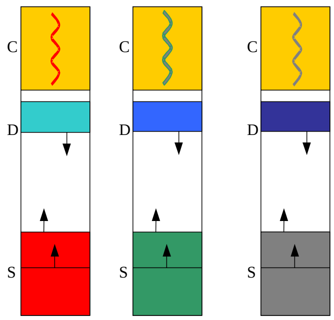
MPI

- **MPI 1**
  - Point to point
  - Collectives
  - Group management
  - Topologies
- **MPI 2**
  - Process management
  - One-sided
  - I/O
- **Some references**
  - http://www-unix.mcs.anl.gov/mpi/
  - http://www.netlib.org/utk/papers/mpi-book/mpi-book.html

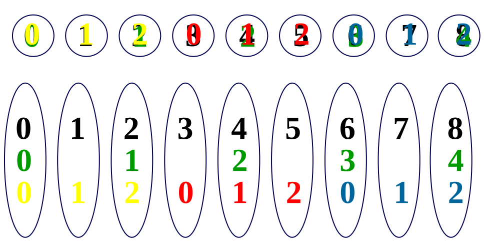
Distributed memory: @ space




```
Includes

Global variables

main () {
my_part = f( who am I)

Compute my part
Communicate if needed

}
```


Point to point communication: whom

- **Name space**
  - Rank
    - ✓ 0..n-1
  - Within Group
  - Communicator
    - ✓ Group + communication context
    - ✓ Predefined
      - MPI_COMM_WORLD
      - MPI_COMM_SELF
- **Designation of source/sink of communication**
  - (Communicator, rank)



Point to point communication: what

- **What is communicated**
  - Set of objects of a given type
- **Data types**
  - Predefined
    - ✓ Fortran: MPI_INTEGER, MPI_REAL, MPI_CHARACTER,…
    - ✓ C: MPI_CHAR, MPI_SHORT, MPI_INT, MPI_LONG, MPI_FLOAT,…
    - ✓ MPI_BYTE, MPI_PACKED
  - Derived
    - ✓ Mechanism to define new types
- **Send and receive types must match for the program to be correct. No type conversion**
- **Type representation conversion**

Point to point communication: synch.

- **End to end (communication modes)**
  - Buffered
  - Synchronous
  - Standard
  - Ready
- **Local**
  - Blocking call
  - Non-blocking call:
    - ✓ Inmediate calls

Point to point communication: semantics

- **Communication semantics**
  - Order: no overtaking
    - ✓ between messages that match the same receive, receives that match the same send
    - ✓ Between the same pair of processes
  - Progress
  - Fairness: not guaranteed

MPI-1 Interface: communication model

- **Point to point sends**

Rank within group

  - MPI_Send (buf, count, datatype, dest, tag, comm)
  - MPI_Bsend(buf, count, datatype, dest, tag, comm)
  - MPI_Rsend(buf, count, datatype, dest, tag, comm)
  - MPI_Ssend(buf, count, datatype, dest, tag, comm)

Identifyer for later enquiry

  - MPI_Isend (buf, count, datatype, dest, tag, comm, request)
  - MPI_Ibsend(buf, count, datatype, dest, tag, comm, request)
  - MPI_Issend(buf, count, datatype, dest, tag, comm, request)
  - MPI_Irsend(buf, count, datatype, dest, tag, comm, request)

mode

Attribute for receive selection

context

MPI-1 Interface: communication model

- **Point to point receive**

Rank
Specific
MPI_ANY_SOURCE

Selector
Specific
MPI_ANY_TAG

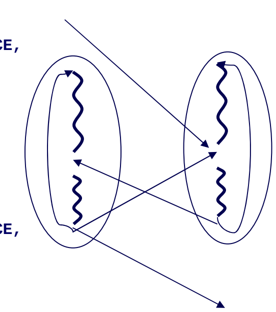
Max

- MPI_Recv (buf, count, datatype, source, tag, comm, status)
- MPI_Get_count(status, datatype, count)

Example

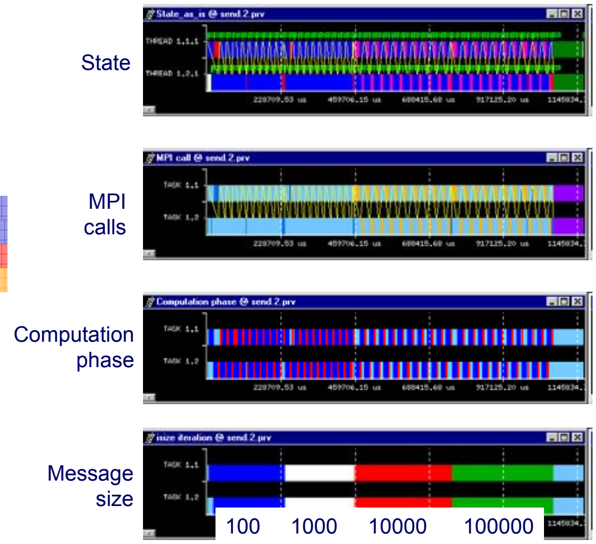
Sizes: 100, 1000, 10000, 100000

```
  Do isize=1,4
     msgsize = sizes(isize)
     if (rank .eq. 0) then
       call MPI_send(sndmsg, msgsize, MPI_INTEGER1, dest, rank,
1         MPI_COMM_WORLD, error)
     endif

    do i=1, NITERS
       call Compute(delay_time1)
       call MPI_Recv(rcvmsg, msgsize, MPI_INTEGER1, MPI_ANY_SOURCE,
1           MPI_ANY_TAG, MPI_COMM_WORLD, status, error)
       call Compute(delay_time2)
       call MPI_send(sndmsg, msgsize, MPI_INTEGER1, dest, rank,
1           MPI_COMM_WORLD, error)
     enddo

     if (rank .gt. 0) then
       call MPI_Recv(rcvmsg, msgsize, MPI_INTEGER1, MPI_ANY_SOURCE,
1          MPI_ANY_TAG, MPI_COMM_WORLD, status, error)
     endif
  enddo
```



