Smith College
Computer Science

CSC352

Week #7 — Spring 2017
Introduction to MPI

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Introduction to MPI

D. Thiebaut

Inspiration & Reference

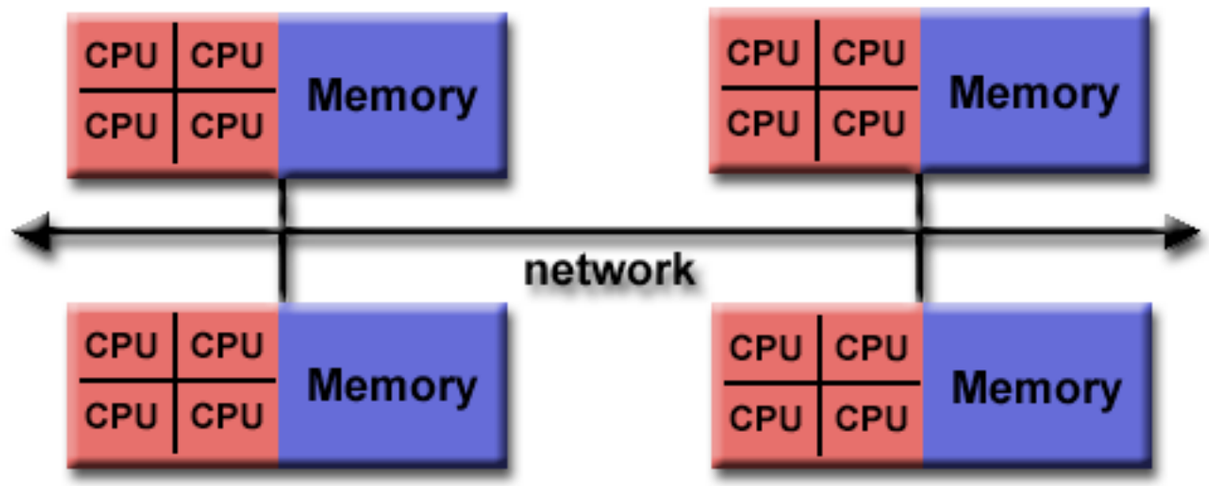
- MPI by Blaise Barney, Lawrence Livermore National Lab https://computing.llnl.gov/tutorials/mpi

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** (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:

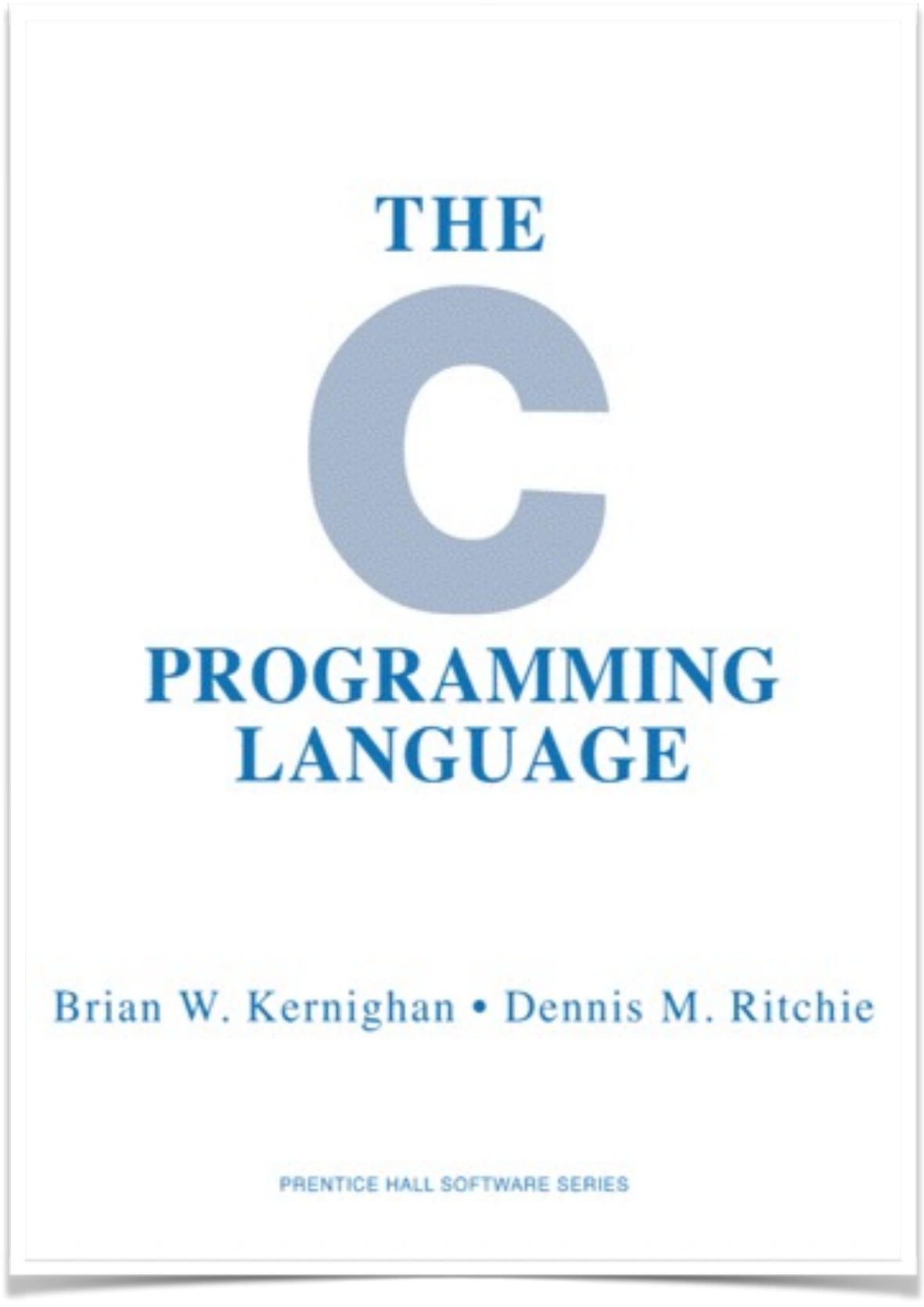
http://www.netlib.org/benchmark/hpl/

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

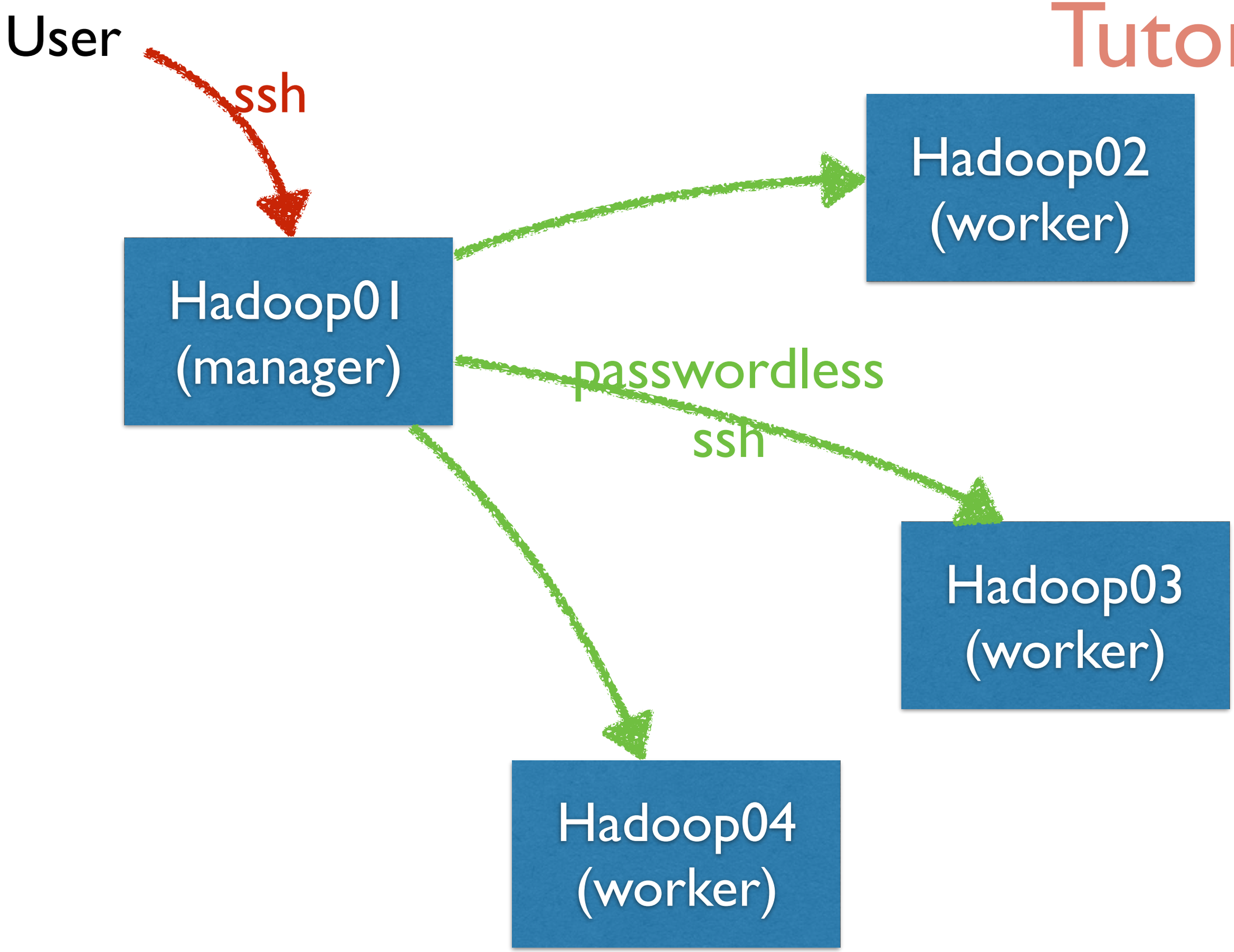
- Follow the tutorial at this URL

  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)

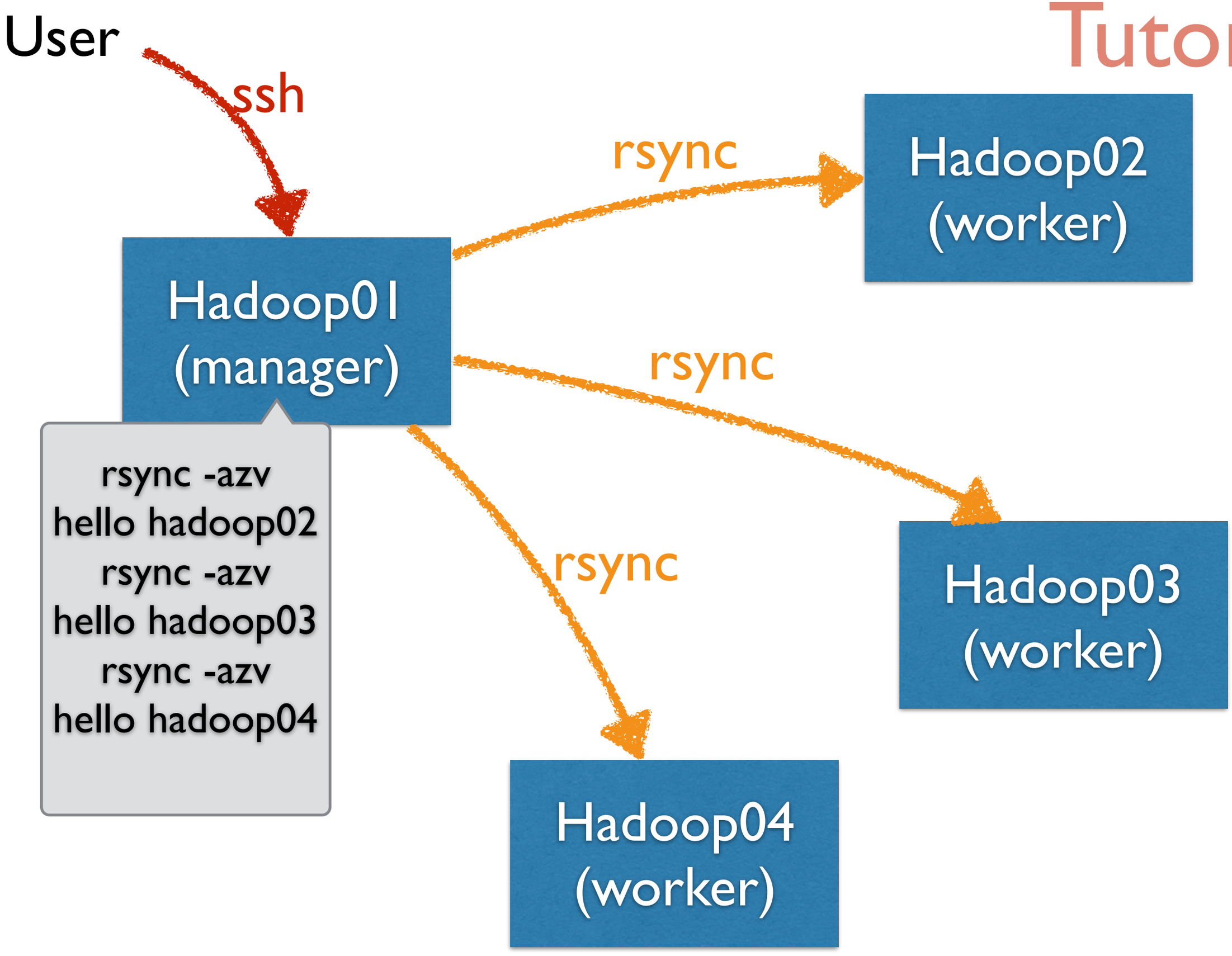
mpicc
helloWorld.c
-o hello

Hadoop02
(worker)

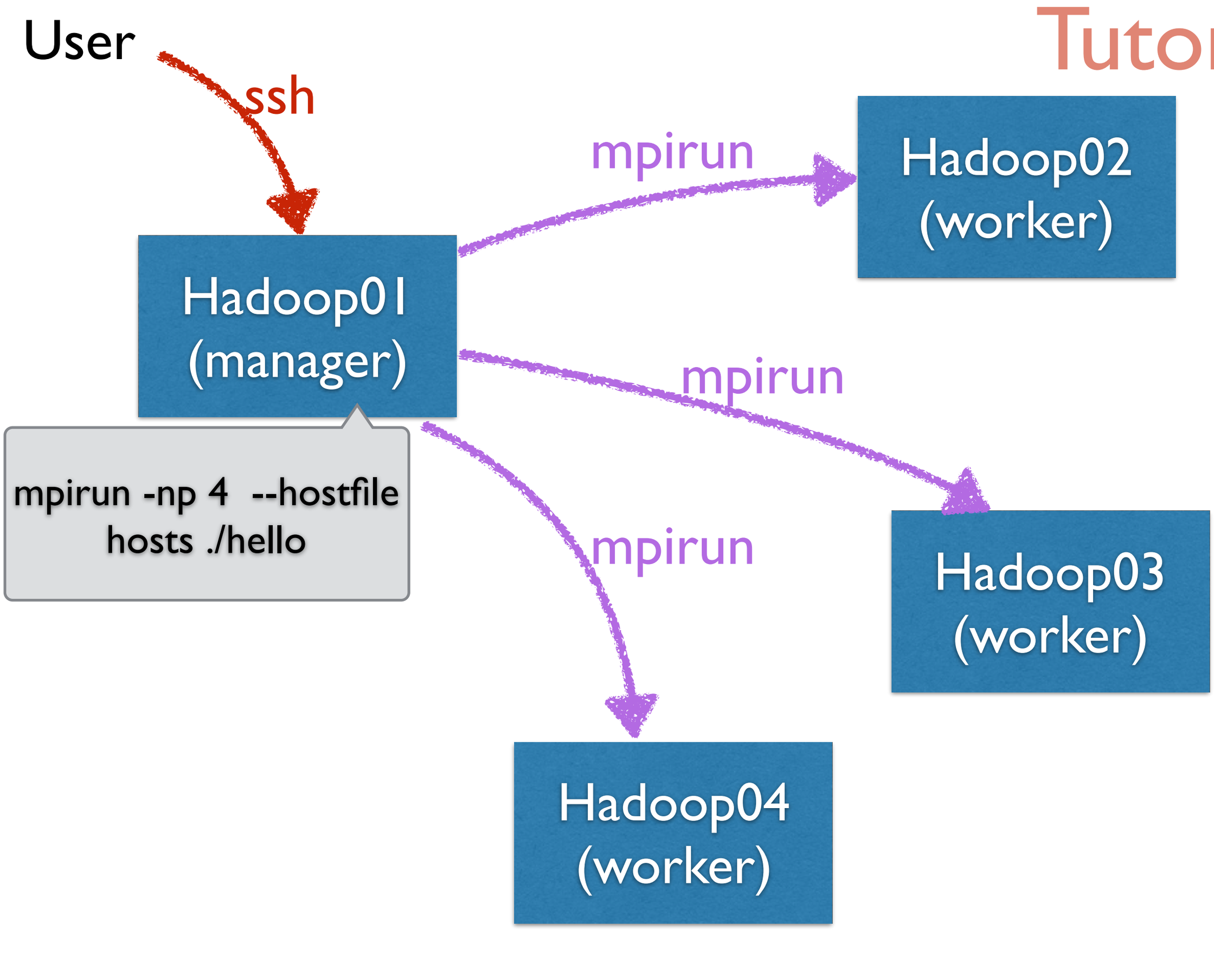
Hadoop03
(worker)

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
Hadoop02
(worker)
mpirun
Hadoop03
(worker)
mpirun
Hadoop04
(worker)
mpirun -np 4 --hostfile
hosts ./hello

