Programming with Message Passing PART I: Basics

HPC Fall 2012

Prof. Robert van Engelen

Overview

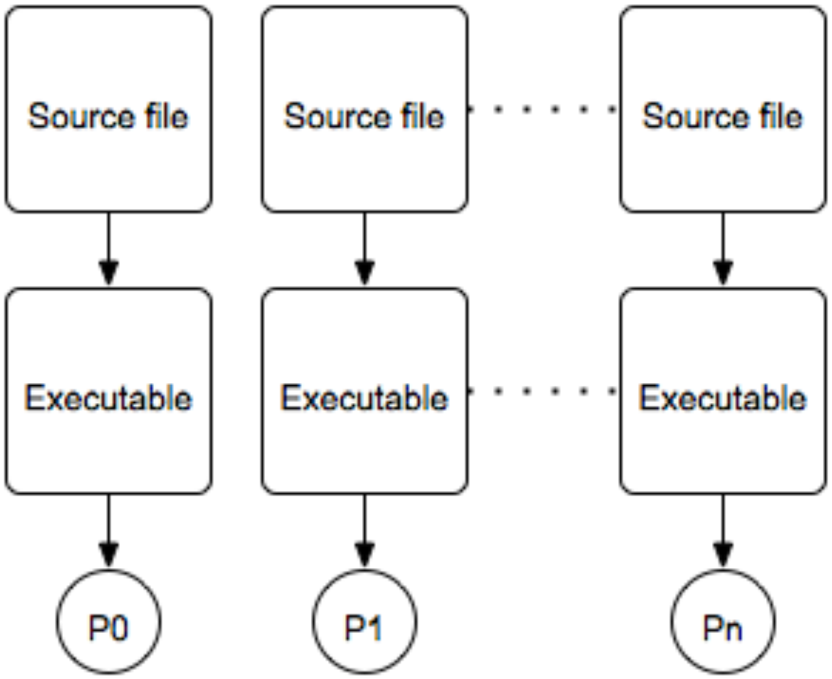
- Communicating processes
- MPMD and SPMD
- Point-to-point communications
  - Send and receive
  - Synchronous, blocking, and nonblocking message passing
  - Message selection
- Collective communications
  - broadcast, gather, scatter, barrier
- Further reading

Process Creation

- Processes communicate via message passing
- How are processes created?
  - *Static process creation*
    - All processes are specified before execution
    - Fixed number of processes executed
    - Example: **`mpirun`** command to start MPI program on *n* processors: **`mpirun -np`** *n*
  - *Dynamic process creation*
    - Processes are created during the execution of other processes
    - Processes can fork new processes
    - Management (start/stop), synchronization, and communication are more difficult

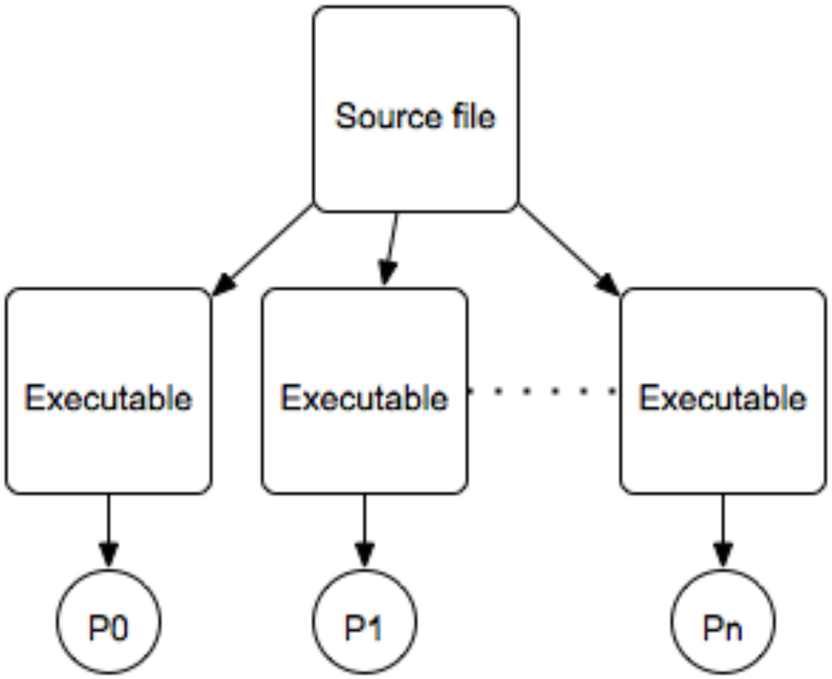
MPMD Versus SPMD

Multiple Program Multiple Data (MPMD)



