Message Passing Interface

DPHPC15

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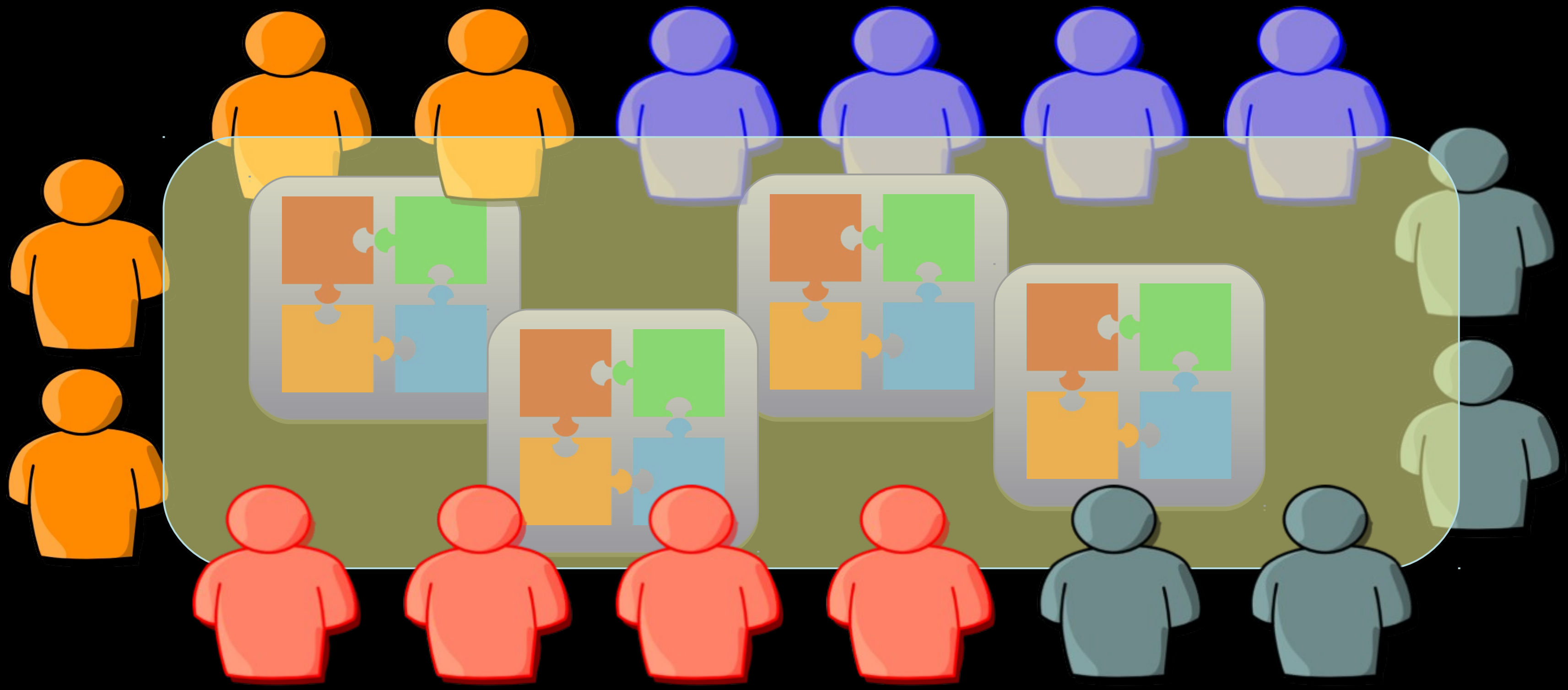
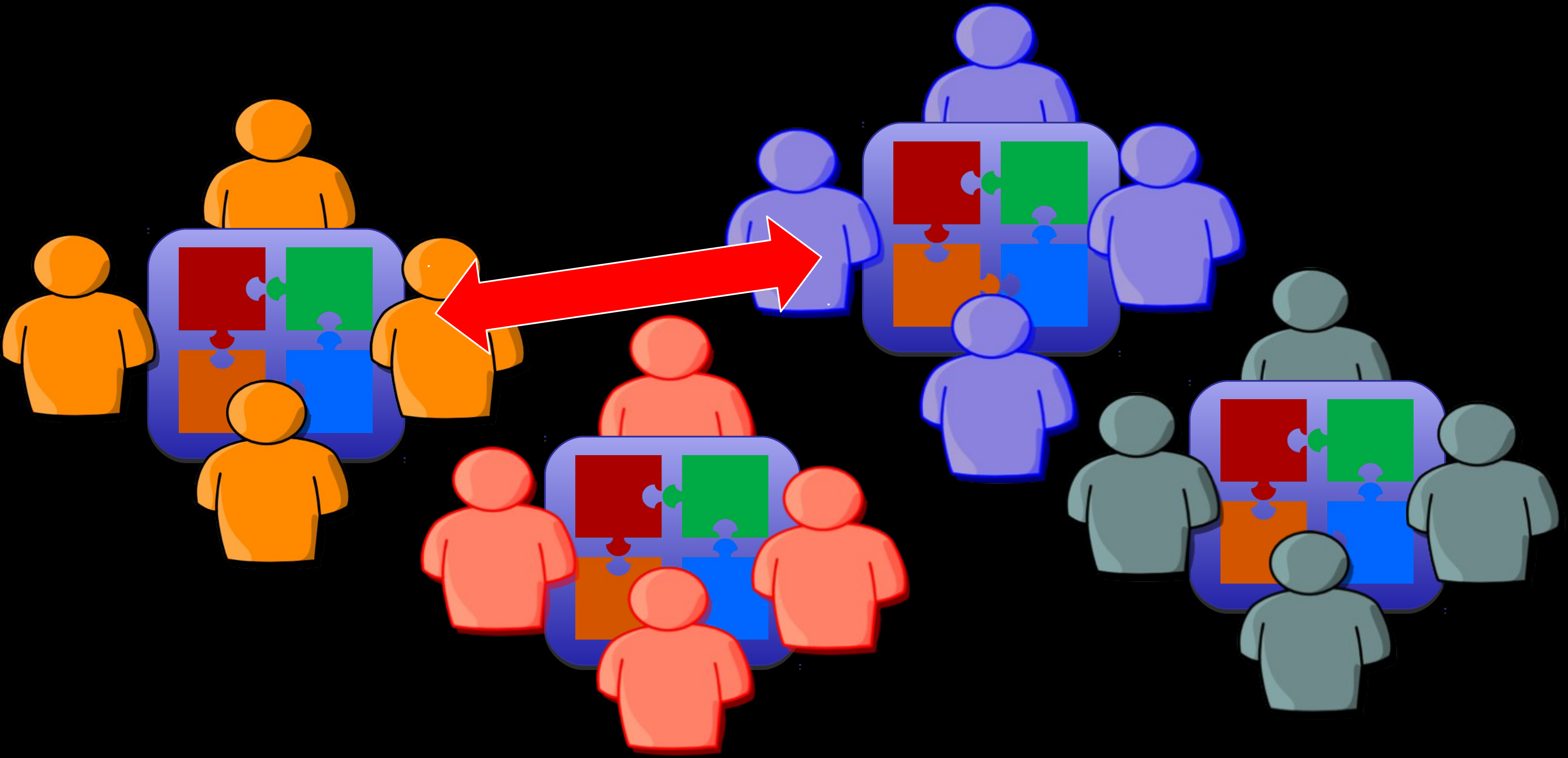
DSM (Distributed Shared Memory)