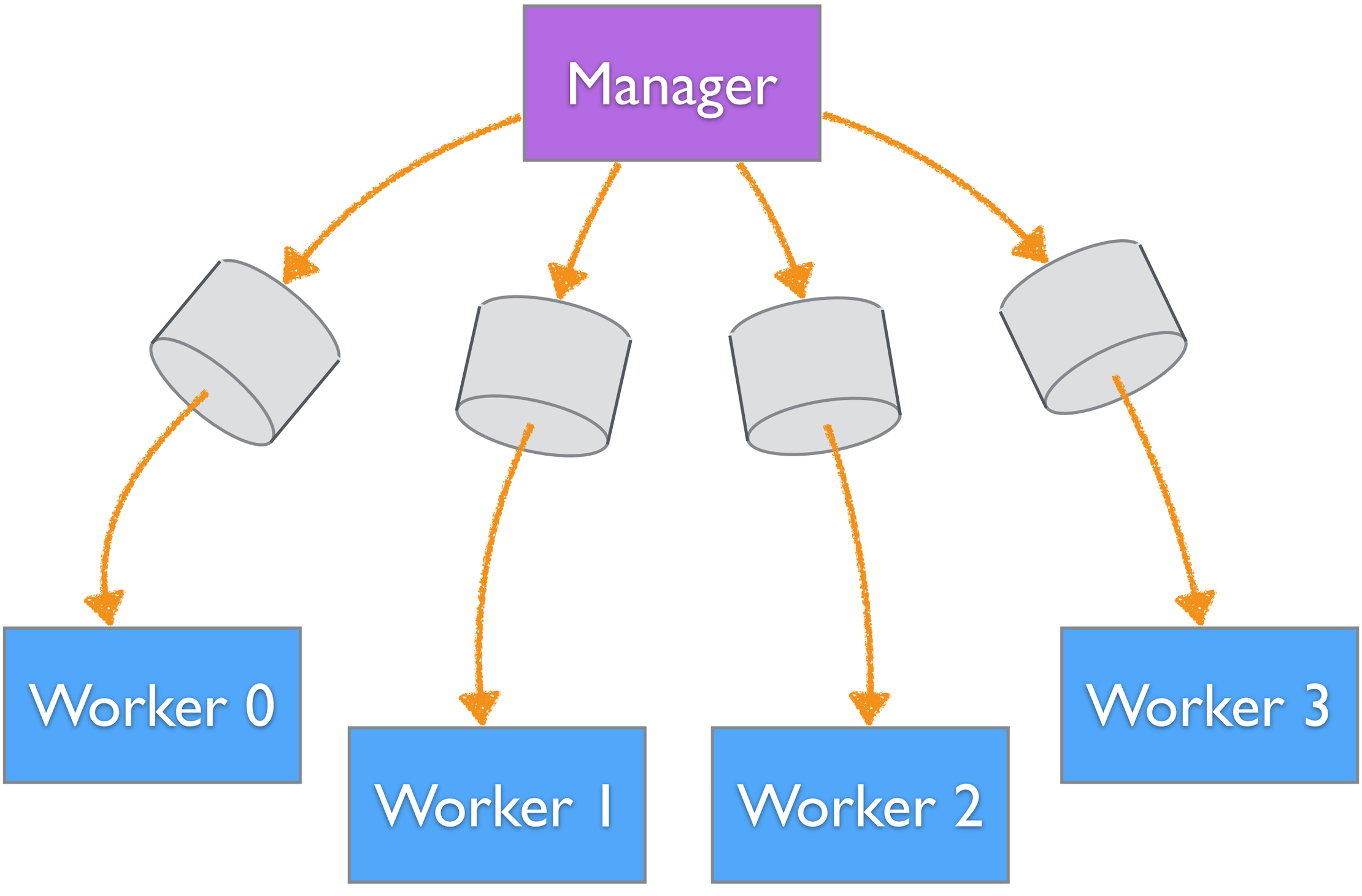
Deploy HelloWorld on the Hadoop Cluster

We Stopped Here Last Time

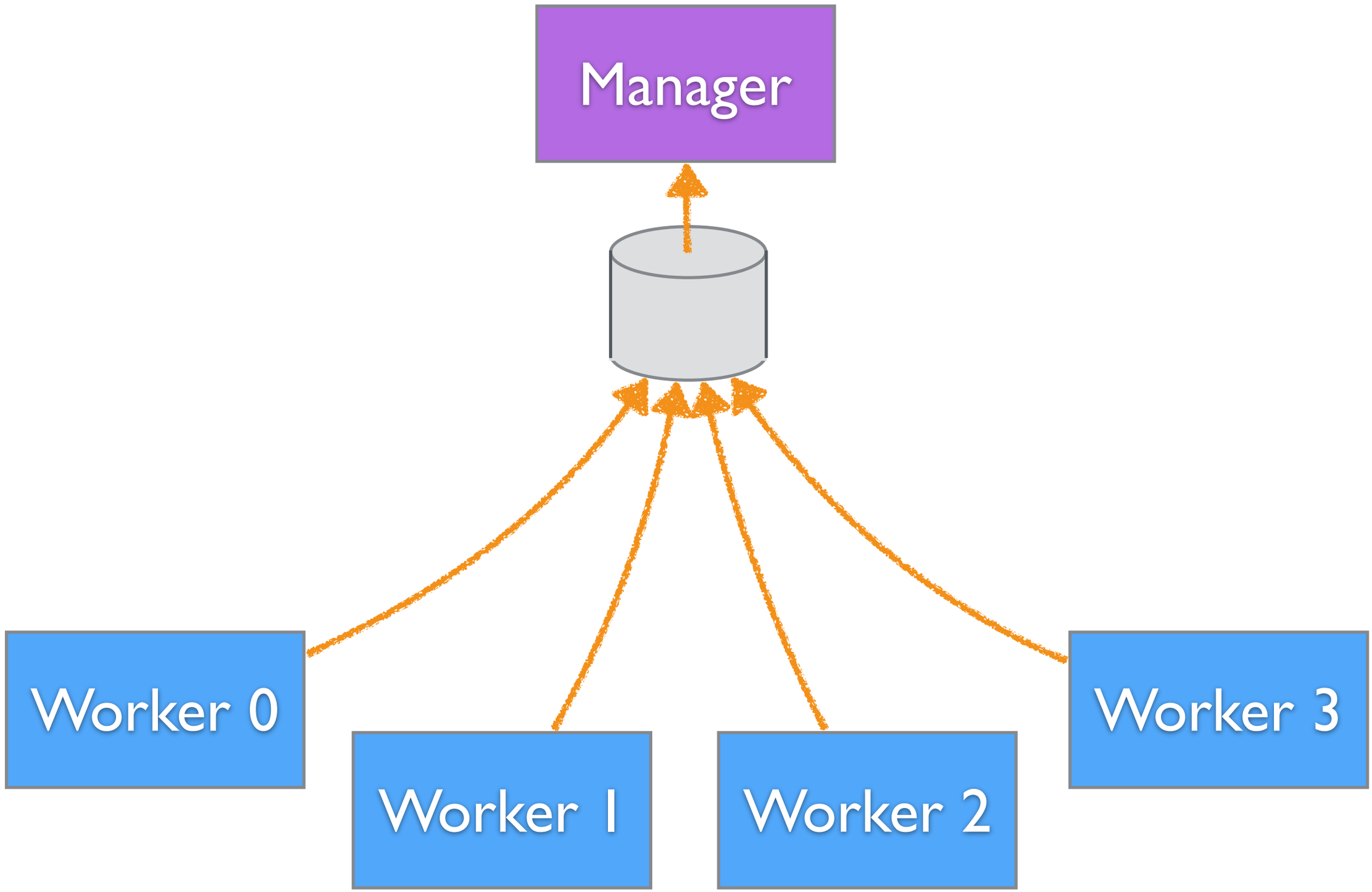
http://www.genengnews.com/media/images/genhighlight/Mar12_2014_8296129_StopSigns_GeronTrialHalt2322361121.jpg

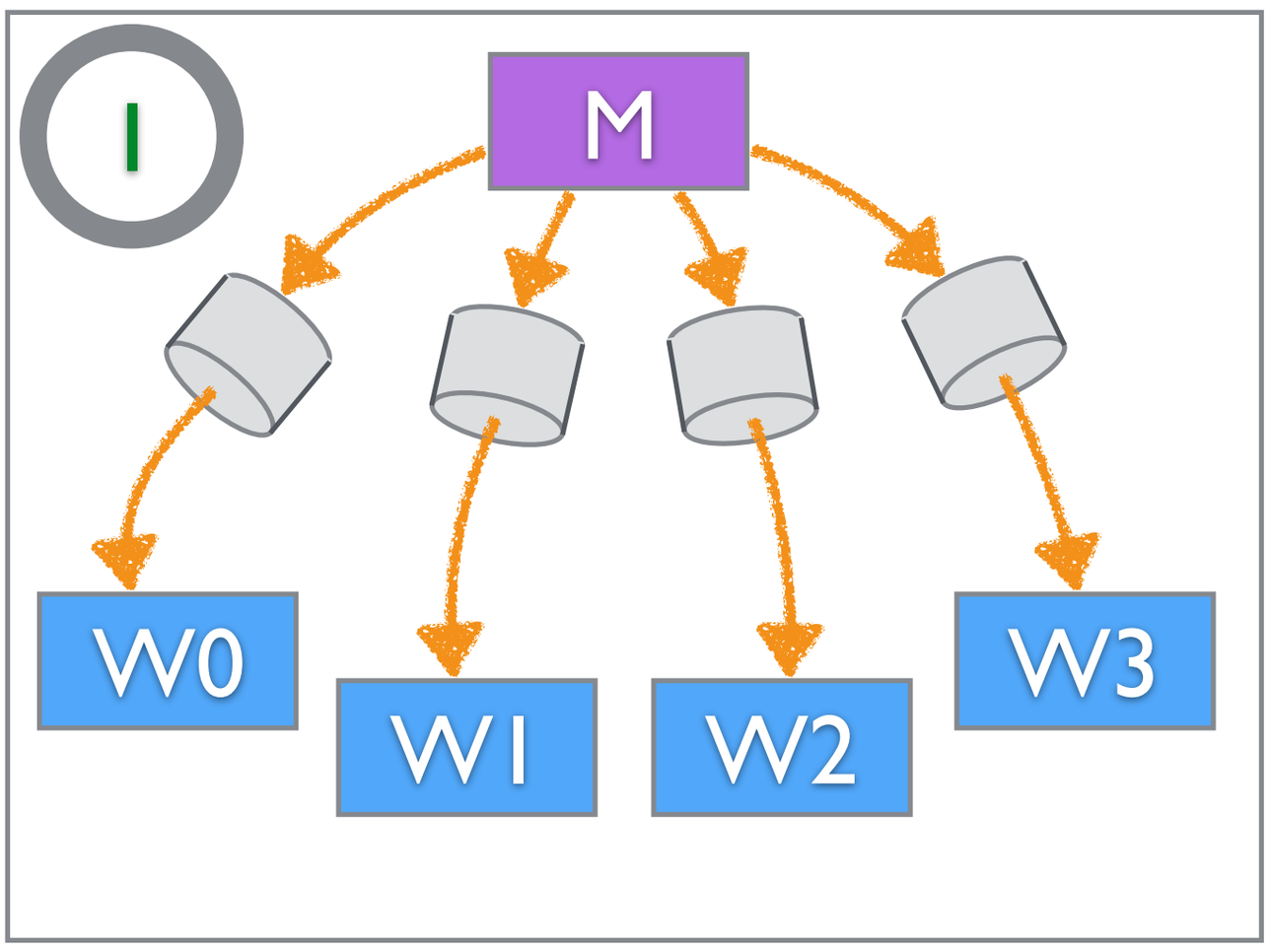
Go Over Java Multithreaded Game of Life Homework