Example: web server and web browsers

Single Program Multiple Data (SPMD)



Example: MPI program

Basic Send and Receive

- Send and receive operations w/o source and destination process ID

send(&x)	send **x** to any destination
recv(&y)	receive **y** from any source

- Send and receive operations with source and destination process ID

send(&x, destID)	send **x** to destination **destID**
recv(&y, srcID)	receive **y** from source **srcID**

- Data type of **x** and **y** must match
- What about *rendezvous*?
  - Should the sender wait until message is received by destination?

Synchronous and (non)Blocking Send Operations

- *Synchronous (also called blocking)*
  - □ Both sender and receiver wait until entire message is delivered

- *(Locally) blocking send*
  - □ Sender sends x and may continue operating on x
  - □ Copy of x is buffered (causing process to be temporarily suspended until copy is completed) or immediately transmitted (when x is small)
  - □ A receiver may accept message at any time

- *Nonblocking send*
  - □ Sender initiates a “send” of x and immediately continues
  - □ Sender cannot further operate on x (data x is in *transfer state*)
  - □ Receiver may accept message at any time

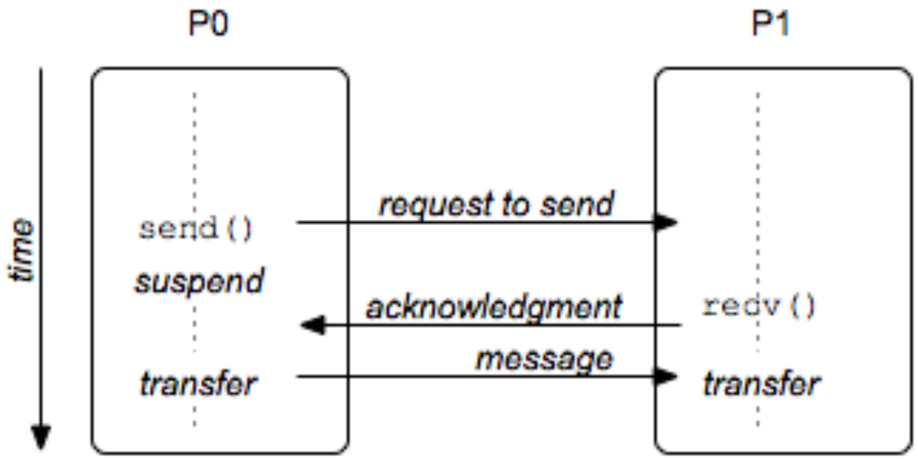
Blocking and Nonblocking Receive Operations

- *Blocking receive*
  - Receiver waits for data to be completely transferred

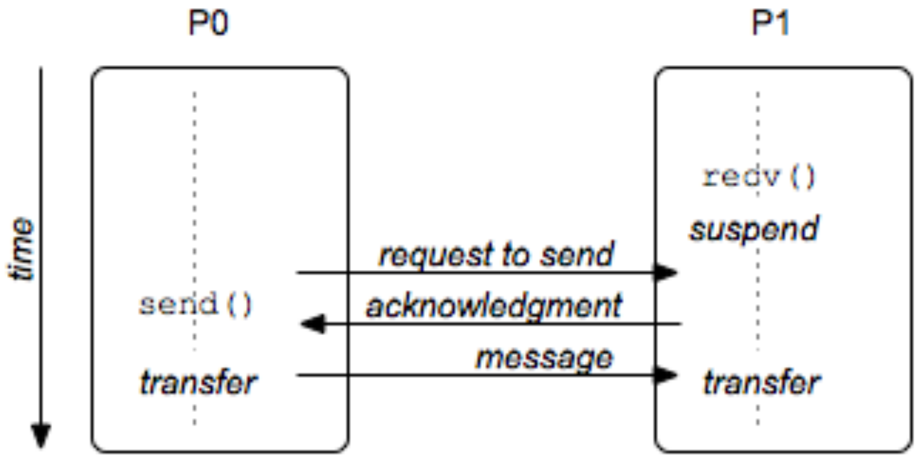
- *Nonblocking receive*
  - Receiver indicates it is ready to receive data into y
  - A *handle* is returned that allows the receiver to query the status of the received data for y

