# MPI (Message Passing Interface)

- De facto message passing standard for parallel computing
- Available on virtually all platforms; both proprietary and open source versions (MPICH)
- Grew out of an earlier message passing system, PVM (Parallel Virtual Machine), still actively used, but now outdated

# MPI Process Creation/Destruction

MPI_Init(int *argc, char ***argv)

Initializes the MPI execution environment.

(Note the extra level of indirection.)

MPI_Finalize(void)

Terminates MPI execution environment. If you forget to make all processes call this routine, you may leave orphans on the system (run ps on all nodes to find them).

# MPI Process Identification

MPI_Comm_size(comm, &size )

Determines the number of processes

MPI_Comm_rank(comm, &pid )

Pid is the process identifier of the caller (consecutive ints, starting with 0)

comm is typically MPI_COMM_WORLD.

NB: by default the program dies if any call fails; return values can safely be ignored.

# MPI Basic Send

MPI_Send(buf, count, datatype, dest, tag, comm)

- buf: address of send buffer
- count: number of elements
- datatype: data type of send buffer elements
- dest: process id of destination process
- tag: message tag (ignore for now)
- comm: communicator (ignore for now)

# MPI Basic Receive

MPI_Recv(buf, count, datatype, source, tag, comm, &status)

- buf: address of receive buffer
- count: size of receive buffer in elements
- datatype: data type of receive buffer elements
- source: source process id or MPI_ANY_SOURCE
- tag and comm: ignore for now
- status: status object (indicates sender and tag)

# MPI Matrix Multiply (initial version)

```
main(int argc, char *argv[])
{
   MPI_Init (&argc, &argv);
   MPI_Comm_rank(MPI_COMM_WORLD, &me);
   MPI_Comm_size(MPI_COMM_WORLD, &p);
   /* Data distribution */ ...
   /* Computation */ ...
   /* Result gathering */ ...
   MPI_Finalize();
}
```

# MPI Matrix Multiply (initial version)

```
/* Data distribution */
  if (me == 0) {
    for (i = 1; i < p; i++) {
      MPI_Send(&a[i*N/p][0], N*N/p, MPI_INT, i, 0,
                  MPI_COMM_WORLD);
      MPI_Send(b, N*N, MPI_INT, i, 0, MPI_COMM_WORLD);
    }
  } else {
    MPI_Recv(&a[me*N/p][0], N*N/p, MPI_INT, 0, 0,
                          MPI_COMM_WORLD, 0);
    MPI_Recv(b, N*N, MPI_INT, 0, 0,
                          MPI_COMM_WORLD, 0);
  }
```

# MPI Matrix Multiply (initial version)

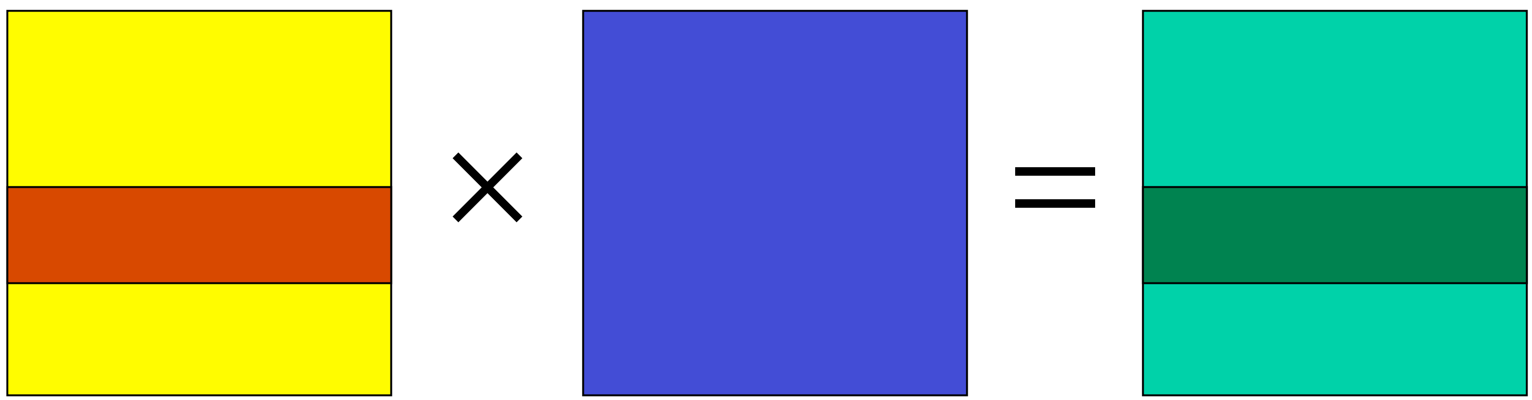
```
/* Computation */

    for (i = me*N/p; i < (me+1)*N/p; i++) {
        for (j = 0; j < N; j++) {
            c[i][j] = 0;
            for (k = 0; k < N; k++) {
                c[i][j] += a[i][k] * b[k][j];
            }
        }
    }
```