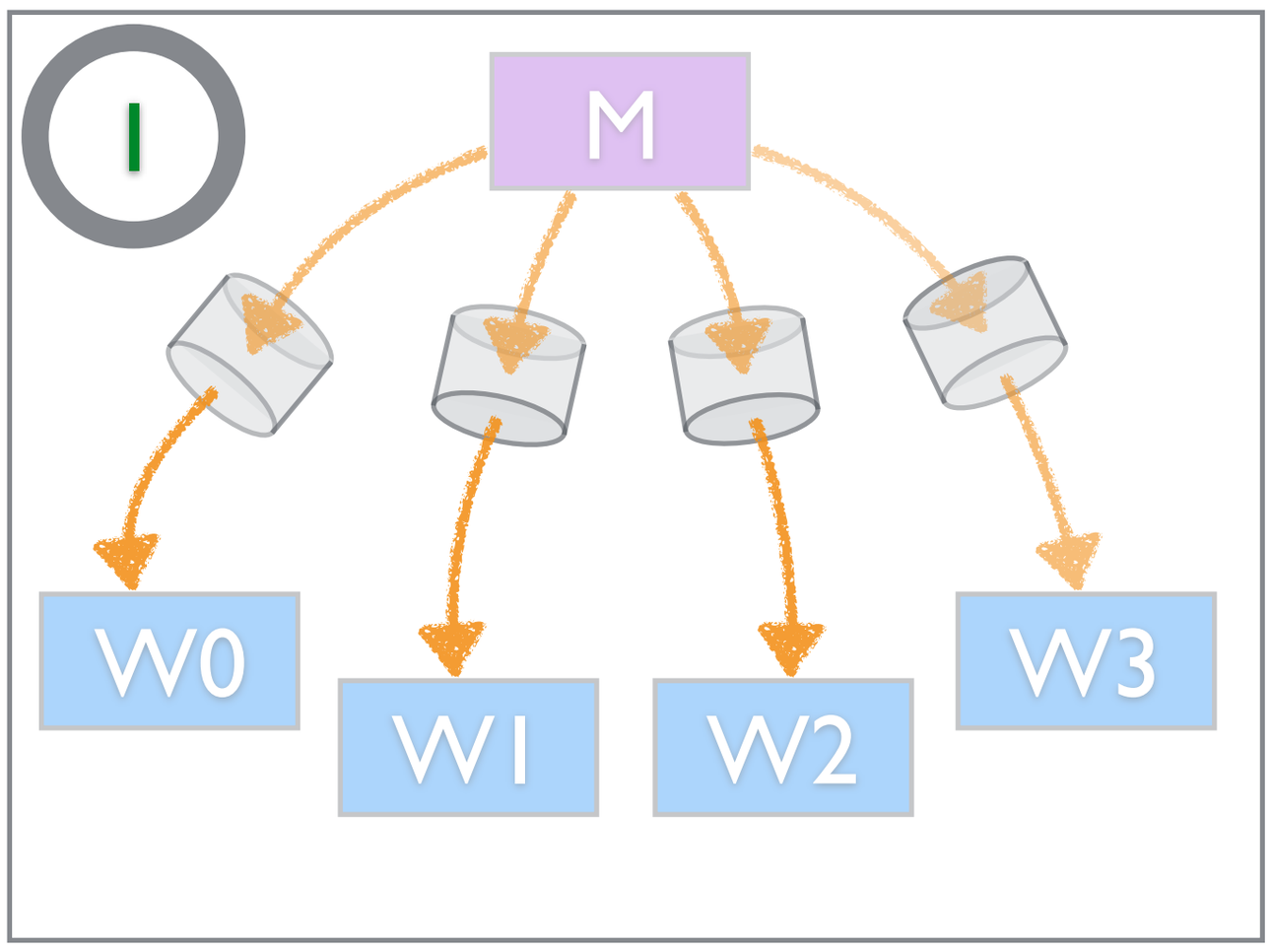
Communication Patterns

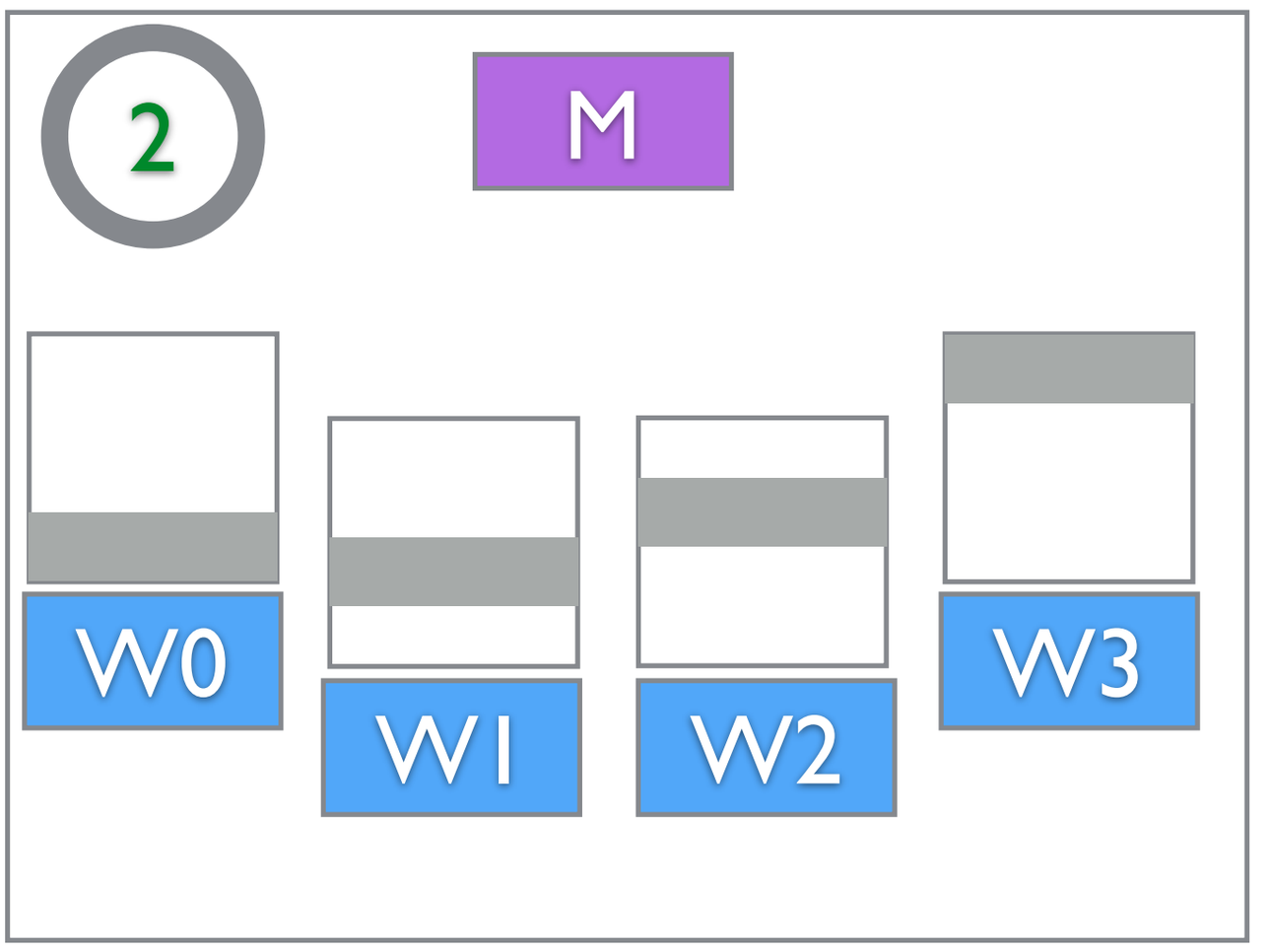


Communication Patterns

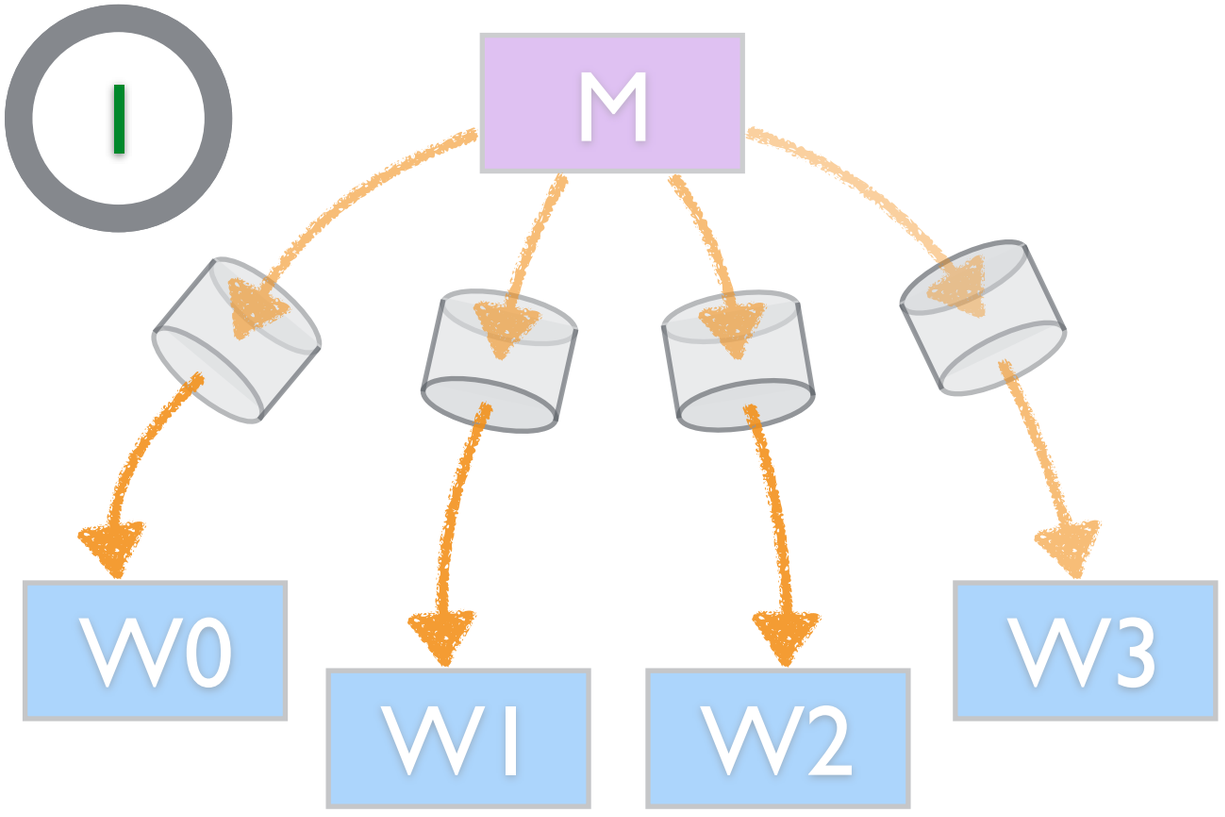



I
M
W0
W1
W2
W3

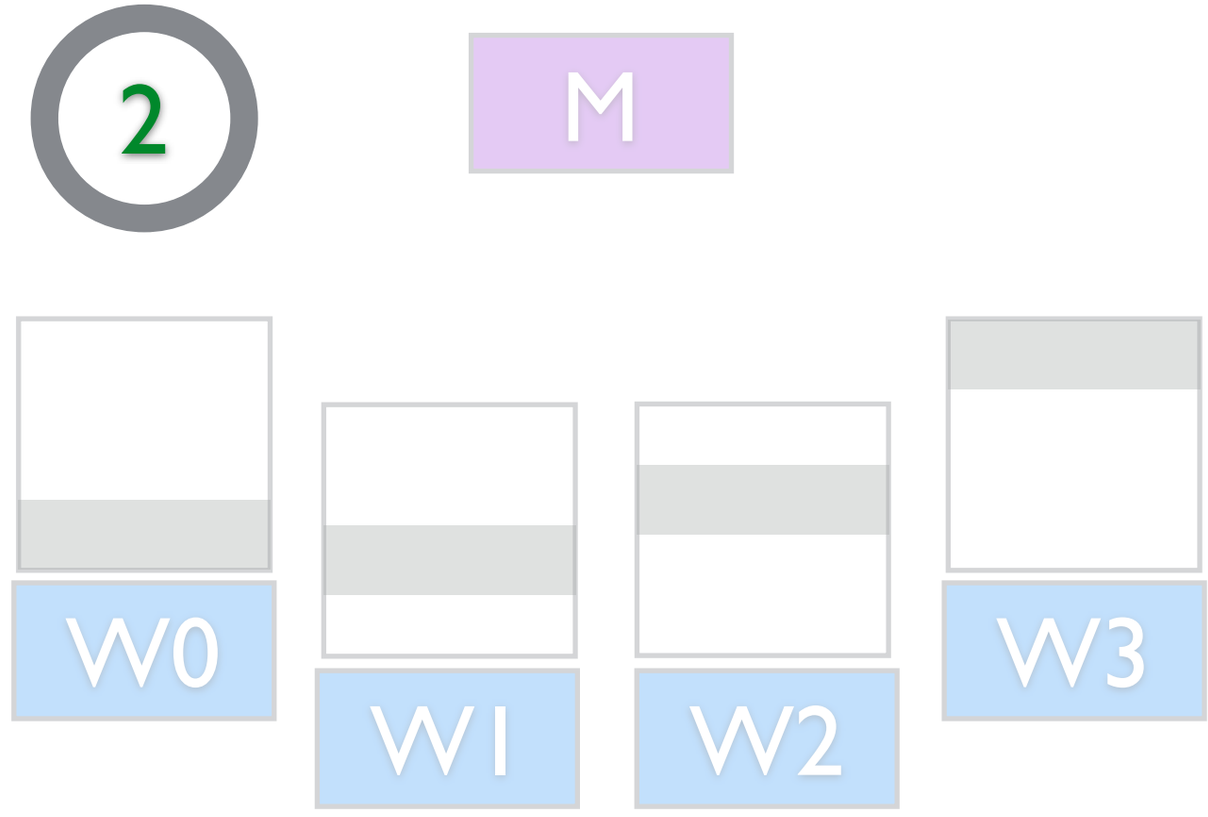

1
M
W0
W1
W2
W3


2
M
W0
W1
W2
W3

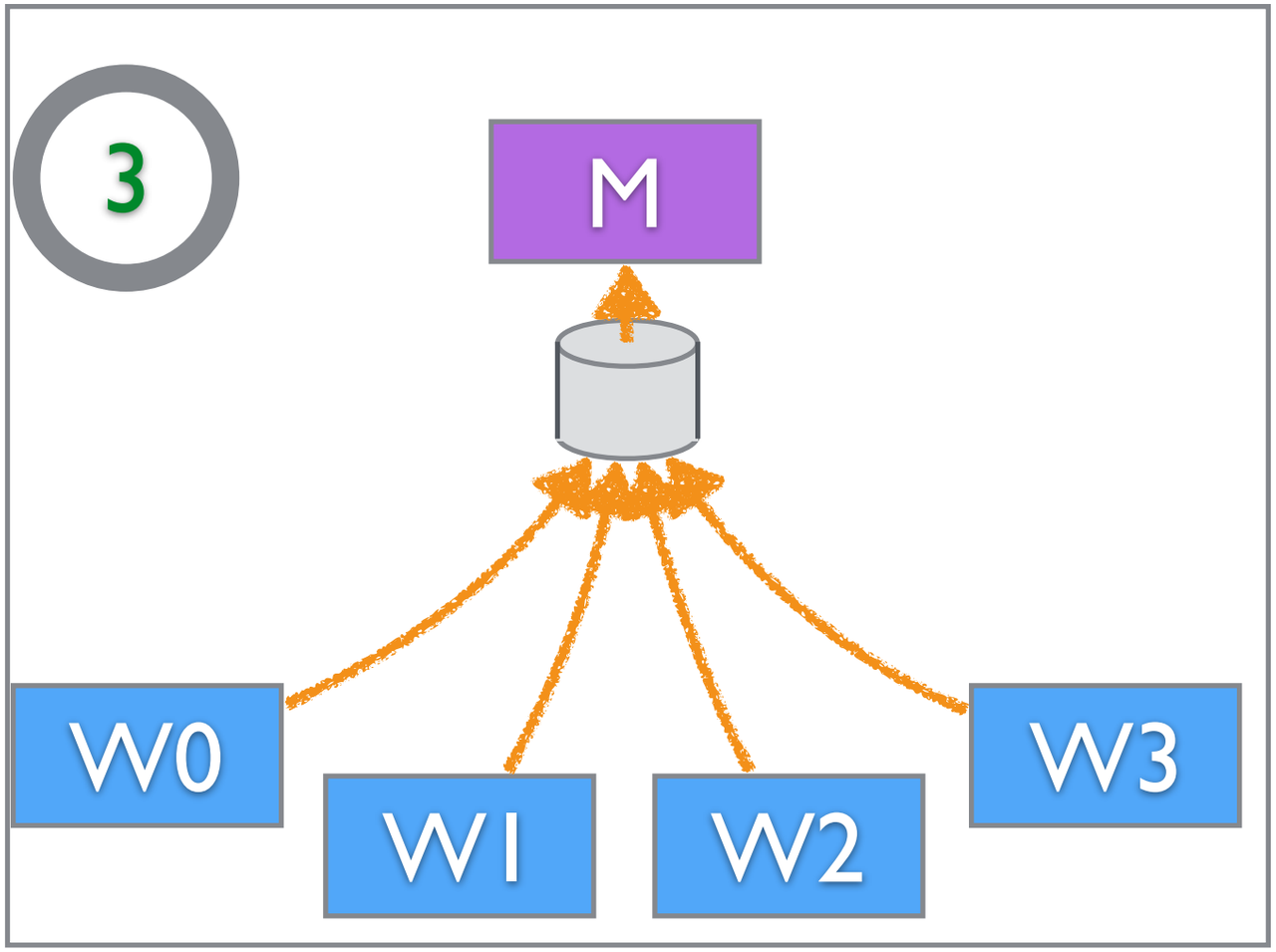
1



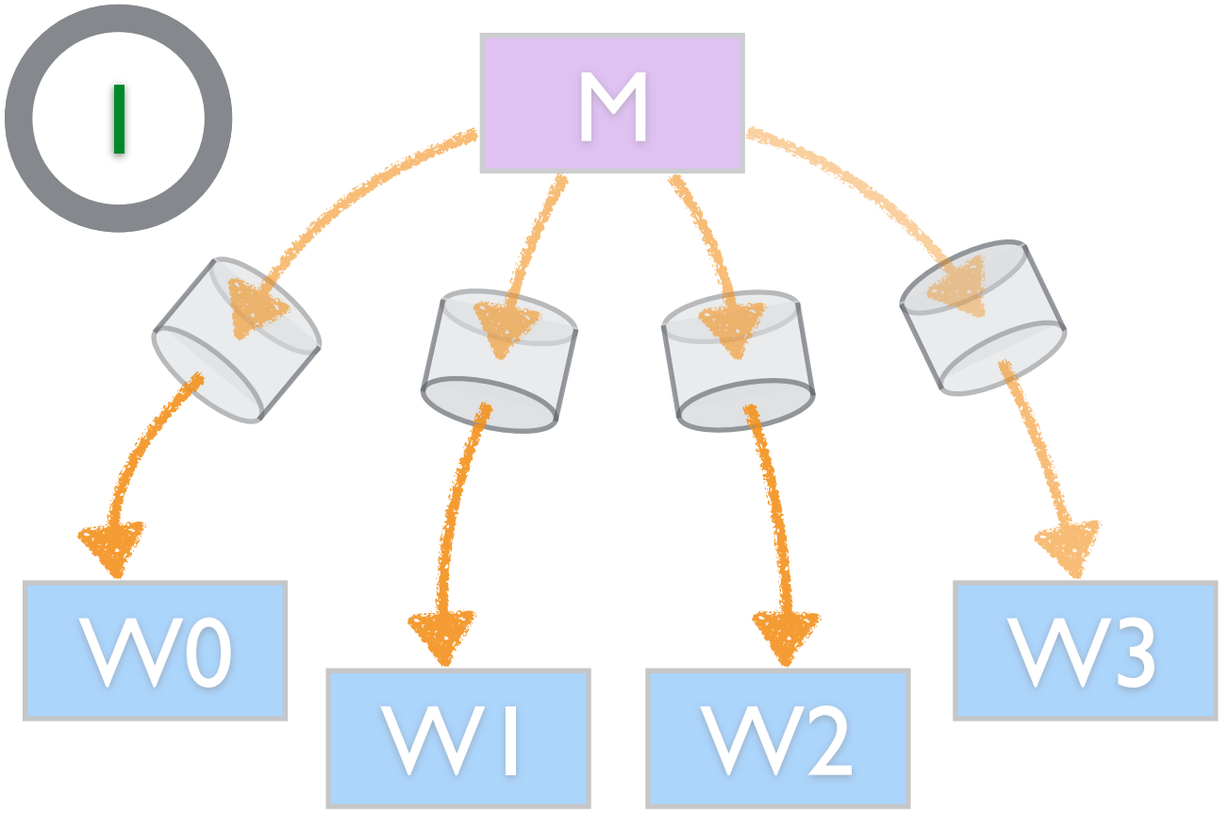
2



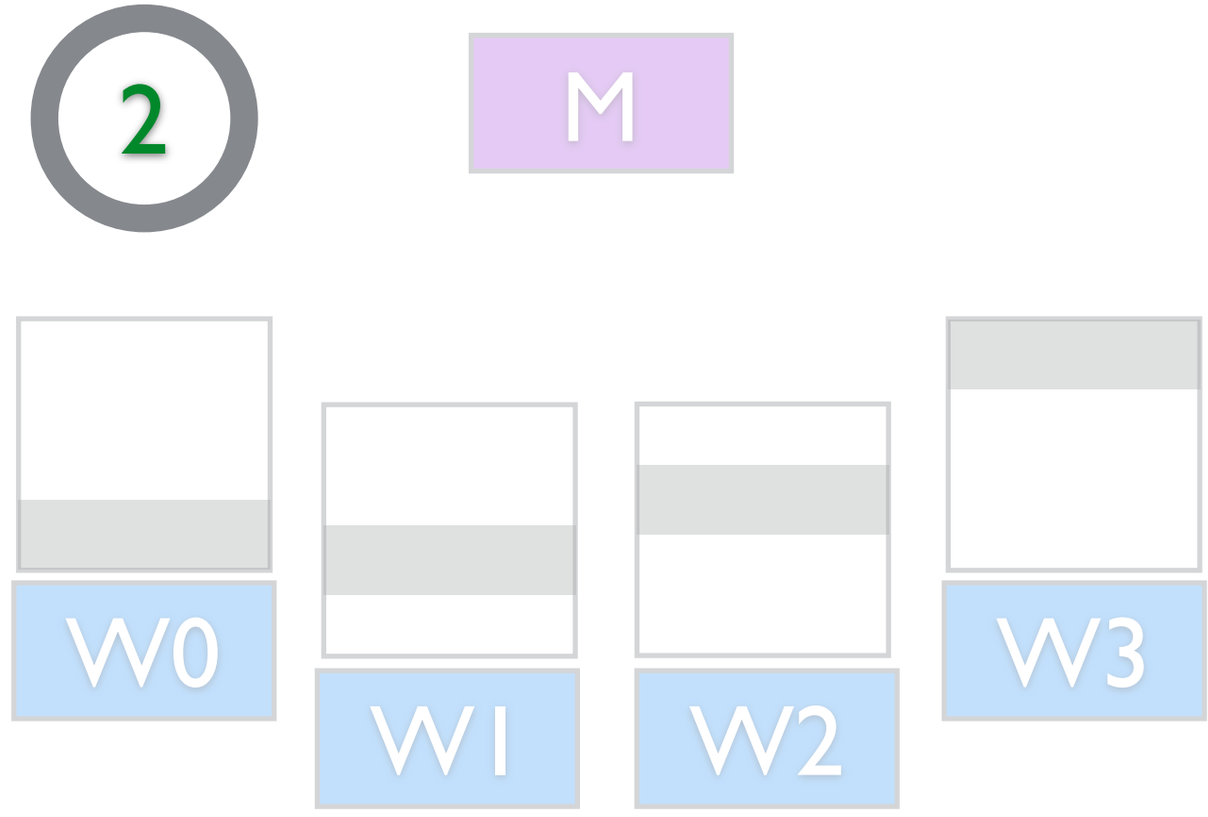
3



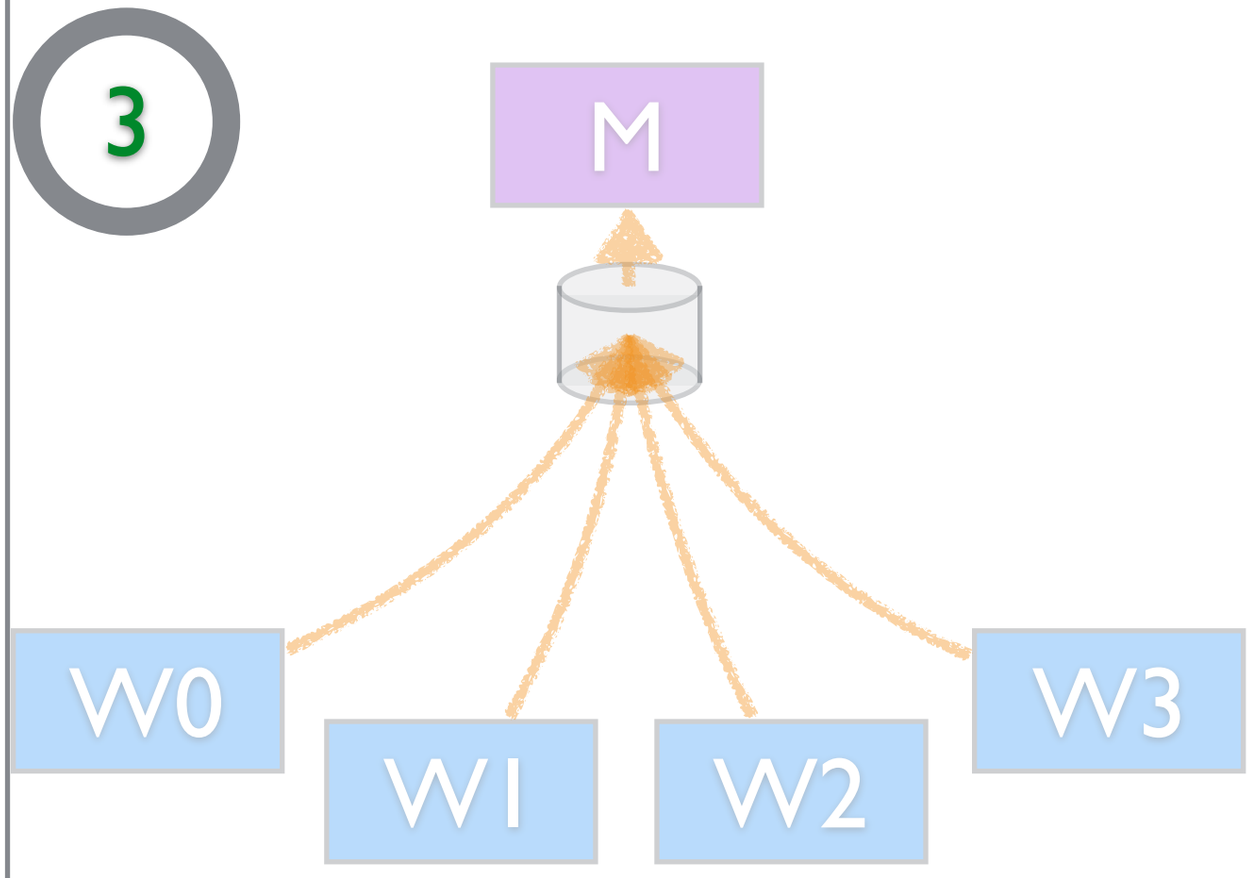
1



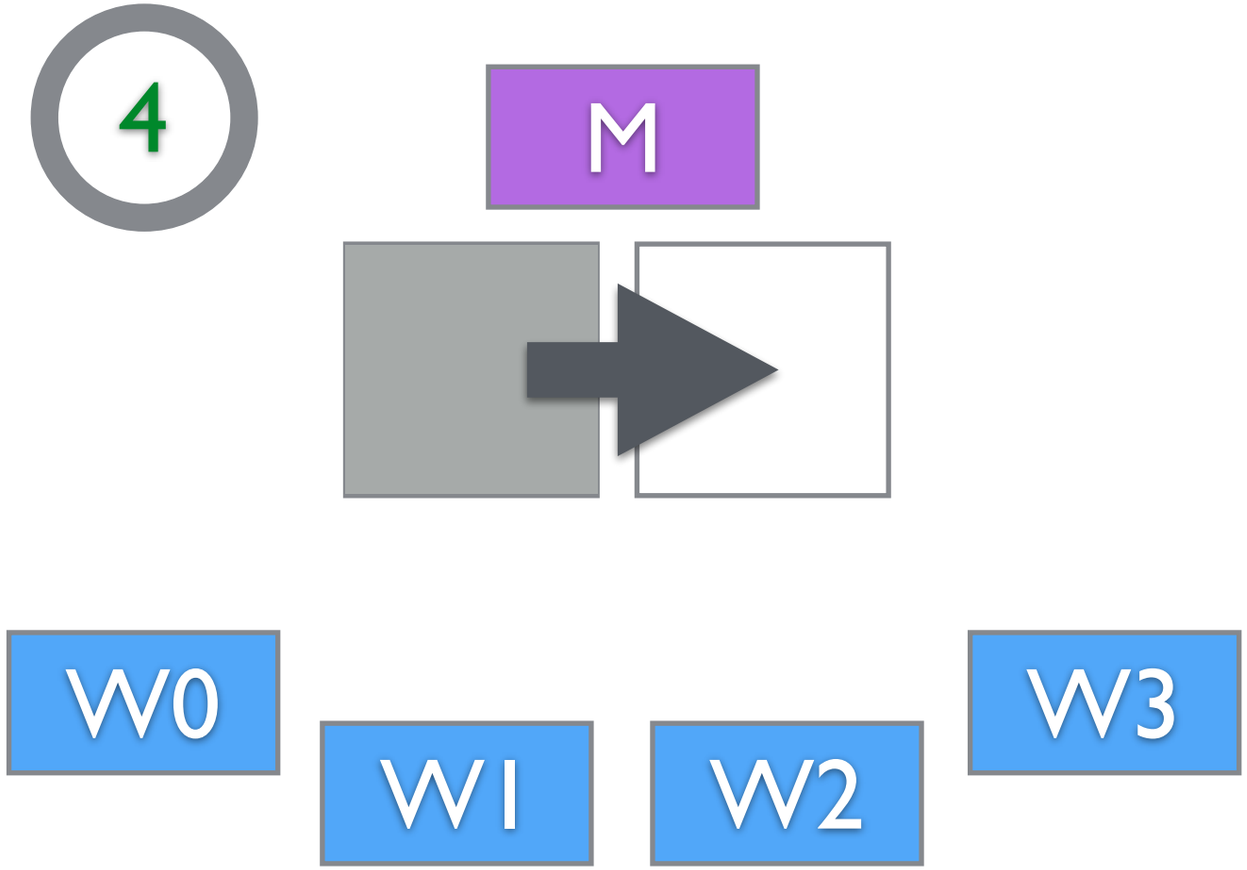
2



3



4



1

M

Go Ahead

W0

W1

W2

W3

2

M

W0

W1

W2

W3

Running Life()

3

M

We're Done!

W0

W1

W2

W3

4

M

Copy Dish

W0

W1

W2

W3

Thread Run()

```
/*
 * This will apply life repeatedly to the half of the dish array that
 * belongs to this thread.
 *
 * @see java.lang.Thread#run()
 */
public void run() {
    int noRows   = dataN.dish.length;           // number of rows in dish
    int startRow = Id * noRows / N;             // where thread starts computing life
    int endRow   = ((Id+1) * noRows / N) ;      // where thread stop computing life
    if ( Id == N-1 ) endRow = noRows;           // if last thread, make sure include last

    int command = 1;
    while ( command != 0 ) {
        life( startRow, endRow );
        // send a token, wait for token
        try {
            toManager.put( Id );
            command = fromManager.take();
        } catch (InterruptedException e) {
            e.printStackTrace();
        }
    }
}
```

getcopy GameOfLifeNThreads.java

Manager Main Loop

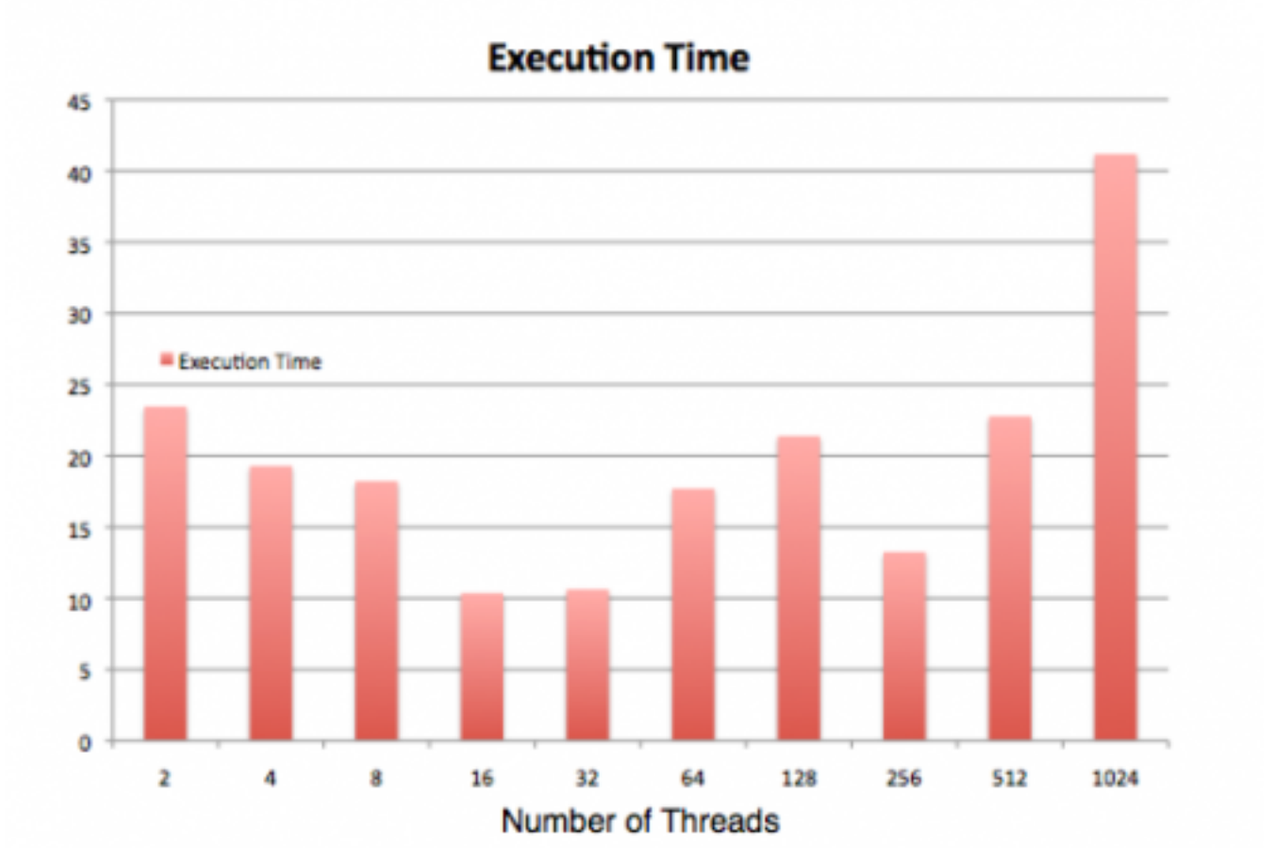
```
// go through generations
for ( int i = 0; i < gens; i++ ) {
    if ( verbose ) System.out.println( "generation " + i );

    // wait for N threads to finish their computation of
    // life
    for ( int t=0; t<N; t++ ) {
        try {
            int c = QFromThreads.take();
            if ( verbose ) System.out.println( "  Received \"Done\" message from Thread " + c );
        } catch (InterruptedException e) {
        }
    }

    if ( verbose ) System.out.println( "  Heard from all threads..." );

    // copy newGen to dish
    for ( int row=0; row < dataN.dish.length; row++ )
        dataN.dish[row] = dataN.newGen[row];

    if ( verbose ) System.out.println( "  dish copied" );