- Note: any type of send can be paired with any type of receive

Synchronous Send and Recv

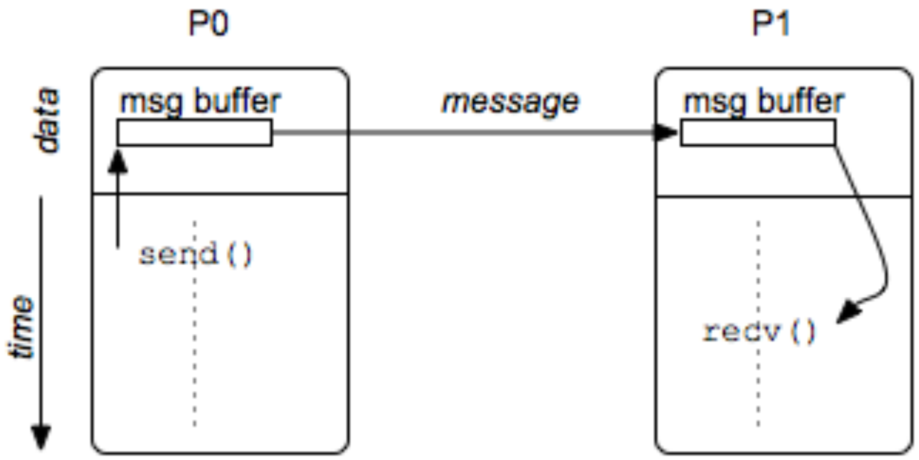


`send()` *occurs before* **`recv()`**
P0 is suspended until a receiver is ready



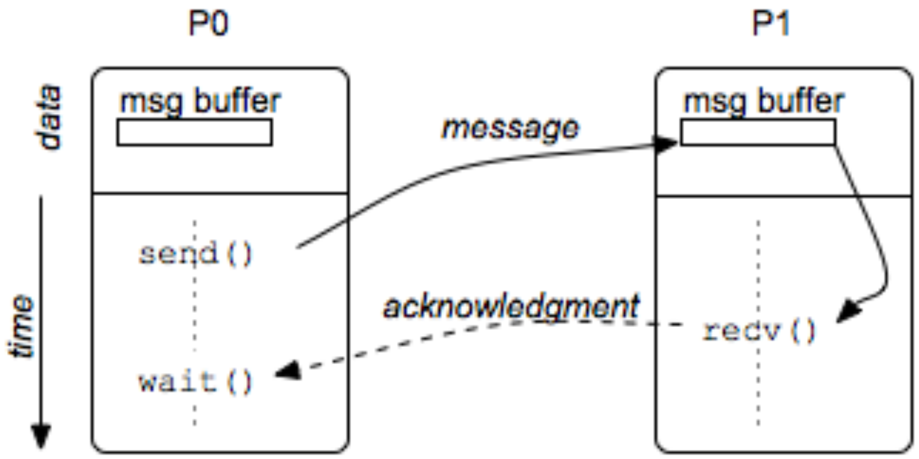
`recv()` *occurs before* **`send()`**
P1 is suspended until a sender is ready

(non)Blocking Send and Recv



In a (locally) blocking **send()***, process P0 continues after the message is locally buffered or in transit to receiver, and* <u>*it is safe for P0 to modify the data*</u>

