Smith College
Computer Science

CSC352

Week #7 — Spring 2017
Introduction to MPI

Dominique Thiébaut
dthiebaut@smith.edu

Introduction to MPI

D. Thiebaut

Inspiration Reference

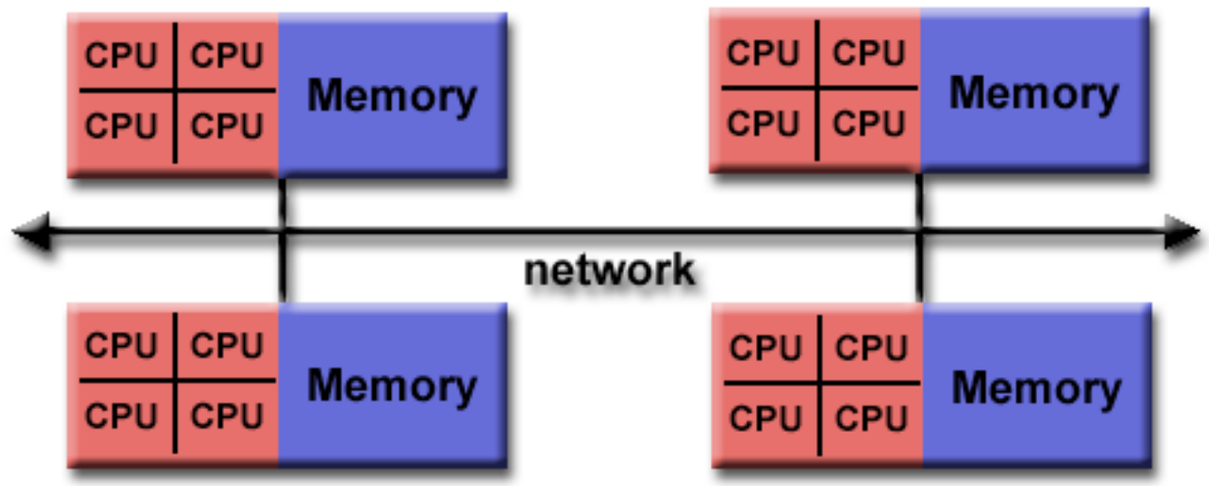
- MPI by Blaise Barney, Lawrence Livermore National Lab https://computing.llnl.gov/tutorials/mpi

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** (430 functions in MPI-3)
- 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:

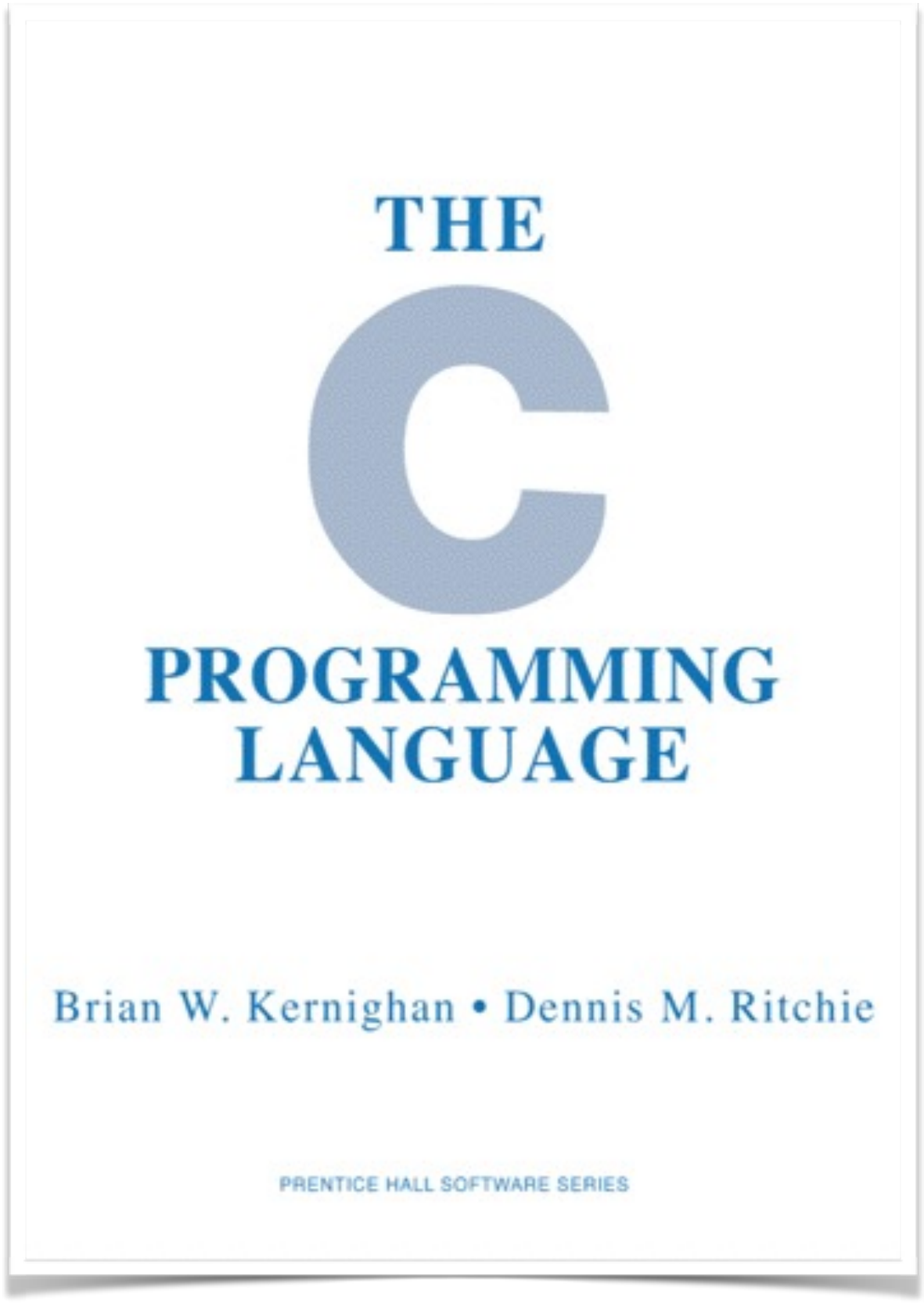
http://www.netlib.org/benchmark/hpl/

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$:
```

Different Syntaxes

- `mpirun -np 2 ./hello`
- `mpirun -n 2 ./hello`
- `mpiexec -n 2 ./hello`
- `mpiexec -np 2 ./hello`

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
```

Exercise

Hello World on Aurora

- 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.

We Stopped Here Last Time

http://www.genengnews.com/media/images/genhighlight/Mar12_2014_8296129_StopSigns_GeronTrialHalt2322361121.jpg

Next…

- Hello World on Cluster of 4 Servers
- MPI_Send/MPI_Recv/MPI_COMM_WORLD
- Potato (Exercise)
- Pi (Example)
- One-To-Many, Many-To-One Communication
- Load-Balancing and Scheduling
- MPI on **AWS**

