# Lecture 6

Programming with Message Passing

# Announcements

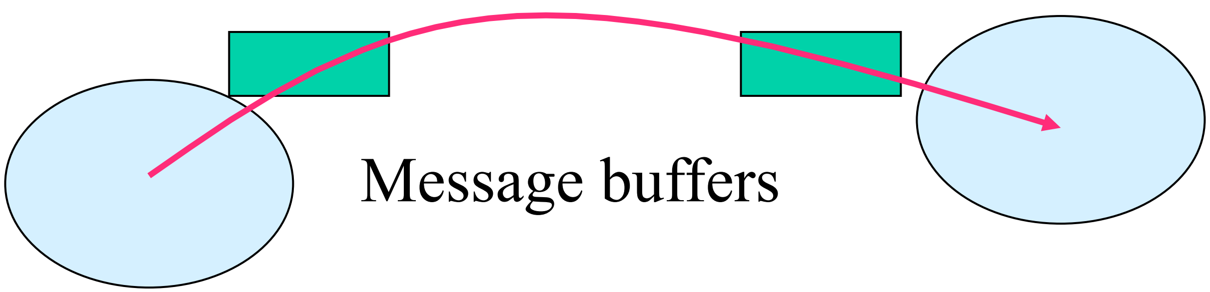
- Project Proposals
  - What are the goals of your project? Are they realistic?
  - What are your hypotheses?
  - What is your experimental method for proving or disproving your hypotheses?
  - What experimental result(s) do you need to demonstrate?
  - What would be the significance of those results?
  - What code will you need to implement? What software packages or previously written software will use?
  - A tentative division of labor among the team members.
- See me to discuss your project

# Programming with Message Passing

- The primary model for implementing parallel applications
- Useful for understanding fundamental behavior in various types of parallel computers
- Programs execute as a set of P processes
  - We specify P when we run the program
  - Assume each process is assigned a different physical processor
- Each physical process
  - is initialized with the same code, but has private state
    SPMD = "Same Program Multiple Data"
  - executes instructions at its own rate
  - has an associated *rank*, a unique integer in the range 0:P-1
- The sequence of instructions each process executes depends on its rank and the messages it sends and receives
- Program execution is often called "bulk synchronous" or "loosely synchronous"

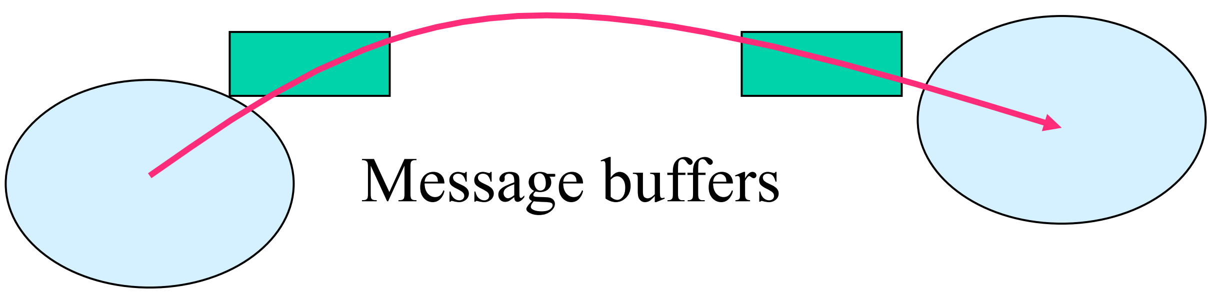
# Message Passing

- Messages are like email
- To send a message 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



# Message Passing

- Message based communication requires that sender and receiver be aware of one another
- There must be an explicit recipient of the message
- Message passing performs two events
  - Memory to memory block copy
  - Synchronization signal on receiving end: "Data arrived"



# Minimal message passing

- Query functions

  nproc( ) = # processors

  myRank( ) = this process's rank

- *Point-to-point* communication
  - Simplest form of communication
  - Send a message to another process

    Send(Object, Destination process ID)
  - Receive a message from another process

    Receive(Object)