Blocking: P0 suspends until a **recv()** *is posted*



In a nonblocking **send()***, process P0 immediately continues and executes while message is delivered (hides the messaging latency)*

P0 <u>*cannot modify data in transit,*</u> *explicitly probe message status or wait until message was received*

Deadlock

SPMD program

Process 1

```
A := 0
for i = 1..N/2
  A := A+f(i)
send A to P2
receive B from P2
A := A + B
```

Synchronous blocking sends

Process 2

```
A := 0
for i = 1..N/2
  A := A+f(i)
send A to P1
receive B from P1
A := A + B
```

Deadlock with synchronous blocking send operations: both processors wait for data to be send to a receiver that is not ready to accept the message

Note: nonblocking sends and sendrecv() operations (send-recv exchanges) are safe to use for this example

Message Selection

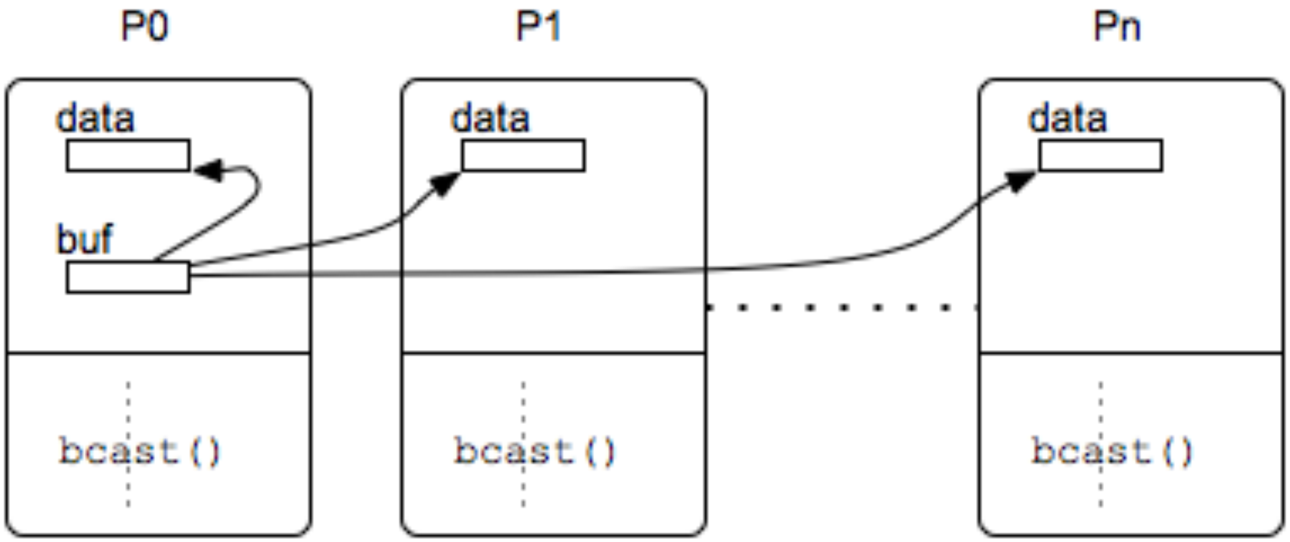
- Send and receive operations indicate source/destination process ID
  - Id can be a wildcard
- What if multiple messages are *asynchronously transmitted out-of-order* to a destination?
  - Messages may be queuing up and end up being transmitted or accepted in different order, as if they “crossed” in transit
  - Cannot rely on message ordering with blocking/nonblocking send, even when sends are initiated by one processes
  - *Message tags* are used to match send and receive operations

    send(&x, destID, tag)
    recv(&y, srcID, tag)