Important Remarks

- 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 current process*

Tutorial

Hello World on Hadoop01

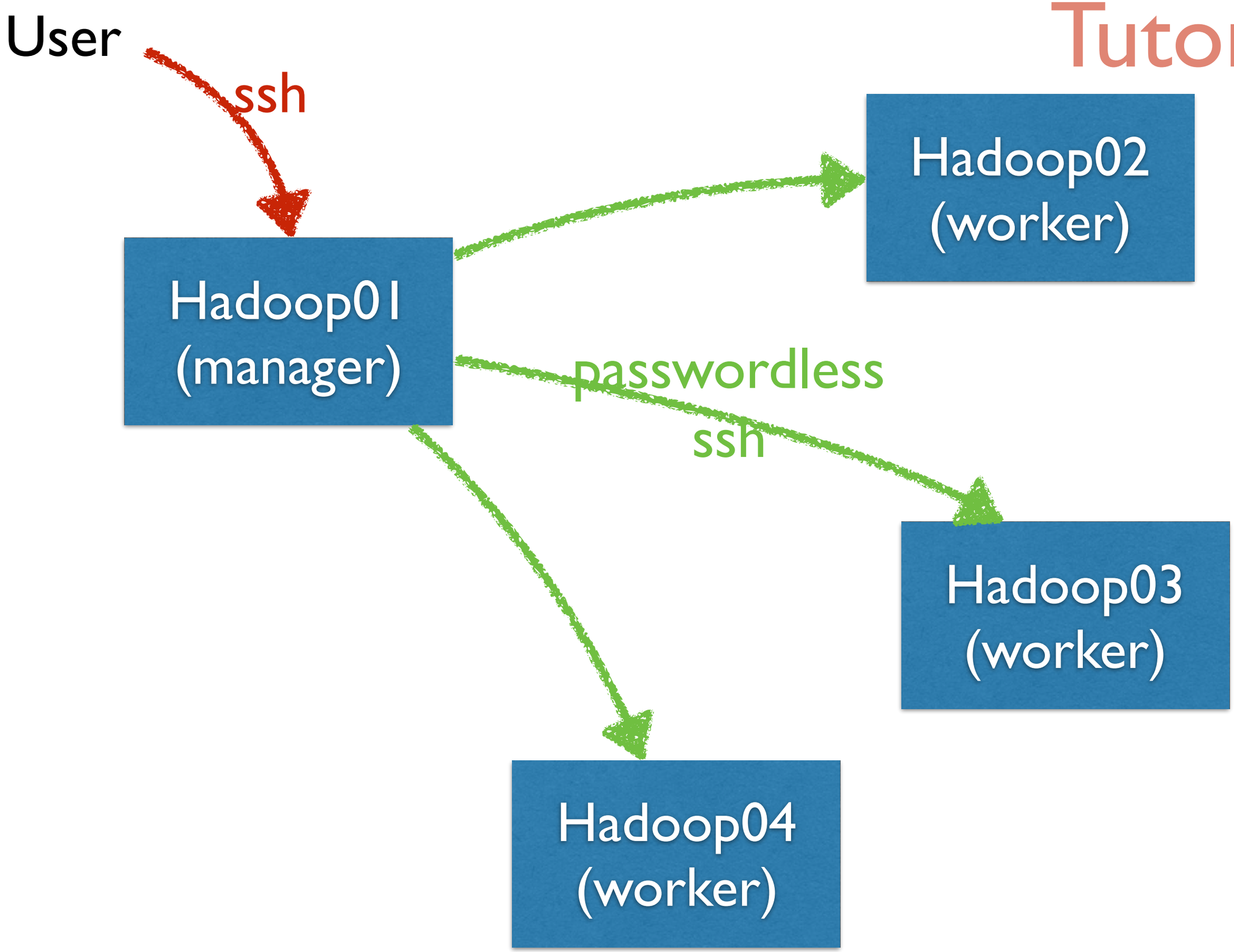
- Follow the tutorial at this URL

  http://www.science.smith.edu/dftwiki/index.php/Setup_MPI_on_Hadoop_Cluster

  to run MPI on a cluster of 4 servers

- See next slides for process overview

Tutorial


User
ssh
Hadoop01
(manager)
Hadoop02
(worker)
passwordless
ssh
Hadoop03
(worker)
Hadoop04
(worker)

Tutorial

User

ssh

Hadoop01
(manager)

emacs
helloWorld.c

Hadoop02
(worker)

Hadoop03
(worker)

Hadoop04
(worker)

Tutorial

User

ssh

Hadoop01
(manager)

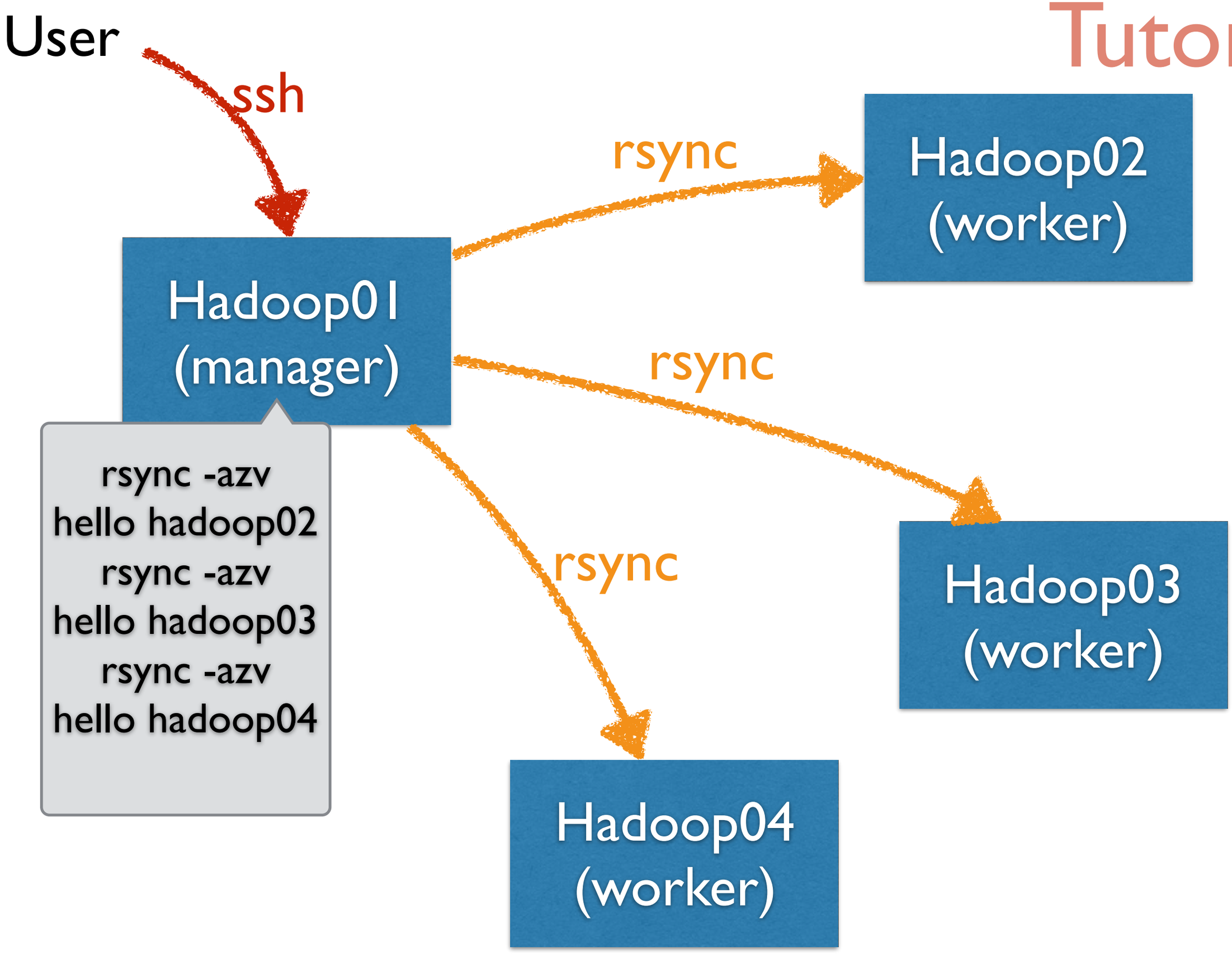
mpicc
helloWorld.c
-o hello

Hadoop02
(worker)

Hadoop03
(worker)

Hadoop04
(worker)

Tutorial


User
ssh
Hadoop01
(manager)
rsync -azv
hello hadoop02
rsync -azv
hello hadoop03
rsync -azv
hello hadoop04
rsync
Hadoop02
(worker)
rsync
Hadoop03
(worker)
rsync
Hadoop04
(worker)

Tutorial

User

ssh

Hadoop01
(manager)

mpirun -np 4 --hostfile hosts ./hello

mpirun

Hadoop02
(worker)

mpirun

Hadoop03
(worker)

mpirun

Hadoop04
(worker)

Deploy HelloWorld on the Hadoop Cluster

Point-to-Point Blocking Communication

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
```

Basic blocking send operation. Routine returns only after the application buffer in the sending task is free for reuse. Note that this routine may be implemented differently on different systems.

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

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
```

Receive a message and block until the requested data is available in the application buffer in the receiving task.