    Receive(Source process, Object)

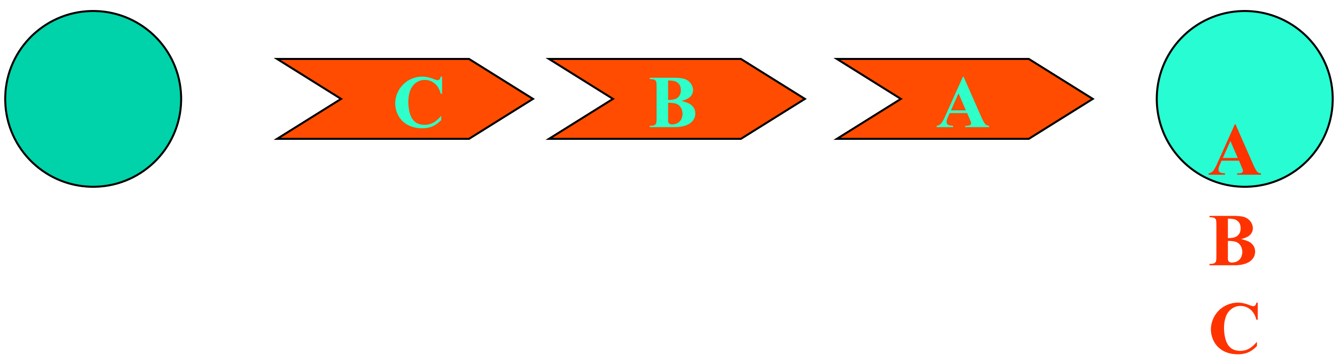
# Send and Recv

- When **Send( )** returns, the message is "in transit"
  - A return doesn't tell us if the message has been received
  - 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
- Error if the source and destination object don't have *identical* types

| Process 0 | Process 1 |
|---|---|
| Send(x,1)<br>Recv(y)<br>Print x, y | Send(x,0)<br>Recv(y)<br>Print x, y |

