Message-Passing Programming with MPI

Message-Passing Concepts

David Henty
d.henty@epcc.ed.ac.uk
EPCC, University of Edinburgh

Overview

- This lecture will cover
  - message passing model
  - SPMD
  - communication modes
  - collective communications

Programming Models

Serial Programming

Concepts

Arrays, Subroutines, Control flow, Variables, Human-readable, OO

Languages

C/C++, Python, Java, Fortran, struct, if/then/else

Implementations

gcc -O3, pgcc -fast, icc, crayftn, craycc, javac

Message-Passing Parallel Programming

Concepts

Processes, Send/Receive, SPMD, Collectives, Groups

Libraries

MPI, MPI_Init()

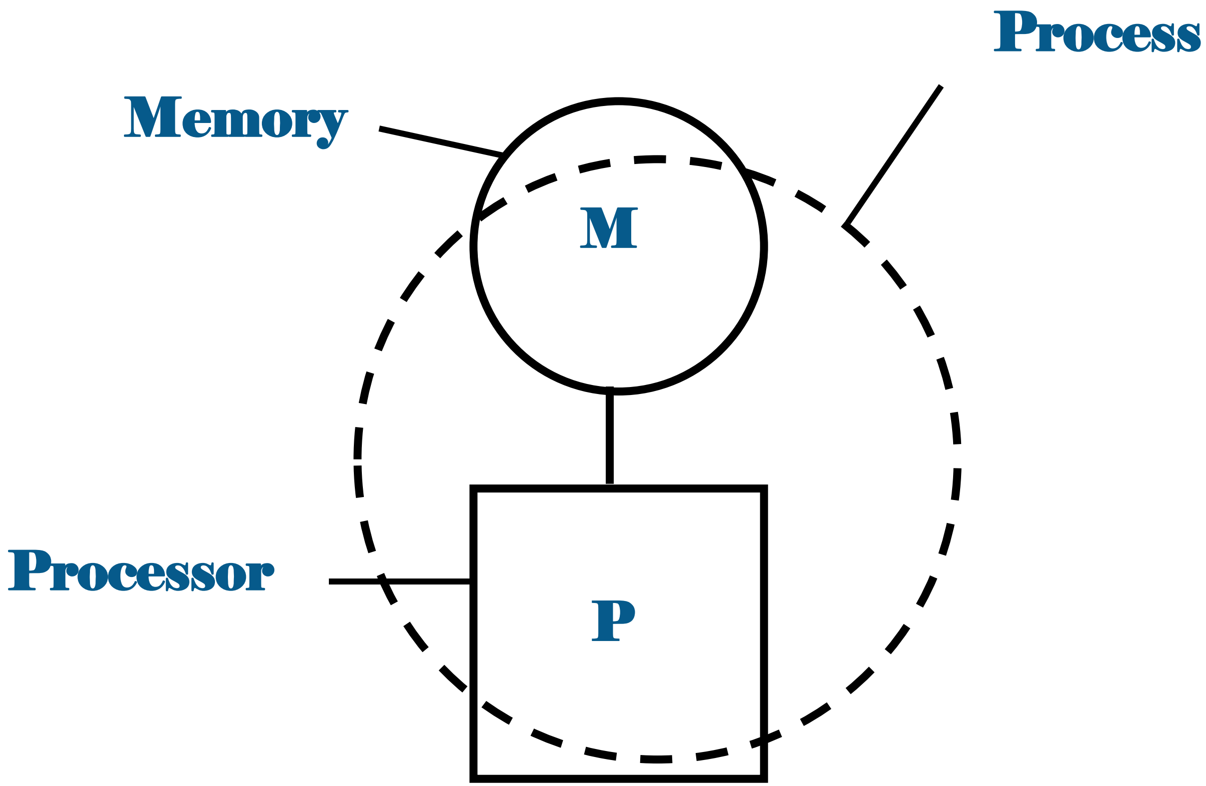
Implementations

Intel MPI, MPICH2, Cray MPI, OpenMPI, IBM MPI

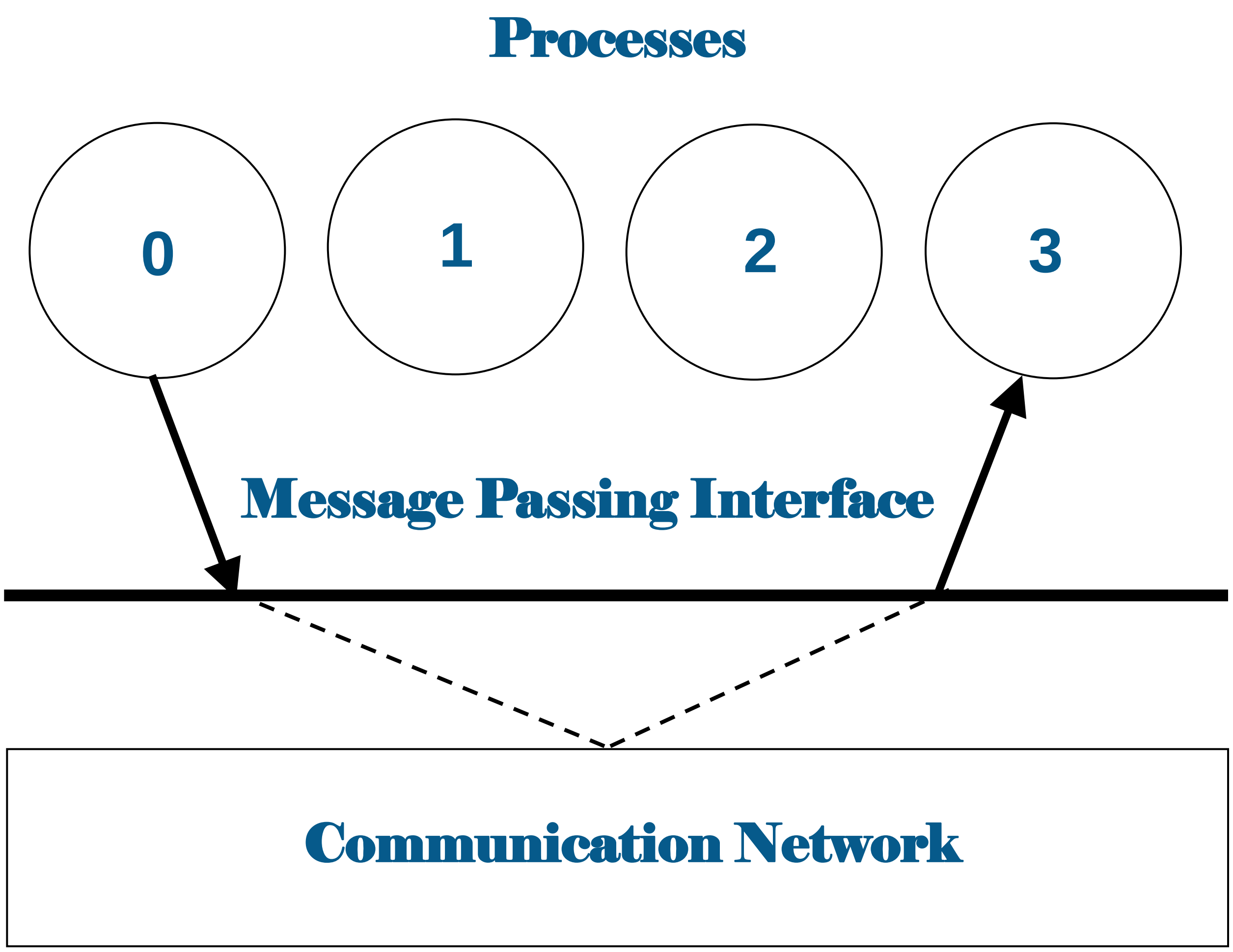
Message Passing Model

- The message passing model is based on the notion of processes
  - can think of a process as an instance of a running program, together with the program's data
- In the message passing model, parallelism is achieved by having many processes co-operate on the same task
- Each process has access only to its own data
  - ie all variables are private
- Processes communicate with each other by sending and receiving messages
  - typically library calls from a conventional sequential language