    message is transferred when **tag** value matches

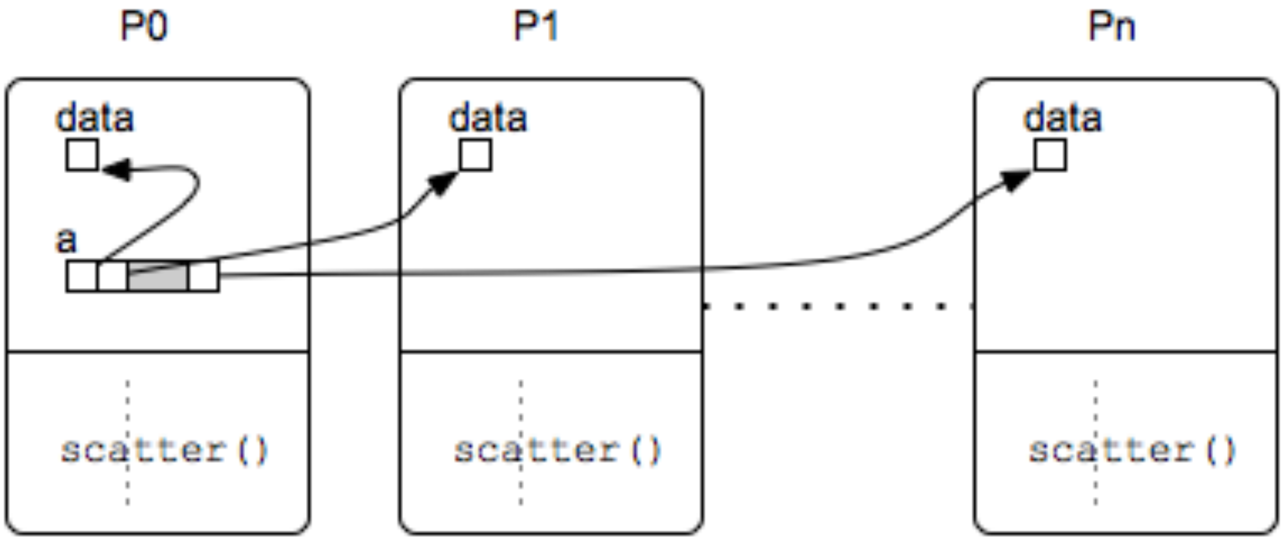
Broadcast

- *Multicast*: a *root process* sends a message to a specific subset of processes
- *Broadcast* = *multicast* within a process group
- First a group must be formed and root process selected



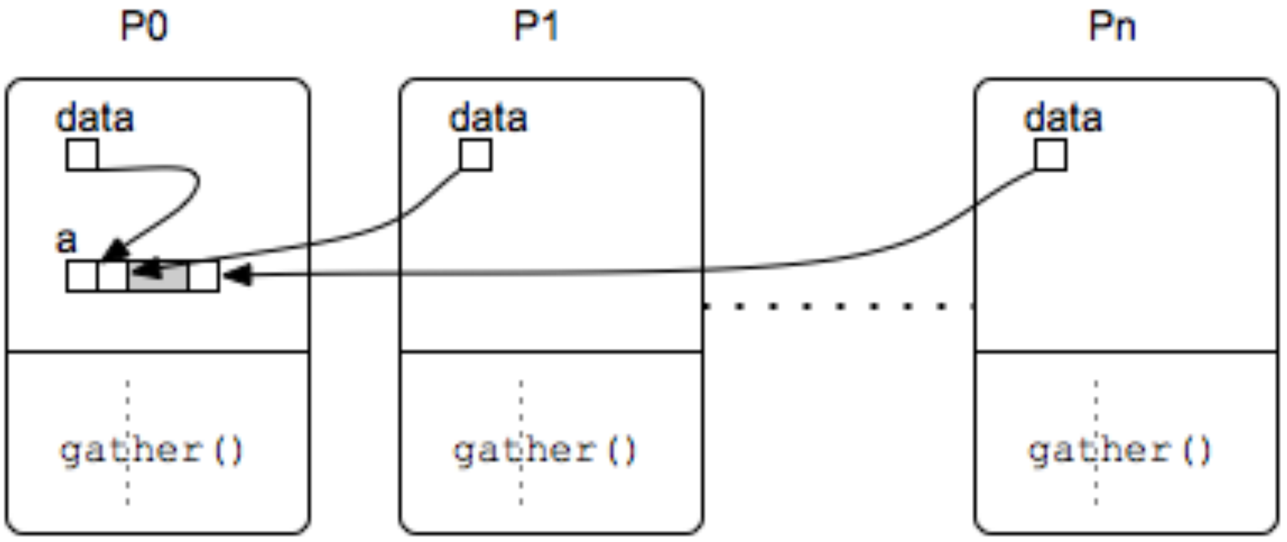
Scatter

- *Scatter*: a *root process* sends elements of an array a[0,…,n] to the enumerated processes P_i, $i=0,\ldots,n$
- First a group must be formed and root process selected