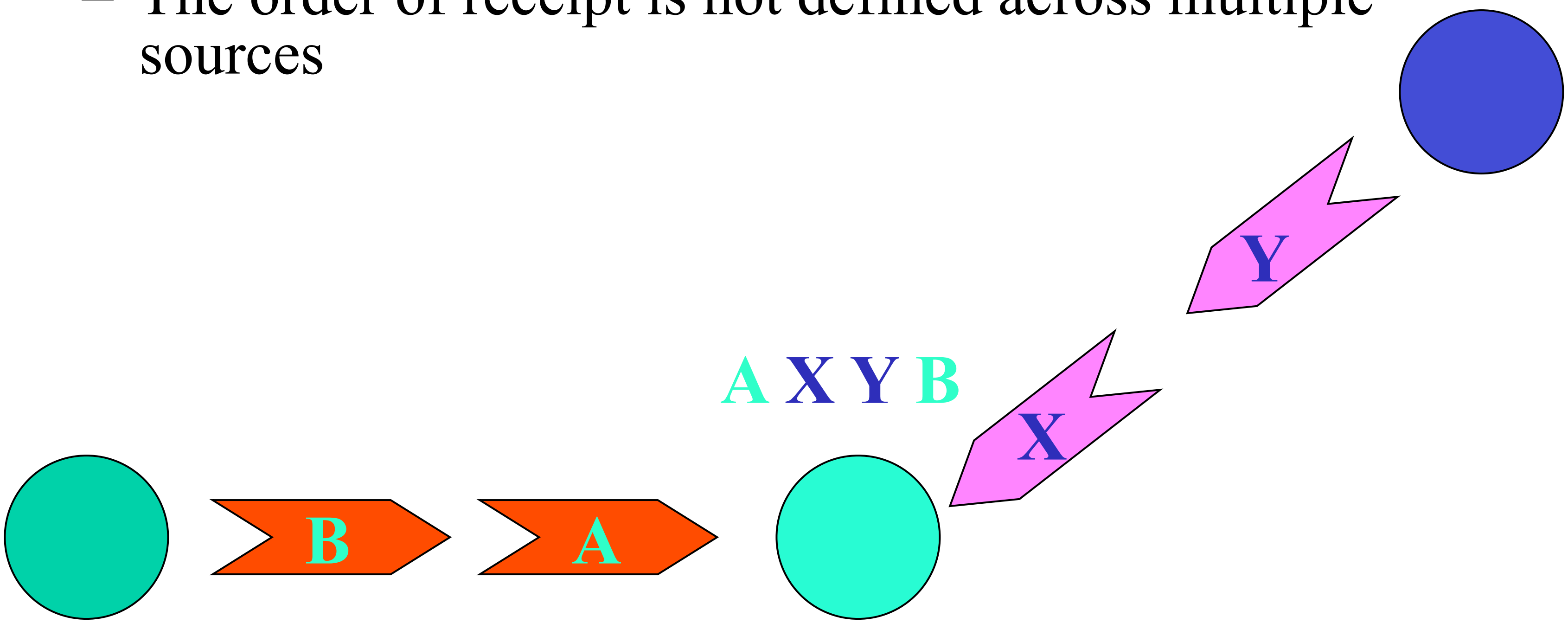
# Causality

- 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 processes



# Causality

- If different processes send messages to the same destination
  - The order of receipt is defined from a single source
  - The order of receipt is not defined across multiple sources



# Non-blocking communication

- We've seen *blocking* calls that cause the program to wait for completion
- There is asynchronous, *non-blocking* communication
- These are needed to express certain algorithms
- Also used to improve performance

# Non-blocking communication

- Non-blocking communication is ***split-phased***
  - Phase 1: initiate communication with the immediate 'I' variant of the point- to-point call

    IRecv( ), ISend( )
  - Phase 2: synchronize

    Wait( )
  - We can carry out unrelated computations between the two phases
- Building a blocking call

  Recv( ) = IRecv( ) + Wait( )

# Program behavior

| Process 0 | Process 1 |
|---|---|
| Recv (x)<br>Send(y,1) | Recv(x)<br>Send(y,0) |

| Process 0 | Process 1 |
|---|---|
| IRecv(x)<br>Send(y,1) | IRecv(x)<br>Send(y,0) |

- A message buffer may not be accessed between an IRecv( ) (or ISend( )) and its accompanying wait( )
- Each pending IRecv() must have a distinct buffer

# MPI

- We’ll program with a library called MPI
  “Message Passing Interface”
- We’ll use a variant of MPI called MPI-CH
- Callable from C, C++, Fortran, etc.
- All major vendors support MPI, but implementations differ in quality

# Using MPI

- 125 routines in MPI-1
- 7 minimal routines needed by nearly 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**

# Functionality we'll will cover today

- Point-to-point communication
- Communicators
- Data types
- Tags
- Non-blocking communication
- Message Filtering

# A first MPI program : “hello world”

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

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

# A second MPI program

```
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("I am process %d of %d.\n",
         rank, size);
 MPI_Finalize();
}
```

# Sending and receiving messages

- MPI provides a rich collection of routines to move data between address spaces
- A single pair of communicating processes use ***point-to-point*** communication
- Later on we'll cover ***collective communication***, when all the processors communicate together
- In point-to-point message passing we can filter messages in various ways
- This allows us to organize message passing activity conveniently

# What's in an MPI message?

- 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 receptacle to hold the incoming data

# Communicators

- One way of screening messages is through a communicator
- 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)

# 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 Buffer

Message length

# 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);
```

Data type

SOURCE Process ID

Destination Process ID

# Send and Recv

Message Tag

Communicator

```
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);
```

# 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
- Built-in MPI types (for C binding)
- In C: **MPI_INT, MPI_FLOAT, MPI_DOUBLE, MPI_CHAR, MPI_LONG, MPI_UNSIGNED, MPI_BYTE,…**
- User defined types, e.g. structs

# MPI Tags

- Each sent message is accompanied by a user-defined integer *tag*:
  - Receiving process can use this information to organize messages
  - May also filter messages (like a subject: line in email)
  - **MPI_ANY_TAG** inhibits screening.

# Message status

- An MPI_Status variable is a struct that contains the sending processor and the message tag
- This information is useful when we haven't filtered the 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
```