# MPI Matrix Multiply (initial version)

```
/* Result gathering */
  if (me != 0) {
    MPI_Send(&c[me*N/p][0], N*N/p, MPI_INT, 0, 0,
                MPI_COMM_WORLD);
  } else {
    for (i = 1; i < p; i++) {
      MPI_Recv(&c[i*N/p][0], N*N/p, MPI_INT, i, 0,
                MPI_COMM_WORLD, 0);
    }
  }
```

# Work Performed by One Process



Why store the unused portions?

# MPI Matrix Multiply (with index renaming)

```
/* Data distribution */
  if (me == 0) {
     for (i = 1; i < p; i++) {
        MPI_Send(&a[i*N/p][0], N*N/p, MPI_INT, i, 0,
                    MPI_COMM_WORLD);
        MPI_Send(b, N*N, MPI_INT, i, 0, MPI_COMM_WORLD);
     }
  } else {
     MPI_Recv(a, N*N/p, MPI_INT, 0, 0, MPI_COMM_WORLD, 0);
     MPI_Recv(b, N*N, MPI_INT, 0, 0, MPI_COMM_WORLD, 0);
  }
```

# MPI Matrix Multiply (with index renaming)

```
/* Computation */

for (i = 0; i < N/p; i++) {
    for (j = 0; j < N; j++) {
        c[i][j] = 0;
        for (k = 0; k < N; k++) {
            c[i][j] += a[i][k] * b[k][j];
        }
    }
}
```

# MPI Matrix Multiply (with index renaming)

```
/* Result gathering */
  if (me != 0) {
    MPI_Send(c, N*N/p, MPI_INT, 0, 0,
                    MPI_COMM_WORLD);
  } else {
    for (i = 1; i < p; i++) {
      MPI_Recv(&c[i*N/p][0], N*N/p, MPI_INT, i,
                    0, MPI_COMM_WORLD, 0);
    }
  }
```

# Running an MPI Program

- mpirun
  -np num_processes
  -machinefile filename
  <program_name> <arguments>
- Creates specified number of Unix processes, on nodes listed in the specified file

# Global Operations (1 of 2)

- So far, we have only looked at point-to-point or one-to-one message passing facilities
- Often, it is useful to have one-to-many or many-to-one message communication
- This is what MPI's global operations do

# Global Operations (2 of 2)

- MPI_Barrier
- MPI_Bcast
- MPI_Scatter
- MPI_Gather
- MPI_Allgather
- MPI_Alltoall
- MPI_Reduce
- MPI_Allreduce

# Barrier

MPI_Barrier(comm)

Global barrier synchronization, as with shared memory: all processes wait until all have arrived.