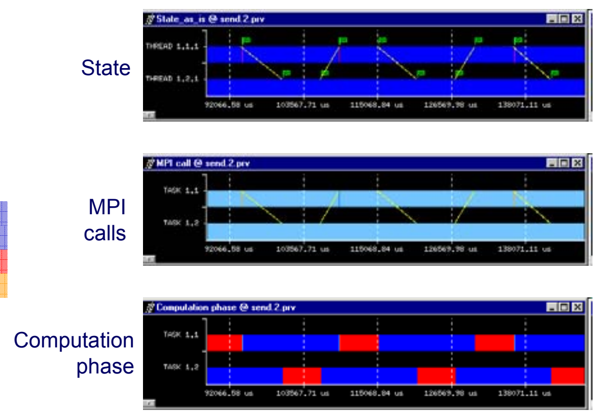
All sizes

```
Do isize=1,4
   msgsize = sizes(isize)
   if (rank .eq. 0) then
     call MPI_send(...)
   endif

  do i=1, NITERS
     call Compute(delay_time1)
     call MPI_Recv(...)
     call Compute(delay_time2)
     call MPI_send(...)
   enddo

   if (rank .gt. 0) then
     call MPI_Recv(...)
   endif
enddo
```



Short messages

```
Do isize=1,4
   msgsize = sizes(isize)
   if (rank .eq. 0) then
     call MPI_send(...)
   endif

  do i=1, NITERS
     call Compute(delay_time1)
     call MPI_Recv(...)
     call Compute(delay_time2)
     call MPI_send(...)
   enddo

   if (rank .gt. 0) then
     call MPI_Recv(...)
   endif
enddo
```



Message size = 100

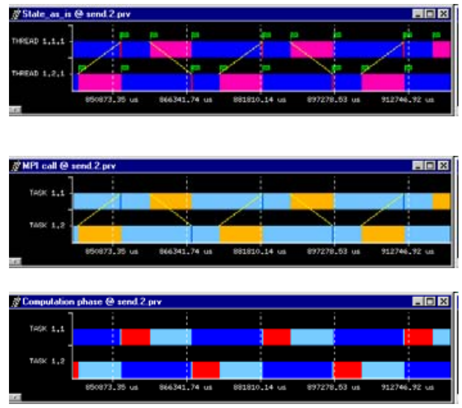
Long messages

```
Do isize=1,4
   msgsize = sizes(isize)
   if (rank .eq. 0) then
     call MPI_send(...)
   endif

  do i=1, NITERS
     call Compute(delay_time1)
     call MPI_Recv(...)
     call Compute(delay_time2)
     call MPI_send(...)
   enddo

   if (rank .gt. 0) then
     call MPI_Recv(...)
   endif
enddo
```

State

MPI calls

Computation phase



Message size = 100000

MPI-1 Interface: communication model

- **Point to point receive**

  - MPI_Irecv (buf, count, datatype, dest, tag, comm, request)
  - MPI_Wait(request, status)
  - MPI_Test(request, flag, status)

  Finished?

  - MPI_Get_count(status, datatype, count)

MPI-1 Interface: communication model

- **Wait/check finalization of Inmediate call**

  - MPI_Waitany (count, array_of_requests, index, status)
  - MPI_Waitall (count, array_of_requests, array_of_statuses)
  - MPI_Waitsome (incount, array_of_requests, outcount, array_of_indices, array_of_statuses)

  - MPI_Testany (count, array_of_requests, index, flag, status)
  - MPI_Testall (count, array_of_requests, flag, array_of_statuses)
  - MPI_Testsome (incount, array_of_requests, outcount, array_of_indices, array_of_statuses)

MPI-1 Interface: communication model

- **Check receive machings**

  Receive call will be matched

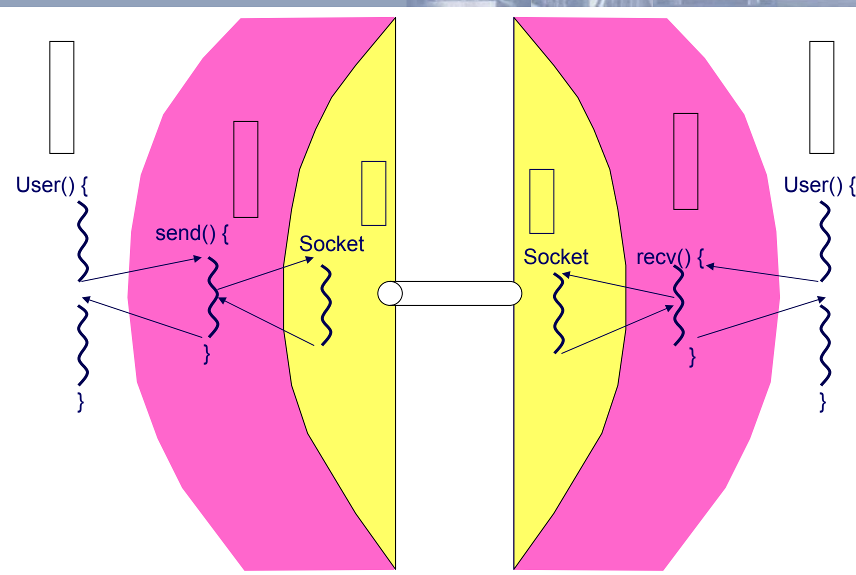
  - MPI_Iprobe (source, tag, comm, flag, status)
    - ✓ Non blocking check for arrival of matching message