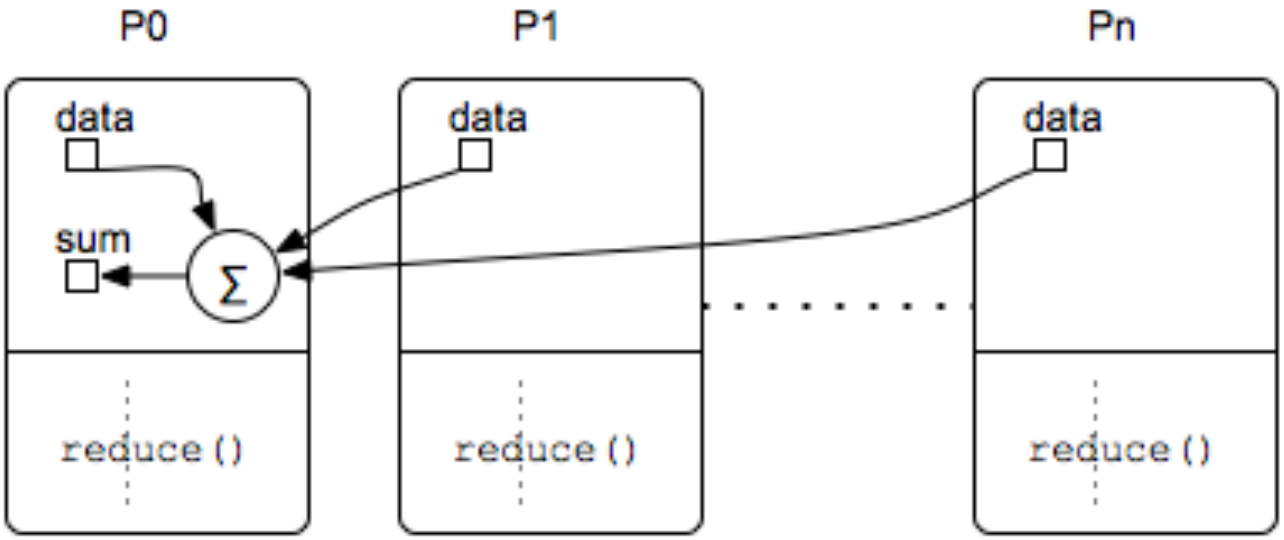
Gather

- *Gather*: a *root process* collects data from the enumerated processes P_i, i=0,…,n and puts them into the elements of an array a[0,…,n]
- First a group must be formed and root process selected



