CSE 160
Lecture 15

Message Passing

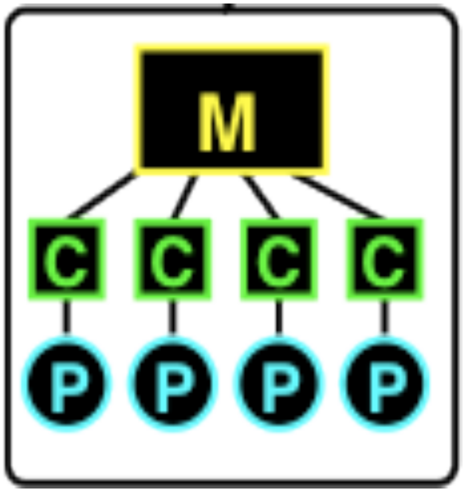
Announcements

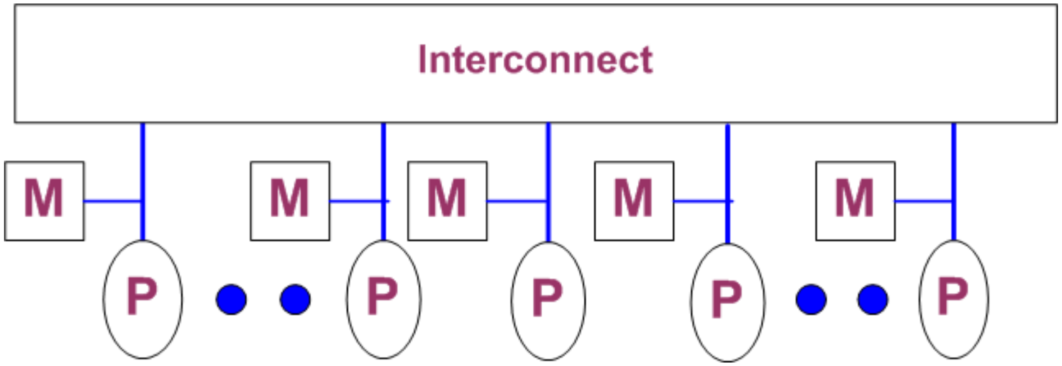
Today’s lecture

- Message passing
- The Message Passing Interface - MPI
- A first MPI Application –
  The Trapezoidal Rule

Multiprocessor organization

- Recall that with shared memory, the hardware automatically performs the global to local mapping using address translation mechanisms
- 2 types, depends on uniformity of memory access times
  - **UMA**: *Uniform* Memory Access time
    Also called a Symmetric Multiprocessor (SMP)
  - **NUMA**: *Non-Uniform* Memory Access time





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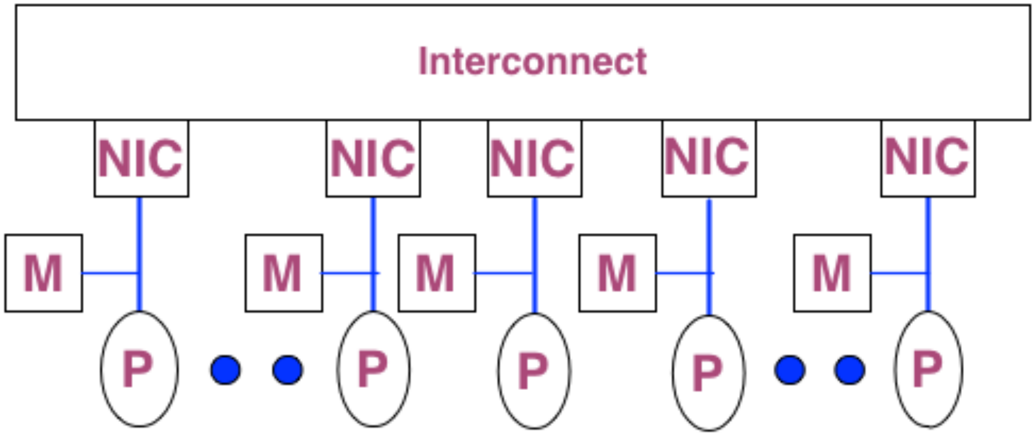
Architectures without shared memory