# Non-blocking communication in MPI

- An extra request argument is required

```
MPI_Request request;
MPI_Irecv(buf, count, type, source, tag,
comm,
                              &request)
```

- We use the request variable to specify which message we are synchronizing in `MPI_Wait()`

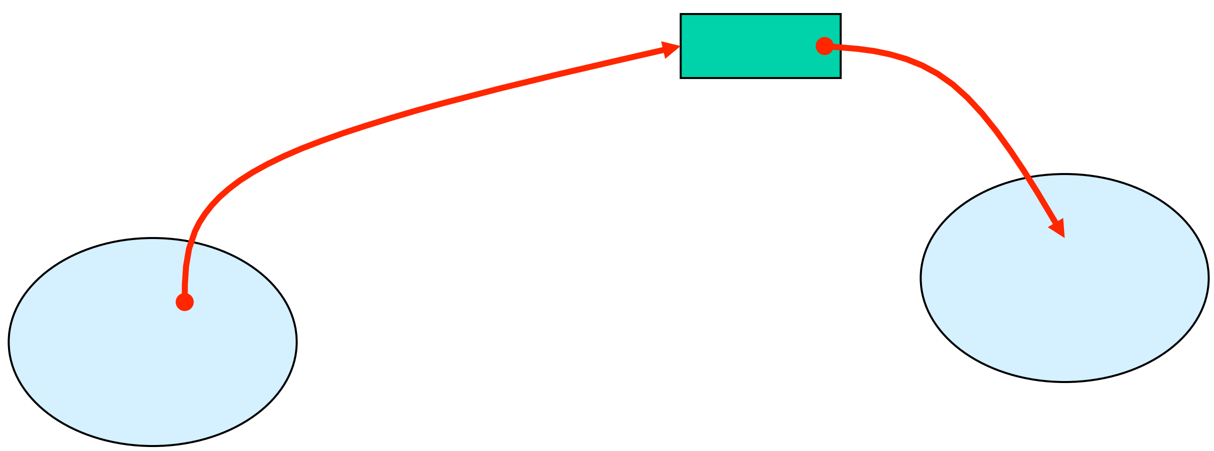
```
 MPI_Wait(&request, &status)
```

- Making above 3 calls in succession is equivalent to

```
 MPI_Recv(buf, count, type, source,
                               tag, comm, &status)
```

# Buffering

- If there is not a pending receive, then an incoming message is placed in an anonymous system buffer
- When the receive gets posted, the message is moved into the user specified buffer
- Double copying reduces communication performance



# Avoiding the overhead

- Non-blocking communication can help ameliorate this problem
- For more information see
  *MPI: The Complete Reference,* by Marc Snir et al.
  www.netlib.org/utk/papers/mpi-book/mpi-book.html
  "Buffering and Safety"

# Rendezvous

- When a long message is to be sent, can MPI just send the message?
- If so, then it sends the message. This is called a ***rendezvous*** implementation.  What are the advantages and disadvantages?

# Rendezvous and eager limits

- In an ***eager*** implementation, we just send the message
- The ***eager limit*** is the longest message that can be sent in eager mode
- Maximum value on IBM SP systems is 256K
- See M. Banikazemi et al., IEEE TPDS, 2001, “MPI-LAPI: An Efficient Implementation of MPI for IBM RS/6000 SP Systems”
- What about longer messages?