    //print( dataN.dish );

    // tell N threads to resume computation
    for ( int t=0; t<N; t++ ) {
        int command = 1;
        if (i==gens-1)
            command = 0;
        try {
            QToThreads[t].put( command );
        } catch (InterruptedException e) {
        }
    }

    if ( verbose ) System.out.println( "  all threads alerted to continue..." );
}
```

getcopy GameOfLifeNThreads.java

Manager Main Loop

```
// go through generations
for ( int i = 0; i < gens; i++ ) {
    if ( verbose ) System.out.println( "generation " + i );

    // wait for N threads to finish their computation of
    // life
    for ( int t=0; t<N; t++ ) {
        try {
            int c = QFromThreads.take();
            if ( verbose ) System.out.println( "  Received \"Done\" message from Thread " + c );
        } catch (InterruptedException e) {
        }
    }

    if ( verbose ) System.out.println( "  Heard from all threads..." );

    //copy newGen to dish
    for ( int row=1; row<=dataN.rows; row++ )
        dataN.dish[row] = dataN.newGen[row];
    if ( verbose ) System.out.println( "  dish copied" );
    //print( dataN.dish );

    // tell N threads to resume computation
    for ( int t=0; t<N; t++ ) {
        int command = 1;
        if (i==gens-1)
            command = 0;
        try {
            QToThreads[t].put( command );
        } catch (InterruptedException e) {
        }
    }

    if ( verbose ) System.out.println( "  all threads alerted to continue..." );
}
```

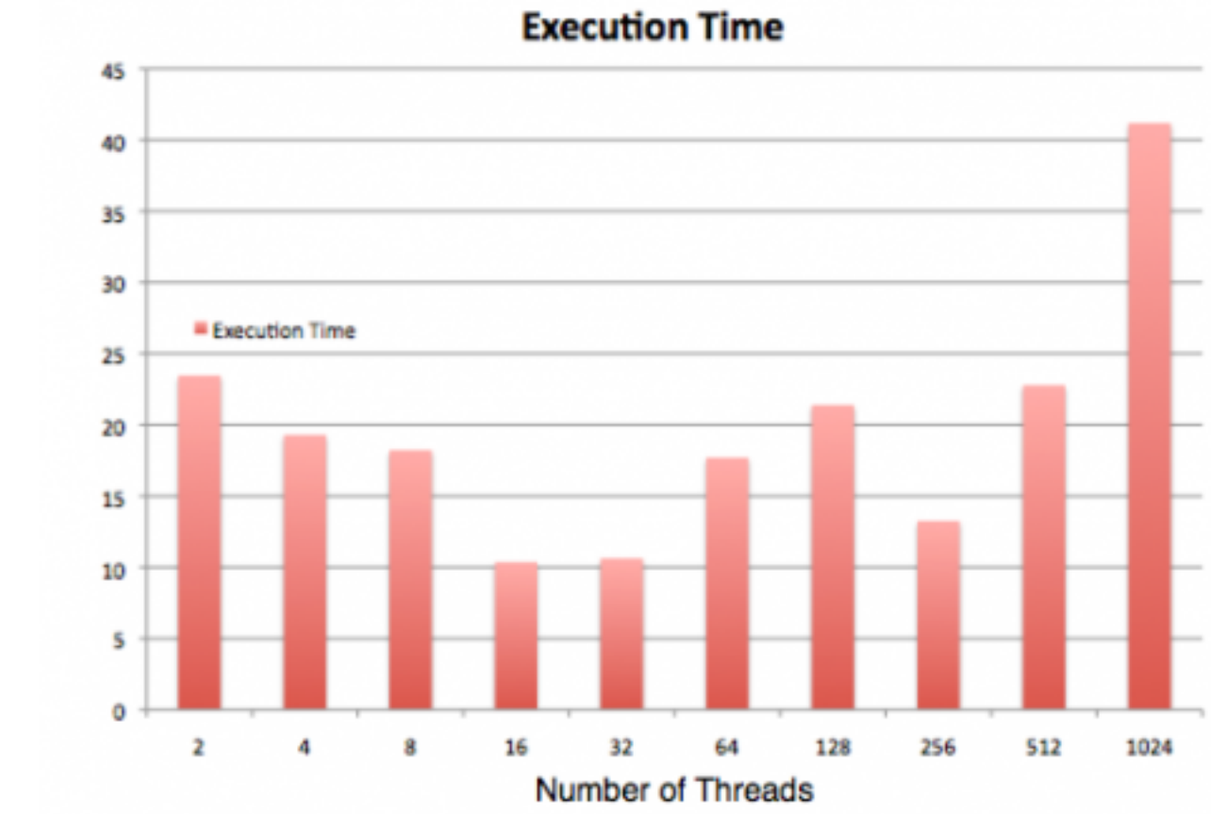
http://www.science.smith.edu/dftwiki/index.php/CSC352_Game_of_Life_in_Java,_N_Threads#Source

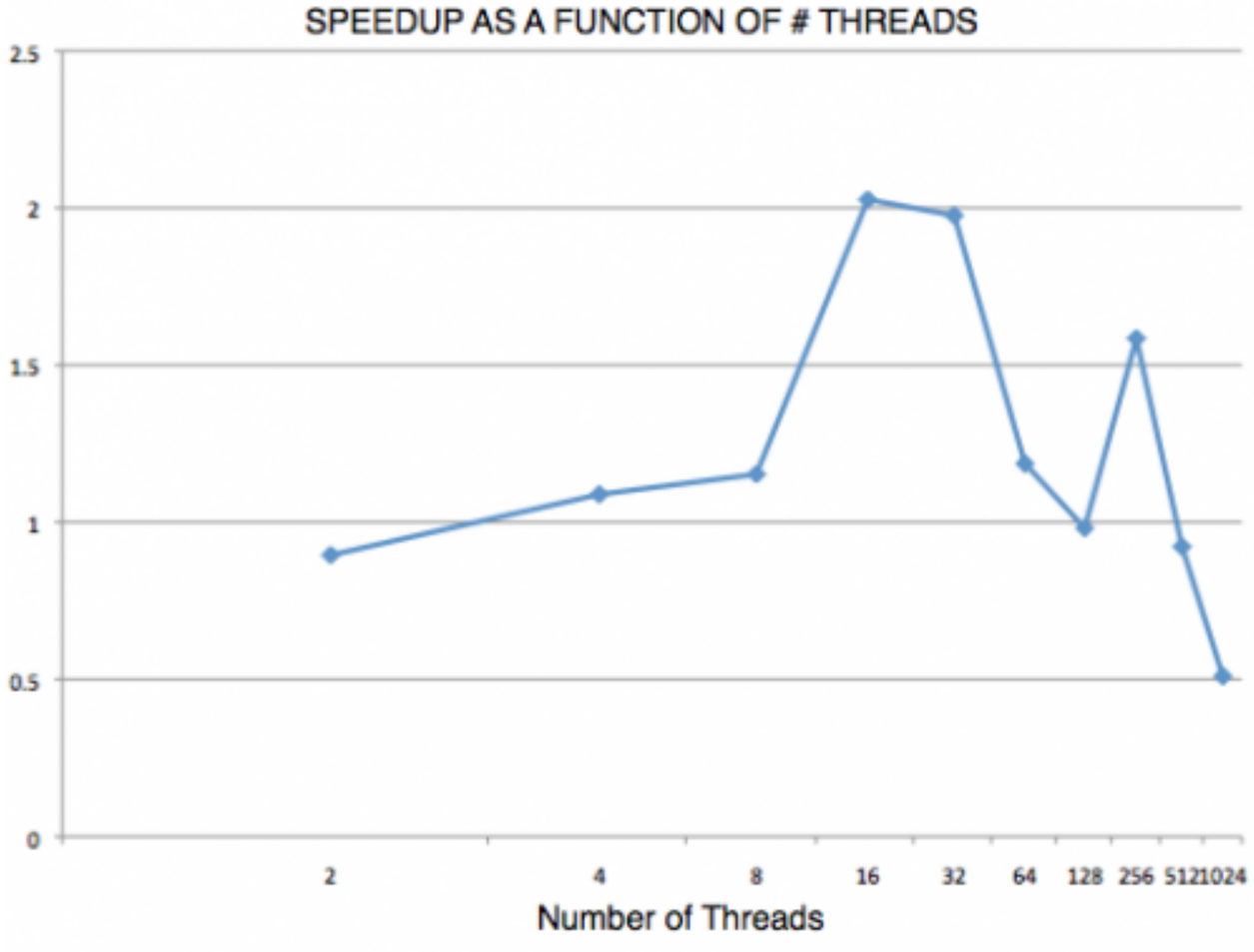


Performance

2048 rows, 80 cells wide
MacBook Pro 2014
4 cores, 2.8 GHz

Performance





Threads	Speedup
2	0.895231676
4	1.088301802
8	1.152712505
16	2.026521961
32	1.976106799
64	1.186445303
128	0.981590412
256	1.584739771
512	0.921974566
1024	0.510000713

Questions

- What serial program should be used to compute the speedup?
- What does the speedup curve tell us?
- What is the general shape of the speedup curve? How could we make it "smoother"?
- What could be done to the Java program to make it faster? *Think hard…*

Back to MPI!