- Each core has direct access to local memory only
- Send and receive *messages* to obtain copies of data from other nodes
- We call this a *shared nothing* architecture, or a *multicomputer*
- Similarity to NUMA



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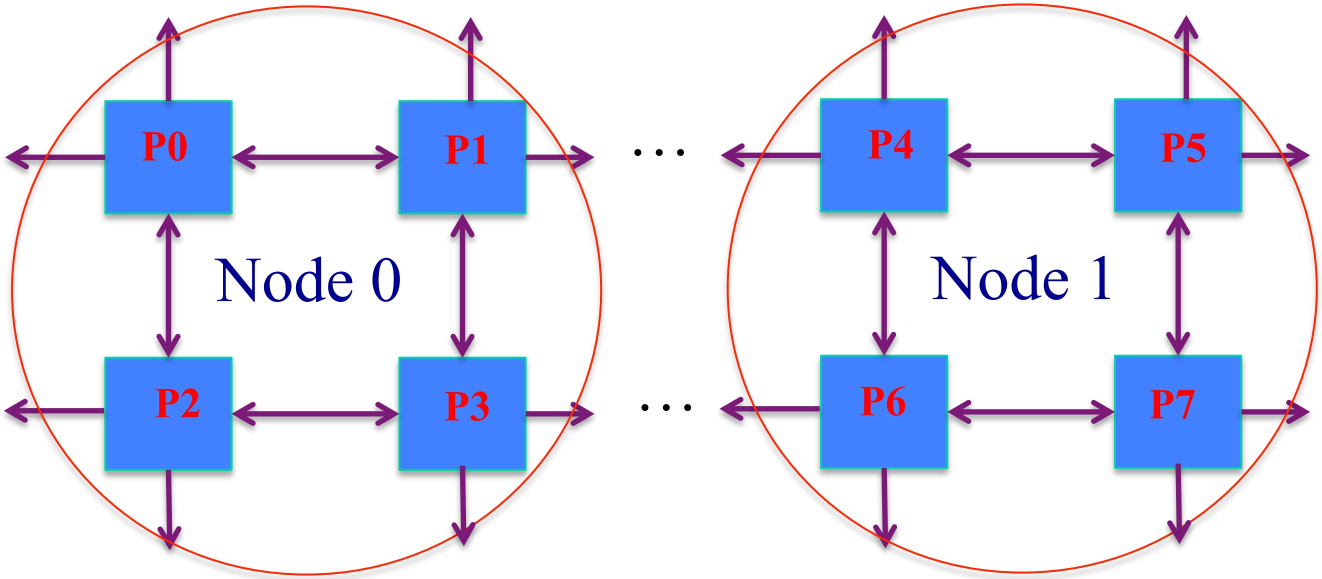
Programming with Message Passing

- Programs execute as a set of P processes (user specifies P)
- Each process assumed to run on a different core
  - Usually initialized with the same code, but has private state
    SPMD = "Same Program Multiple Data"
  - Communicates with other processes by sending and receiving messages
  - Executes instructions at its own rate according to its *rank* (0:P-1) and the messages it sends and receives
- Program execution is often called "bulk synchronous" or "loosely synchronous"



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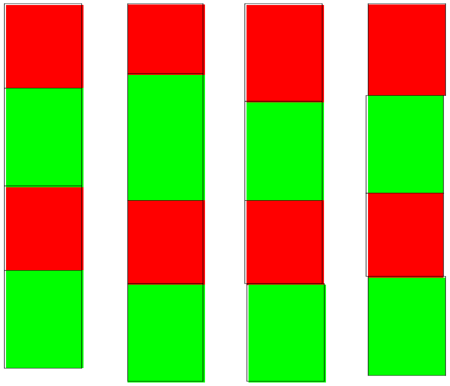
Bulk Synchronous Execution Model