  - MPI_Probe (source, tag, comm, status)
    - ✓ Blocking check for arrival of matching message

MPI-1 Interface: communication model

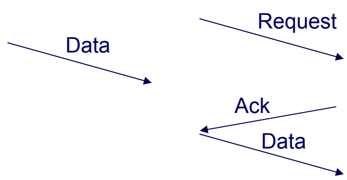
- **Other issues**
  - Cancellation
  - Persistent communication requests
  - Send-receive
  - MPI_PROC_NULL
  - Derived data types
    - ✓ MPI_TYPE_CONTIGUIOUS, MPI_TYPE_VECTOR, MPI_TYPE_INDEXED,MPI_TYPE_STRUCT, …
    - ✓ MPI_TYPE_COMMIT
  - MPI_PACK, MPI_UNPACK

MPI Run Time Library

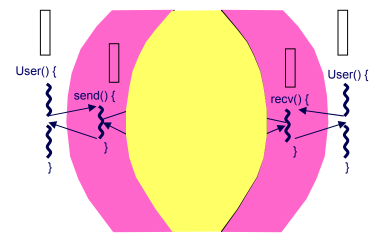


Implementation issues

- **Buffering**
  - At sender
    - ✓ Fast local response
  - At receiver
    - ✓ Advance transmission
- **Protocol**
  - Small/large messages

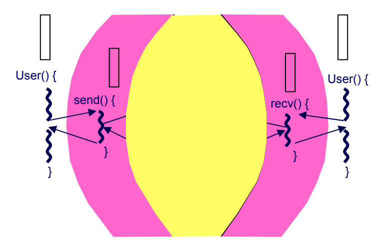


- Buffer management
  - ✓ amount
  - ✓ Static reservation/ Dynamic allocation
    - – Efficiency / Overhead



Implementation issues

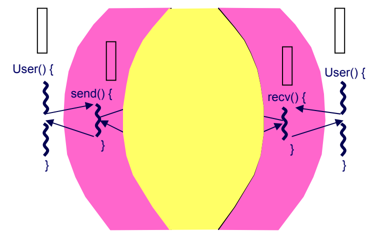
- **Flow control**
  - Avoid overflow of incoming messages
  - Tokens/credit
- **Matching**
  - Search overhead




```
MPI_Recv(…)
{
    if ( found in library buffer) return
    do {get from socket/link
        if (matches user request)    user buffer
        else    library buffer
    } until matched request
}
```

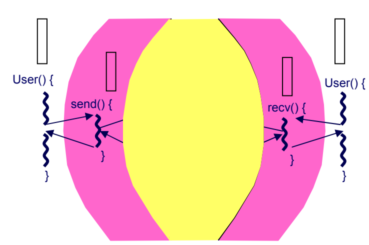
Implementation issues

- **Start of request (isend)**
  - inmediate
  - At the next blocking call
    - ✓ i.e. allow for sequence of requests



Implementation issues

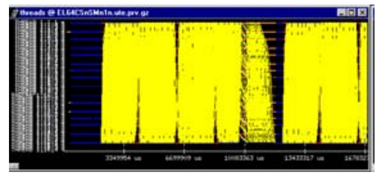
- **Number of copies**
- **Injection**
  - system call
    - ✓ sockets
  - memory mapped devices
    - ✓ Efficient user mode access
    - ✓ Resource consumption

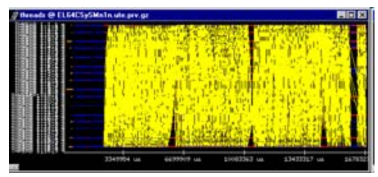


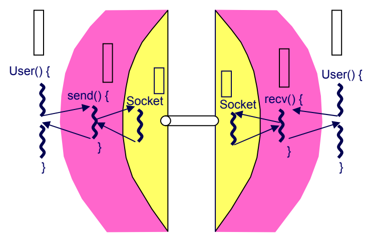
Jesús Labarta, MP, 2008

Implementation issues

- **Incoming arrival detection**
  - Interrupt
    - ✓ Signal
    - ✓ Threads:
      - Influence on OS scheduling
  - Poll

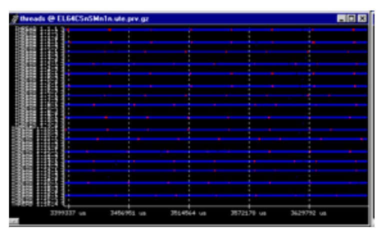


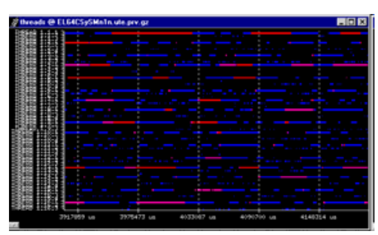


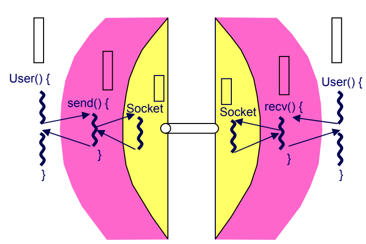


Implementation issues

- **Incoming arrival detection**
  - Interrupt
    - ✓ Signal
    - ✓ Threads:
      - Influence on OS scheduling
  - Poll



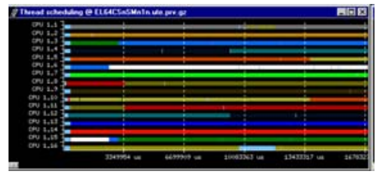




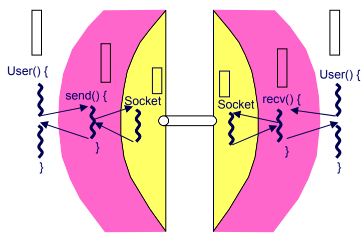
Implementation issues

- **Incoming arrival detection**
  - Interrupt
    - ✓ Signal
    - ✓ Threads:
      - – Influence on OS scheduling
  - Poll