Message Passing



MPI (Message Passing Interface)

- A message passing specification implemented by different vendors (Cray-, IBM-, Intel-, Microsoft-MPI) and groups (Open MPI, MPICH)

- Context: distributed memory parallel computers
  - Each processor has its own memory and cannot access the memory of other processors
  - Any data to be shared must be explicitly transmitted from one to another

- Most message passing programs use the *single program multiple data (SPMD)* model
  - Each processor executes the same set of instructions
  - Parallelization is achieved by letting each processor operation a different piece of data
  - MIMD (Multiple Instructions Multiple Data)

SPMD example

```
main(int argc, char **argv){
    if(process is assigned Master role){
      /* Assign work and coordinate workers and collect results */
      MasterRoutine(/*arguments*/);
     } else {  /* it is worker process */
      /* interact with master and other workers. Do the work and
    send results to the master*/
      WorkerRoutine(/*arguments*/);
     }
}
```

Why MPI?

- Small
  - Many programs can be written with only 6 basic functions
- Large
  - MPI’s extensive functionality from many functions
- Scalable
  - Point-to-point communication
- Flexible
  - Don’t need to rewrite parallel programs across platforms

What we need to know...

Basic functions

Function	Description
int MPI_Init(int *argc, char **argv)	Initialize MPI
int MPI_Finalize()	Exit MPI
int MPI_Comm_size(MPI_Comm comm, int *size)	Determine number of processes within a comm
int MPI_Comm_rank(MPI_Comm comm, int *rank)	Determine process rank within a comm
int MPI_Send(void *buf, int count, MPI_Datatype datatype, int dest, int tag, MPI_Comm comm)	Send a message
int MPI_Recv(void *buf, int count, MPI_Datatype datatype, int src, int tag, MPI_Comm comm, MPI_Status *status)	Receive a message

Communicator

- An identifier associated with a group of processes
  - Each process has a unique rank within a specific communicator from 0 to (#processes-1)
  - Always required when initiating a communication by calling an MPI function
- Default: MPI_COMM_WORLD
  - Contains all processes
- Several communicators can co-exist
  - A process can belong to different communicators at the same time

Hello World

```
#include "mpi.h”
int main( int argc, char *argv[] ) {
    int nproc, rank;
    MPI_Init (&argc,&argv); /* Initialize MPI */

    MPI_Comm_size(MPI_COMM_WORLD,&nproc); /* Get Comm Size*/
    MPI_Comm_rank(MPI_COMM_WORLD,&rank); /* Get rank */

    printf(“Hello World from process %d\n”, rank);

    MPI_Finalize(); /* Finalize */
    return 0;
}
```

How to compile…

- Need to tell the compiler where to find the MPI include files and how to link to the MPI libraries.
- Fortunately, most MPI implementations come with scripts that take care of these issues:
  - mpicc mpi_code.c –o a.out
- Two widely used (and free) MPI implementations
  - MPICH (http://www-unix.mcs.anl.gov/mpi/mpich)
  - OPENMPI (http://www.openmpi.org)

Blocking Message Passing

- The call waits until the data transfer is done
  - The sending process waits until all data are transferred to the system buffer
  - The receiving process waits until all data are transferred from the system buffer to the receive buffer
  - Buffers can be freely reused

Blocking Message Send

MPI_Send (void *buf, int count, MPI_Datatype dtype, int dest, int tag, MPI_Comm comm);

- buf Specifies the starting address of the buffer.
- count Indicates the number of buffer elements
- dtype Denotes the datatype of the buffer elements
- dest Specifies the rank of the destination process in the group associated with the communicator comm
- tag Denotes the message label
- comm Designates the communication context that identifies a group of processes

Blocking Message Send

Standard (MPI_Send)	The sending process returns when the system can buffer the message or when the message is received and the buffer is ready for reuse.
Buffered (MPI_Bsend)	The sending process returns when the message is buffered in an application-supplied buffer.
Synchronous (MPI_Ssend)	The sending process returns only if a matching receive is posted and the receiving process has started to receive the message.
Ready (MPI_Rsend)	The message is sent as soon as possible.