# Broadcast

MPI_Bcast(inbuf, incnt, intype, root, comm)

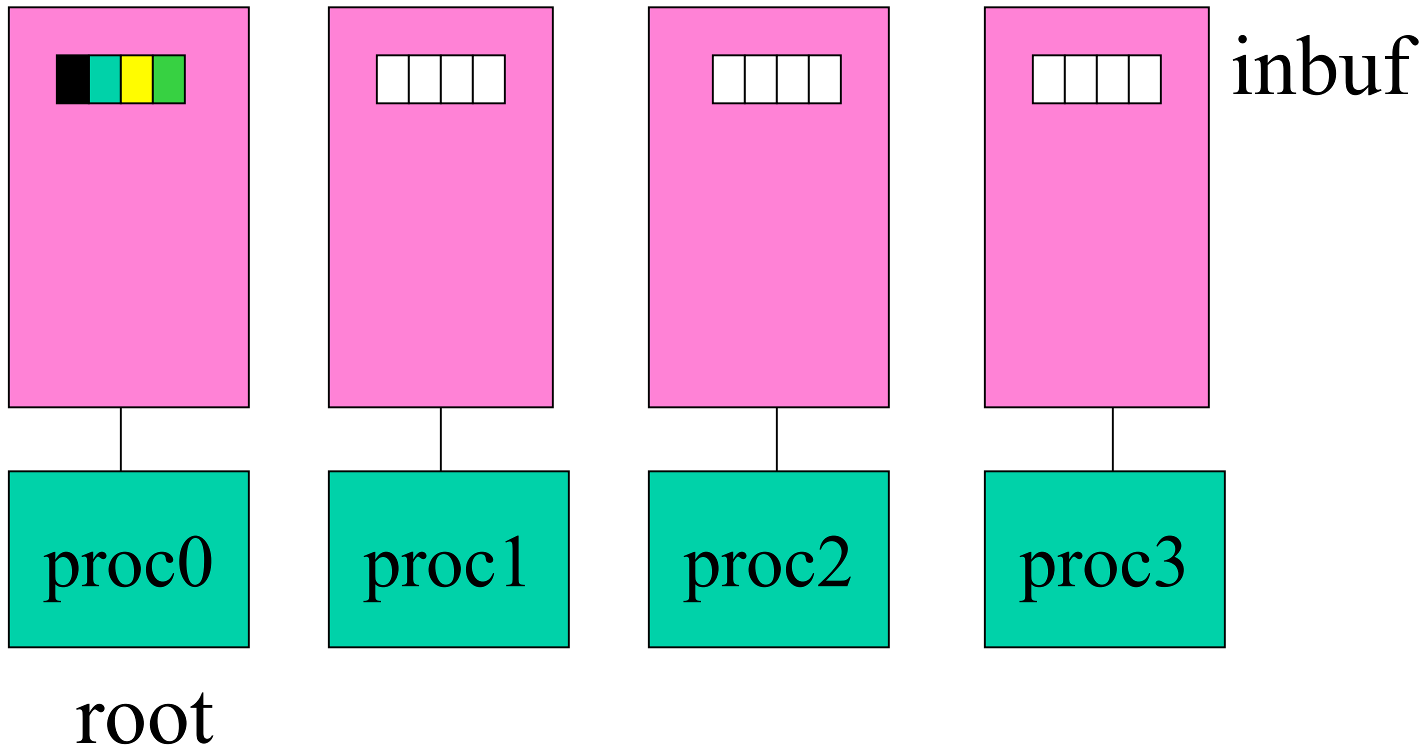
inbuf: address of input buffer (on root);
address of output buffer (elsewhere)