Time span : ≈ 6 s



Time span : ≈ 12 s



Environment variables

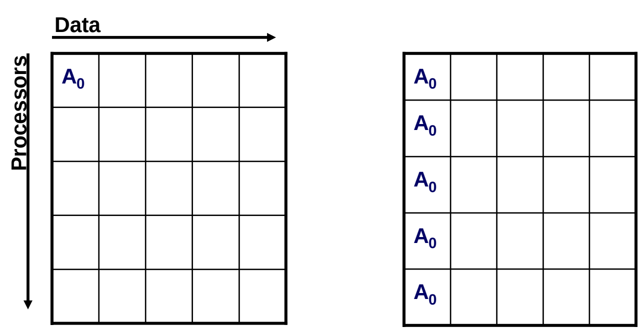
- **Mechanism for the user to control the implementation mechanisms**
- **Machine specific: IBM**
  - MP_SHARED_MEMORY yes/no
  - MP_EAGER_LIMIT value
  - MP_CSS_INTERRUPT yes/no
  - MP_EUILIB us/ip

MPI-1 Interface: communication model

- **Collective synchronization**
  - Called by all processes within a group
  - MPI_Barrier (comm)

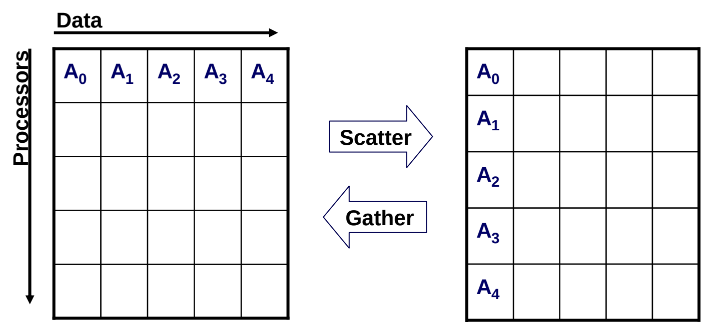
MPI-1 Interface: communication model

- **Collective communication**
  - MPI_Bcast (buffer, count, datatype, root, comm)



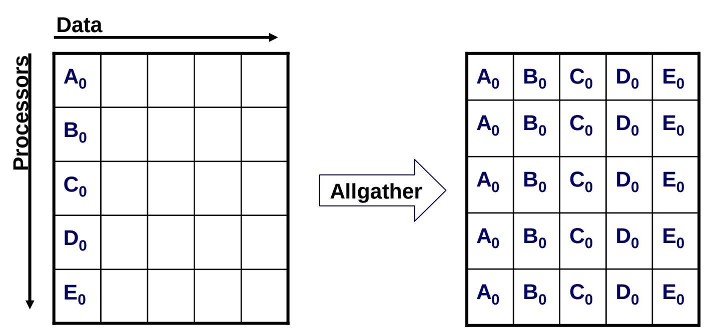
MPI-1 Interface: communication model

- **Collective communication**
  - MPI_Gather (sendbuf, sendcount, sendtype, recvbuf, recvtype, root, comm)
  - MPI_Scatter (sendbuf, sendcount, sendtype, recvbuf, recvtype, root, comm)



MPI-1 Interface: communication model

- **Collective communication**
  - MPI_Allgather (sendbuf, sendcount, sendtype, recvbuf, recvtype, comm)



MPI-1 Interface: communication model

- **Collective communication**
  - MPI_Alltoall (sendbuf, sendcount, sendtype, recvbuf, recvtype, comm)

Data →

Processors ↓

A_0	A_1	A_2	A_3	A_4
B_0	B_1	B_2	B_3	B_4
C_0	C_1	C_2	C_3	C_4
D_0	D_1	D_2	D_3	D_4
E_0	E_1	E_2	E_3	E_4

Alltoall ⇒

A_0	B_0	C_0	D_0	E_0
A_1	B_1	C_1	D_1	E_1
A_2	B_2	C_2	D_2	E_2
A_3	B_3	C_3	D_3	E_3
A_4	B_4	C_4	D_4	E_4

MPI-1 Interface: communication model

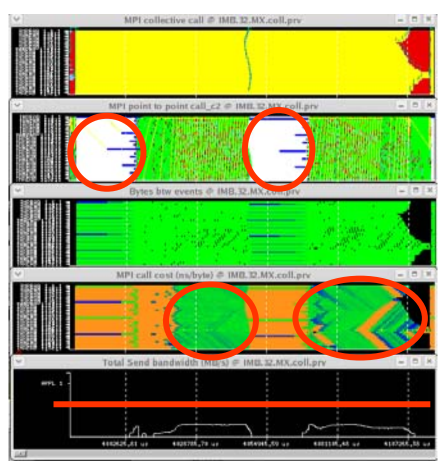
- **Collective reductions**
  - MPI_Reduce (sendbuf, recvbuf, count, datatype, op, root, comm)
    - ✓ MPI_MAX, MPI_MIN, MPI_SUM, MPI_PROD, ….
  - MPI_Allreduce (sendbuf, recvbuf, count, datatype, op, comm)
  - MPI_Reduce_scatter (sendbuf, recvbuf, recvcounts, datatype, op, comm)
  - MPI_Scan (sendbuf, recvbuf, count, datatype, op, comm)

Collective implementation issues

- **Based on point to point**
  - Tree based communications to minimize
    - ✓ # communications
    - ✓ Dependence chain
  - Partitioned message
    - ✓ # concurrent network injection links
    - ✓ Pipelining
  - On SMP
    - ✓ Local and remote