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

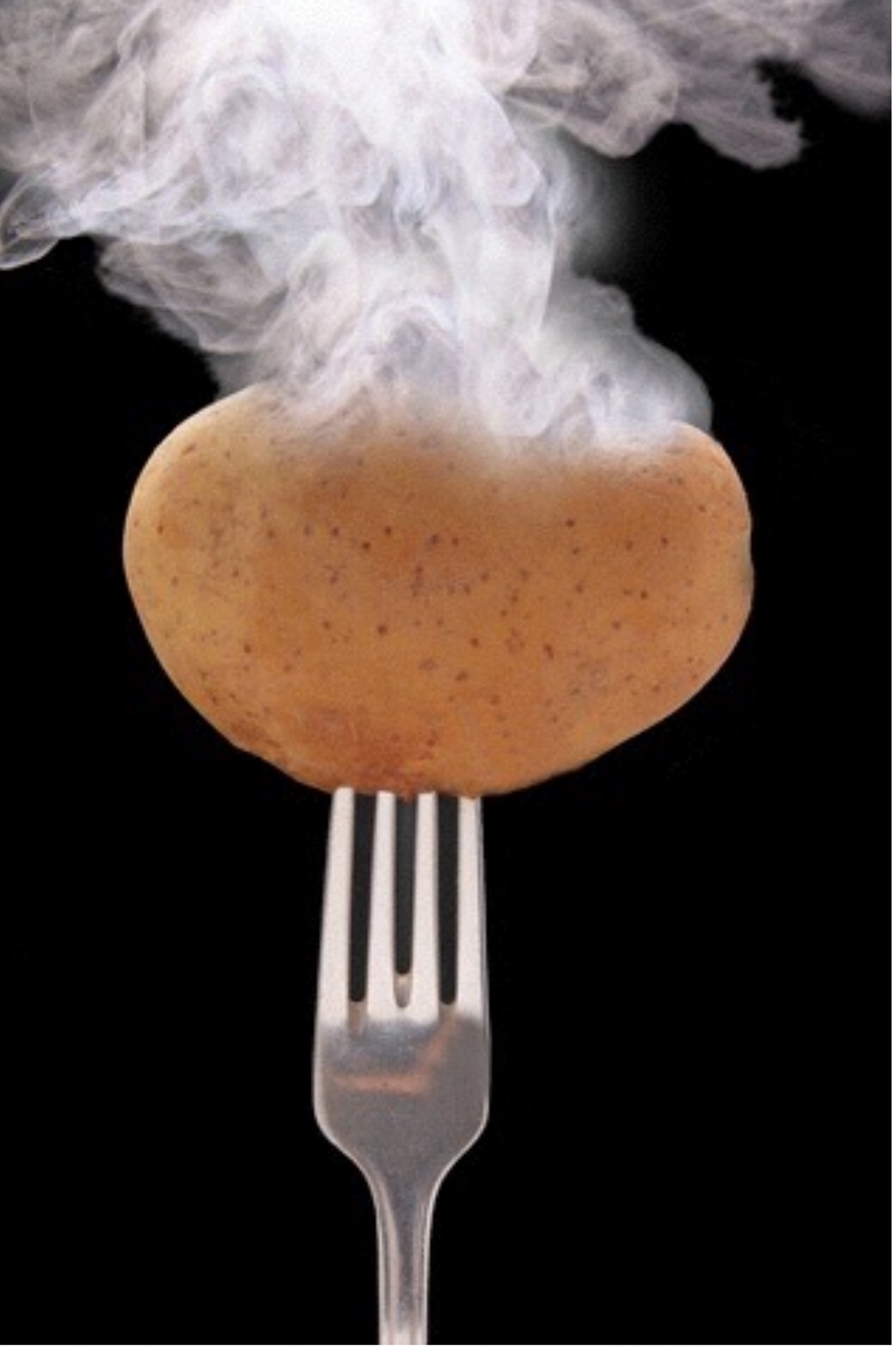
Status Structure

```
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

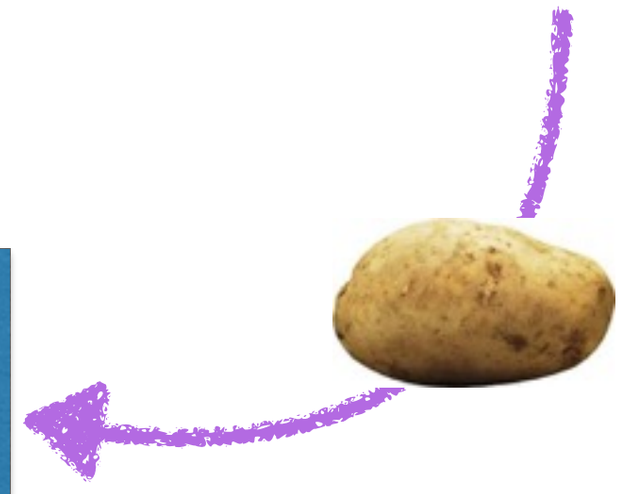
Worker 2

Worker N-1

Worker 1

Manager

Worker 2

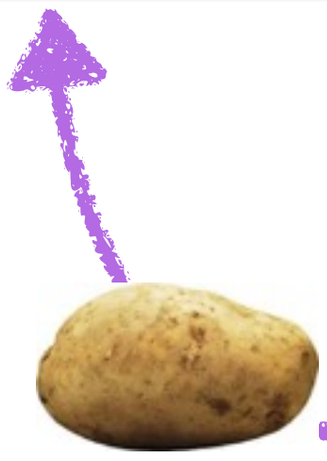


Worker N-1

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 the command line.

```
#include <stdlib.h>

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

First program generated in class

```c
/* hotPotato.c
   D. Thiebaut
   Hot potato passing around, with N processes.

   The manager (Process 0) passes the potato to Worker 1,
   which passes it to worker 2, etc... until the manager
   gets it back again and quits.

 */
#include <stdio.h>
#include <mpi.h>

#define MANAGER 0
int main ( int argc, char *argv[] ) {
  int rank, size;
  int potato =  1213;
  MPI_Status status;   // required variable for receive routines

  MPI_Init (&argc, &argv);      /* starts MPI */
  MPI_Comm_rank (MPI_COMM_WORLD, &rank);        /* get current process id */
  MPI_Comm_size (MPI_COMM_WORLD, &size);        /* get number of processes */


  if ( rank == MANAGER ) {
    //        buffer   #items  item-size src/dest       tag   world
    MPI_Send( &potato, 1,      MPI_INT,  1,             0,    MPI_COMM_WORLD );
    printf( "Manager sent potato!\n" );
    MPI_Recv( &potato, 1,      MPI_INT,  size-1,        0,    MPI_COMM_WORLD, &status  );
    printf( "Manager got potato back!\n" );
  }
  else {
    MPI_Recv( &potato, 1,      MPI_INT,  rank-1,        0, MPI_COMM_WORLD, &status );
    printf( "Worker %d got potato!\n", rank );
    MPI_Send( &potato, 1,      MPI_INT,  (rank+1)%size, 0, MPI_COMM_WORLD );
  }

  MPI_Finalize();
  return 0;
}
```

First program generated in class

```
/* hotPotato.c
   D. Thiebaut
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  int rank, size;
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  MPI_Status status;   // required

  MPI_Init (&argc, &argv);      /* starts MPI */
  MPI_Comm_rank (MPI_COMM_WORLD, &rank);        /* get current process id */
  MPI_Comm_size (MPI_COMM_WORLD, &size);        /* get number of processes */


  if ( rank == MANAGER ) {
    //        buffer   #items  item-size src/dest       tag   world
    MPI_Send( &potato, 1,      MPI_INT,  1,             0,    MPI_COMM_WORLD );
    printf( "Manager sent potato!\n" );
    MPI_Recv( &potato, 1,      MPI_INT,  size-1,        0,    MPI_COMM_WORLD, &status  );
    printf( "Manager got potato back!\n" );
  }
  else {
    MPI_Recv( &potato, 1,      MPI_INT,  rank-1,        0, MPI_COMM_WORLD, &status );
    printf( "Worker %d got potato!\n", rank );
    MPI_Send( &potato, 1,      MPI_INT,  (rank+1)%size, 0, MPI_COMM_WORLD );
  }

  MPI_Finalize();
  return 0;
}
```
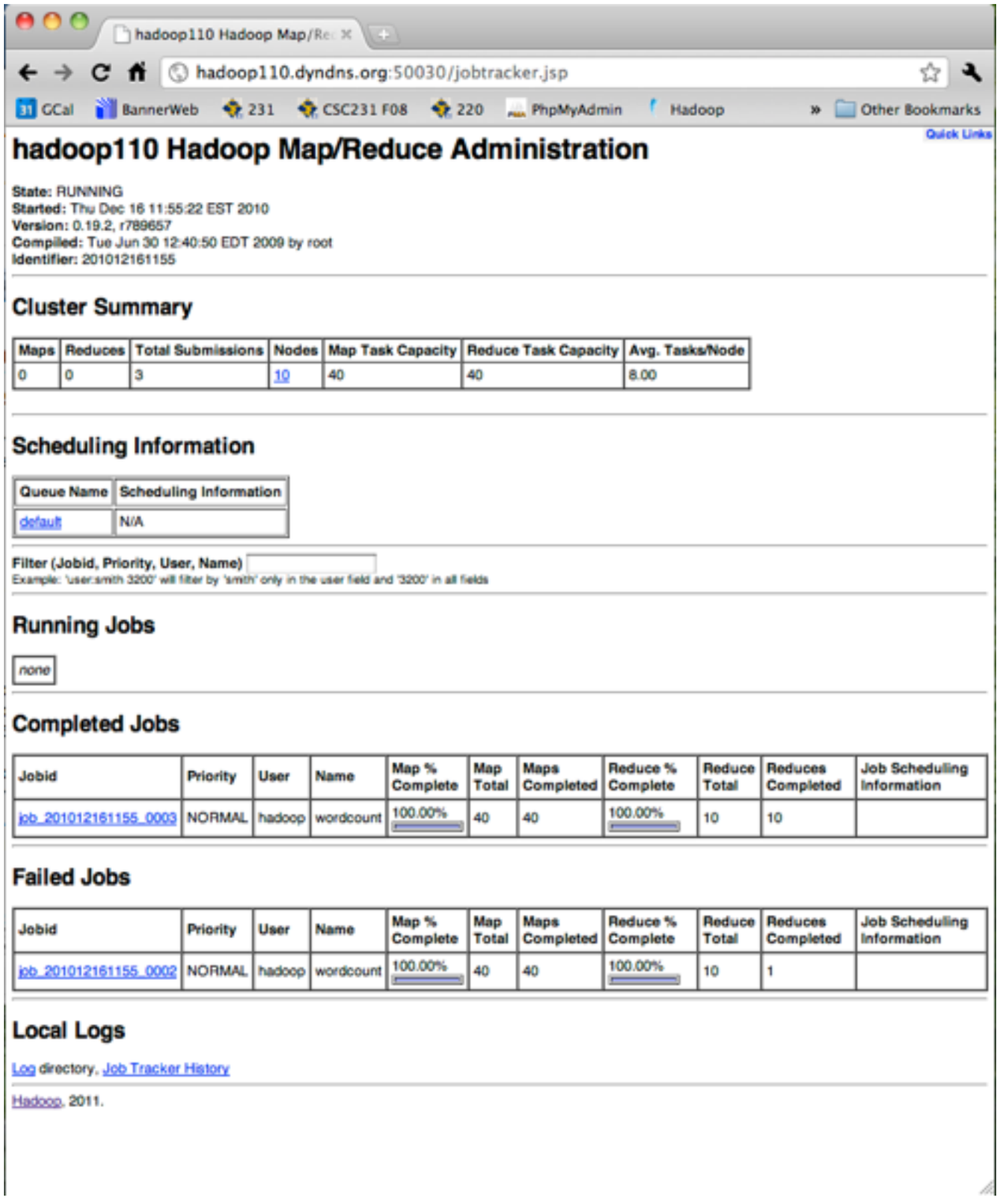

```
352b@aurora ~/handout/mpi $ mpicc hotPotato.c -o hotPotato
352b@aurora ~/handout/mpi $ mpirun -np 2 ./hotPotato
Manager sent potato!
Worker 1 got potato!
Manager got potato back!
352b@aurora ~/handout/mpi $
```

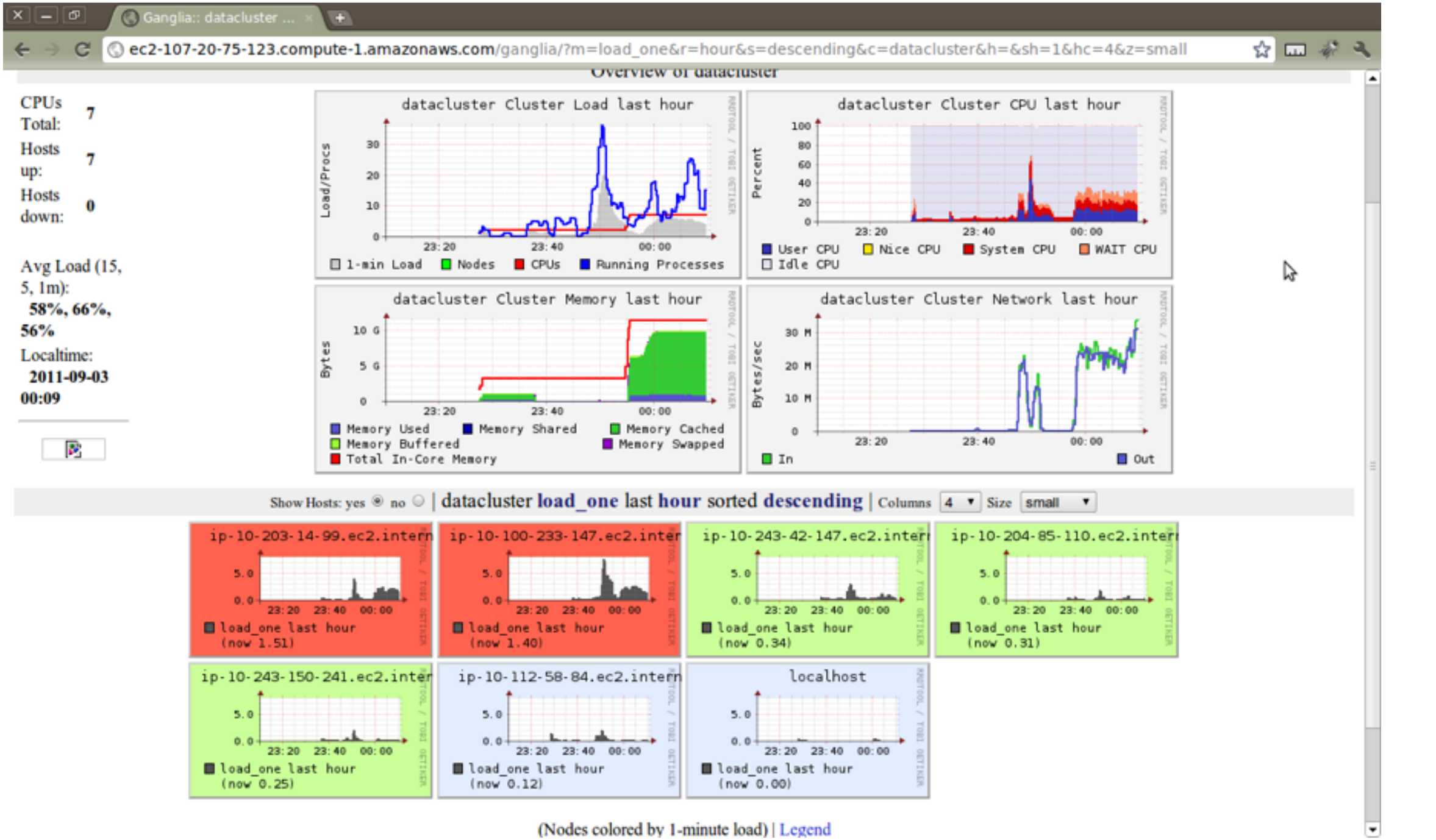
We Stopped Here Last Time

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

Misc Notes on Paper Presentations

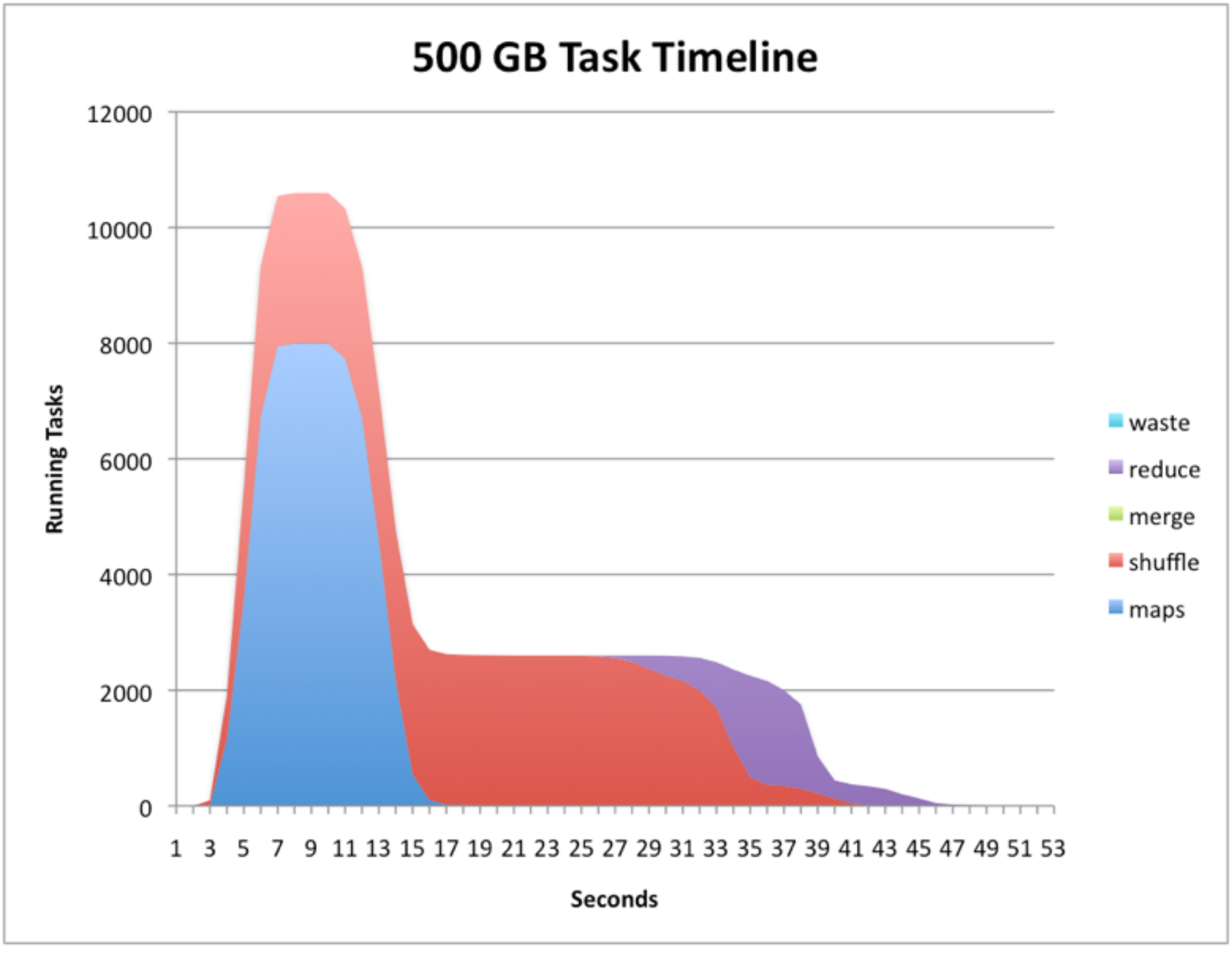


Hadoop Web Console



Ganglia Console for Hadoop

Typical Map-Reduce Job



In reference to “Nobody ever got fired…”

PROCESSING WIKIPEDIA DUMPS

A Case-Study comparing the XGrid and MapReduce Approaches

Dominique Thiébaut, Yang Li, Diana Jaunzeikare, Alexandra Cheng, Ellysha Raelen Recto,
Gillian Riggs, Xia Ting Zhao, Tonje Stolpestad, Cam Le T Nguyen
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Keywords: Grid Computing, XGrid, Hadoop, wikipedia, data mining, performance .