# Send Modes

- MPI provides four different ***modes*** for sending a message
  - Standard: Send ***may or may not*** complete until matching receive is posted (whether or not the data is buffered is up to the implementation)
  - Synchronous: Send does not complete until matching receive is posted
  - Ready: Matching receive must already have been posted
  - Buffered: data is moved to a user-supplied buffer before sending
- See the handy reference at http://www-unix.mcs.anl.gov/mpi/sendmode.html

# Sends that block

- Consider the following example of an “unsafe” program
- It may deadlock if there isn’t enough storage to receive the incoming message (s)

| Process 0 | Process 1 |
|---|---|
| Send(x,1)<br>Recv(y) | Send(x,0)<br>Recv(y) |

# Avoiding an unsafe program

- The system has pre-allocated storage for the incoming messages so there's no possibility of running out of storage

| Process 0 | Process 1 |
| --- | --- |
| IRecv(x)<br>Send(y,1) | IRecv(x)<br>Send(y,0) |

# Communication performance

- Communication performance is a major factor in determining the overall performance of an application
- Let the message have a length n
- The simplest communication cost model is transfer time = $\alpha + \beta^{-1}_{\infty}\, n$

  $\alpha$ = message startup time

  $\beta_{\infty}$ = peak bandwidth (bytes per second)

  n = message length

# Startup and bandwidth

- The startup term dominates when the message is sufficiently short

$$\alpha \gg \beta^{-1}_{\infty}\, n$$

- The bandwidth term dominates when the message is sufficiently long

$$\beta^{-1}_{\infty}\, n \gg \alpha$$

# Half power point

- Let $T(n) =$ time to send a message of length n
- Let $\beta(n) =$ the effective bandwidth