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

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

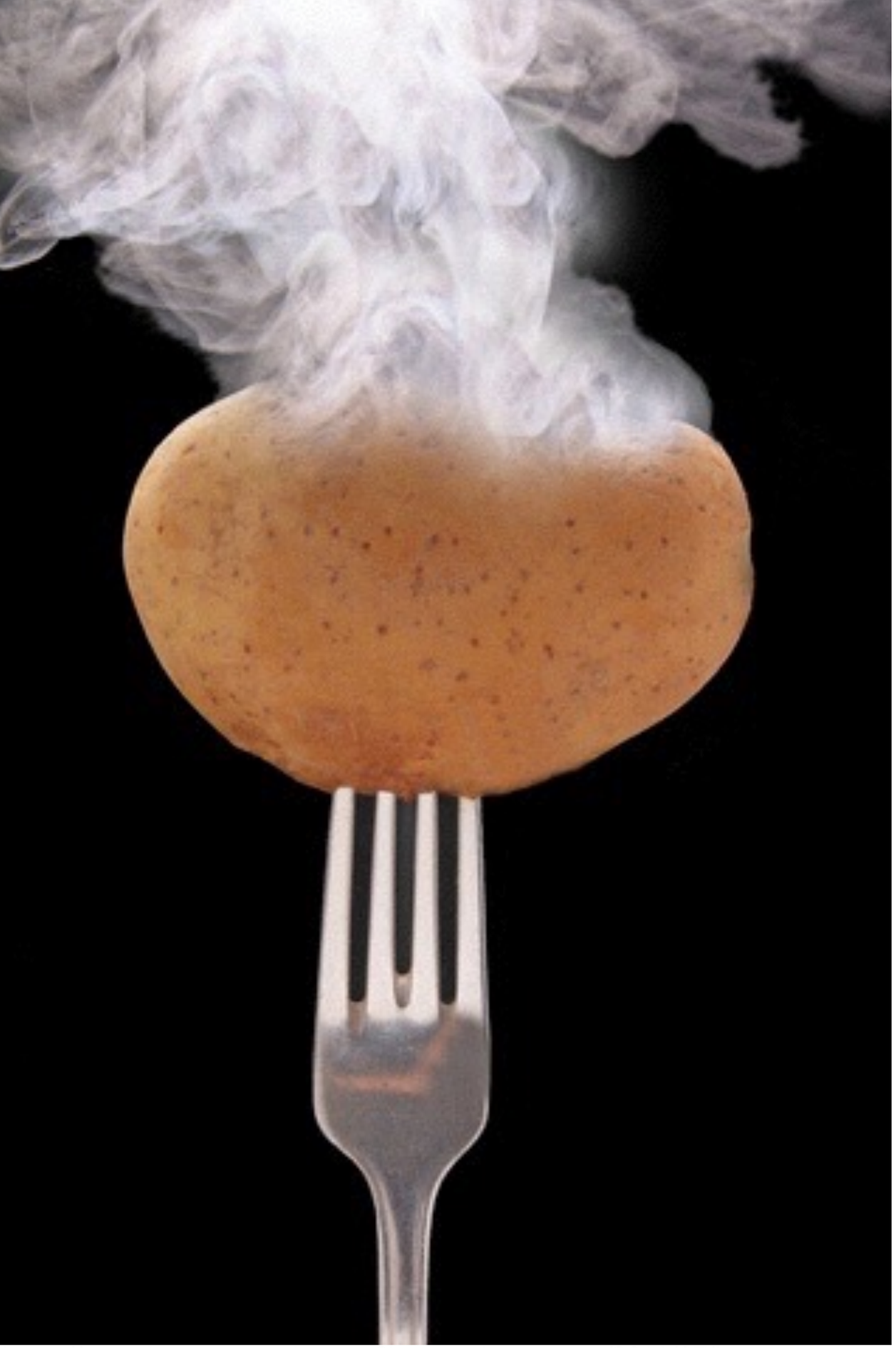
Status Structure

```
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 );
```

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

HOT POTATO



https://soundscapemusictherapy.files.wordpress.com/2011/07/hot-potato.jpg

Worker 1

Manager

Worker 2

Worker N-1

Worker 1

Manager

Worker 2

Worker N-1

Worker 1

Manager

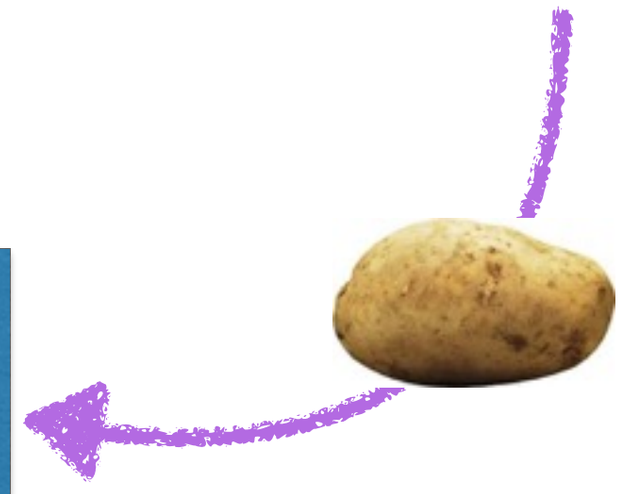
Worker 2

Worker N-1

Worker 1

Manager

Worker 2

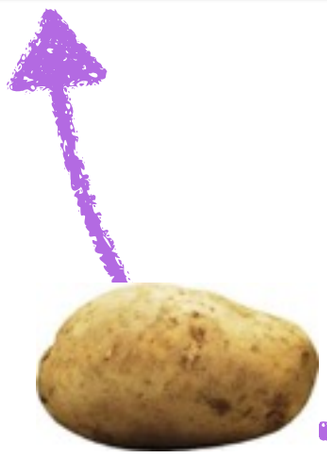


Worker N-1

Worker 1

Manager

Worker 2



Worker N-1

Worker 1

!!!!!

Manager

Worker 2

Worker N-1

- Implement the Hot Potato game in MPI and run it on **Aurora**. Make the potato go once around. (What is a good data-type to use for the potato?)

- Make each node of the cluster increment the potato as it passes around. Make the manager print the value of the potato when it gets it.

- Modify the MPI program so that the number of rounds can be specified on command line.

```
#include <stdlib.h>

int N;
N = atoi( argv[1] );
```

An Example: Computing Pi With MPI

Computing Pi

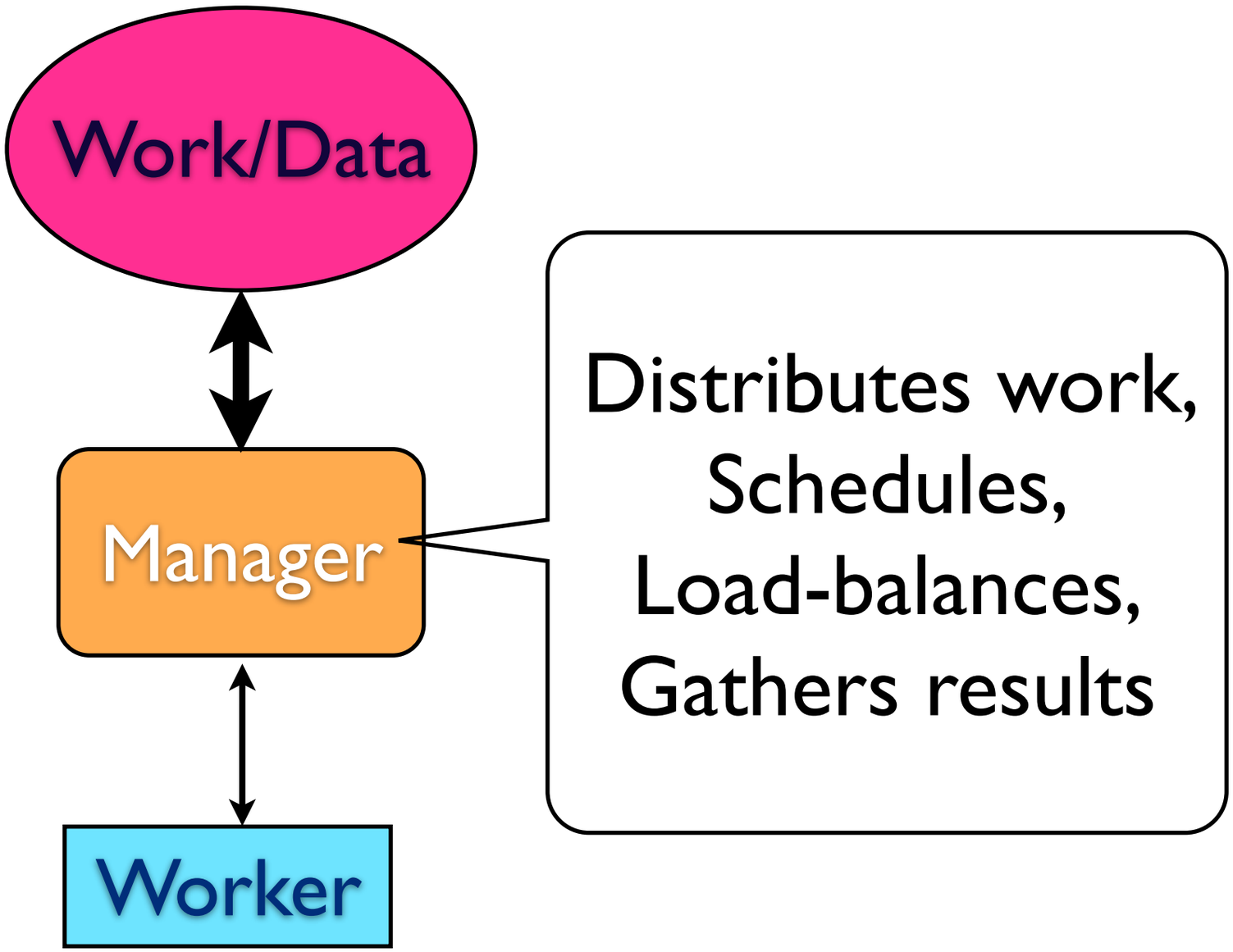
(serial version in C)

```
// 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 );
}
```