- A process is either communicating or computing
- Generally, all processors are performing the same activity at the same time
- There can be instances when some are computing and some are communicating
- Pathological cases, when workloads aren't well balanced

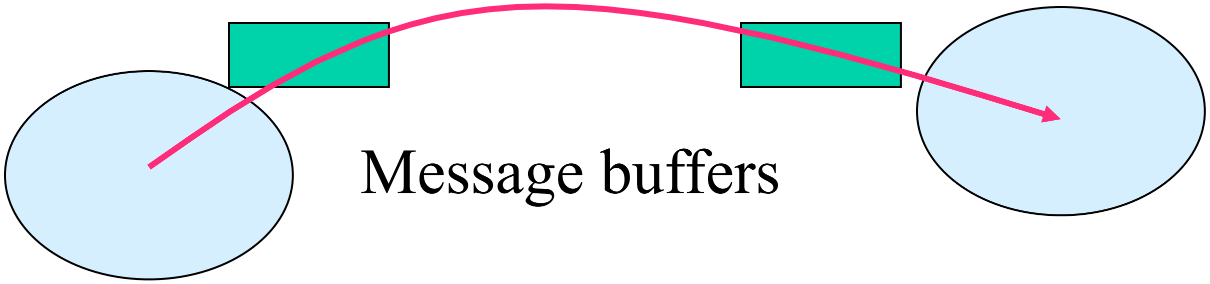


Message passing

- There are two kinds of communication patterns
- ***Point-to-point*** communication:
  a single pair of communicating processes copy data between address space
- ***Collective communication***: all the processors participate, possibly exchanging information

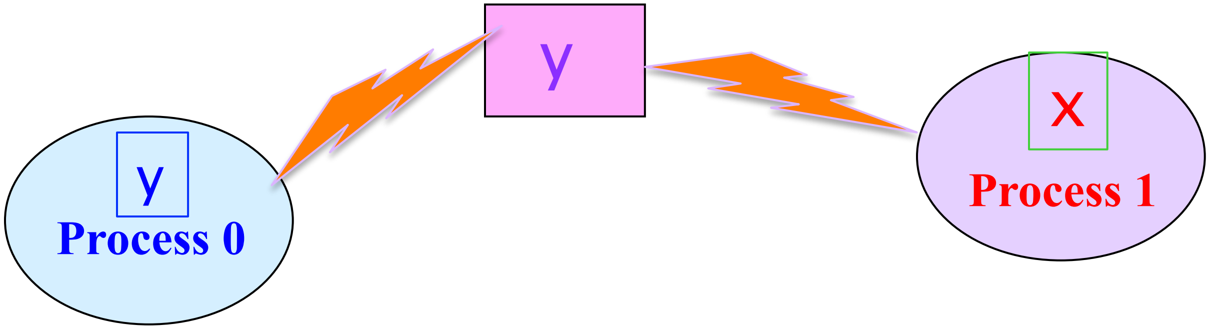
Point-to-Point communicatoin

- Messages are like email; to send one, we specify
  - A destination
  - A message body (can be empty)
- To receive a message we need similar information, including a receptacle to hold the incoming data
- Requires a sender and an explicit recipient that must be aware of one another
- Message passing performs two events
  - Memory to memory block copy
  - Synchronization signal at recipient: “Data has arrived”