MPI collectives: Broadcast

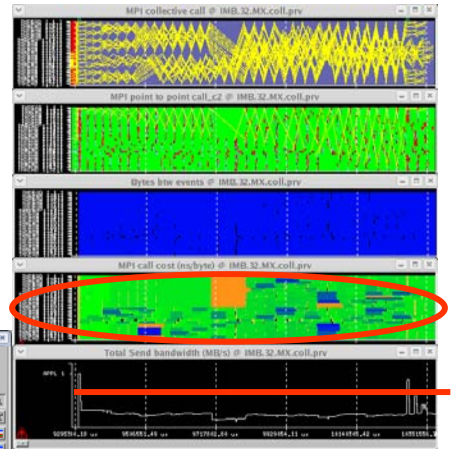
- **Drain/sink bandwdith**
- **2 broadcasts, 4MB**
  - Heavy cost of initial phase
  - Bubbles!!
  - Fraction of available bandwidth
- **Possibility of local network**
  - Within Bladecenter
  - Low cost

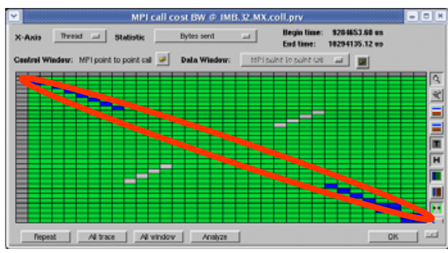


Jesús Labarta, MP, 2008

MPI collectives: Alltoall

- **1 AlltoAll, 4MB**
  - Contention?
  - Send to self !!
  - Fraction of available bandwidth

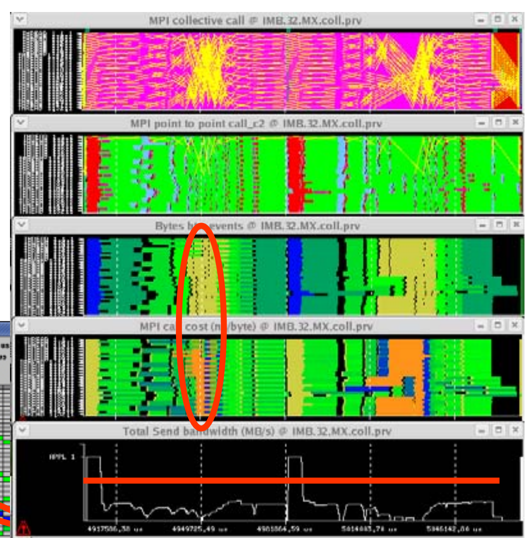


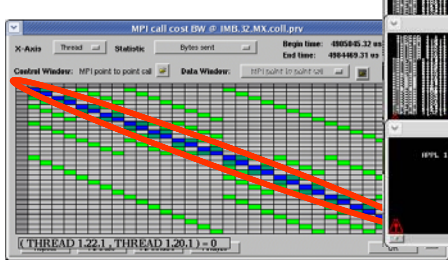


Jesús Labarta, MP, 2008

MPI collectives: AllReduce

- **2 allreduces, 4MB**
  - Send to self !!
  - Contention !!

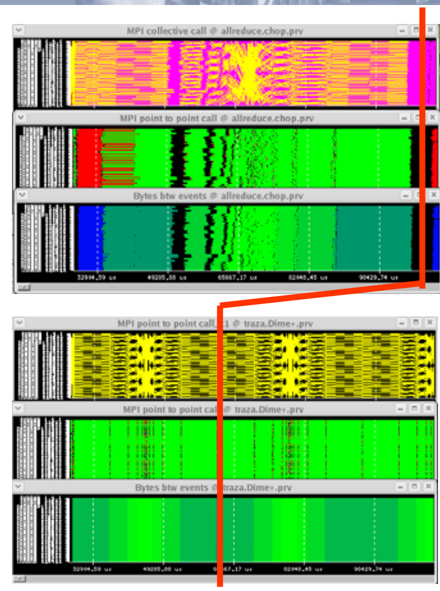




Jesús Labarta, MP, 2008

MPI collectives: AllReduce

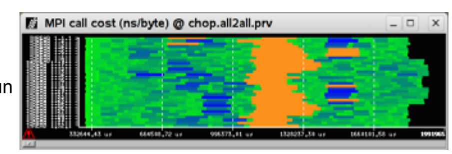
- **1 AllReduce**
  - Reality vs Dimemas?
- **Causes**
  - Contention?



Contention @ collectives

- **P2p transfers within alltoall**
- **MPI call cost in ns/byte**
  - Real vs
  - Dimemas vs
  - Dimemas + Venus

Actual run



No contention

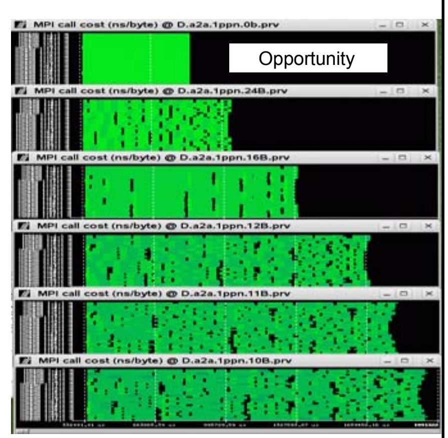
24 concurrent transfers

16 concurrent transfers

12 concurrent transfers

11 concurrent transfers

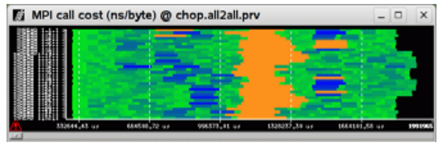
10 concurrent transfers



Contention @ collectives

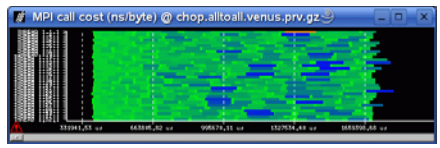
- **P2p transfers within alltoall**

Actual run



- **MPI call cost in ns/byte**
  - Real vs
  - Dimemas vs
  - Dimemas + Venus

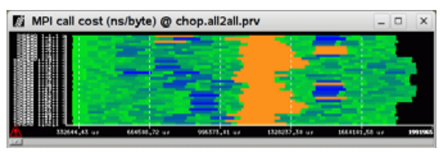
D&V



Contention @ collectives

- **MPI call cost in ns/byte**
  - Real vs
  - Dimemas vs
  - Dimemas + Venus
  - Impact of eager limit