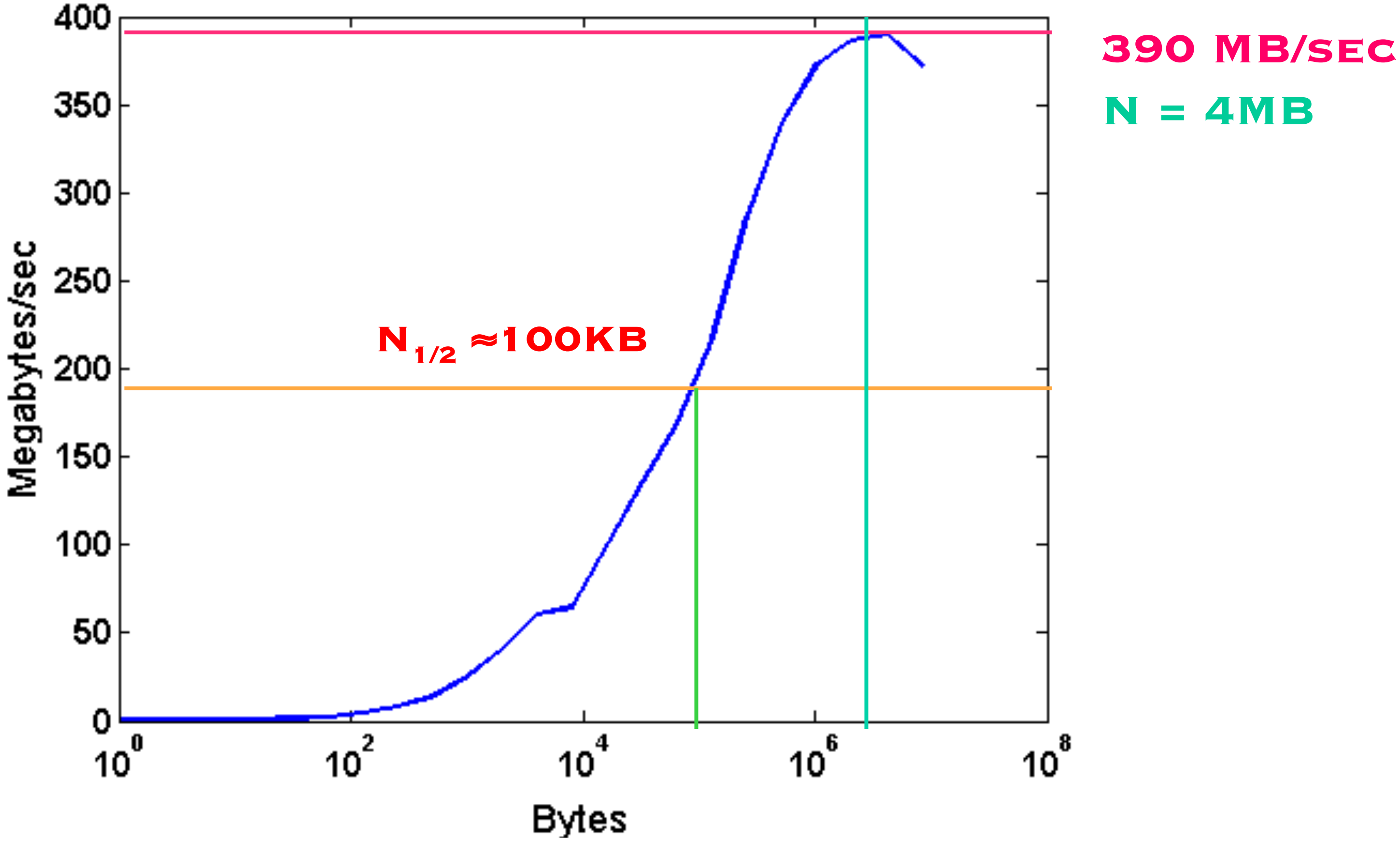
  $$\beta^{-1}(n) = n / T(n)$$

- We define the ***half power point*** $n_{1/2}$ as the message size required to achieve ½ $\beta_\infty$