Send and Recv

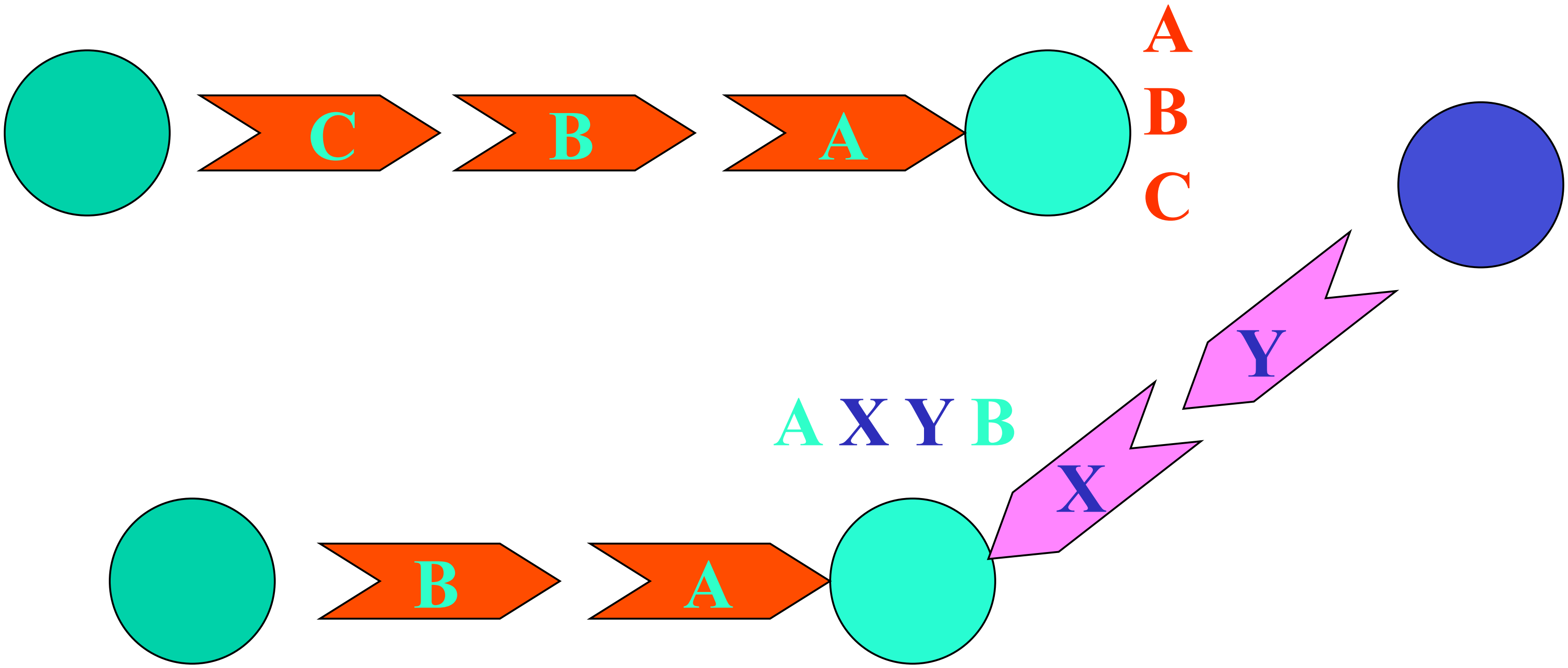
- Primitives that implement Pt to Pt communication
- When **Send( )** returns, the message is “in transit”
  - A return doesn’t tell us if the message has been received
  - The data is somewhere in the system
  - Safe to overwrite the buffer
- **Receive( )** blocks until the message has been received
  - Safe to use the data in the buffer



Send(y,1)	Recv(x)

Causality

- If a process sends multiple messages to the same destination, then the messages will be received in the order sent
- If different processes send messages to the same destination, the order of receipt isn’t defined across sources



Today's lecture

- Message passing
- The Message Passing Interface - MPI
- A first MPI Application –
  The Trapezoidal Rule

MPI

- We’ll program with a library called **MPI**

  “Message Passing Interface”

  - 125 routines in MPI-1
  - 7 minimal routines needed by every MPI program
    - start, end, and query MPI execution state (4)
    - non-blocking point-to-point message passing (3)
- Reference material: see http://www-cse.ucsd.edu/users/baden/Doc/mpi.html
- Callable from C, C++, Fortran, etc.
- All major vendors support MPI, but implementations differ in quality