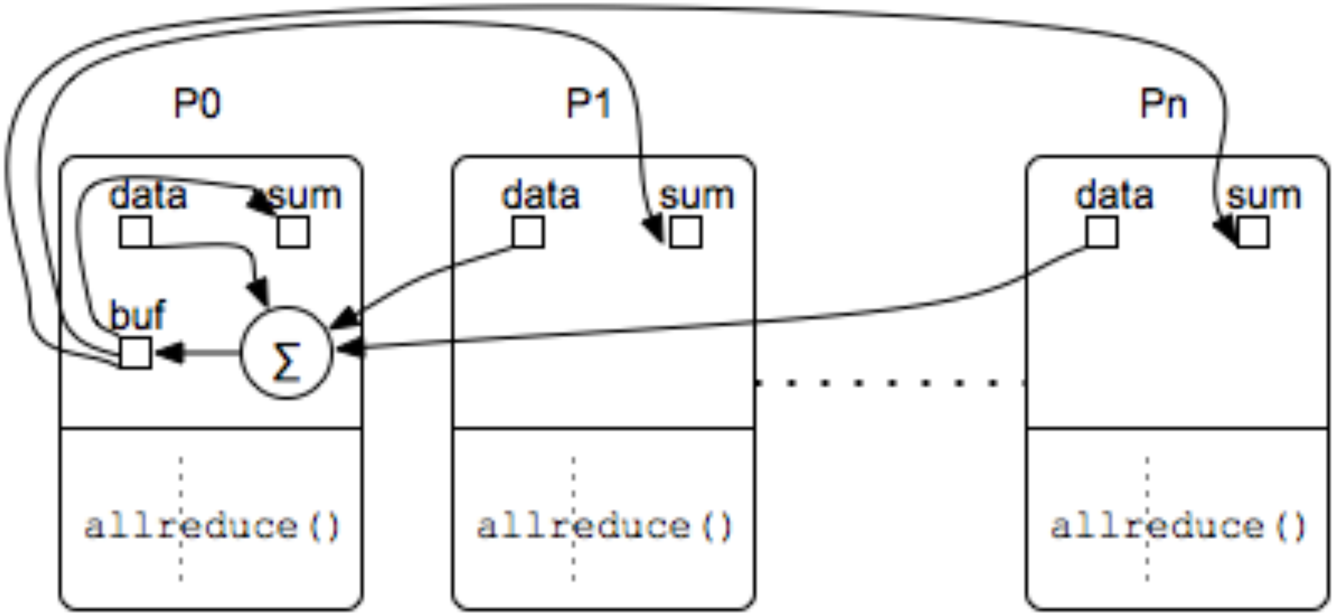
Reduce

- *Reduce*: a *root process* collects data from the enumerated processes P_i, $i=0,\ldots,n$ and reduces it to a single value
- First a group must be formed and root process selected



AllGather and AllReduce

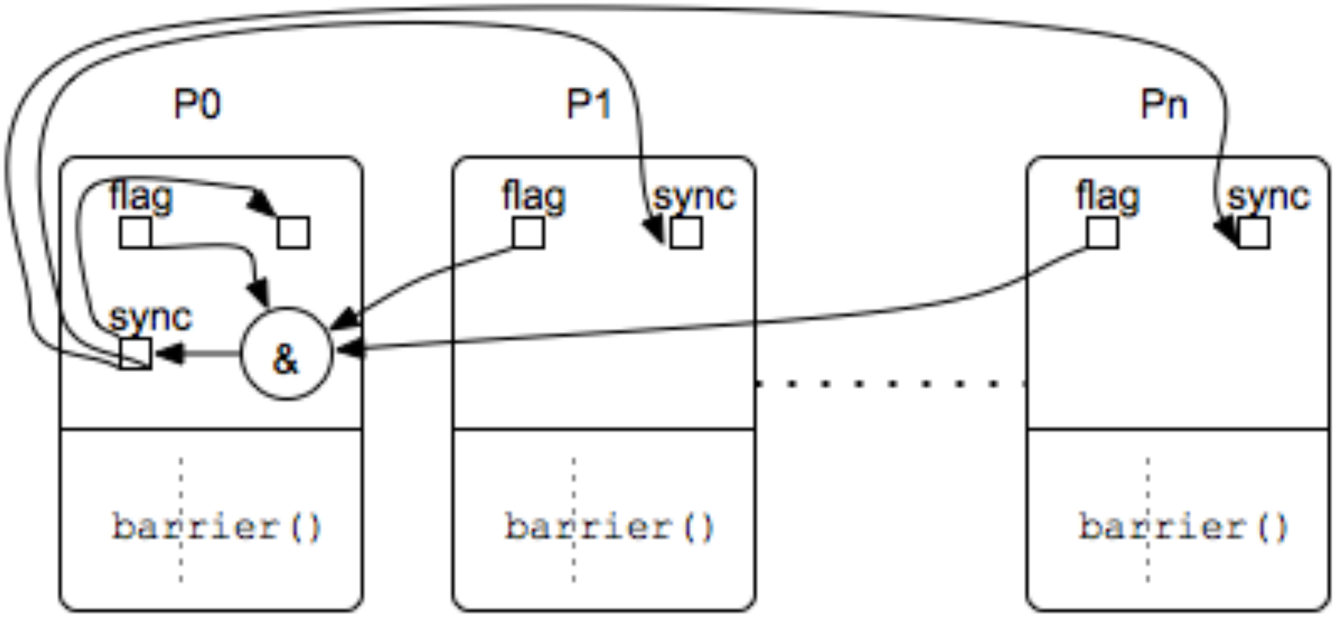
- *AllGather and AllReduce*: perform gather/reduce and broadcast result
- First a group must be formed and root process selected