incnt: number of elements

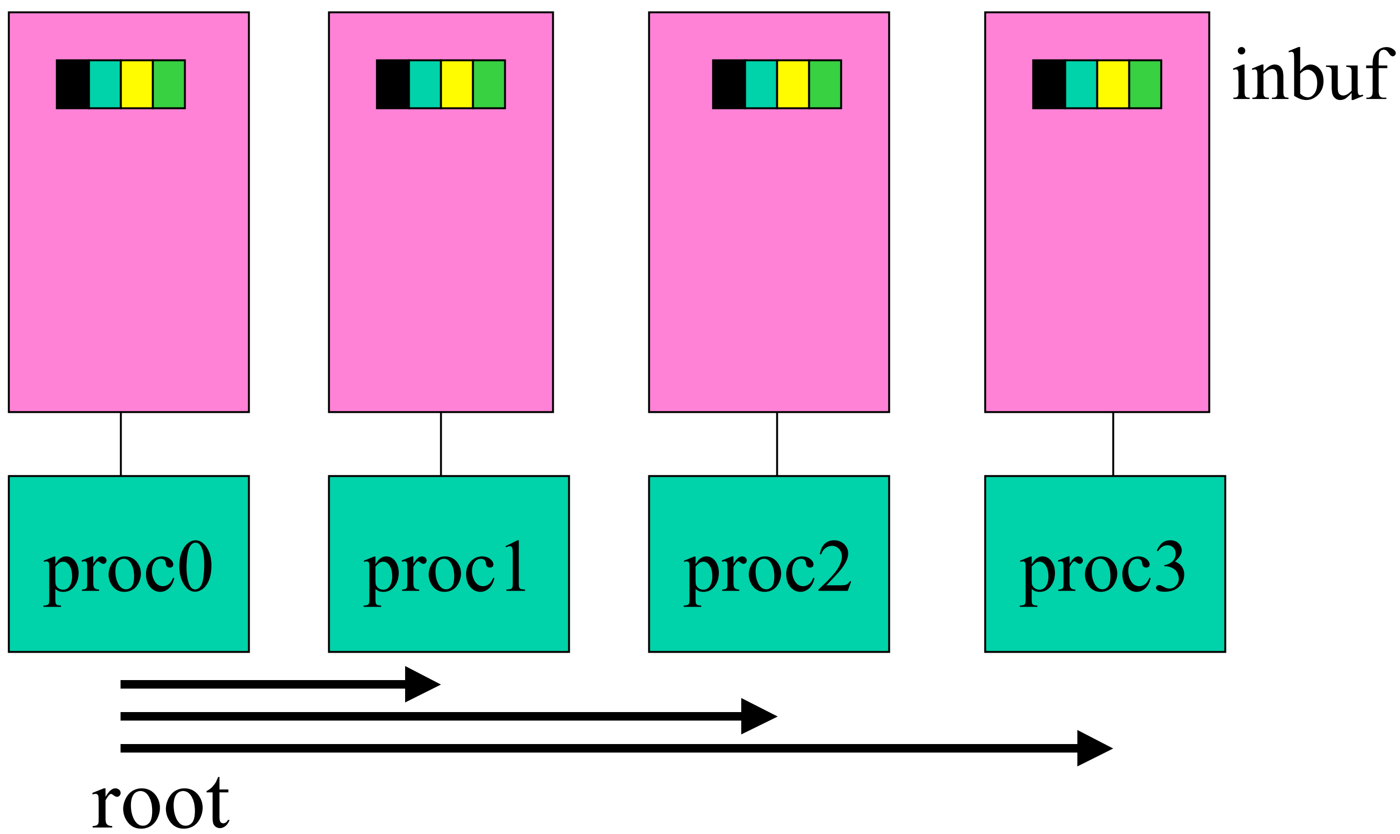
intype: type of elements

root: process id of root (sender) process

# Before Broadcast



# After Broadcast



# Scatter

MPI_Scatter(inbuf, incnt, intype, outbuf,
outcnt, outtype, root, comm)