Functionality we'll will cover today

- Point-to-point communication
- Message Filtering
- Communicators and Tags
- Application: the trapezoidal rule
- Collective Communication

A first MPI program : “hello world”

```
#include "mpi.h”
int main(int argc, char **argv ){
 MPI_Init(&argc, &argv);
 int rank, size;
 MPI_Comm_size(MPI_COMM_WORLD,&size);
 MPI_Comm_rank(MPI_COMM_WORLD,&rank);
 printf("Hello, world! I am process %d of %d.\n”,
   rank, size);
 MPI_Finalize();
 return(0);
}
```

MPI's minimal interface

- Opening and closing MPI
  - MPI_Init and MPI_Finalize
- Query functions

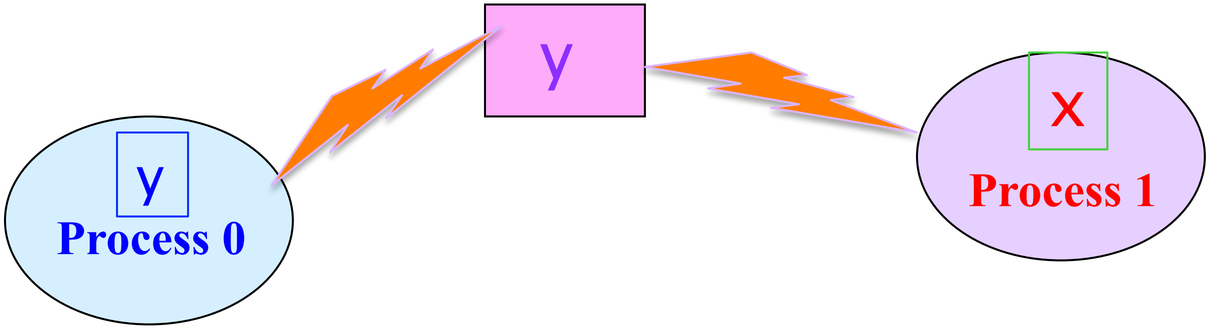
  MPI_Comm_size( ) = # processes

  MPI_Comm_rank( ) = this process' rank
- *Point-to-point* communication
  - Simplest form of communication
  - Send a message to another process

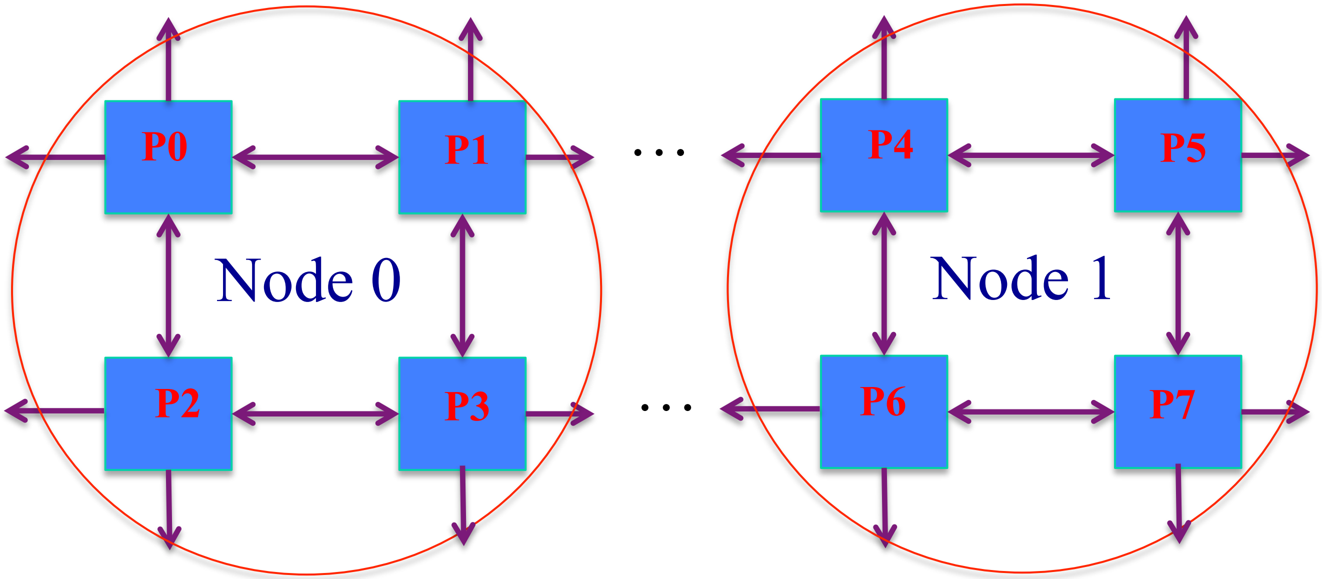
    MPI_Isend( )   MPI_Send( ) = Isend+Wait
  - Receive a message from another process