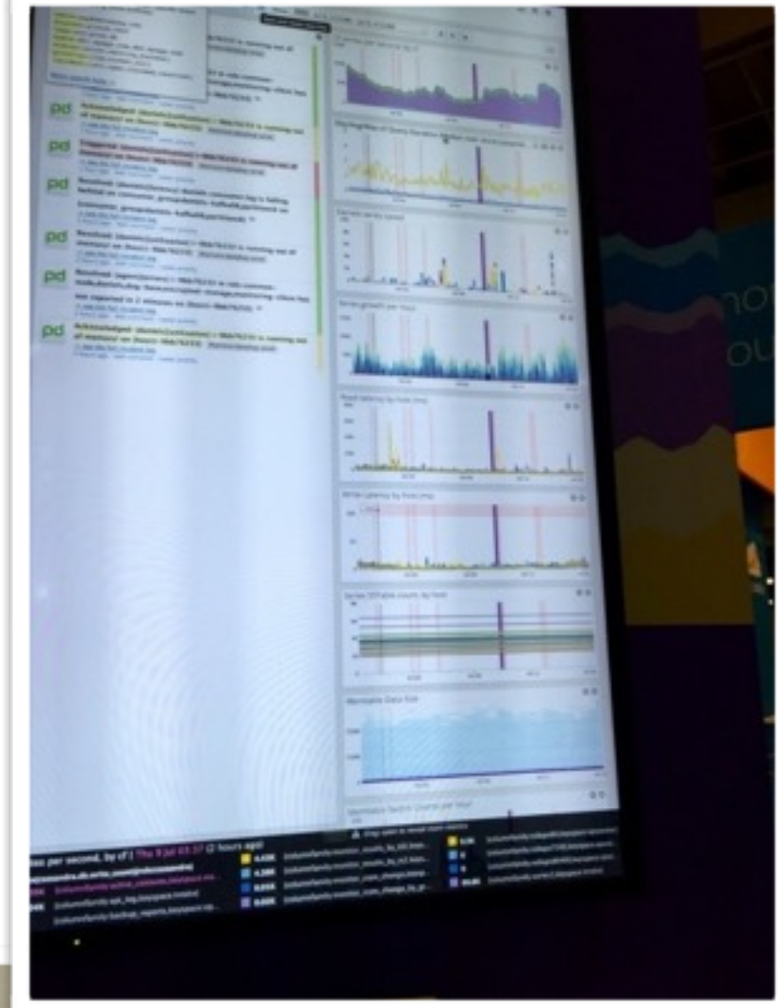
Abstract: We present a simple comparison of the performance of three different cluster platforms: Apple’s XGrid, and Hadoop the open-source version of Google’s MapReduce as the total execution time taken by each to parse a 27-GByte XML dump of the English wikipedia. A local hadoop cluster of Linux workstation, as well as an Elastic MapReduce cluster rented from Amazon are used. We show that for this specific workload, XGrid yields the fastest execution time, with the local Hadoop cluster a close second. The overhead of fetching data from Amazon’s Simple Storage System (S3), along with the inability to skip the reduce, sort, and merge phases on Amazon penalizes this platform targeted for much larger data sets.

1 INTRODUCTION

The aim of this paper is to find the fastest parallel computer cluster available at Smith College for processing Wikipedia dumps and for generating word statistics. We implement the parsing of the XML dump of the English wikipedia, and the gathering of word usage on an Apple XGrid system, and on two Hadoop clusters, one local, the other hosted on Amazon, and report on the performance obtained from paper we investigate whether hadoop is a contender, and under which conditions the execution time of the parsing process is comparable on both frameworks.

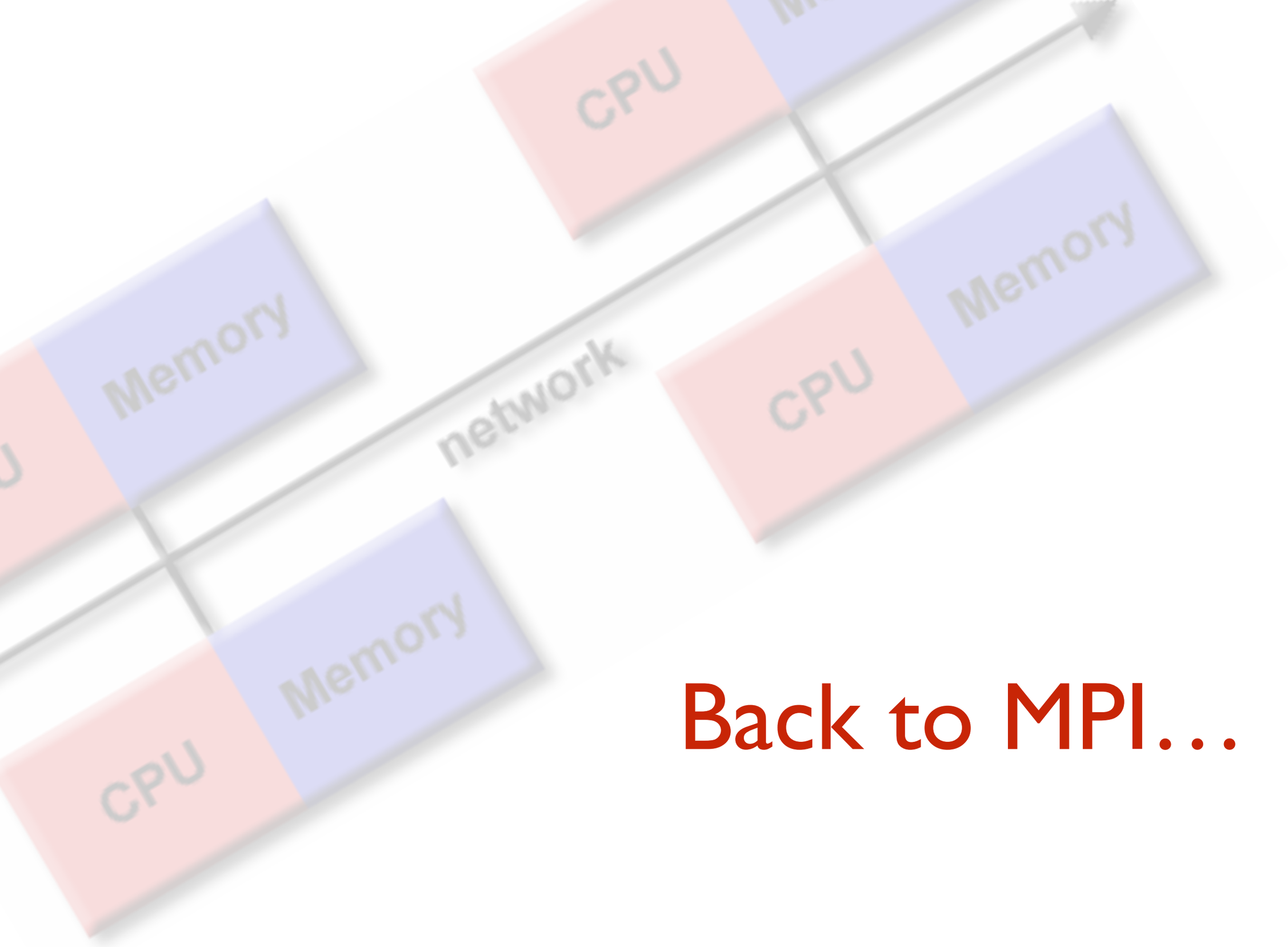
When low-cost, powerful, and easily accessible parallel computational platforms are available, it is important to better understand their source of performance and pick the best one for a solving a given problem.

AWS 2015 NYC



SC 16
Salt Lake City

https://i2.wp.com/www.appentra.com/wp-content/uploads/2016/11/sc16.jpg?fit=1200%2C618



Back to MPI…

An Example: Computing Pi With MPI

$$
\begin{aligned}
\delta &= 1/N \\
\pi &= 4\delta(4 + 4/(1+\delta^2) + 4/(1+(2\delta)^2) + \ldots + 4/(1+((N-1)\delta)^2))
\end{aligned}
$$

Computing Pi

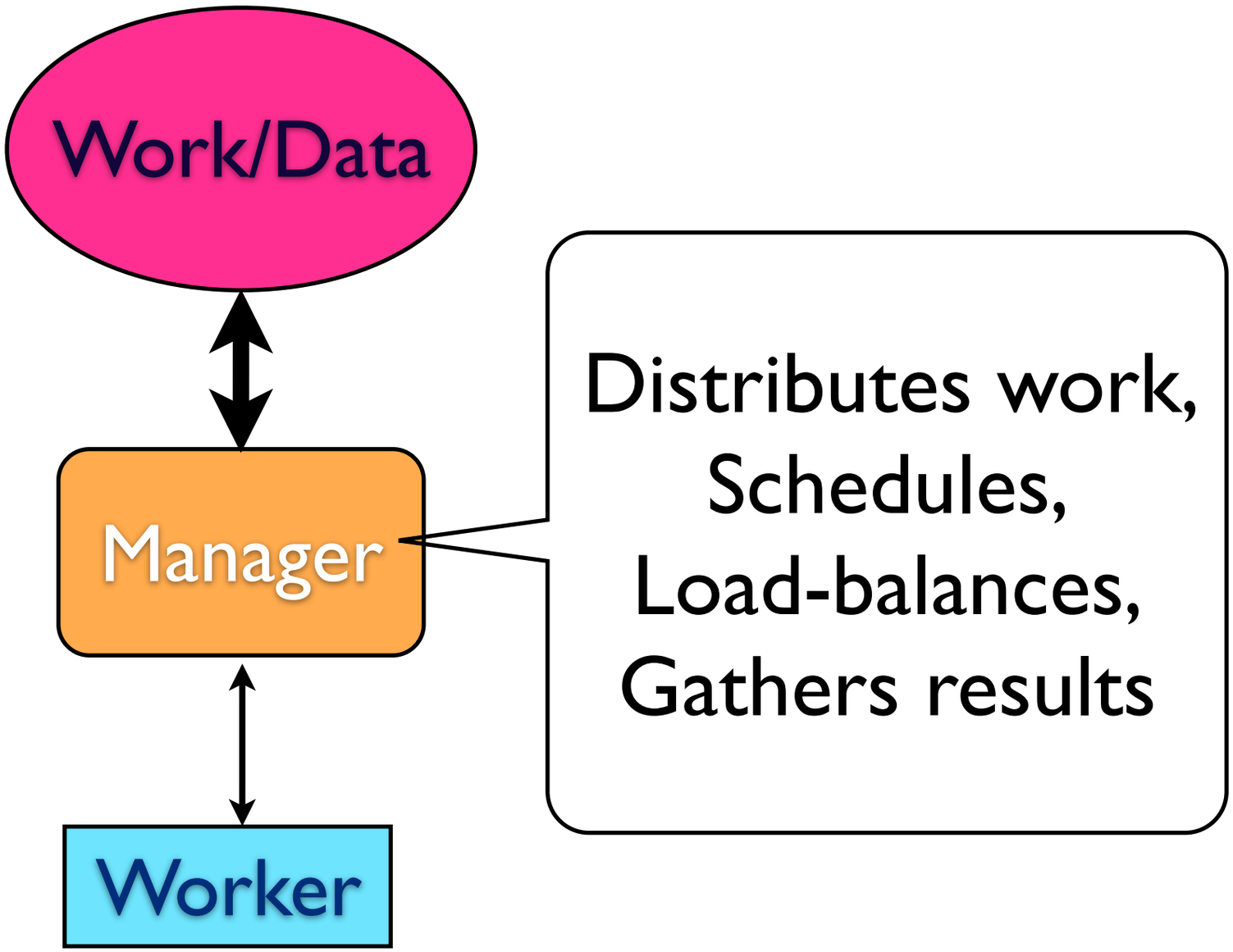
(serial version in C)

```
// 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 );
}
```

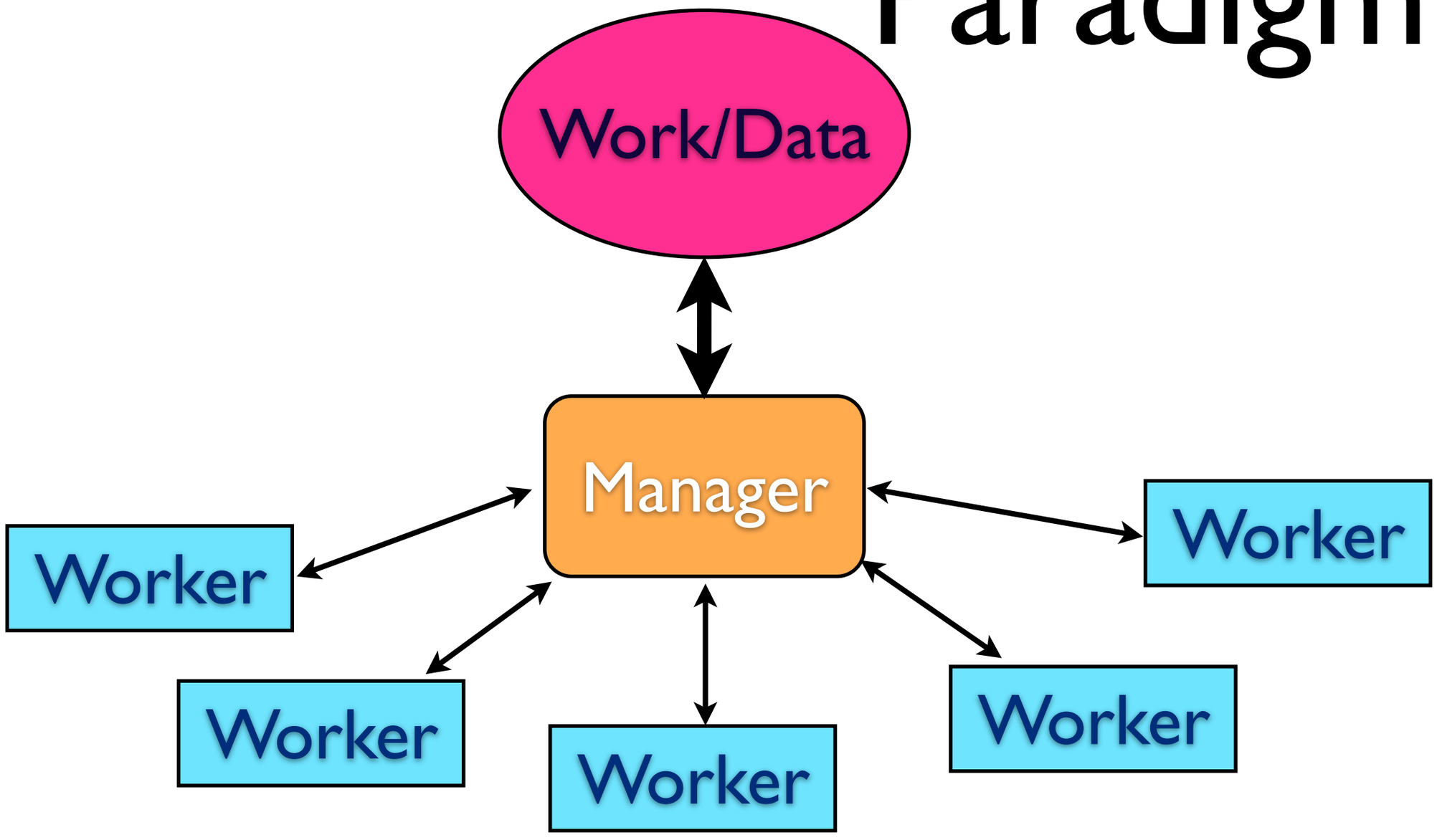
```
cc -o pi pi.c
./pi 100000
100000 iterations: Pi = 3.141603
```

getcopy mpi/pi.c

Manager/Worker Paradigm



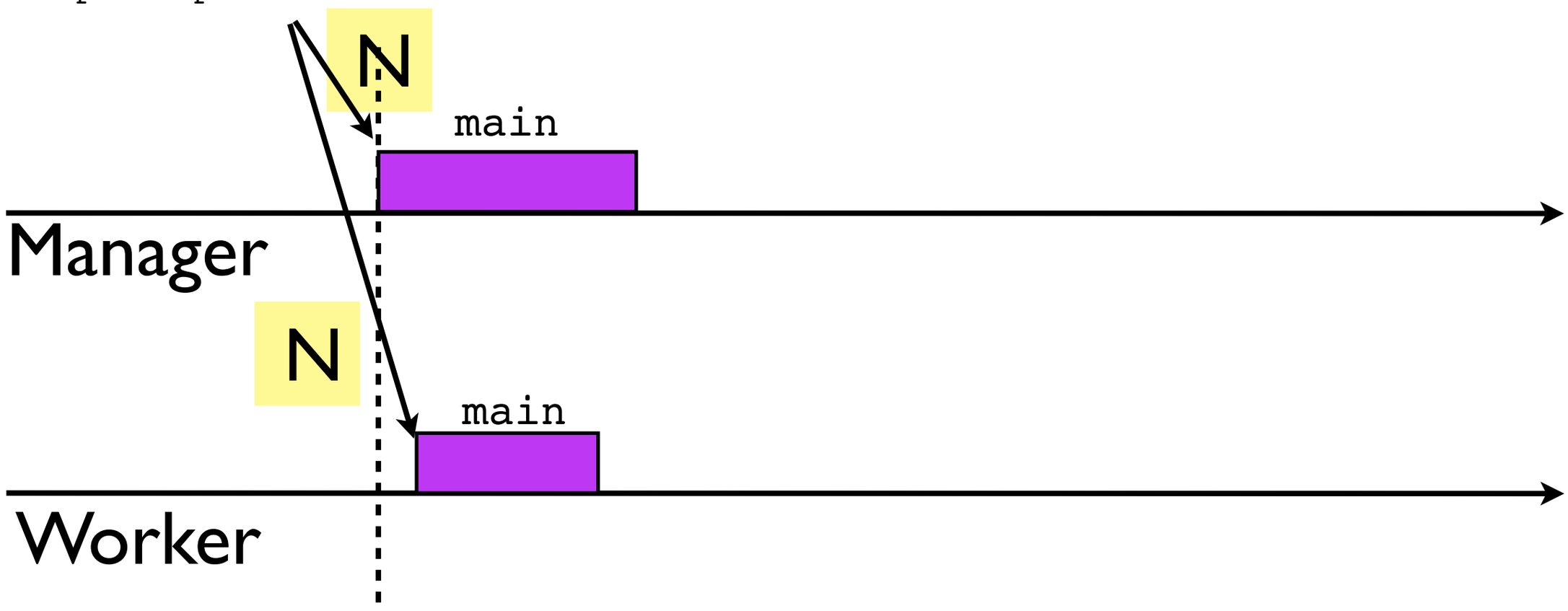
Manager/Worker Paradigm



Computing Pi
(Parallel version in MPI)