inbuf: address of input buffer

incnt: number of elements sent to each process

intype: type of input elements

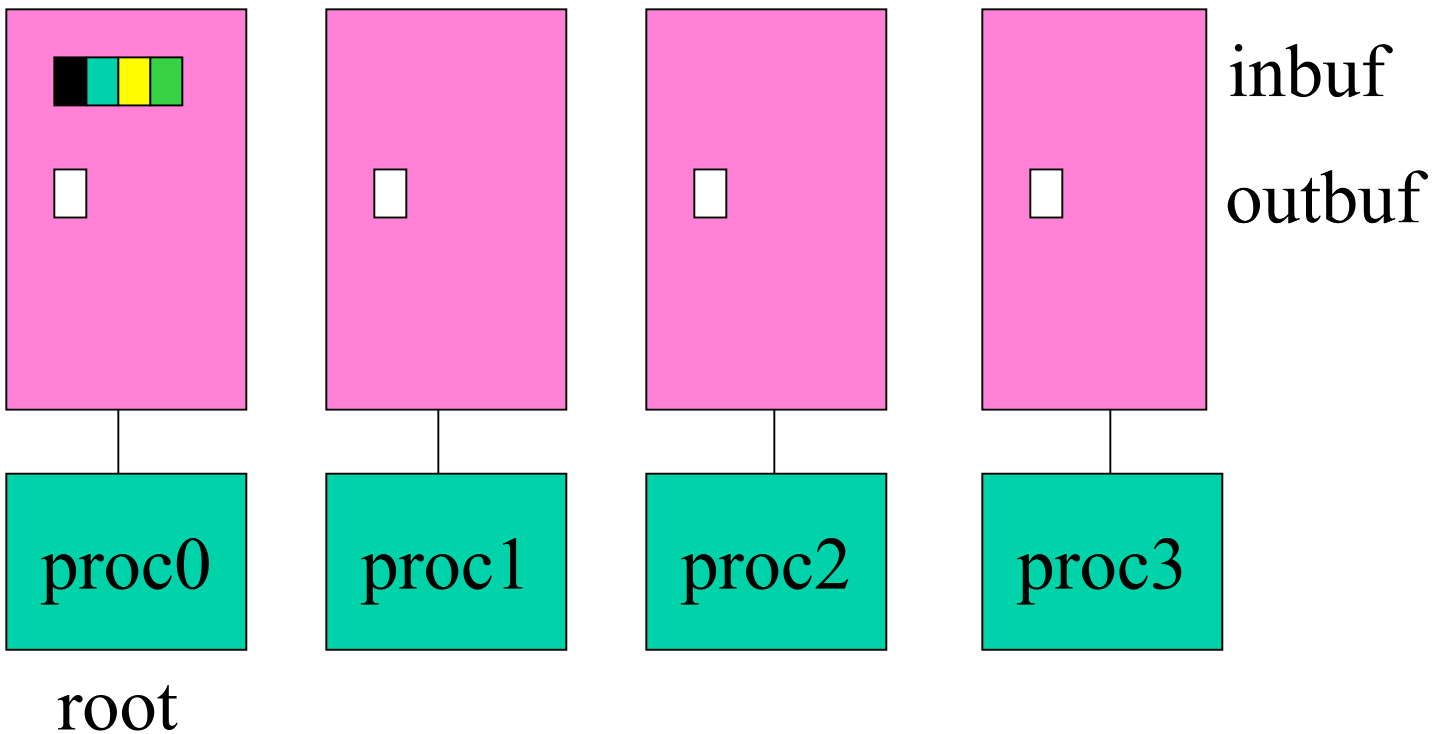
outbuf: address of output buffer

outcnt: number of output elements