    MPI_Irecv( )   MPI_Recv( )   = Irecv +Wait
  - Wait on an incoming message: MPI_Wait( )

Point to Point Communication



Send(y,1)	Recv(x)



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Point-to-point messages

- To send a message we need
  - A destination
  - A “type”
  - A message body (can be empty)
  - A context (called a “communicator” in MPI)
- To receive a message we need similar information, including a place to hold the incoming data
- We can filter messages, enabling us organize message passing activity

Send and Recv

```
const int Tag=99;
int msg[2] = { rank, rank * rank};
if (rank == 0) {
        MPI_Status status;
        MPI_Recv(msg, 2,
                 MPI_INT, 1,
                 Tag, MPI_COMM_WORLD, &status);

}
else  MPI_Send(msg, 2,
                 MPI_INT, 0,
                 Tag, MPI_COMM_WORLD);
```

Message length

SOURCE Process ID

Message Buffer

Message Tag

Communicator

Destination Process ID

Communicators

- A communicator is a name-space (or a context) describing a set of processes that may communicate
- MPI defines a default communicator **MPI_COMM_WORLD** containing all processes
- MPI provides the means of generating uniquely named subsets (later on)
- A mechanism for screening messages

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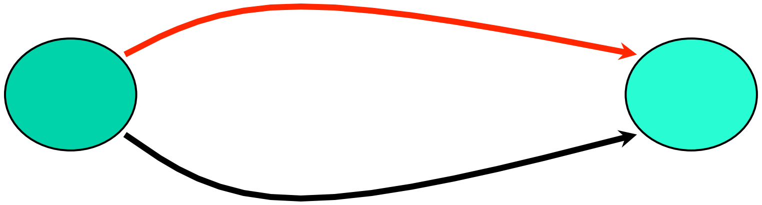
MPI Tags

- Tags enable processes to organize or screen messages
- Each sent message is accompanied by a user-defined integer *tag*:
  - Receiving process can use this information to organize or *filter* messages
  - **MPI_ANY_TAG** inhibits tag filtering



Message status

- An MPI_Status variable is a struct that contains the sending processor and the message tag
- This information is useful when we aren't filtering messages
- We may also access the length of the received message (may be shorter than the message buffer)

```
MPI_Recv( message, count,
          TYPE, MPI_ANY_SOURCE,
          MPI_ANY_TAG, COMMUNICATOR,
          &status);
MPI_Get_count(&status, TYPE, &recv_count );
status.MPI_SOURCE     status.MPI_TAG
```

MPI Datatypes

- MPI messages have a specified length
- The unit depends on the type of the data
    - The length in bytes is sizeof(type) × # elements
    - We don't specify the as the # byte
- MPI specifies a set of built-in types for each of the primitive types of the language
- In C: **MPI_INT, MPI_FLOAT, MPI_DOUBLE, MPI_CHAR, MPI_LONG, MPI_UNSIGNED, MPI_BYTE,…**
- Also defined types, e.g. structs