Actual run



24 concurrent transfers

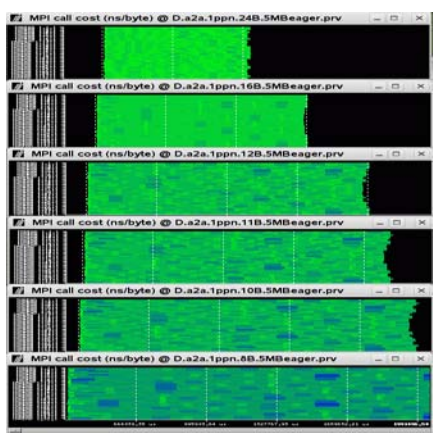
16 concurrent transfers

12 concurrent transfers

11 concurrent transfers

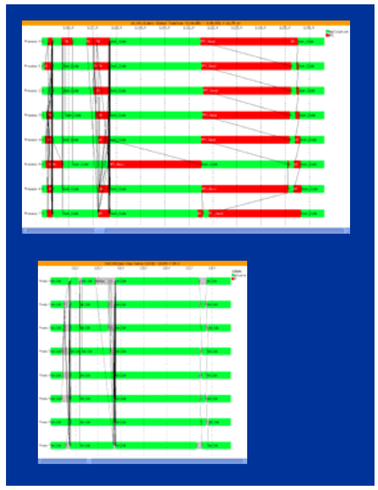
10 concurrent transfers

8 concurrent transfers



Progress issues in point to point

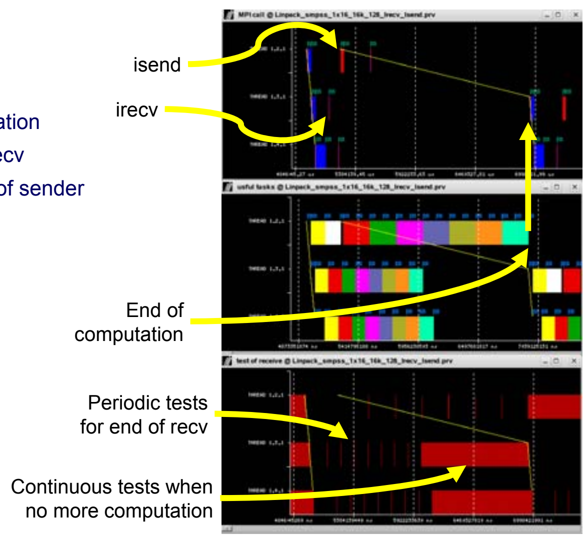
- **Unexpected behavior**
  - IFS on E10000 (MPICH)*
  - IBM SP (@KTH)



* Courtesy FECIT

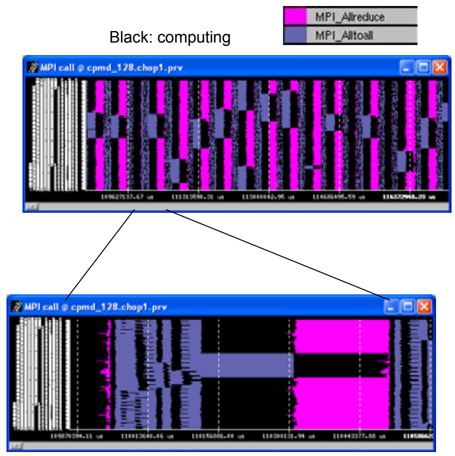
Progress issues in point to point

- **MPICH – GM**
  - Early irecv
  - Isend followed by computation
  - Periodic tests for end of recv
  - No actual transfer till end of sender computation ☹



Progress issue in all2all

- Some processes get stuck in the All2all while others go into the next computation phase.
- When the ones that got out of the all2all call MPI again the stalled ones can proceed…. but they now have to perform the computation
- Actual cause:



Other issues

- **Initialization termination**
- **Time management**
- **Group and communicator management**
  - Definition of sub groups
- **Topologies**
  - Ease “typical” communication patterns
  - Potential to better match platform
- **PMPI: MPI Profiler Interface**
  - Ease portable tools development

MPI-1 Interface: process model

- **Initialization: declare as part of parallel application**
  - MPI_init (argc, argv)
  - MPI_Finalize()

- **Time management**
  - MPI_Wtime()
  - MPI_Wtick()
  - MPI_Wtime_is_global()

MPI-1 Interface: process model

- **Name space management**
  - Self identification
    - ✓ MPI_Comm_rank(comm, rank)
    - ✓ MPI_Group_rank (group, rank)
  - Name space query
    - ✓ MPI_Comm_size(comm, size)
    - ✓ MPI_Group_size (group, size)
  - Name translation
    - ✓ MPI_Group_translate (group1, n, ranks1, group2, ranks2)
    - ✓ MPI_Comm_group (comm, group)