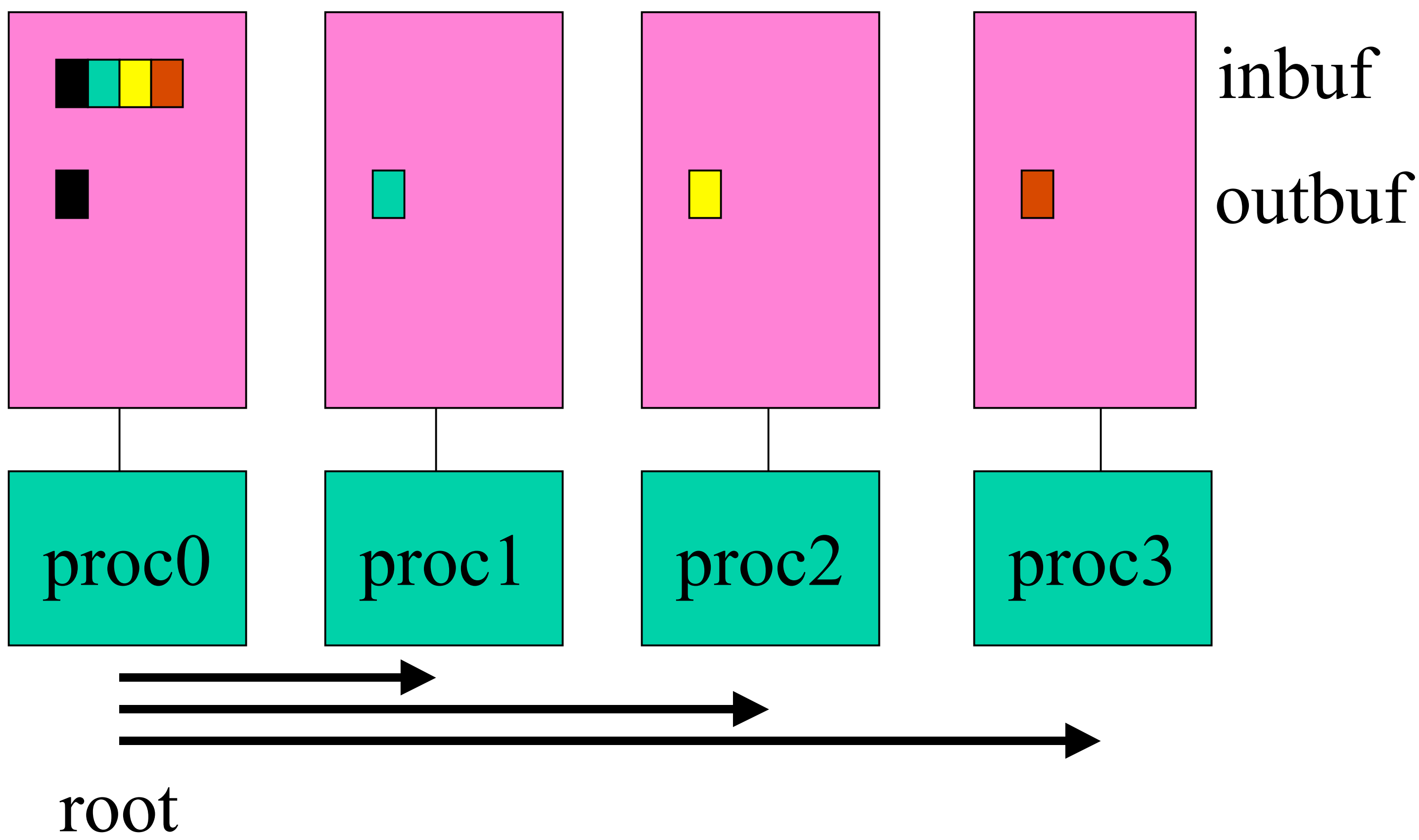
outtype: type of output elements

root: process id of root process

# Before Scatter



# After Scatter



# Gather

MPI_Gather(inbuf, incnt, intype, outbuf,
outcnt, outtype, root, comm)