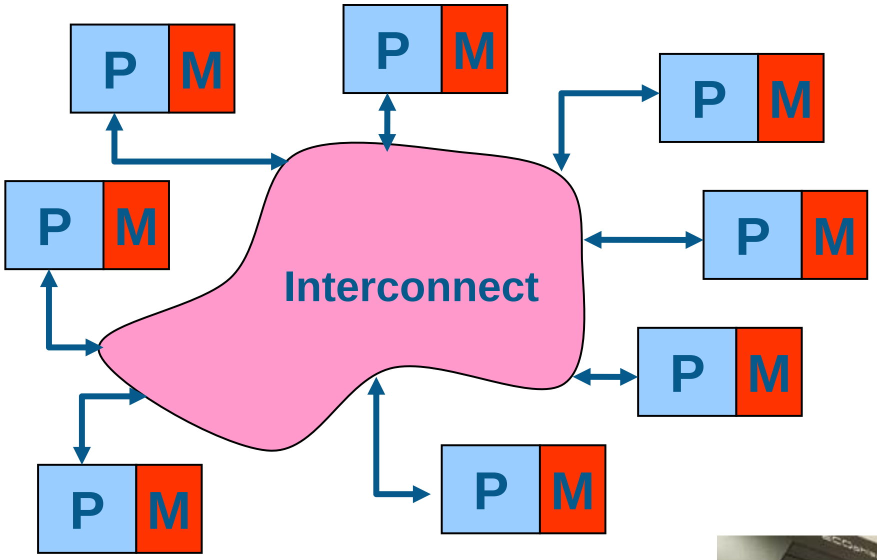
Sequential Paradigm



Parallel Paradigm



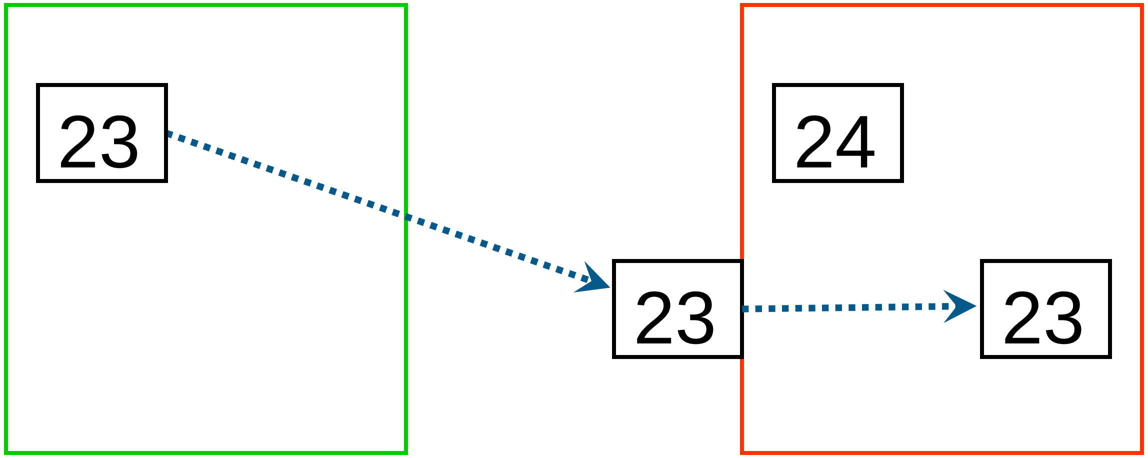
Distributed-Memory Architectures



Process Communication

	Process 1	Process 2
Program	`a=23` `Send(2,a)`	`Recv(1,b)` `a=b+1`

Data



SPMD

- Most message passing programs use the Single-Program-Multiple-Data (SPMD) model
- All processes run (their own copy of) the same program
- Each process has a separate copy of the data
- To make this useful, each process has a unique identifier
- Processes can follow different control paths through the program, depending on their process ID
- Usually run one process per processor / core

Emulating General Message Passing (C)

```
main (int argc, char **argv)
{
            if (controller_process)
            {
                  Controller( /* Arguments */ );
            }
                  else
            {
                  Worker    ( /* Arguments */ );
            }
}
```

Emulating General Message Passing (F)

```
PROGRAM SPMD
    IF (controller_process) THEN
            CALL CONTROLLER ( ! Arguments ! )
    ELSE
            CALL WORKER     ( ! Arguments ! )
    ENDIF
END PROGRAM SPMD
```

Messages

- A message transfers a number of data items of a certain type from the memory of one process to the memory of another process

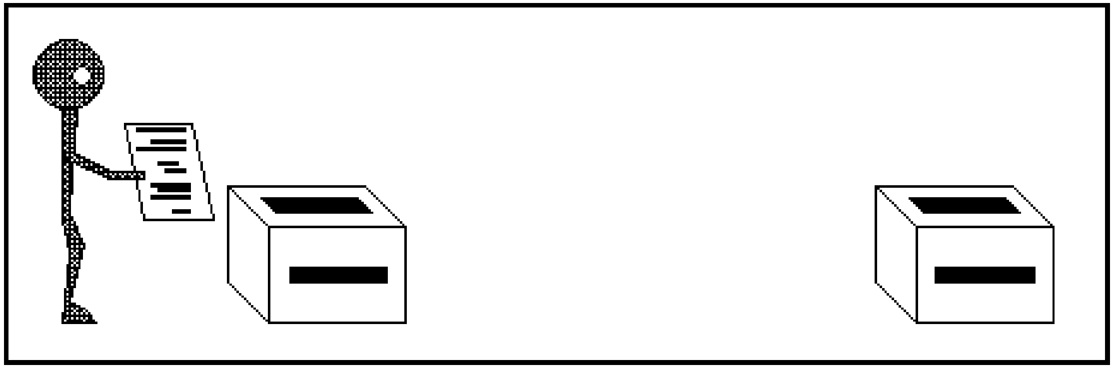
- A message typically contains
  - the ID of the sending processor
  - the ID of the receiving processor
  - the type of the data items
  - the number of data items
  - the data itself
  - a message type identifier