Blocking Message Receive

MPI_Recv (void *buf, int count, MPI_Datatype dtype, int source, int tag, MPI_Comm comm, MPI_Status *status);

- buf — Specifies the starting address of the buffer.
- count — Indicates the number of buffer elements
- dtype — Denotes the datatype of the buffer elements
- source — Specifies the rank of the source process in the group associated with the communicator comm
- tag — Denotes the message label
- comm — Designates the communication context that identifies a group of processes
- status — Returns information about the received message

Example (from http://mpi.deino.net/mpi_functions/index.htm)

```
…
if (rank == 0) {
    for (i=0; i<10; i++)  buffer[i] = i;
    MPI_Send(buffer, 10, MPI_INT, 1, 123, MPI_COMM_WORLD);
} else if (rank == 1) {
    for (i=0; i<10; i++)  buffer[i] = -1;
    MPI_Recv(buffer, 10, MPI_INT, 0, 123, MPI_COMM_WORLD, &status);
    for (i=0; i<10; i++)
       if (buffer[i] != i)
          printf("Error: buffer[%d] = %d but is expected to be %d\n", i, buffer[i], i);
 }
…
```

Non-blocking Message Passing

- Returns immediately after the data transferred is initiated
- Allows to overlap computation with communication
- Need to be careful though
  - When send and receive buffers are updated before the transfer is over, the result will be wrong

Non-blocking Message Passing

```
MPI_Isend (void *buf, int count, MPI_Datatype dtype, int dest, int tag,
    MPI_Comm comm, MPI_Request *req);

MPI_Recv (void *buf, int count, MPI_Datatype dtype, int source, int tag,
    MPI_Comm comm, MPI_Request *req);

MPI_Wait(MPI_Request *req, MPI_Status *status);
```

- req — Specifies the request used by a completion routine when called by the application to complete the send operation.

Blocking	MPI_Send	MPI_Bsend	MPI_Ssend	MPI_Rsend	MPI_Recv
Non-blocking	MPI_Isend	MPI_Ibsend	MPI_Issend	MPI_Irsend	MPI_Irecv

Non-blocking Message Passing

```
…
right = (rank + 1) % nproc;
left = rank - 1;
if (left < 0)       left = nproc – 1;
MPI_Irecv(buffer, 10, MPI_INT, left, 123, MPI_COMM_WORLD, &request);
MPI_Isend(buffer2, 10, MPI_INT, right, 123, MPI_COMM_WORLD,
    &request2);
MPI_Wait(&request, &status);
MPI_Wait(&request2, &status);
…
```

How to execute MPI codes?

- The implementation supplies scripts to launch the MPI parallel calculation
  - mpirun –np #proc a.out
  - mpiexec –n #proc a.out

- A copy of the same program runs on each processor core within its own process (private address space)

- Communication
  - through the network interconnect
  - through the shared memory on SMP machines

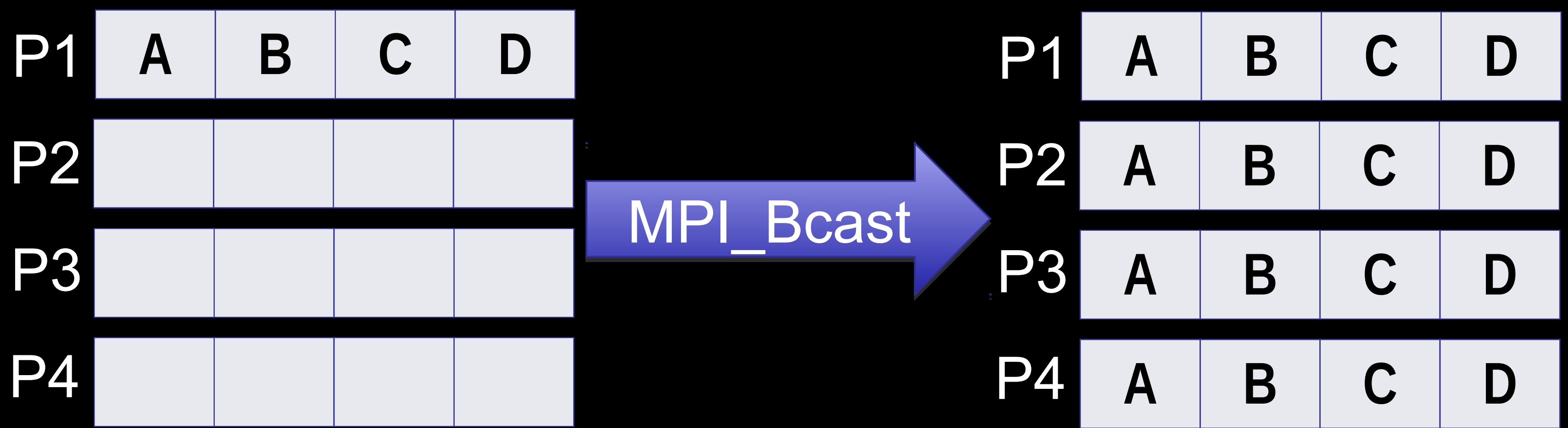
Collective communications

- A single call handles the communication between all the processes in a communicator