inbuf: address of input buffer

incnt: number of input elements

intype: type of input elements

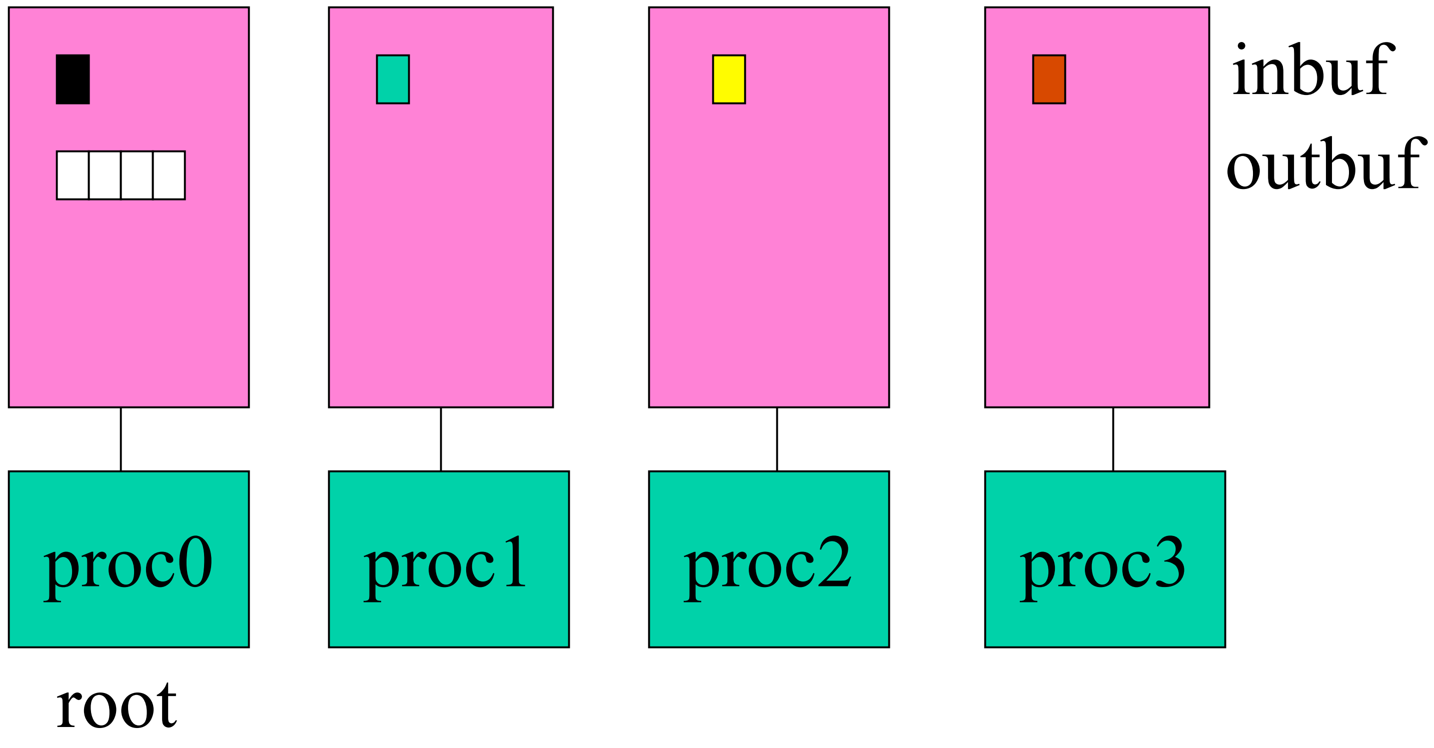
outbuf: address of output buffer

outcnt: number of output elements

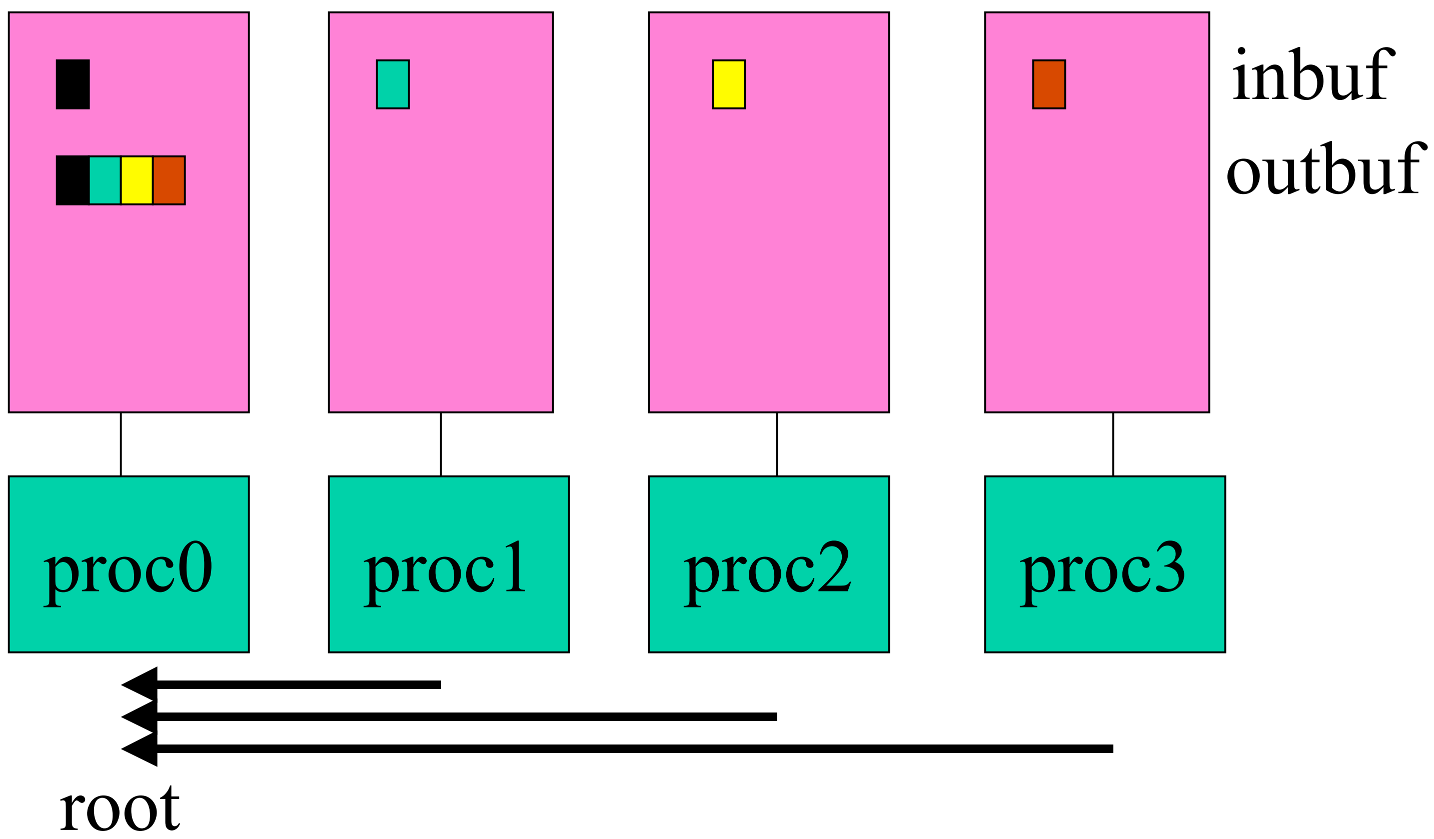
outtype: type of output elements

root: process id of root process

# Before Gather



# After Gather



# MPI Matrix Multiply with index renaming and scatter/gather

```
main(int argc, char *argv[])
{
   MPI_Init (&argc, &argv);
   MPI_Comm_rank(MPI_COMM_WORLD, &me);
   MPI_Comm_size(MPI_COMM_WORLD, &p);
   MPI_Scatter(a, N*N/p, MPI_INT, a, N*N/p,
                  MPI_INT, 0, MPI_COMM_WORLD);
   MPI_Bcast(b, N*N, MPI_INT, 0,
                  MPI_COMM_WORLD);
   . . .
```

# MPI Matrix Multiply with index renaming and scatter/gather

```
    for (i = 0; i < N/p; i++)
        for (j = 0; j < N; j++) {
            c[i][j] = 0;
            for (k = 0; k < N; k++)
                c[i][j] += a[i][k] * b[k][j];
        }
    MPI_Gather(c, N*N/p, MPI_INT, c, N*N/p,
                    MPI_INT, 0, MPI_COMM_WORLD);
    MPI_Finalize();
}
```