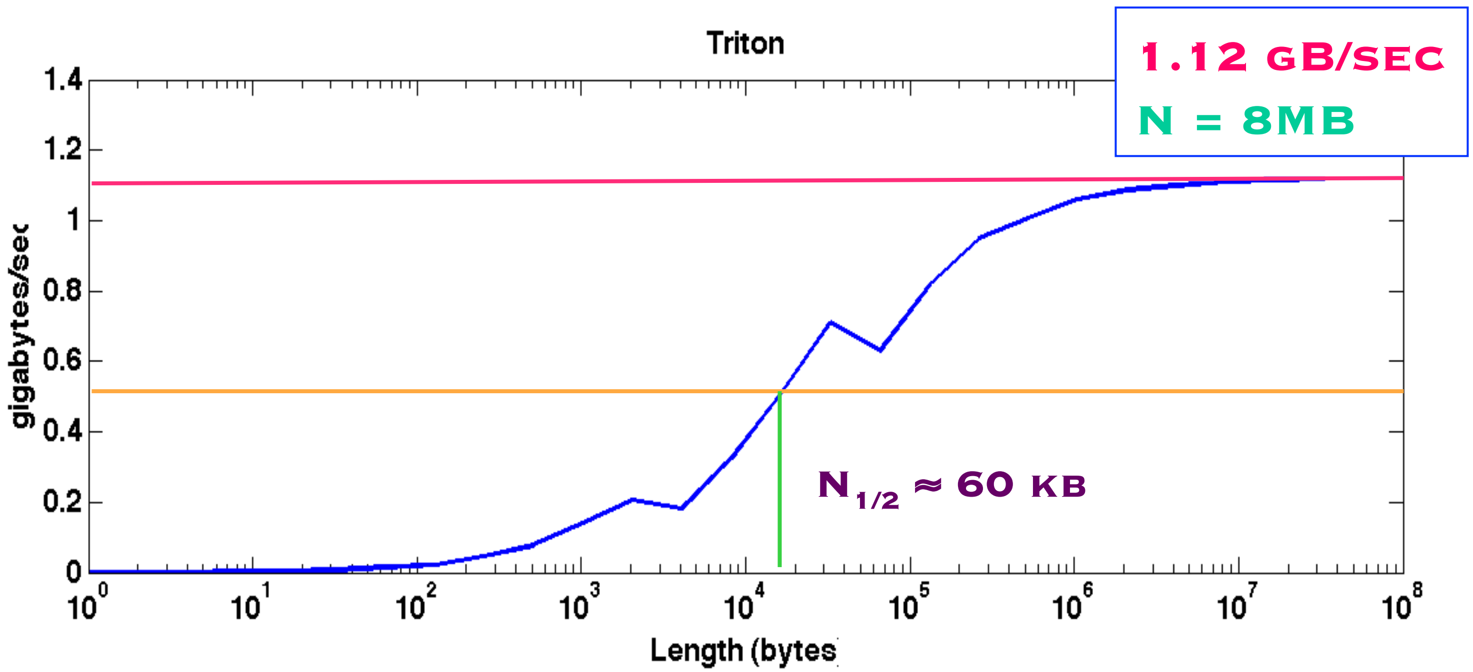
  $$\tfrac{1}{2}\beta^{-1}_\infty = n_{1/2} / T(n_{1/2}) \Rightarrow \beta^{-1}(n_{1/2}) = \tfrac{1}{2}\beta^{-1}_\infty$$