- There are 3 types of collective communications
  - Data movement (e.g. MPI_Bcast)
  - Reduction (e.g. MPI_Reduce)
  - Synchronization (e.g. MPI_Barrier)

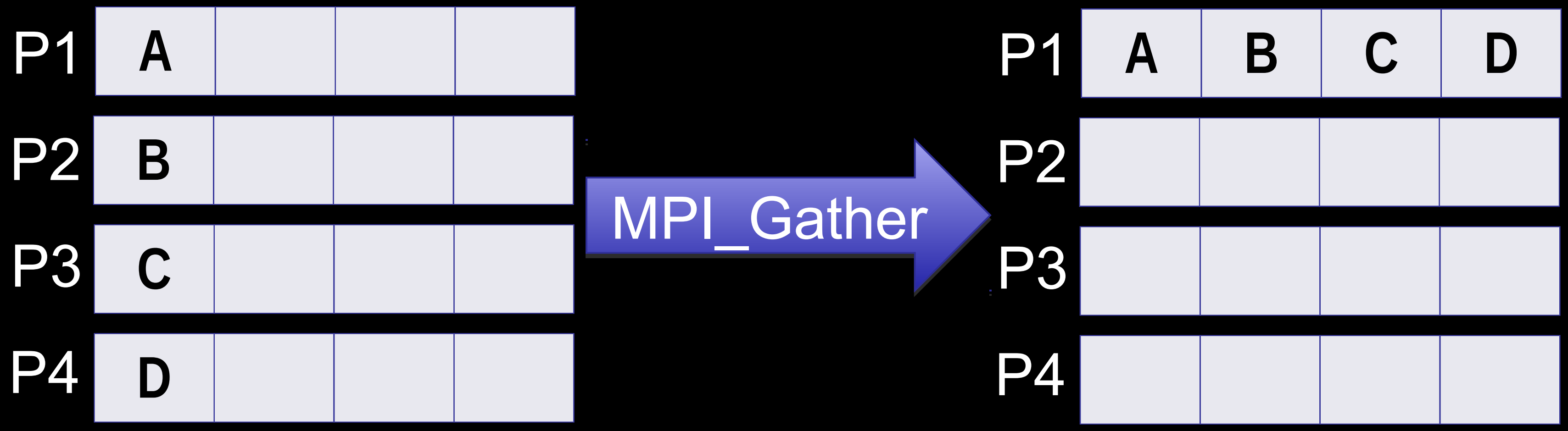
Broadcast

- int MPI_Bcast(void *buffer, int count, MPI_Datatype datatype, int root, MPI_Comm comm);
  - One process (root) sends data to all the other processes in the same communicator
  - Must be called by all the processes with the same arguments