MPI-1 Interface: process model

- **Name space management**
  - Group management
    - ✓ MPI_Group_union (group1, group2, newgroup)
    - ✓ MPI_Group_intersection (group1, group2, newgroup)
    - ✓ MPI_Group_incl (group, n, ranks, newgroup)
    - ✓ MPI_Range_incl (group, n, ranks, newgroup)
    - ✓ MPI_Range_excl (group, n, ranks, newgroup)
    - ✓ MPI_Group_free (group)

MPI-1 Interface: process model

- **Name space management**
  - Communicator management
    - ✓ MPI_Comm_dup (comm, newcomm)
    - ✓ MPI_ Comm_create (comm, group, newcomm)
    - ✓ MPI_Group_split (comm, color, key, newgroup)

    - ✓ MPI_ Group _free (group)

MPI-1 Interface: process model

- **Name space management**
  - Name translation: Topologies
    - ✓ MPI_Cart_create (comm_old, ndims, dims, periods, reorder, newcomm)
    - ✓ MPI_Cartdim_get (comm, ndims)
    - ✓ MPI_Cart_rank (comm, coords, rank)
    - ✓ MPI_Cart_coords (comm, rank, maxdims, coords)
    - ✓ MPI_Cart_shift (comm, direction, disp, rank_source, rank_dest)
    - ✓ MPI_Cart_sub (comm, remain_dims, newcomm)
    - ✓ MPI_Cart_map (comm, ndims, dims, periods, newrank)
    - ✓ MPI_Dims_create (nnodes, ndims, dims)

MPI-1 Interface: process model

- **Name space management**
  - Name translation: Topologies (cont.)
    - ✓ MPI_Graph_create (comm_old, nnodes, index, edges, reorder, comm_graph)
    - ✓ MPI_Topo_test (comm, status)
    - ✓ MPI_Graphdims_get (comm, nnodes, edges)
    - ✓ MPI_Graph_get (comm, maxindex, maxedges,index, edges)
    - ✓ MPI_Graph_neigbors_count (comm, rank, maxneigbor, neigbors)
    - ✓ MPI_Graph_map (comm, nnodes, index, edges, new_rank)

MPI-1 Interface: process model

- **Name space management**
  - and more
    - ✓ MPI_Group_compare (group1, group2, result)
    - ✓ MPI_Comm_compare (comm1, comm2, result)

MPI-1 Interface: type model

- **Type definitions**
  - MPI_Type_contiguous (count, oldtype, newtype)

    Elements
  - MPI_Type_vector (count, blocklength, stride, oldtype, newtype)
  - MPI_Type_hvector (count, blocklength, stride, oldtype, newtype)

    Bytes
  - MPI_Type_indexed (count, array_of_blocklengths, array_of_displacements, oldtype, newtype)
  - MPI_Type_hindexed
  - MPI_Type_struct (count, array_of_blocklengths, array_of_displacements, array_of_types, newtype)

MPI-1 Interface: type model

- **Creation / destruction**
  - MPI_Type_commit (datatype)
  - MPI_Type_free (datatype)

MPI-1 Interface: type model

- **Type queries**
  - MPI_Type_extent (datatype, extent)
  - MPI_Type_size (datatype, size)
    - ✓ Data bytes
  - MPI_Type_count (datatype, count)

Mixed mode programming

- **Programming model: MPI + OpenMP**
  - Main thread does all communication while in sequential OpenMP part
- **Parallelization:**
  - MPI coarse grain
  - OpenMP fine grain
  - Complexity
    - ✓ Seems simple
    - ✓ Two programming models to deal with a problem of two granularities
  - Performance
    - ✓ Possibly conflicting approaches

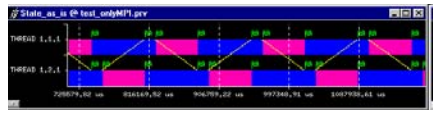
Nested MPI + OpenMP

- **MPI specified as thread safe, not all implementations are**
- **Typical combination**
  - OpenMP used for loops between two communications
  - MPI called by the master thread

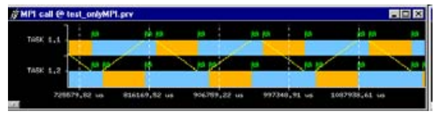
Nested MPI + OpenMP

```
msgsize = 10000
...

do i=1, NITERS

   do j=1,n
     if (rank.eq.0) then
        delay_time1=(N-j)/100
     else
        delay_time1=j/100
     endif
     call Compute(delay_time1)
   enddo
   call MPI_Recv(...)
   call Compute(delay_time2)
   call MPI_send(...)
enddo

...
```

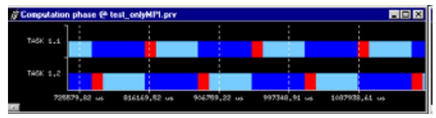
State



MPI calls



Computation phase

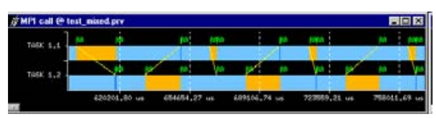


Nested MPI + OpenMP

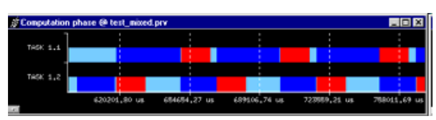
```
msgsize = 10000
...

do i=1, NITERS
C$OMP  PARALLEL DO SCHEDULE(GUIDED)
   do j=1,n
     if (rank.eq.0) then
        delay_time1=(N-j)/100
     else
        delay_time1=j/100
     endif
     call Compute(delay_time1)
   enddo
   call MPI_Recv(...)
   call Compute(delay_time2)
    call MPI_send(...)
enddo

...
```

State

MPI calls



Computation phase



Parallel functions

MPI-1 Interface: comments

- **New concept ≡ lot of new calls**
  - ✓ # functions / concepts used ??
  - ✓ Design by committee ⇒ ∪ proposals
- **Implementation cost = f (# man pages)**
  - ✓ Overhead if just sending array in memory
- **Conclusion: MPI-1 was not enough ⇒ MPI-2**

Batallitas

- **Sweep3D**
- **Environment variables**
- **Metacomputing**
- **Blue Gene**
- **Bet**
  - OpenMP as popular as OpenMP
  - Causa perdida?