Communication modes

- Sending a message can either be synchronous or asynchronous
- A synchronous send is not completed until the message has started to be received
- An asynchronous send completes as soon as the message has gone
- Receives are usually synchronous - the receiving process must wait until the message arrives

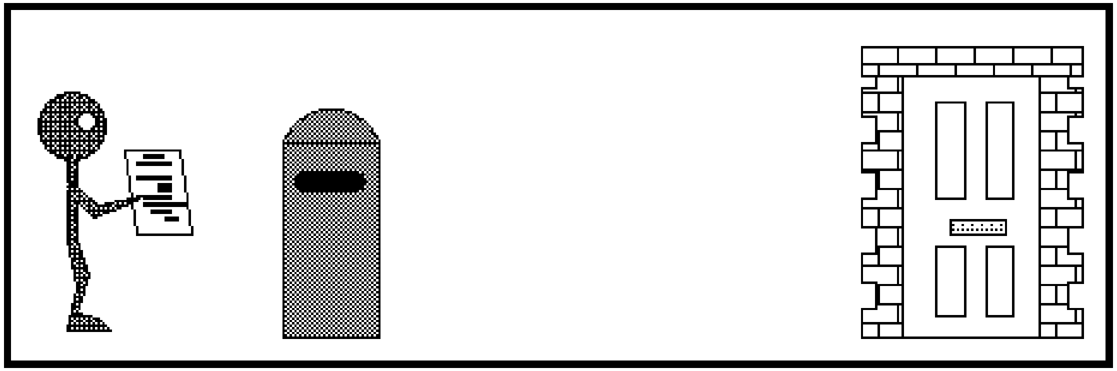
Synchronous send

- Analogy with faxing a letter.
- Know when letter has started to be received.



Asynchronous send

- Analogy with posting a letter.
- Only know when letter has been posted, not when it has been received.