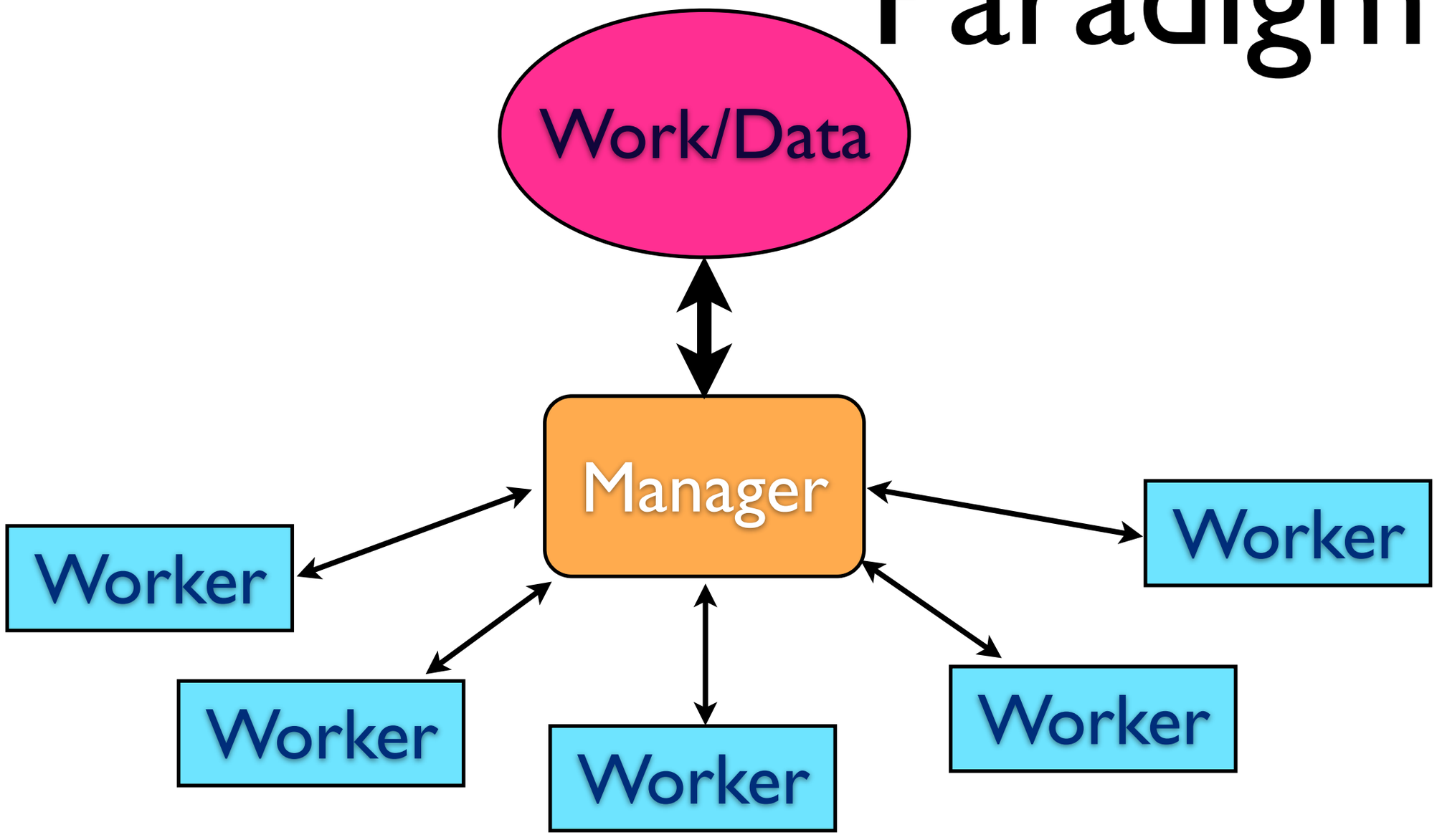
```
cc -o pi pi.c
./pi 100000
100000 iterations: Pi = 3.141603
```

getcopy mpi/pi.c

Manager/Worker Paradigm



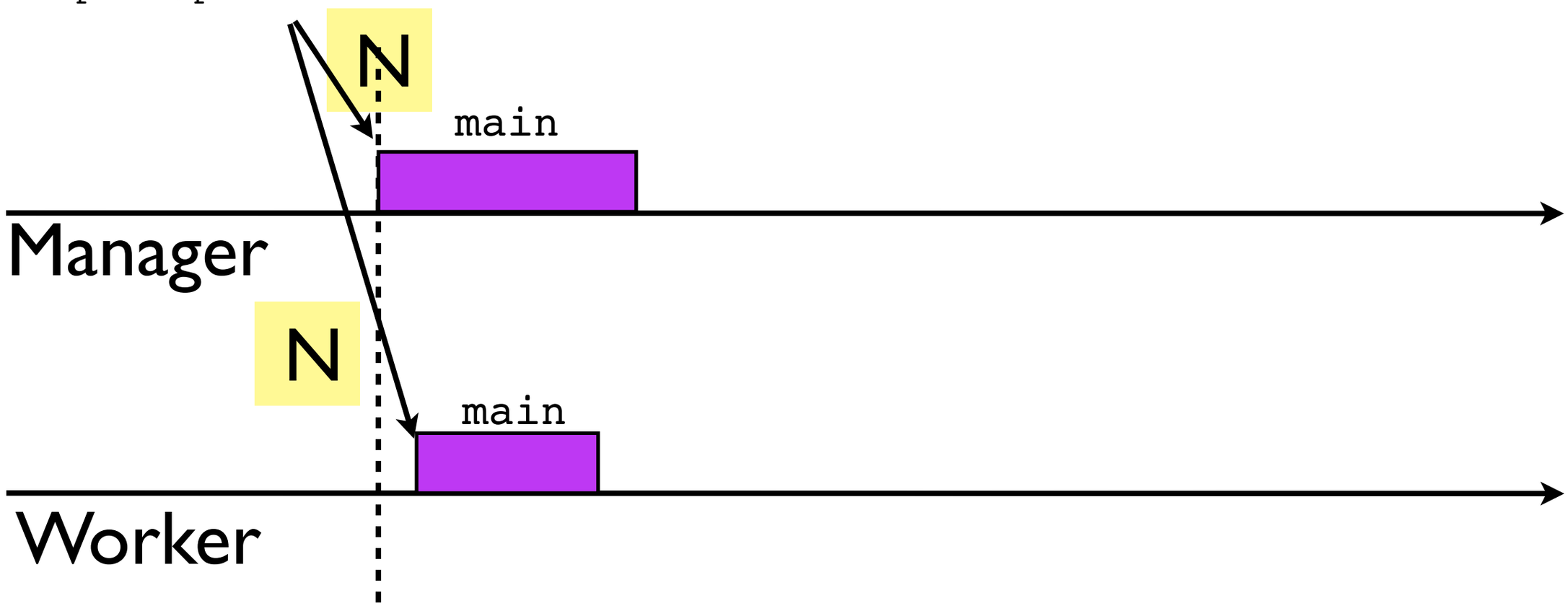
Manager/Worker Paradigm



Computing Pi
(Parallel version in MPI)