Barrier

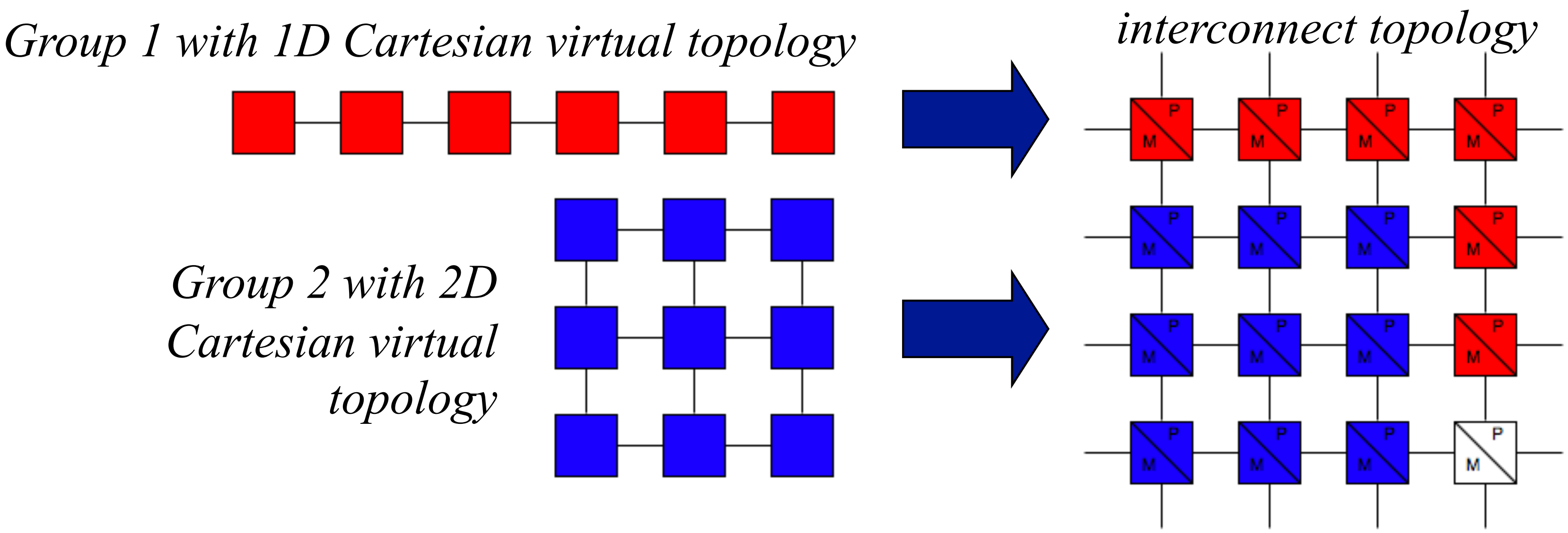
- *Barrier*: synchronization point

Example barrier based on an allReduce
(typically more efficient implementations are used)



Processor Groups and Interconnect Topologies

- A *processor group* is a subset of all processors
  - Collective communications occur within a group
- A group (including the group of all processors) can be mapped to a *virtual topology*
  - When the virtual topology of a group is matched to a *physical interconnect topology* that is a close approximation of the virtual topology, message latencies are more predictable



Group 1 with 1D Cartesian virtual topology

Group 2 with 2D Cartesian virtual topology

interconnect topology

Further Reading

- [PP2] pages 42-51