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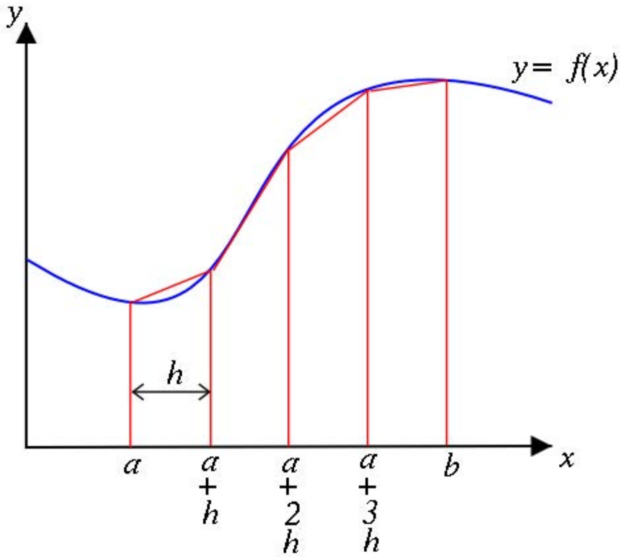
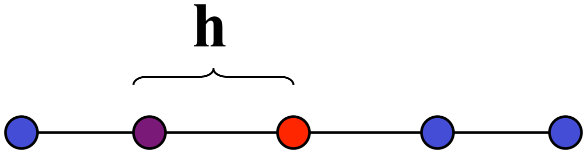
The trapezoidal rule

- Use the trapezoidal rule to numerically approximate a definite integral, area under the curve
- Divide the interval [a,b] into n segments of size h=1/n
- Area under the i^{th} trapezoid
  $\frac{1}{2} (f(a+i\times h)+f(a+(i+1)\times h)) \times h$
- Area under the entire curve
  $\approx$ sum of all the trapezoids

$$\int_a^b f(x)dx$$





a+i*h **a+(i+1)*h**

Reference material

- For a discussion of the trapezoidal rule

http://en.wikipedia.org/wiki/Trapezoidal_rule

- A applet to carry out integration

http://www.csse.monash.edu.au/~lloyd/tildeAlgDS/Numerical/Integration

- Code on Bang (from Pacheco hard copy text)

Serial Code

$PUB/Examples/MPI/Pacheco/ppmpi_c/chap04/serial.c

Parallel Code

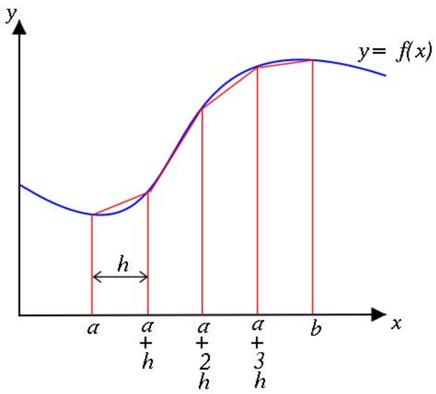
$PUB/Examples/MPI/Pacheco/ppmpi_c/chap04/trap.c

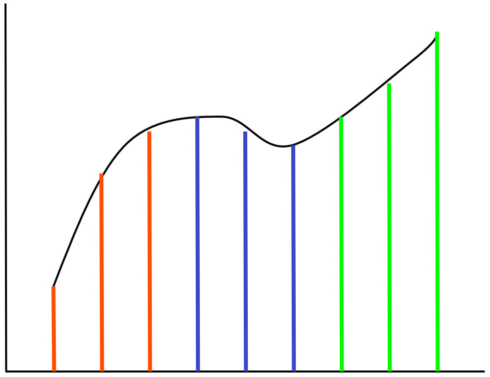
Serial code (Following Pacheco)

```
main() {
  float f(float x)   { return  x*x;  }             // Function we're integrating

  float h = (b-a)/n;                               //   h = trapezoid base width
                                                   //   a and b: endpoints
                                                   //   n = # of trapezoids
  float integral = (f(a) + f(b))/2.0;

  float  x;   int   i;

  for (i = 1, x=a; i <= n-1; i++) {
     x += h;
     integral = integral + f(x);
  }
  integral = integral*h;
 }
```