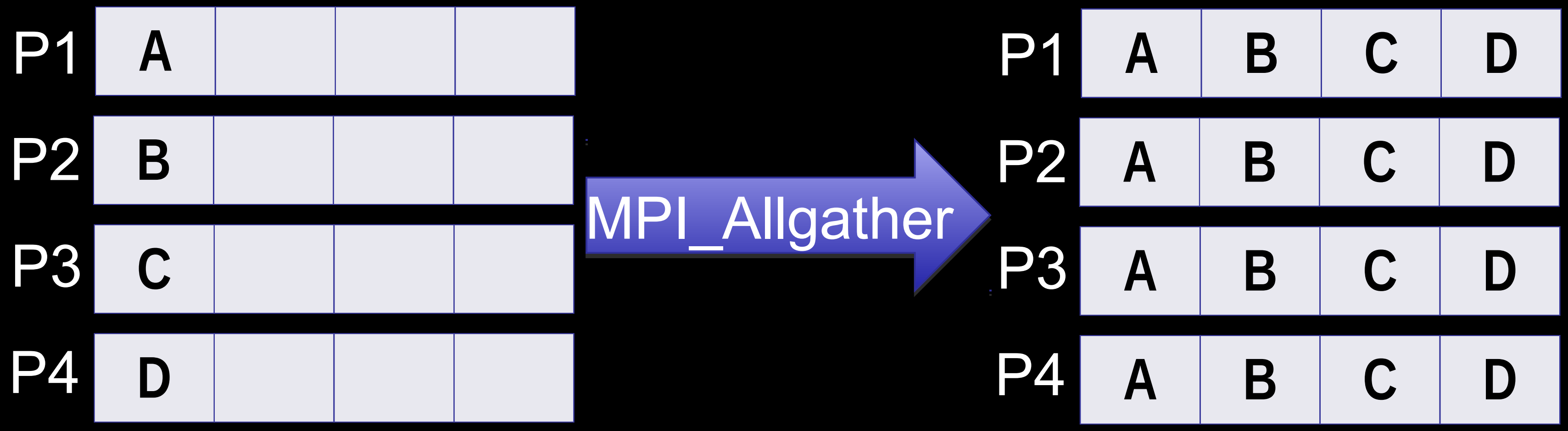
Gather

- int MPI_Gather(void *sendbuf, int sendcnt, MPI_Datatype sendtype, void *recvbuf, int recvcnt, MPI_Datatype recvtype, int root, MPI_Comm comm)
  - One process (root) collects data to all the other processes in the same communicator
  - Must be called by all the processes with the same arguments



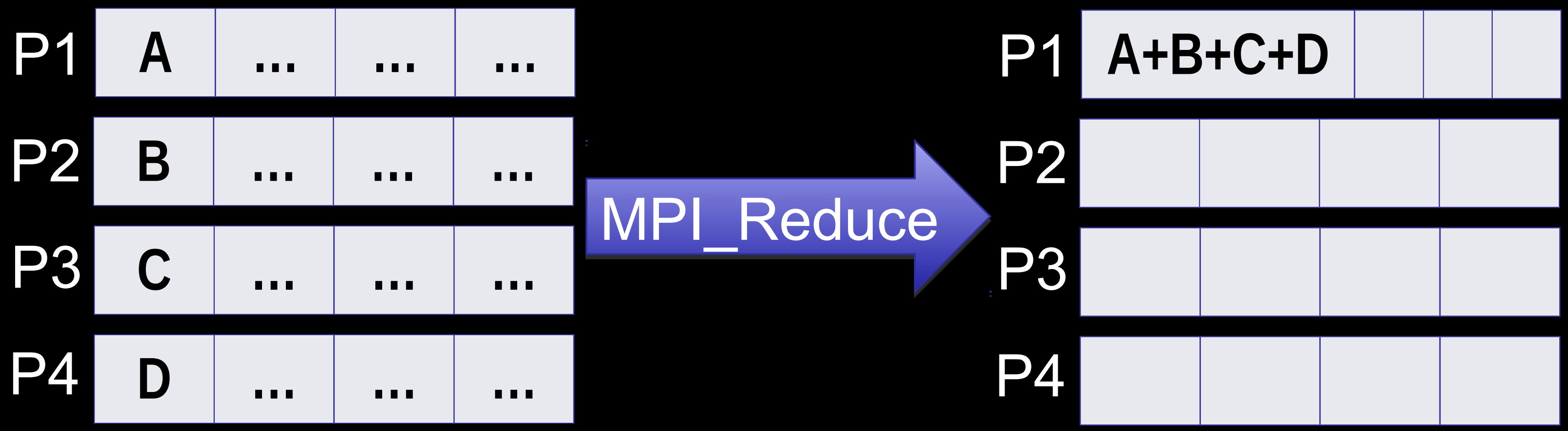
Gather to All

- int MPI_Allgather(void *sendbuf, int sendcnt, MPI_Datatype sendtype, void *recvbuf, int recvcnt, MPI_Datatype recvtype, MPI_Comm comm)
  - All the processes collects data to all the other processes in the same communicator
  - Must be called by all the processes with the same arguments