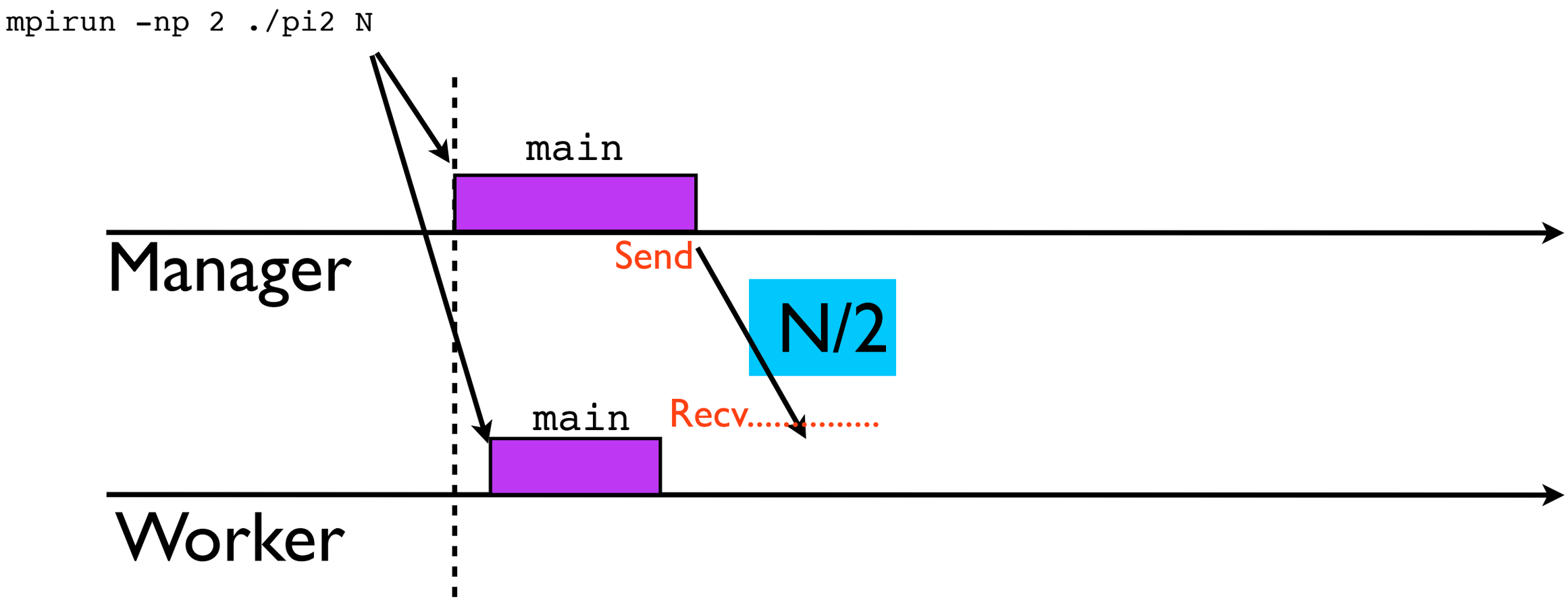
- Manager/Worker setup

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



Computing Pi
(Parallel version in MPI)

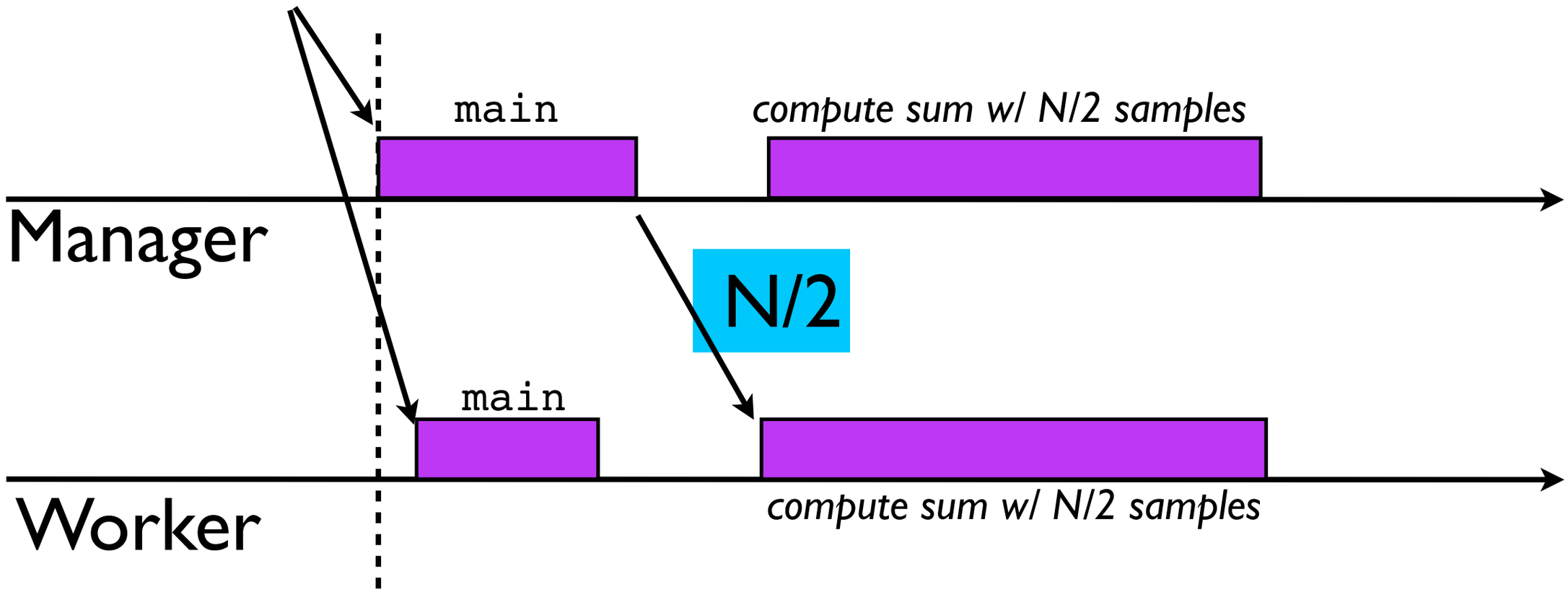
- Manager/Worker setup



Computing Pi
(Parallel version in MPI)

- Manager/Worker setup

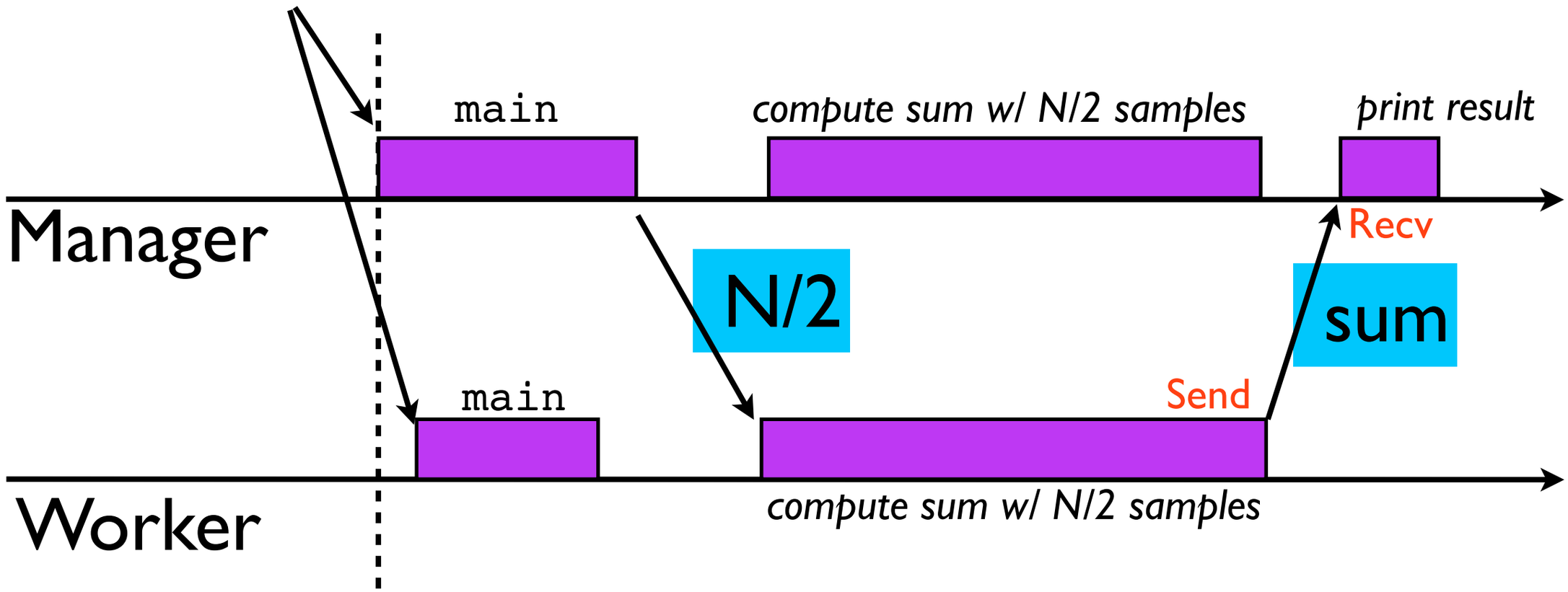
```
mpirun -np 2 ./pi2 N
```



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;
}
```

getcopy handout/mpi/pi2.c

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 );
}
```

Compile and Run

```
(on aurora)
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
```