Parallel Implementation of the Trapezoidal Rule

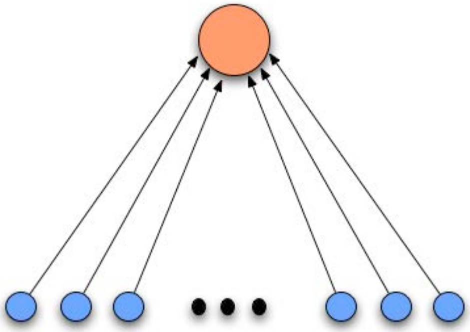
- Decompose the integration interval into sub-intervals, one per processor
- Each processor computes the integral on its local subdomain
- Processors combine their local integrals into a global one





First version of the parallel code

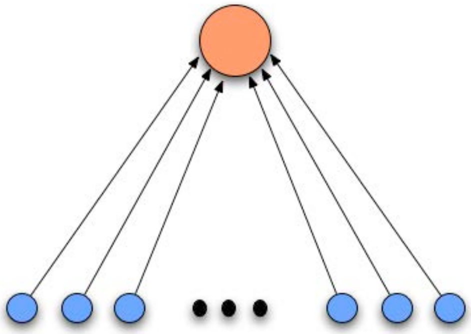
```
int local_n = n/p;        // # trapezoids; assume p divides n evenly
float local_a = a + my_rank*local_n*h,
      local_b = local_a + local_n*h,
      integral = Trap(local_a, local_b, local_n);

if (my_rank == ROOT) {  // Sum the integrals calculated by
                        // all processes
   total = integral;
   for (int source = 1; source < p; source++) {
      MPI_Recv(&integral, 1, MPI_FLOAT, MPI_ANY_SOURCE,
                  tag, WORLD, &status);
      total += integral;
   }
} else
   MPI_Send(&integral, 1,
                  MPI_FLOAT, ROOT, tag, WORLD);
```



Playing the wild card

- We can take the sums in any order we wish
- The result does not depend on the order in which the sums are taken, except to within roundoff
- We use a linear time algorithm to accumulate contributions, but there are other orderings

```
for (int source = 1; source < p; source++)
    MPI_Recv(&integral, 1, MPI_FLOAT,
                    MPI_ANY_SOURCE, tag,
                    WORLD, &status);

      total += integral;
}
```



Using collective communication

- The result does not depend on the order in which the sums are taken, except to within roundoff
- We can often improve performance by taking advantage of global knowledge about communication
- Instead of using point to point communication operations to accumulate the sum, use ***collective*** communication

```
local_n = n/p;
float local_a = a + my_rank*local_n*h,
        local_b = local_a + local_n*h,
        integral = Trap(local_a, local_b, local_n, h);
MPI_Reduce( &integral, &total, 1,
                MPI_FLOAT, MPI_SUM,
                ROOT,MPI_COMM_WORLD)
```

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Collective communication in MPI

- Collective operations are called by **all** processes within a communicator
- Broadcast: distribute data from a designated "root" process to all the others
  MPI_Bcast(in, count, type, root, comm)
- Reduce: combine data from all processes and return to a deisgated root process
  MPI_Reduce(in, out, count, type, op, root, comm)
- Allreduce: all processes get recuction: **Reduce + Bcast**

Final version

```
int local_n = n/p;

float local_a = a + my_rank*local_n*h,
      local_b = local_a + local_n*h,
      integral = Trap(local_a, local_b, local_n, h);

MPI_Allreduce( &integral, &total, 1,
                  MPI_FLOAT, MPI_SUM, WORLD)
```

What we covered today

- Message passing concepts
- A practical interface - MPI
- Next time
  - Asynchronous communication
  - More collective communication primitives
  - NewApplications