- In theory, this occurs when $\alpha = \beta^{-1}_\infty\, n_{1/2} \Rightarrow n_{1/2} = \alpha / \beta^{-1}_\infty$
- Doesn't generally predict actual value of $n_{1/2}$
- For SDSC's DataStar machine
  - $\alpha \approx 7.6\ \mu s$, $\beta_\infty \approx 1580$ Mbytes/sec $\Rightarrow n_{1/2} \approx$ 12KB
  - The actual value of $n_{1/2} \approx$ 38KB
  - In Assignment #2, you'll explore this phenomenon

# Typical bandwidth curve (SDSC Blue Horizon)

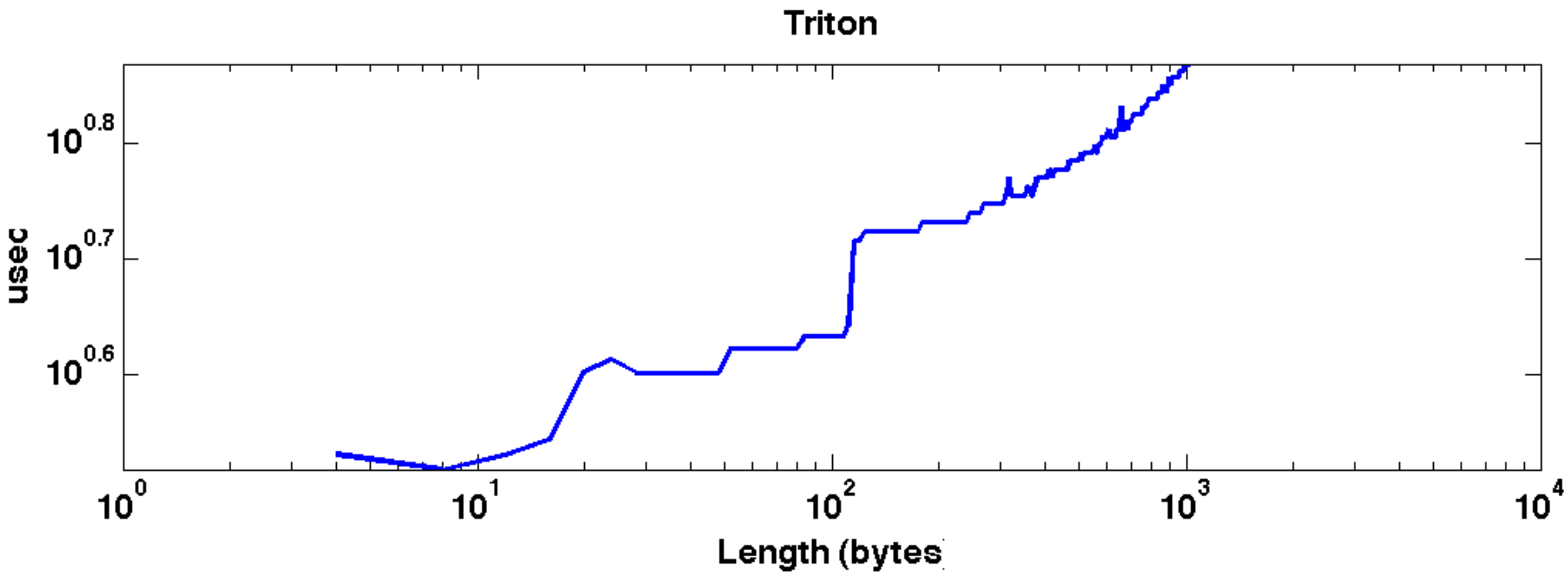


# Typical bandwidth curve (SDSC Triton)

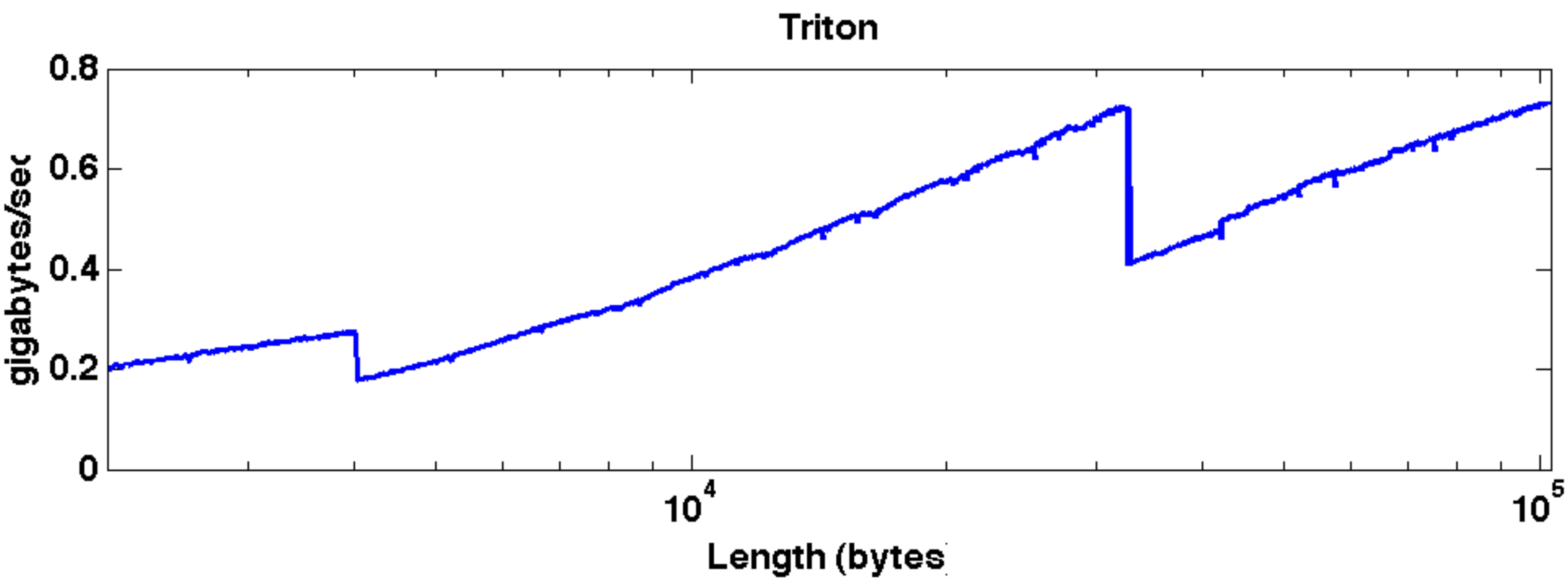



$\alpha = 3.2\ \mu sec$

# Short message behavior



# Intermediate length message behavior



# More about modeling

- LogP model (Culler et al, 1993), is more precise, but the $\alpha$, $\beta$ model is often good enough
- All these models ignore important effects: switch and processor contention

# Where does the time go?

- Under ideal conditions…
  - There is a pending receive waiting for an incoming message, which is transmitted directly to and from the users message buffer
  - There is no other communication traffic
- Assume a contiguous message