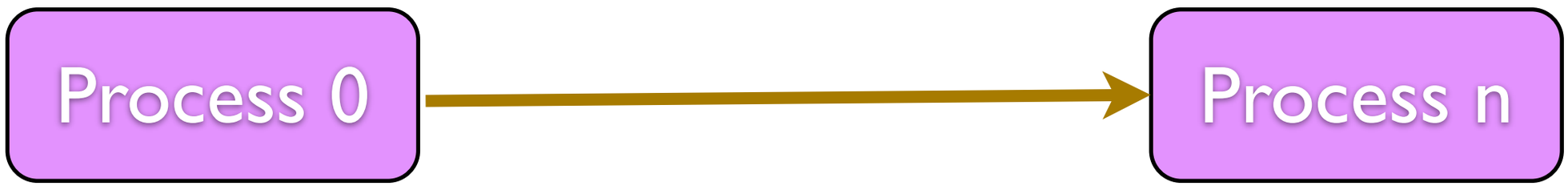
getcopy handout/mpi/pi2b.c

One-to-Many, Many-to-One Communication

Communication

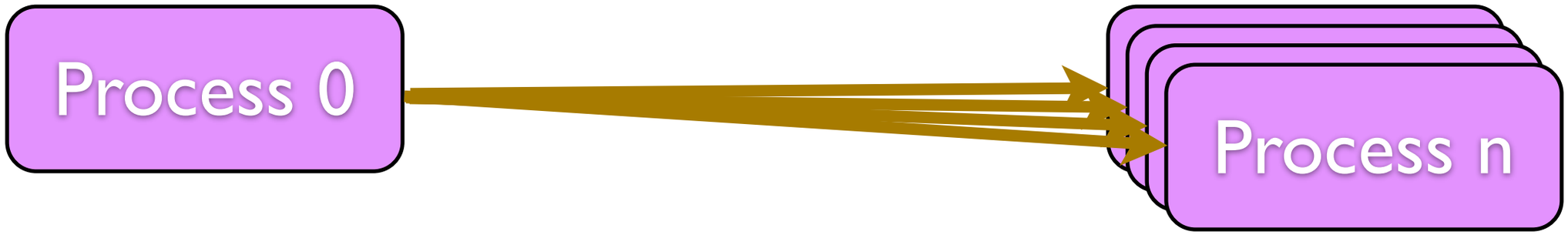
```
MPI_Send(__,__,__,n,__,__)
```

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



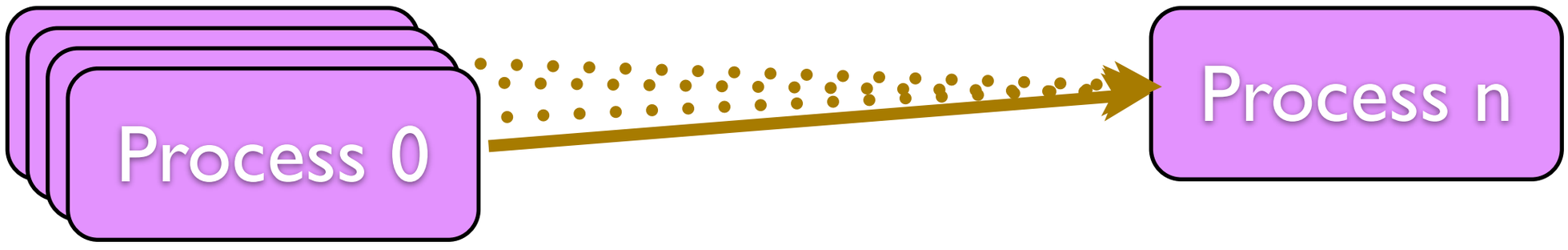

```
MPI_Bcast(__,__,__,__,__)
```

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




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

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



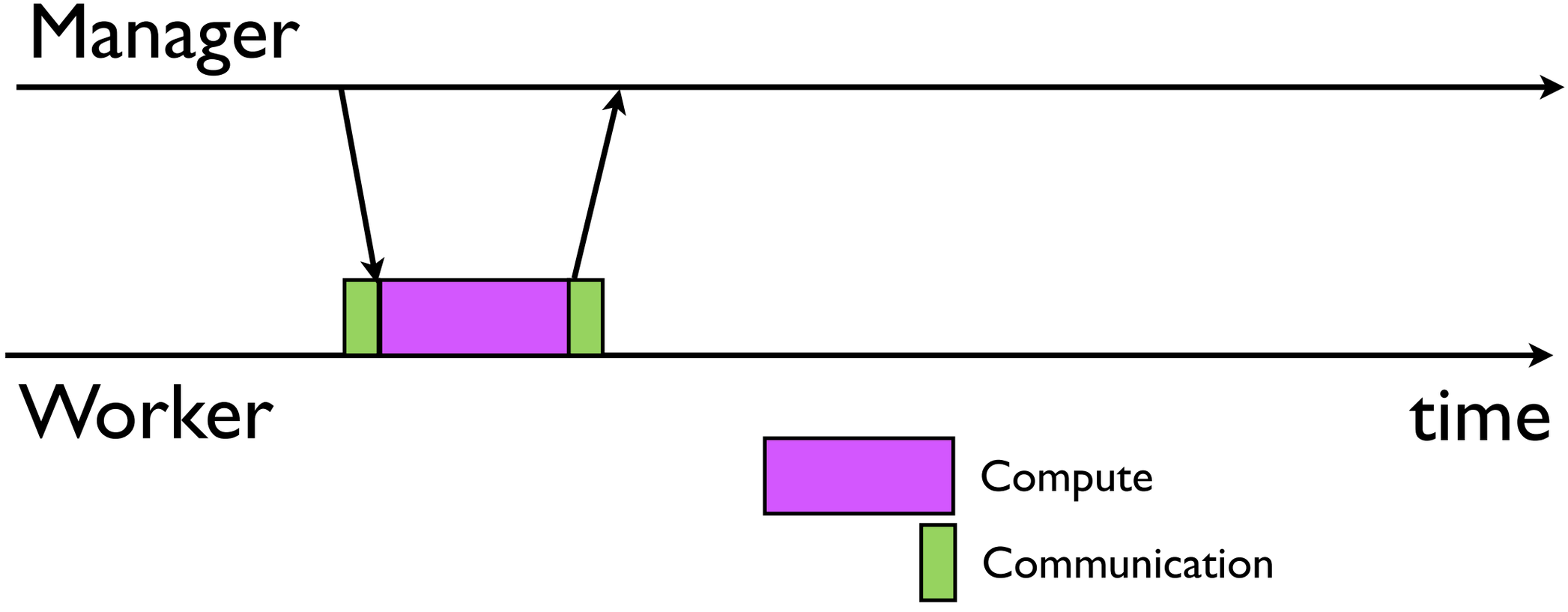
Exercise

- Create/get your own version of the pi program and run it with np=2, 10, 20
  - On the hadoop cluster, or
  - On your laptop or Aurora

Scheduling/ Load-Balancing

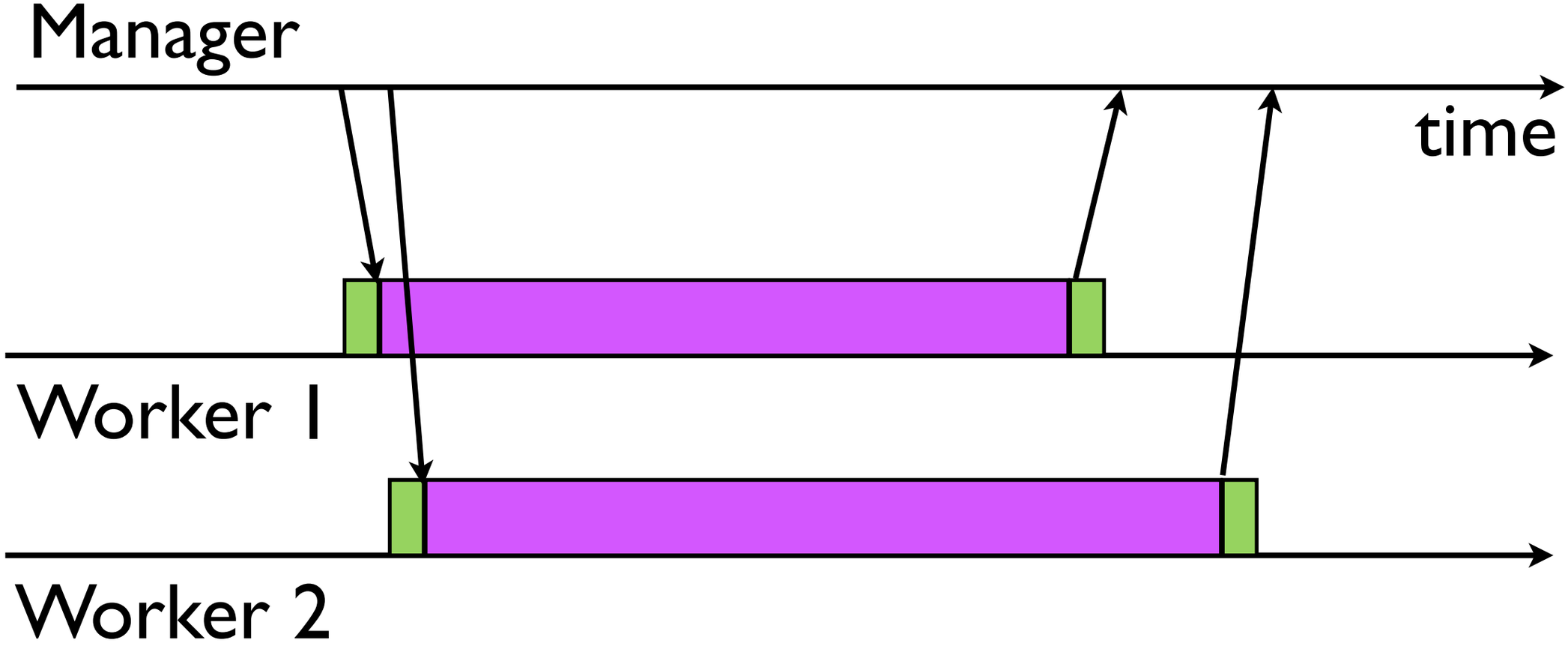
- Similar concepts
- Goal: Maximize performance by transferring tasks from busy to idle processors
- How: Determine parallel tasks + assign tasks to processors