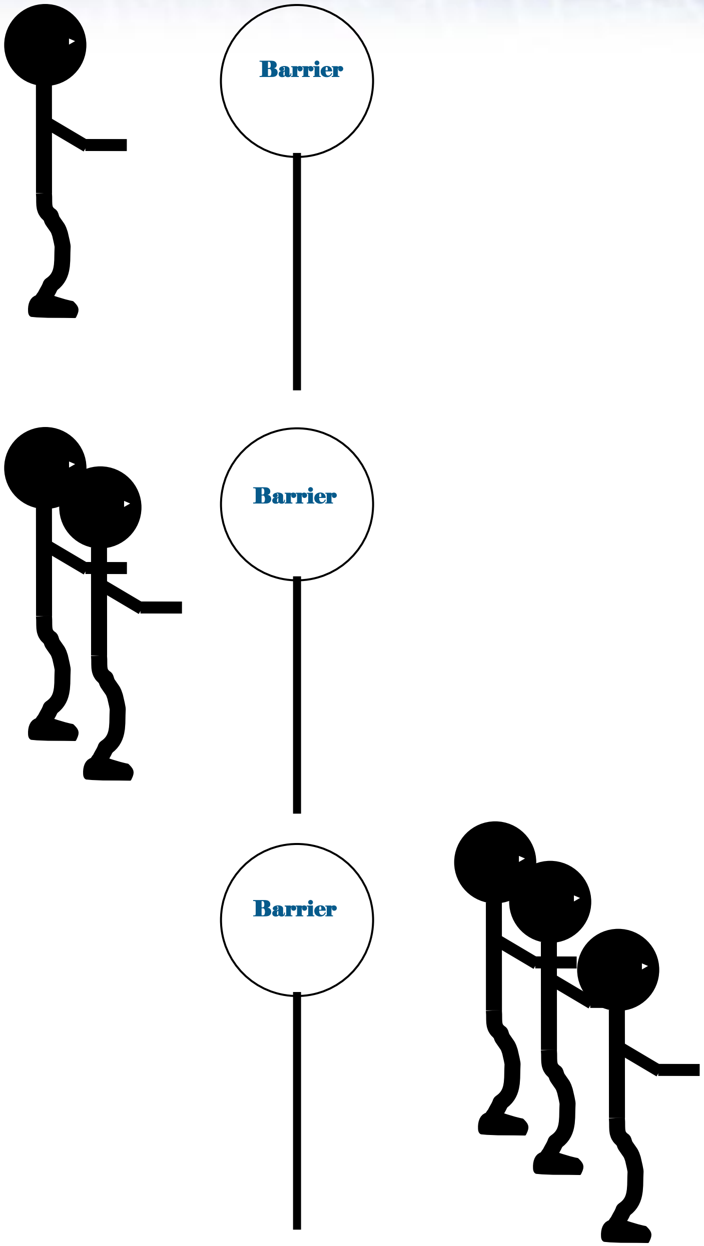
Point-to-Point Communications

- We have considered two processes
  - one sender
  - one receiver
- This is called point-to-point communication
  - simplest form of message passing
  - relies on matching send and receive
- Close analogy to sending personal emails

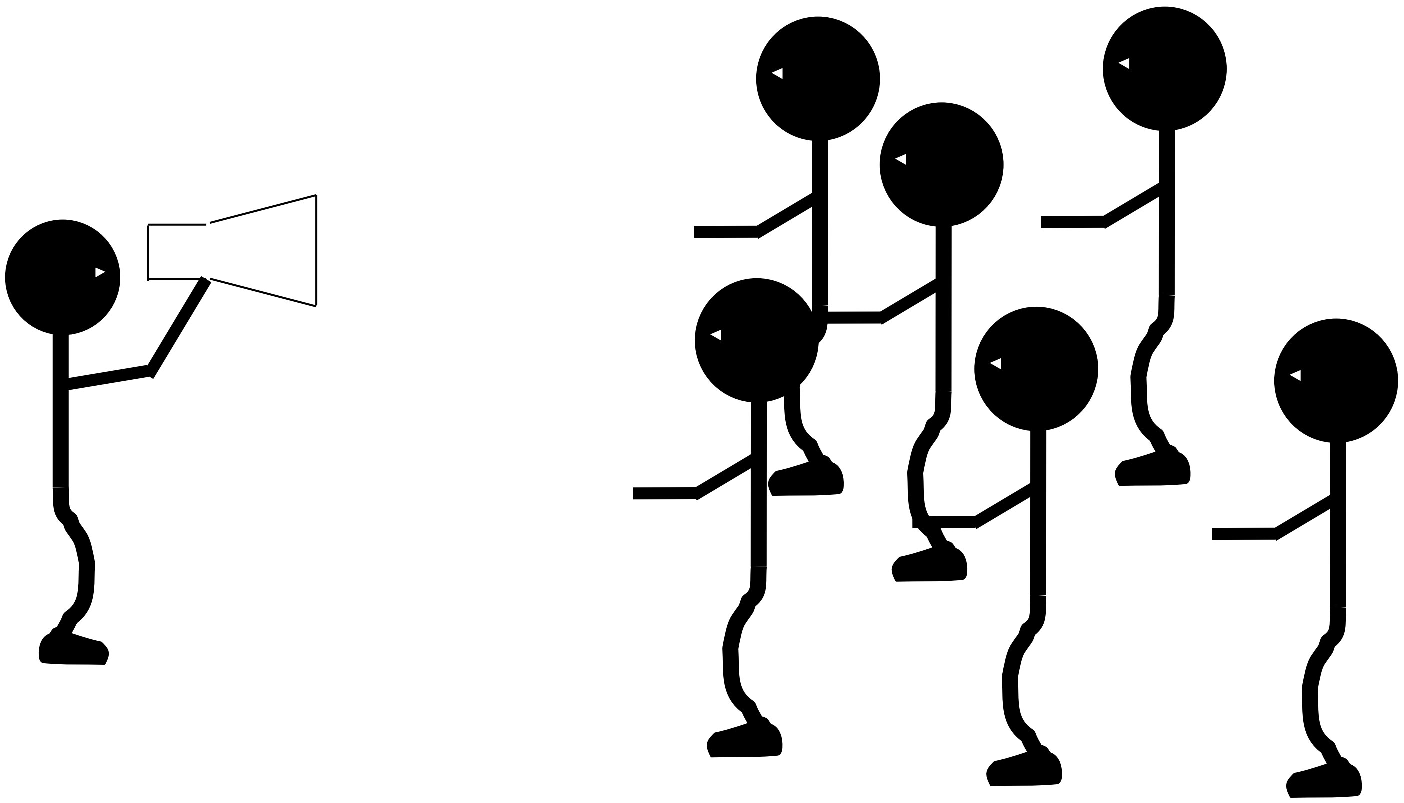
Collective Communications

- A simple message communicates between two processes
- There are many instances where communication between groups of processes is required
- Can be built from simple messages, but often implemented separately, for efficiency