MPI-2

- **Functionalities**
  - Clean-up and clarifications
    - ✓ handful of small problems
  - Process model
    - ✓ Dynamic process creation
  - One-sided communication
    - ✓ ≈ shared memory
  - MPI-I/O
- **Status**
  - Delayed implementations
  - Performance ≈

Jesús Labarta, MP, 2008

MPI-2: Process model

- **Dynamic process creation**

Collective over
Wait MPI_INIT

Binary file
String of args
Granularity

- MPI_Comm_spawn(command, argv, maxprocs, info, root, comm, intecomm, array_of_errcodes)

Resquested
if not possible ….

AOB

Parents + children
MPI_Get_parent
+
Children local

Jesús Labarta, MP, 2008

MPI-2: Process model

- **Dynamic process creation**
  - MPI_Comm_spawn_multiple(count, array_of_command, array_of_argv, array_of_maxprocs, array_of_info, root, comm, intecomm, array_of_errcodes)

MPI-2: Process model

- **Client-server**
  - MPI_Open_port (info, port_name)
  - MPI_Close_port (port_name)
  - MPI_Comm_accept (port_name, info, root, comm, newcomm)
  - MPI_Comm_connect (port_name, info, root, comm, newcomm)
- **Name service**
  - MPI_Publish_name (service_name, info, port_name)
  - MPI_Unpublish_name (service_name, info, port_name)
  - MPI_Lookup_name (service_name, info, port_name)

….familiar

MPI-2: One-Sided Communications

- **Influence of non-coherent shared memory programming models**
  - CRAY shmem
  - Sympathy for Load/store

- **Provide a shared memory interface on distributed machines**
  - Separate communication and synchronization
  - Needs:
    - ✓ Declare accessible address space
    - ✓ Access primitives
    - ✓ Consistency management

MPI-2: One-Sided Communications

- **Declaration of accessible space**
  - Window: region of memory

Memory segment

bytes

With some structure

AOB

  - MPI_win_create (base, size, disp_unit, info, comm, win)

Collective

  - MPI_win_free (win)

MPI-2: One-Sided Communications

- **Info on accessible space**
  - MPI_Win_get_attr (win, queried_atrib, value, flag)
  - MPI_Win_get_group (win, group)

MPI-2: One-Sided Communications

- **Data access**
  - MPI_Put (orig_addr, orig_count, orig_datatype, target_rank, target_disp, target_count,target_datatype, win)
  - MPI_Get (orig_addr, orig_count, orig_datatype, target_rank, target_disp, target_count,target_datatype, win)

From/to region

*disp_unit+ Window_base
=
From/to address

MPI-2: One-Sided Communications

- **Data access (and ...)**
  - MPI_Accumulate(orig_addr, orig_count, orig_datatype, target_rank, target_disp, target_count,target_datatype, op, win)

MPI-2: One-Sided Communications

- **Consistency**
  - Epoch: Time between synchronization calls
    - ✓ Memory state within epoch: who knows
    - ✓ Memory state consistent at end of epoch
- **Epoch synchronization: Two+1 ways**
  - Fence
  - Post/start
  - Locks

MPI-2: One-Sided Communications

- **Fence synchronization**
  - Collective start of new epoch (and end of previous)
  - MPI_Win_fence (assert, win)

MPI-2: One-Sided Communications

- **General synchronization**

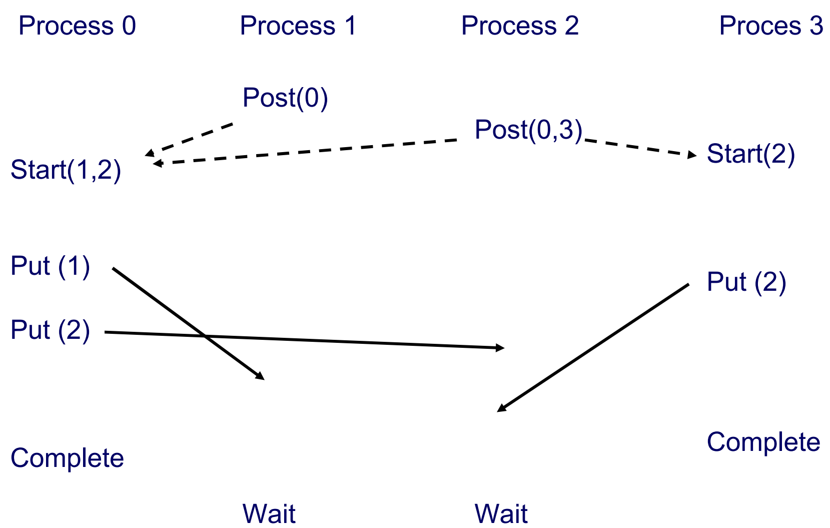
What I want to access

- MPI_Win_start (group, assert, win)
- MPI_Win_complete (win)

To whom I offer

- MPI_Win_post (group, assert, win)
- MPI_Win_wait (win)
- MPI_Win_Test (win)

MPI-2: One-Sided Communications



MPI-2: One-Sided Communications

- **Locks synchronization**
  - Access epoch with mutual exclusion

    MPI_LOCK_EXCLUSIVE
    MPI_LOCK_SHARED

    Locked region

  - MPI_Win_lock (lock_type, rank, assert, win)
  - MPI_Win_unlock (rank, win)