Communication vs. Computation

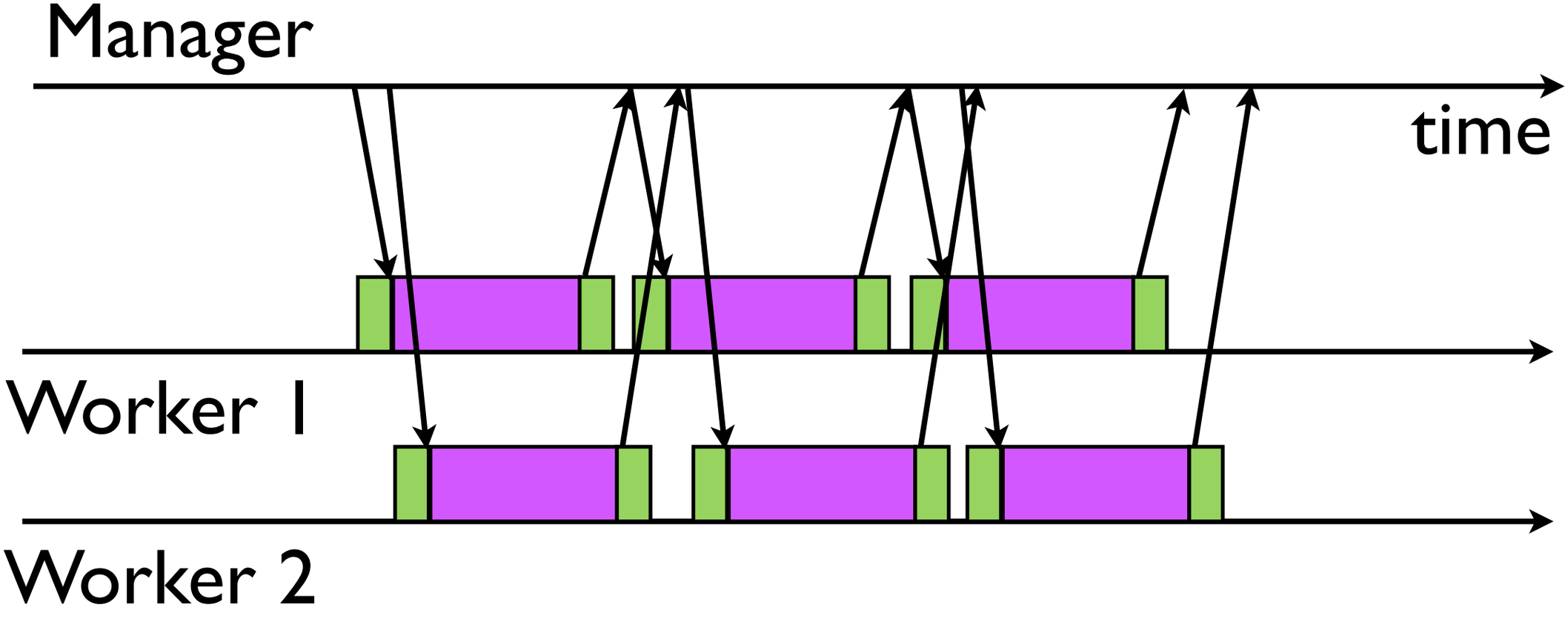


Communication vs. Computation

Coarse-grain parallelism



Communication vs. Computation

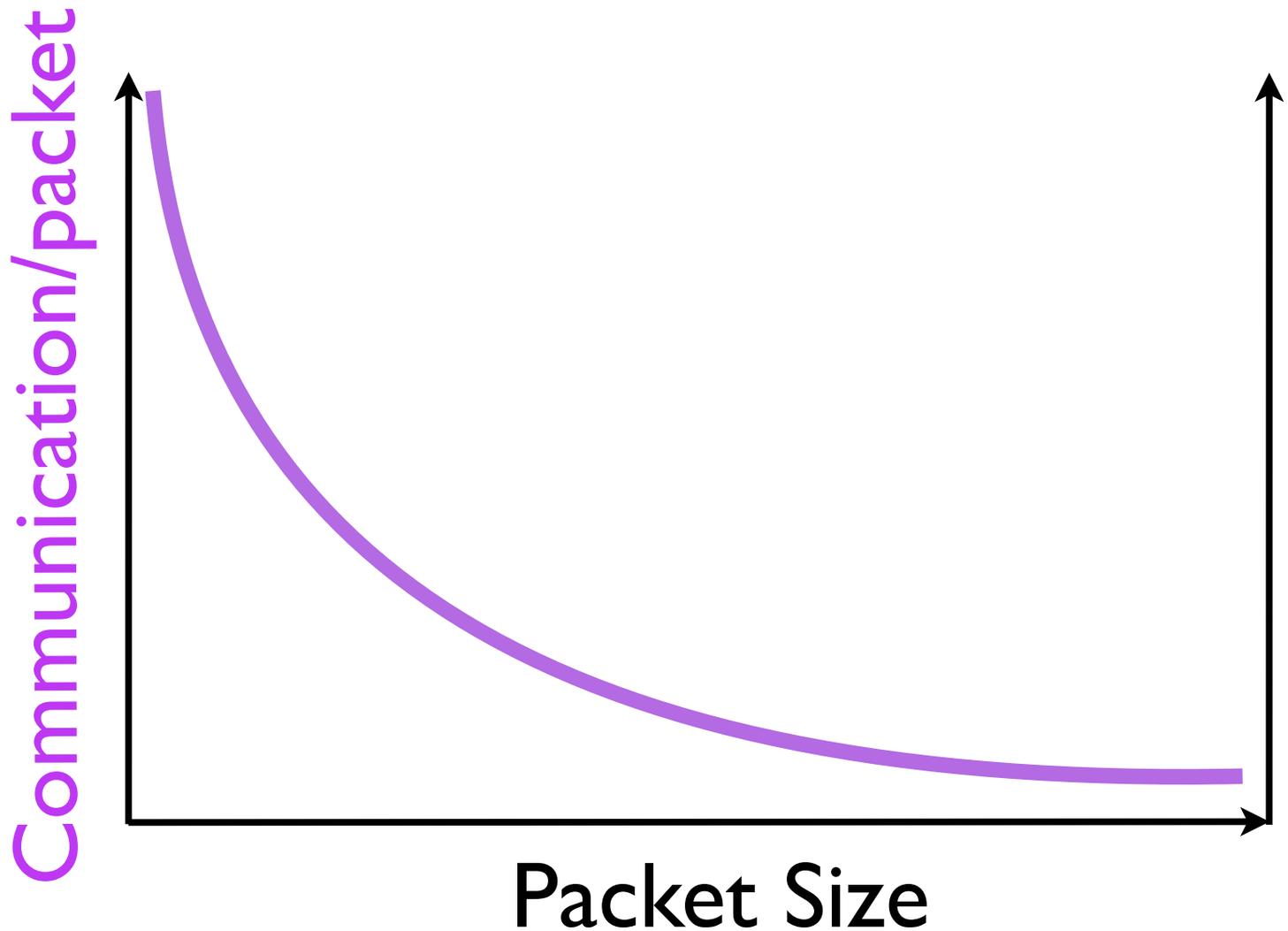


All-Important Graph: Communication vs Computation

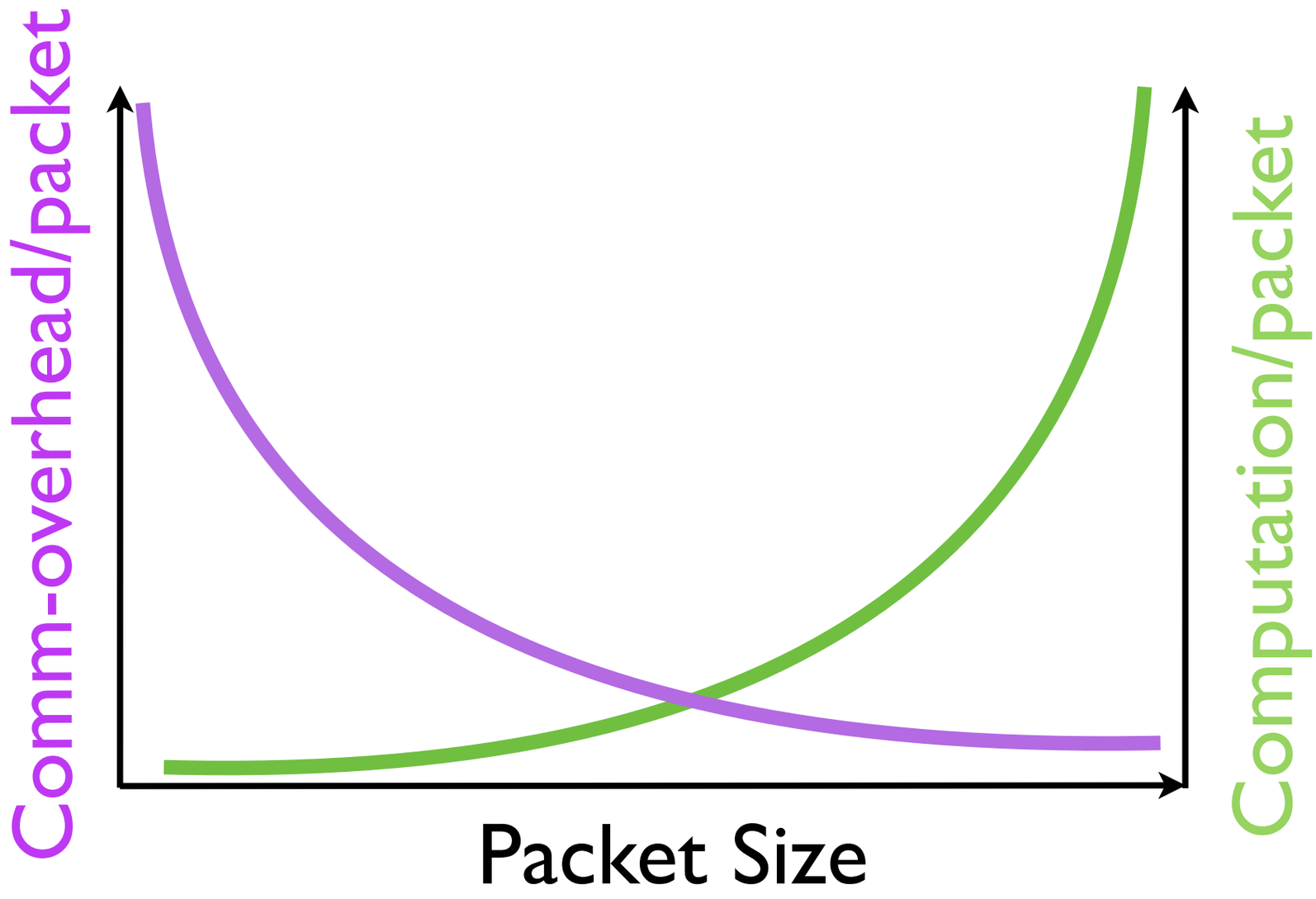
Fixed # Procs

Packet Size

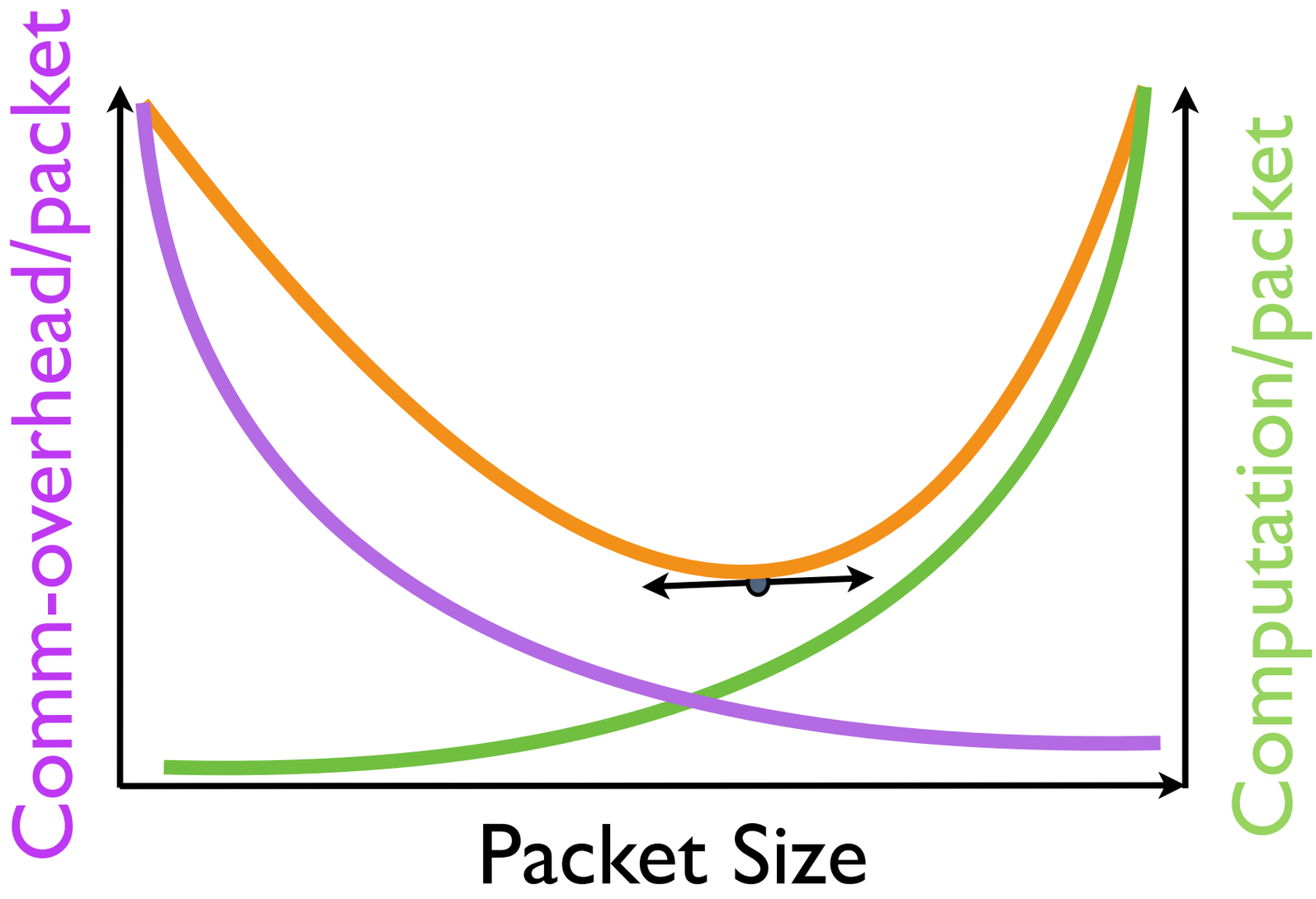
All-Important Graph: Communication vs Computation



All-Important Graph: Communication vs Computation



All-Important Graph: Communication vs Computation



Scheduling w/ Manager/Workers

- Approach:
  - Define a Protocol for exchanging data
  - Figure out how to start // computation
  - Control steady state
  - Define condition to stop
  - Make sure special cases are handled

Exercise

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

Reference

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

MPI on AWS

Installation and Tutorials

- Running MPI on AWS
- Tutorial 1 (StarCluster, He
- Tutorial 2 (Compute Pi on AWS/MPI)

http://www.science.smith.edu/dftwiki/index.php/Tutorial:_Create_an_MPI_Cluster_on_the_Amazon_Elastic_Cloud_(EC2)
http://www.science.smith.edu/dftwiki/index.php/Computing_Pi_on_an_AWS_MPI-Cluster