Barrier: global synchronisation

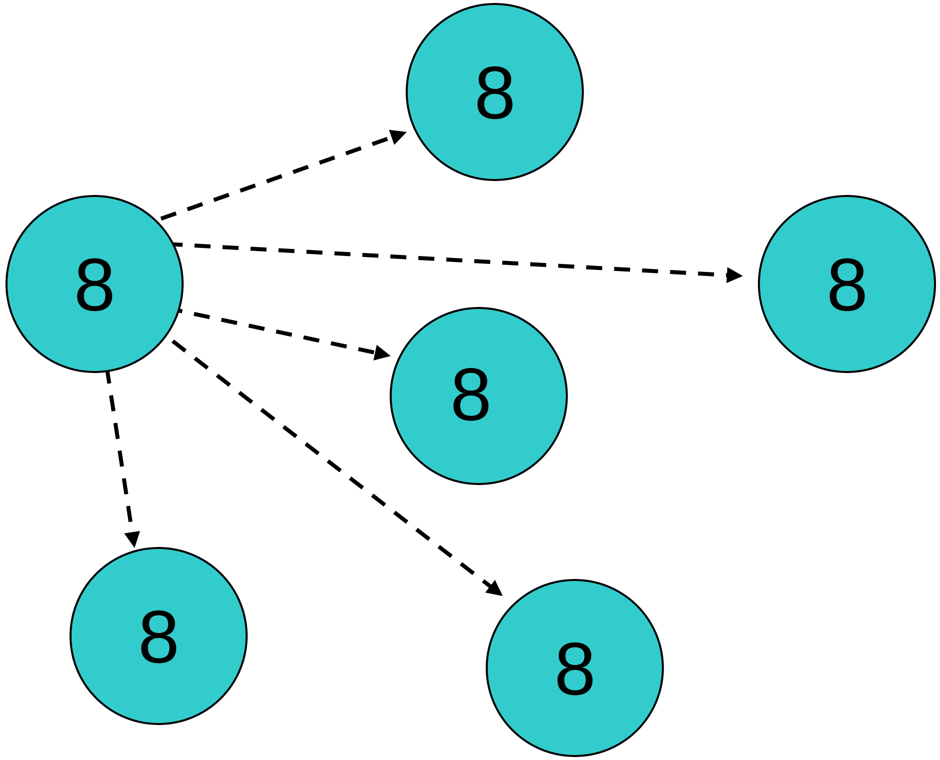


Broadcast: one to all communication



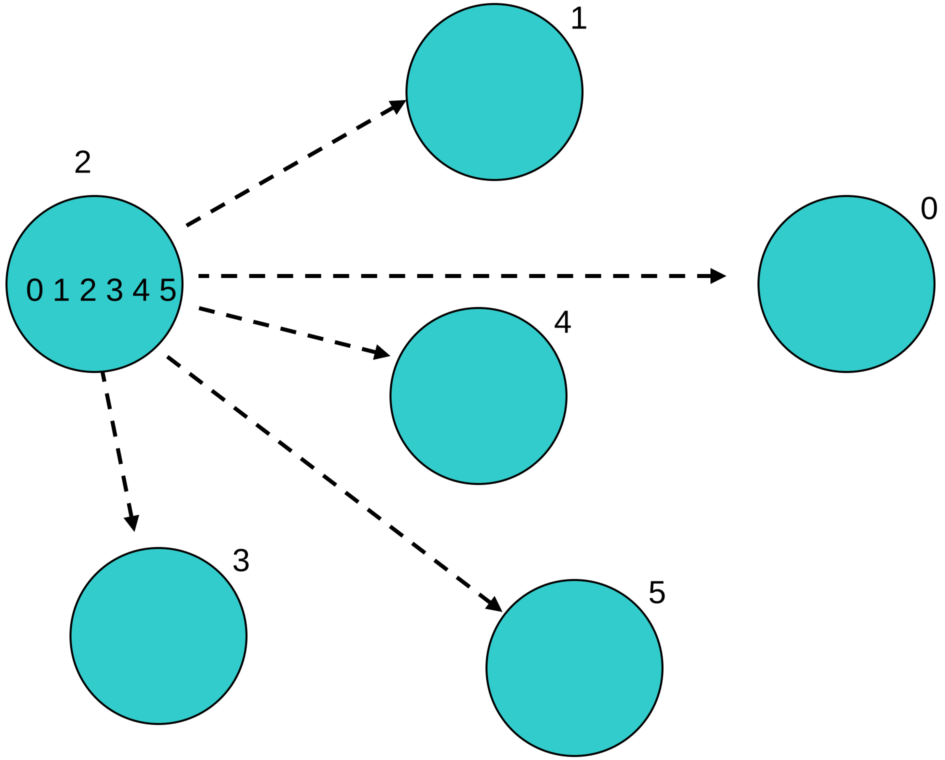
Broadcast

- From one process to all others



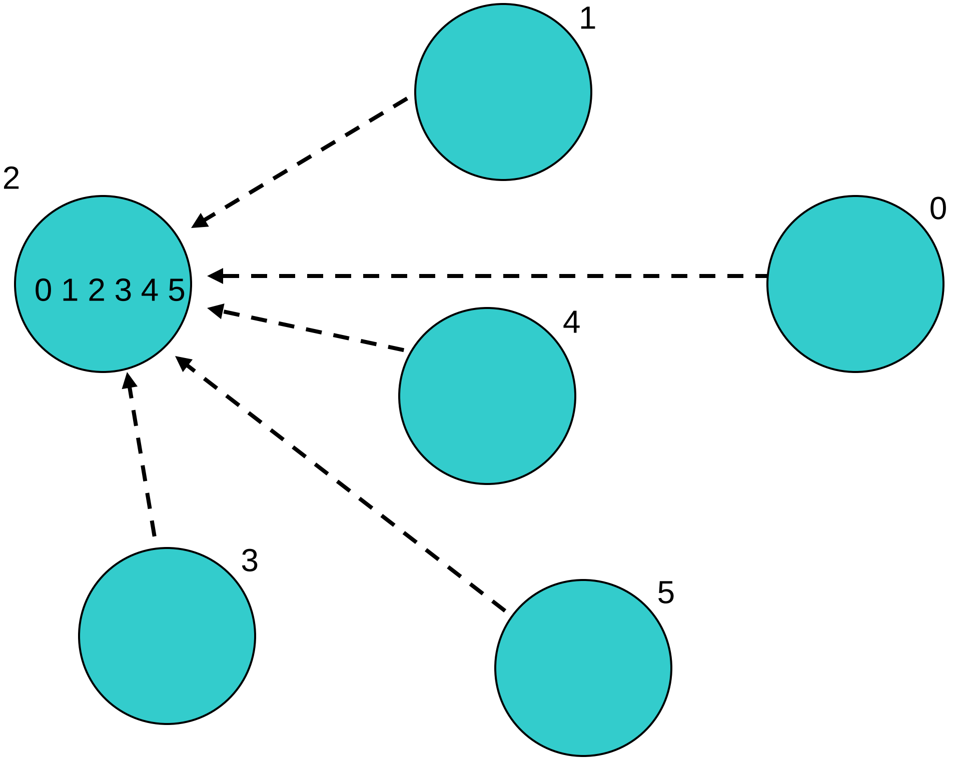
Scatter

- Information scattered to many processes



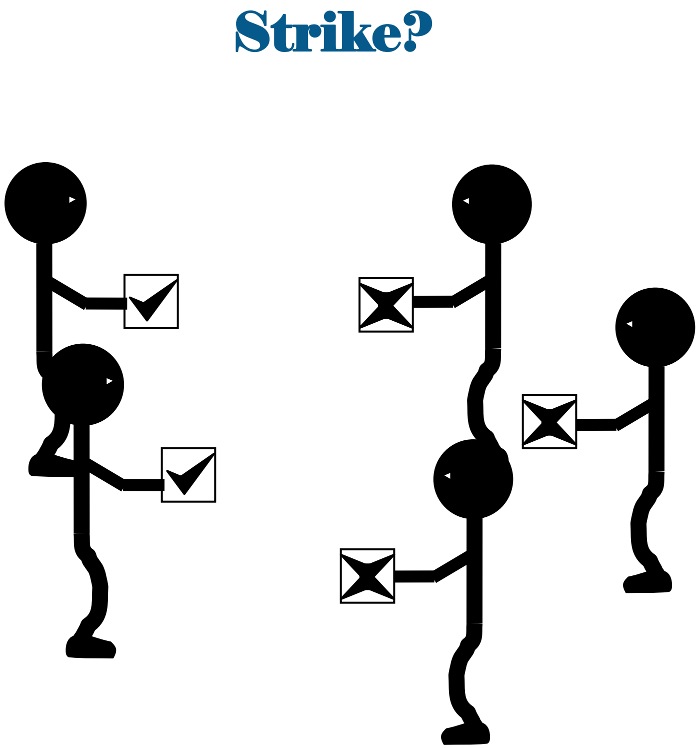
Gather

- Information gathered onto one process



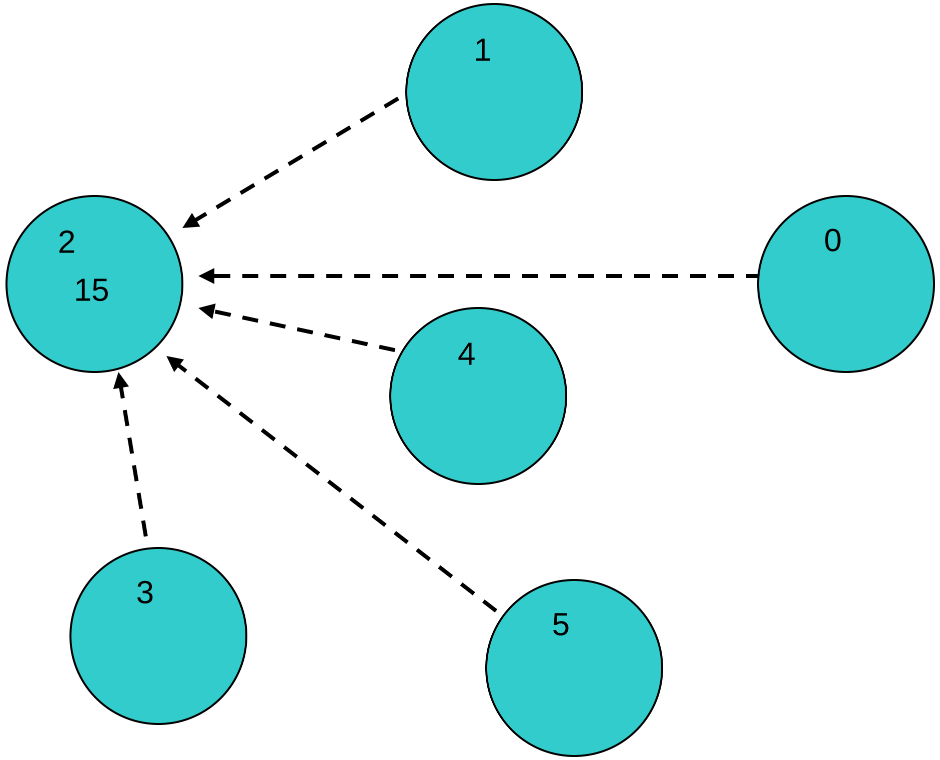
Reduction Operations

- Combine data from several processes to form a single result



Reduction

- Form a global sum, product, max, min, etc.



Launching a Message-Passing Program

- Write a *single piece* of source code
  - with calls to message-passing functions such as send / receive
- Compile with a *standard compiler* and link to a *message-passing library* provided for you
  - both open-source and vendor-supplied libraries exist
- Run *multiple copies* of *same executable* on parallel machine
  - each copy is a separate *process*
  - each has its own private data completely distinct from others
  - each copy can be at a completely different line in the program
- Running is usually done via a launcher program
  - “please run *N* copies of my executable called *program.exe*”

Issues

- Sends and receives must match
  - danger of deadlock
  - program will stall (forever!)
- Possible to write very complicated programs, but …
  - most scientific codes have a simple structure
  - often results in simple communications patterns
- Use collective communications where possible
  - may be implemented in efficient ways

Summary (i)

- Messages are the *only* form of communication
  - all communication is therefore explicit
- Most systems use the SPMD model
  - all processes run exactly the same code
  - each has a unique ID
  - processes can take different branches in the same codes
- Basic communications form is point-to-point
  - collective communications implement more complicated patterns that often occur in many codes

Summary (ii)

- Message-Passing is a programming model
  - that is implemented by MPI
  - the Message-Passing Interface is a library of function/subroutine calls
- Essential to understand the basic concepts
  - private variables
  - explicit communications
  - SPMD
- Major difficulty is understanding the Message-Passing model
  - a very different model to sequential programming

```
if (x < 0)
    print(“Error”);
    exit;
```