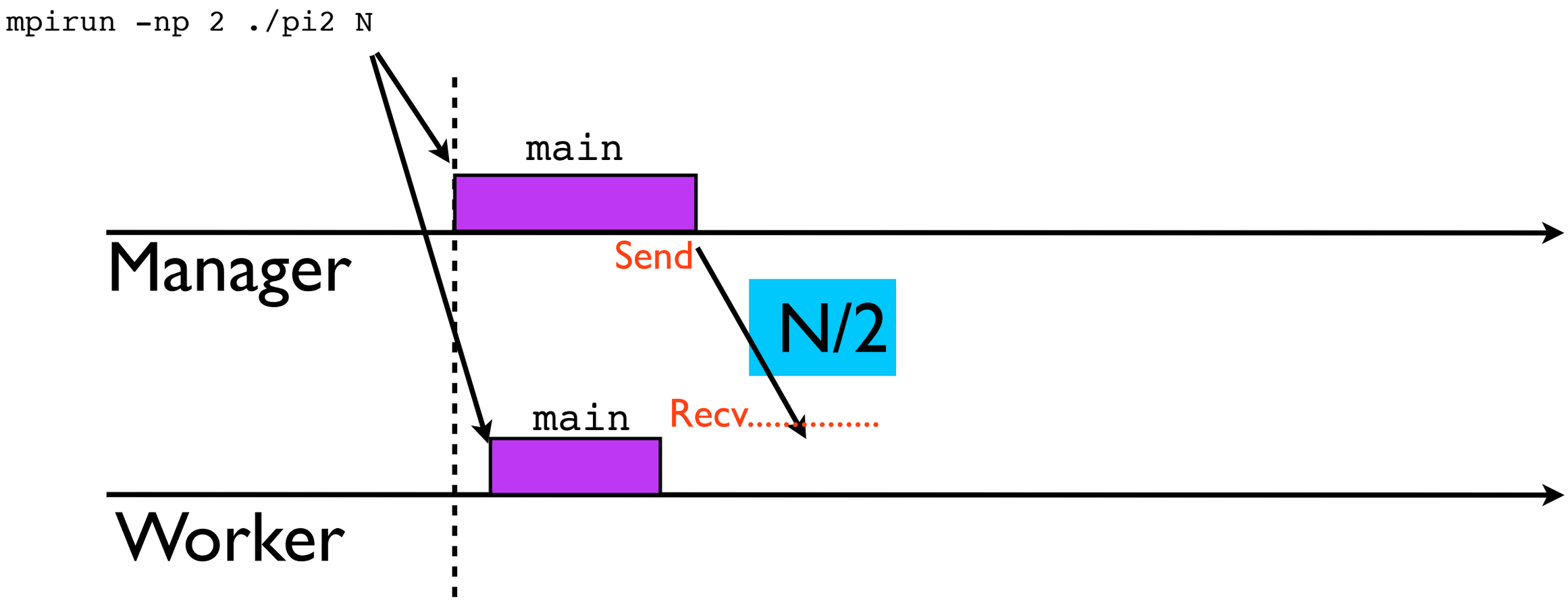
- Manager/Worker setup

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



Computing Pi
(Parallel version in MPI)

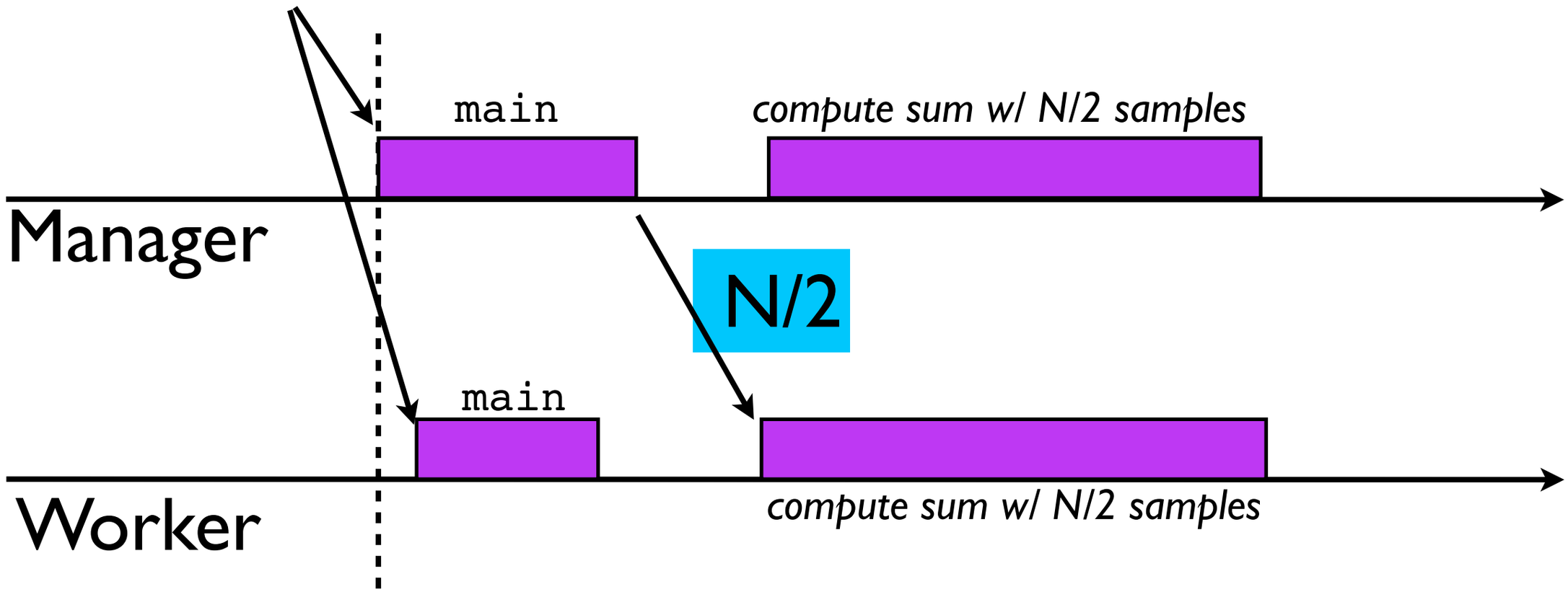
- Manager/Worker setup



Computing Pi
(Parallel version in MPI)

- Manager/Worker setup

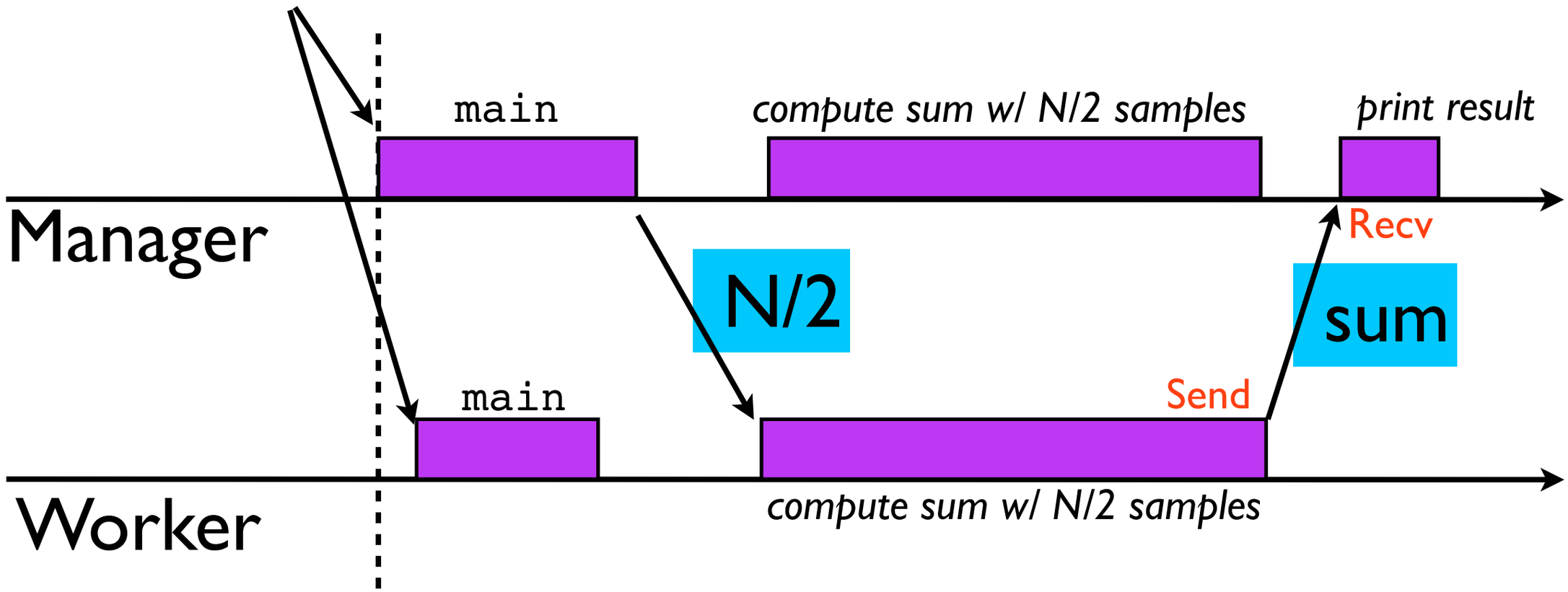
```
mpirun -np 2 ./pi2 N
```



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

Exercise

- Modify the MPI Pi computation program so that the Manager uses 2 Workers to do the computation. The Manager doesn't compute anything, except summing up the results. Worker 0 computes the sum from [0, N/2), and Worker 1 computes the sum from [N/2, N). Develop your code on your laptop or on aurora, for faster results.

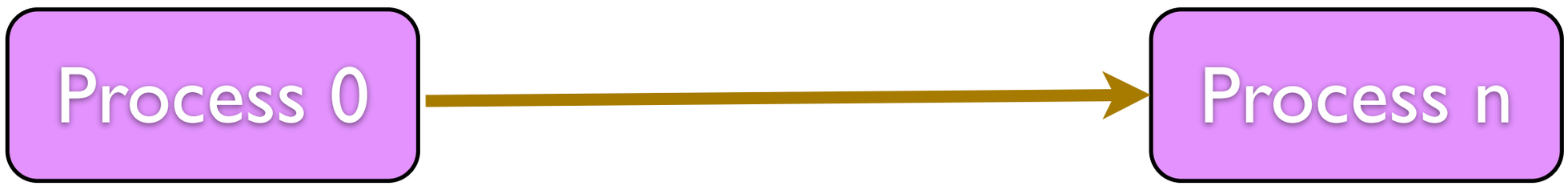
- Run your program for different values of N and compare its execution time to the execution time of the original version. Faster? Slower?

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

Communication

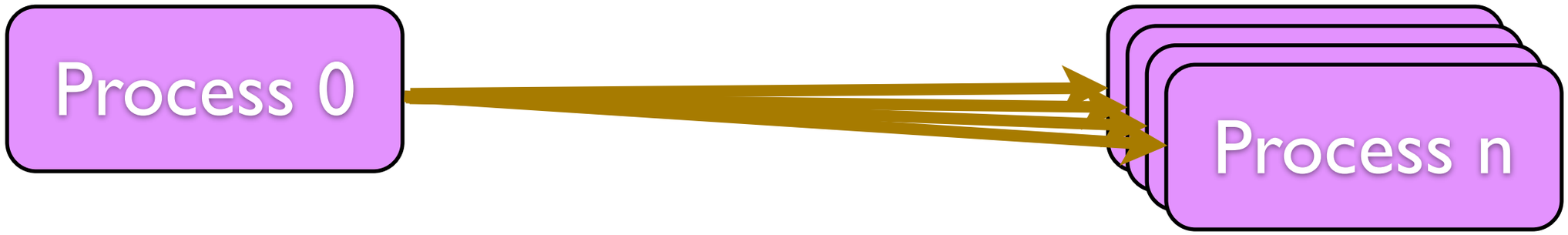
```
MPI_Send(__,__,__,n,__,__)
```

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



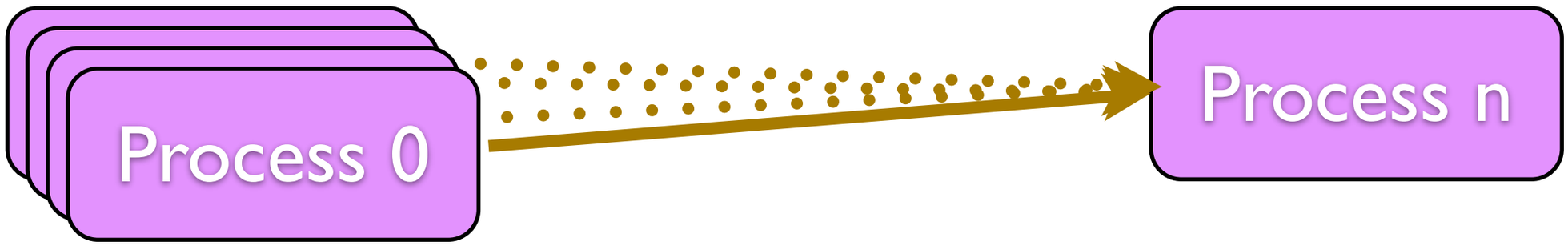

```
MPI_Bcast(__,__,__,__,__)
```

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




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

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



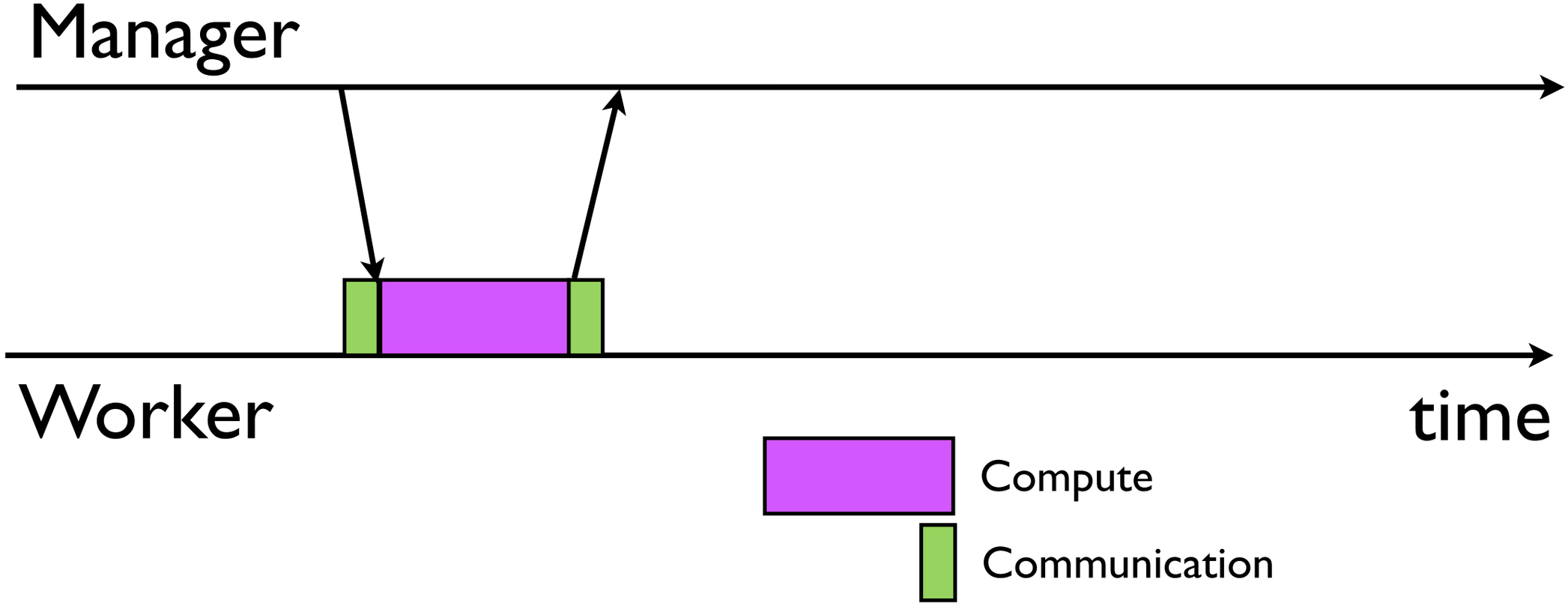
Exercise

- Run your version of the Pi program with 2, 10, 20 Processes:
    - On the hadoop cluster, using 4 processors.
    - On your laptop or Aurora
- Compare the execution times…

Scheduling/ Load-Balancing

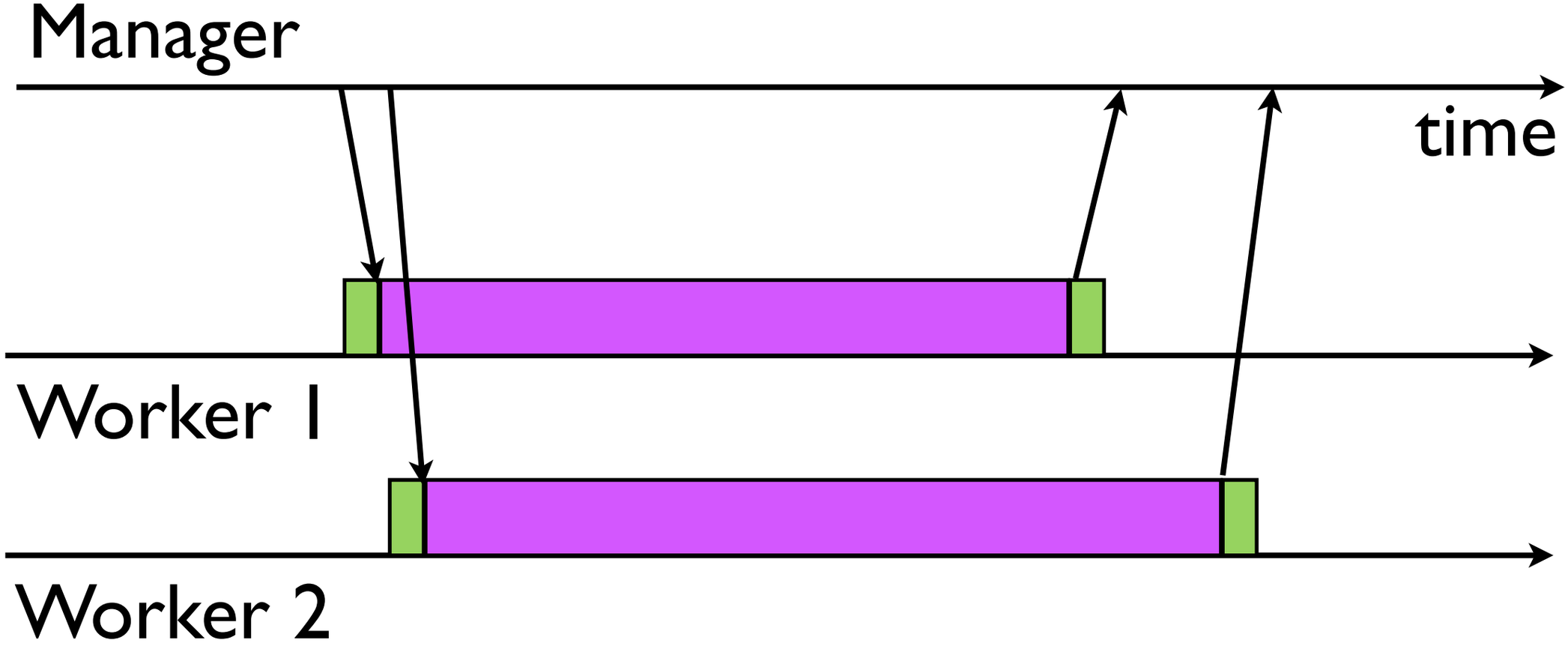
- Similar concepts
- Goal: Maximize performance by transferring tasks from busy to idle processors
- How: Determine parallel tasks + assign tasks to processors