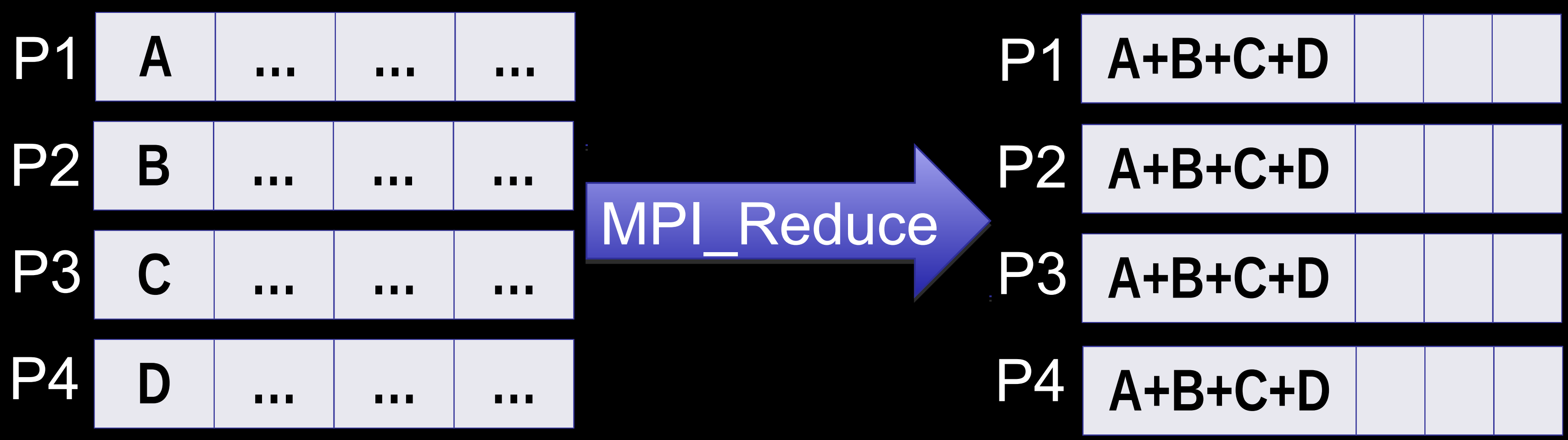
Reduction

- int MPI_Reduce(void *sendbuf, void *recvbuf, int count, MPI_Datatype datatype, MPI_Op op, int root, MPI_Comm comm)
  - One process (root) collects data to all the other processes in the same communicator, and performs an operation on the data
  - MPI_SUM, MPI_MIN, MPI_MAX, MPI_PROD, logical AND, OR, XOR, and a few more
  - MPI_Op_create(): User defined operator



Reduction to All

- int MPI_Allreduce(void *sendbuf, void *recvbuf, int count, MPI_Datatype datatype, MPI_Op op, MPI_Comm comm)
  - All the processes collect data to all the other processes in the same communicator, and perform an operation on the data
  - MPI_SUM, MPI_MIN, MPI_MAX, MPI_PROD, logical AND, OR, XOR, and a few more
  - MPI_Op_create(): User defined operator



Synchronization

- int MPI_Barrier(MPI_Comm comm)

```
#include "mpi.h"
#include <stdio.h>
int main(int argc, char *argv[]) {
    int rank, nprocs;
    MPI_Init(&argc,&argv);
    MPI_Comm_size(MPI_COMM_WORLD,&nprocs);
    MPI_Comm_rank(MPI_COMM_WORLD,&rank);
    MPI_Barrier(MPI_COMM_WORLD);
    printf("Hello, world.  I am %d of %d\n", rank, nprocs);
    MPI_Finalize();
    return 0;
}
```

Homework

- Find an iterative method to calculate Pi (if you cannot find one read http://en.wikipedia.org/wiki/Monte_Carlo_method)
- Write a sequential version in C
- Write a parallel version using MPI (based on seq. Code)