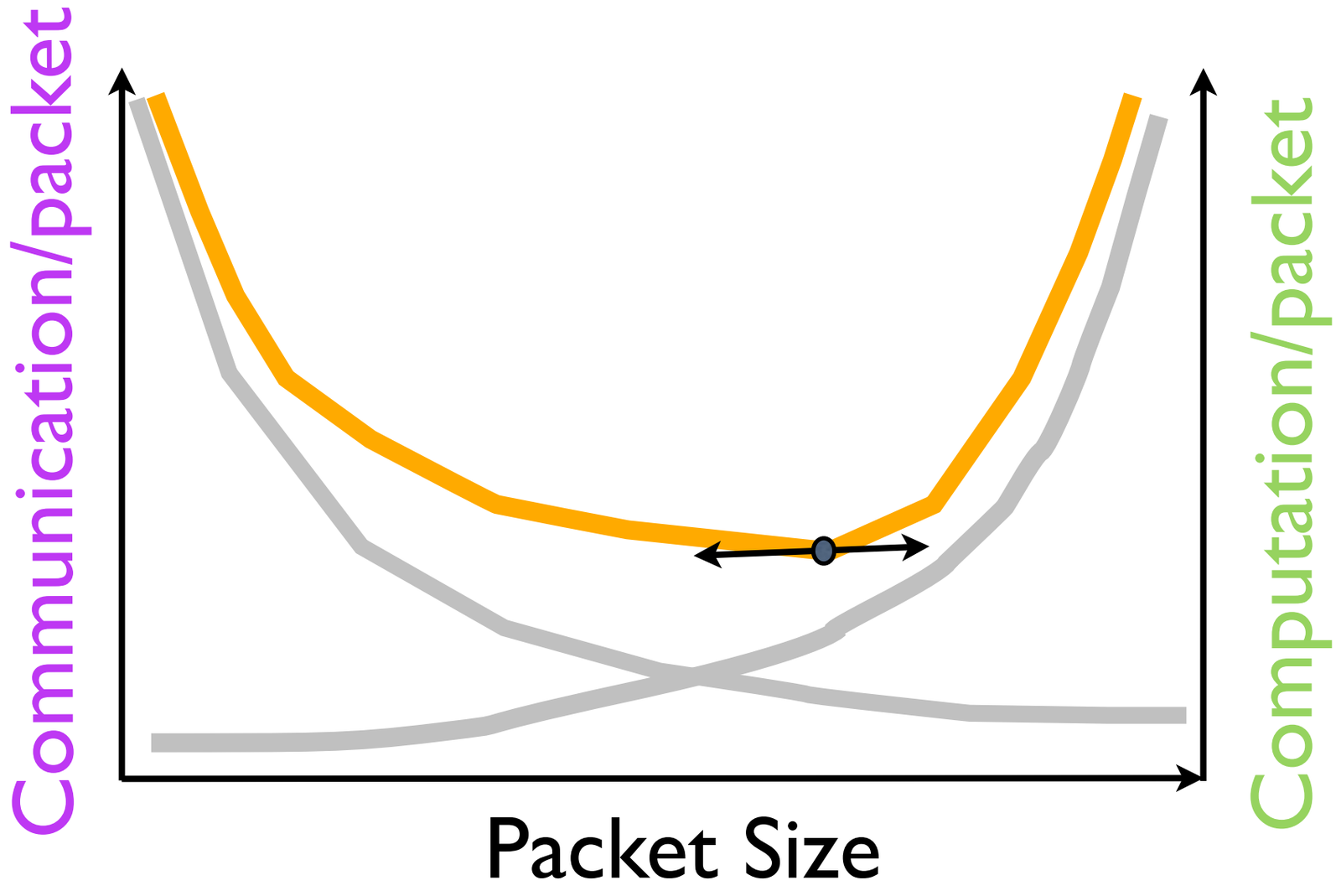
All-Important Graph: Communication vs Computation



All-Important Graph: Communication vs Computation



All-Important Graph: Communication vs Computation



Scheduling w/ Manager/Workers

- Approach:
  - Define a Protocol for exchanging data
  - How to start
  - Control steady state
  - How to stop
  - Make sure special cases are handled

Exercise

- Modify the Pi-approximation program so that the manager distributes computation in small chunks to its *n* workers.

Reference

- List of all MPI functions
  http://www.mcs.anl.gov/research/projects/mpi/www/www3/