Communication vs. Computation

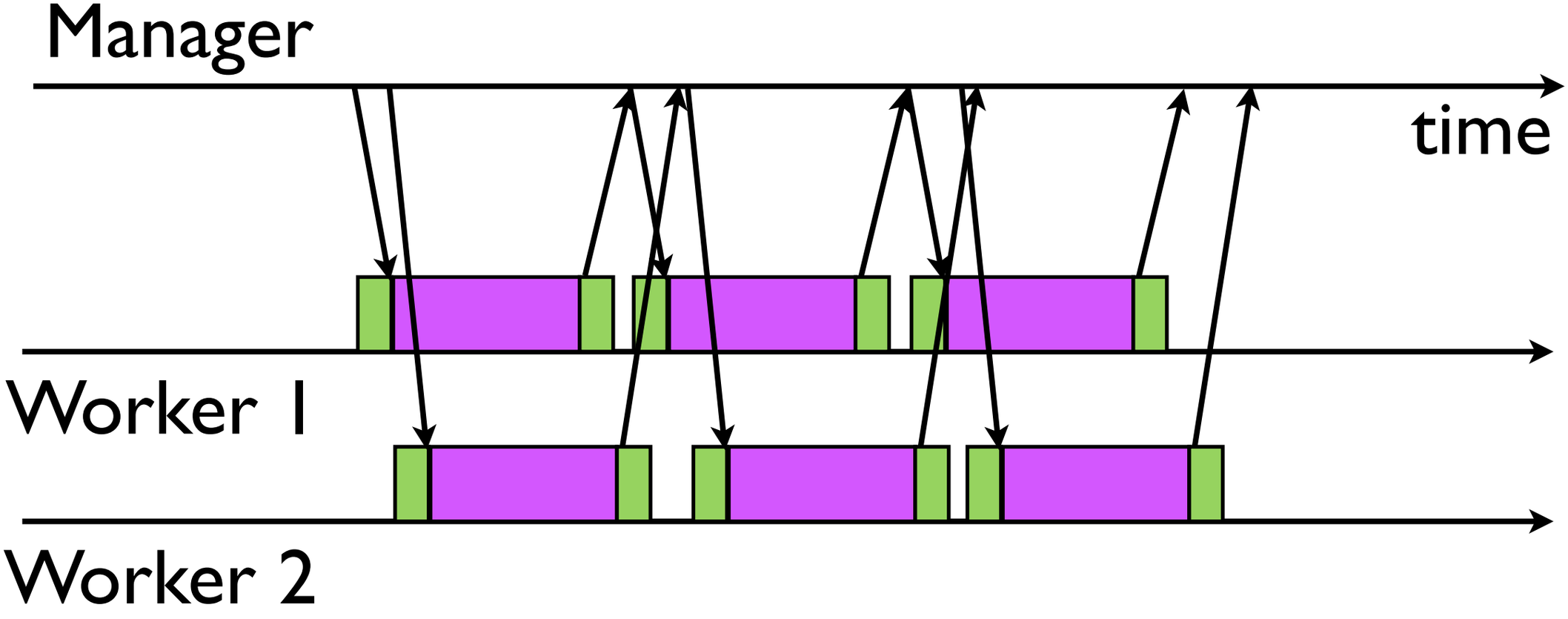


Communication vs. Computation

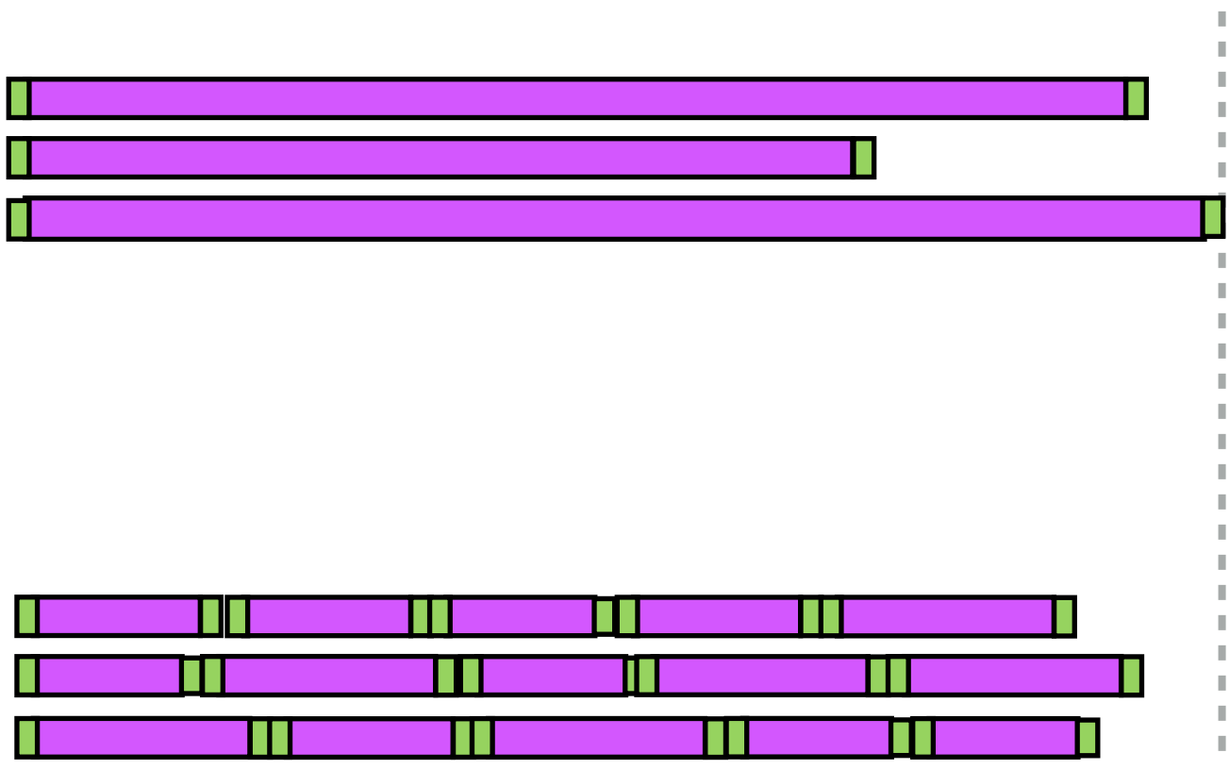
Coarse-grain parallelism



Communication vs. Computation



Communication vs. Computation

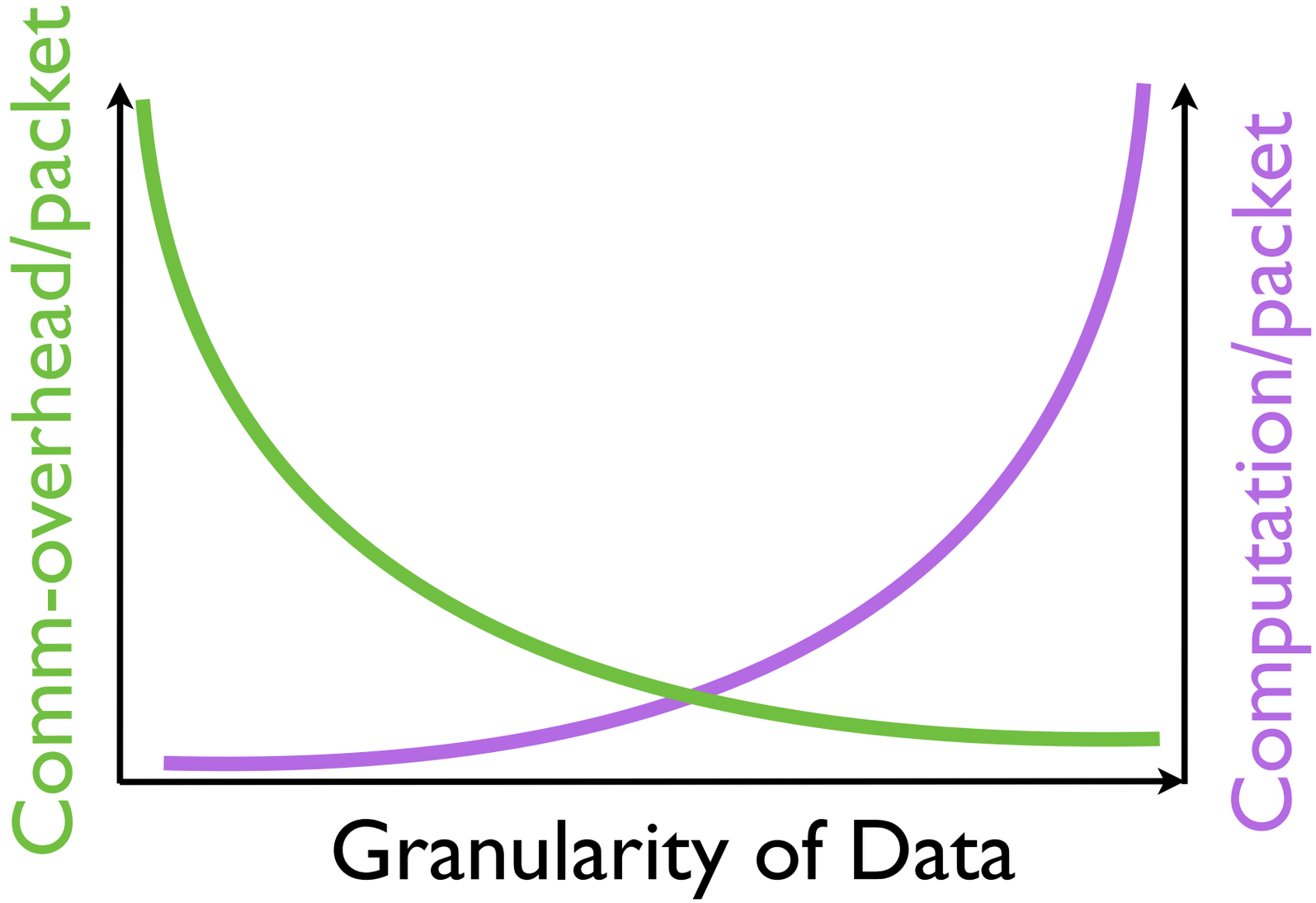


All-Important Graph: Communication vs Computation

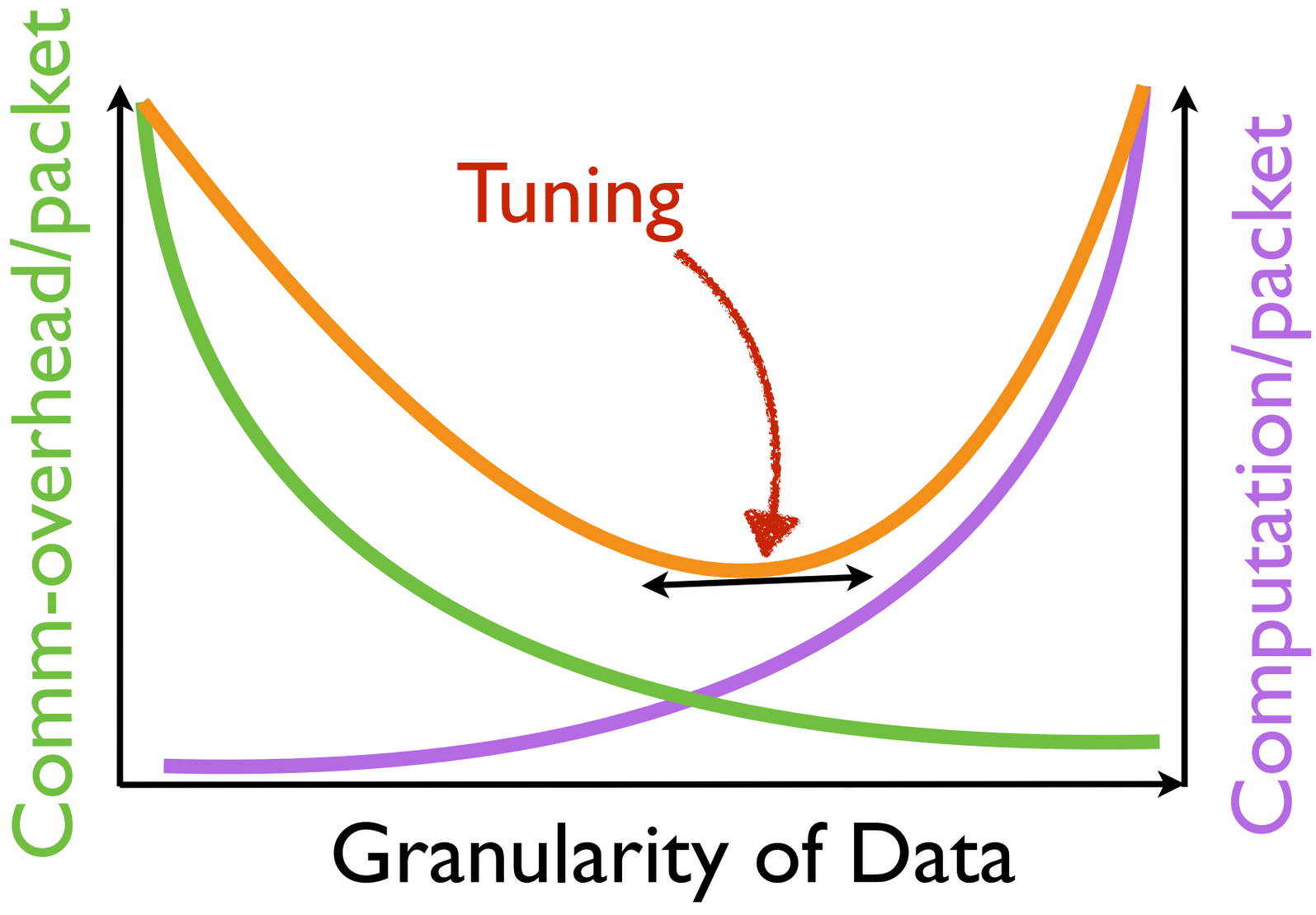
Fixed # Procs

Granularity of Data

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 for when 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.
- See if you can find a combination of *n*, the size and the chunk size that reduces the execution time.

Reference

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

MPI on AWS

Installation and Tutorials

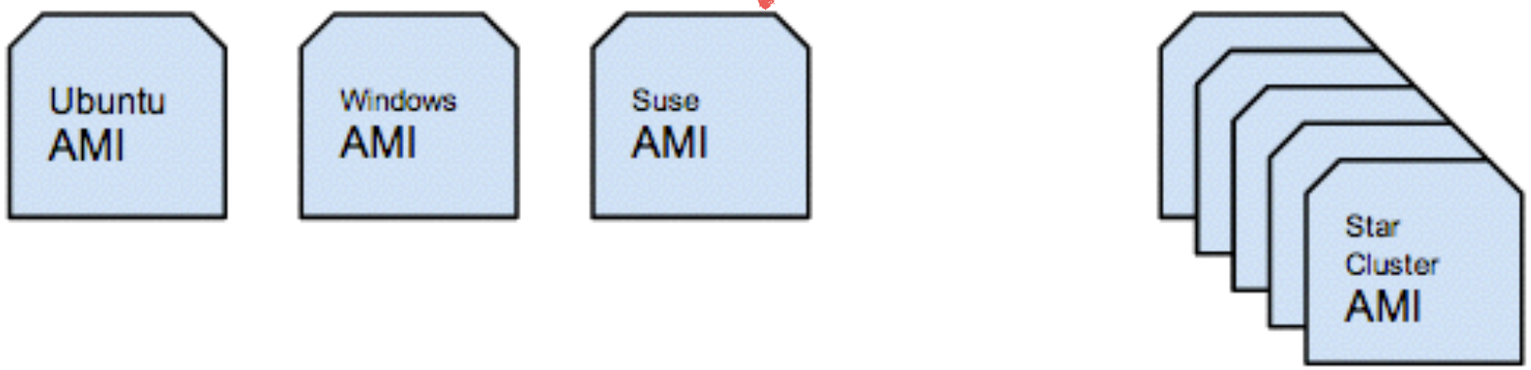
- Running MPI on AWS
- Tutorial 1 (Install StarCluster)
- Tutorial 2 (Compute Pi on AWS/MPI)

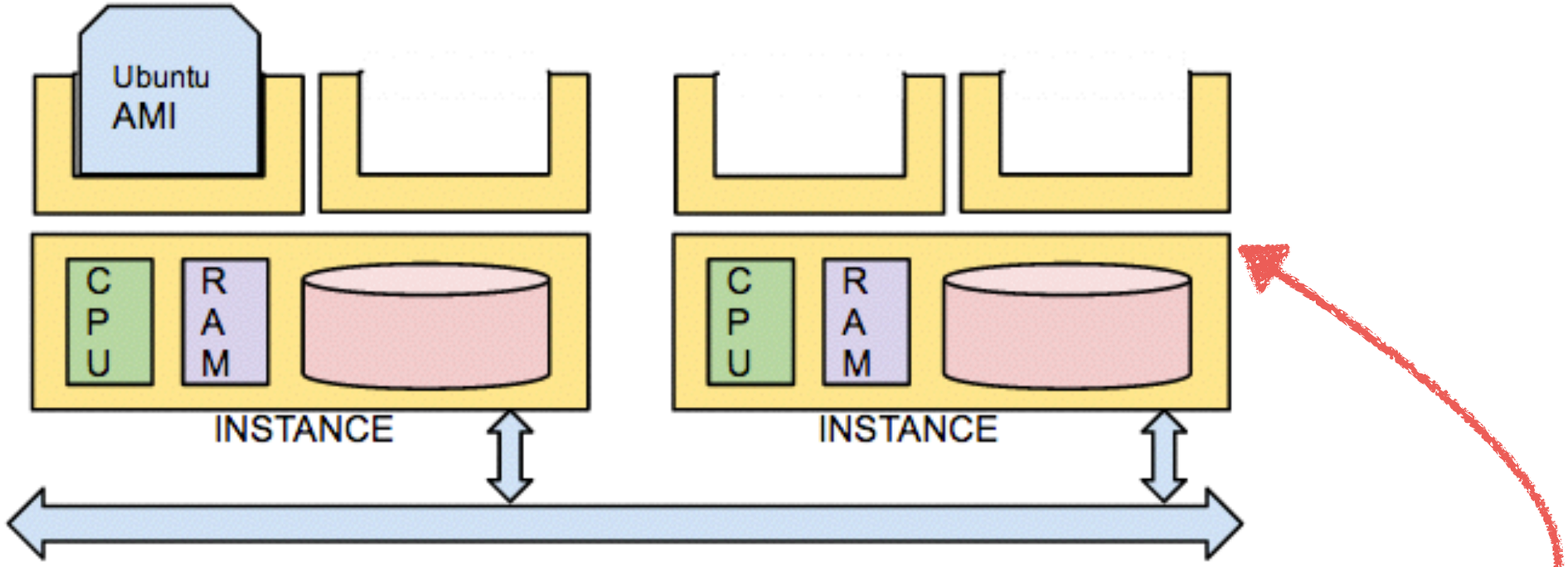
(See next slide…)

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

Amazon Machine Image

AWS





Instance