Message-Passing Programming with MPI

Message-Passing Concepts











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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 00

Languages

C/C++

Python

Java Fortran

struct if/then/else

Implementations

gcc -03 pgcc -fast

icc

crayftn javac craycc

Message-Passing Parallel Programming

Concepts

Processes Send/Receive

SPMD Collectives

Libraries

MPI

MPI Init()

Implementations

Intel MPI

MPICH2

Cray MPI

OpenMPI

IBM MPI





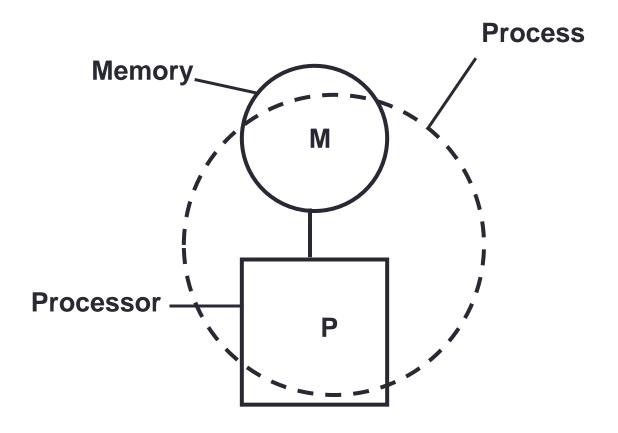
Message Passing Model

- 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





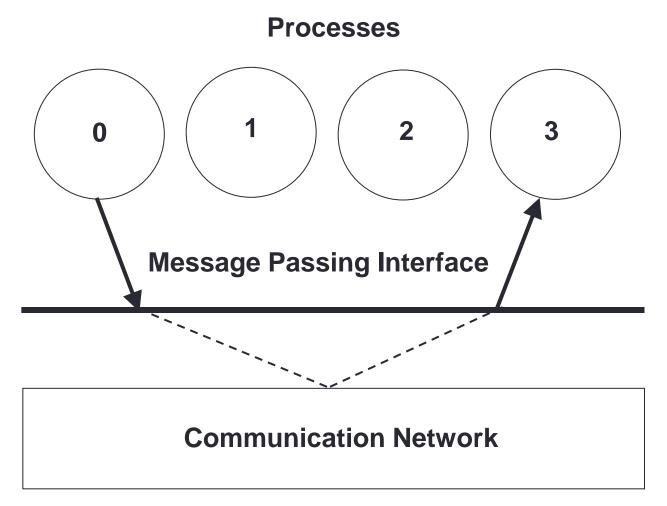
Sequential Paradigm







Parallel Paradigm







Cluster of Workstations

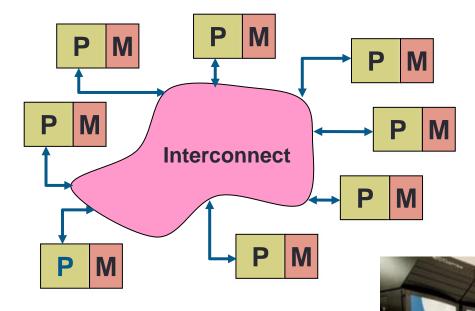
Aim to run a single computation across all workstations







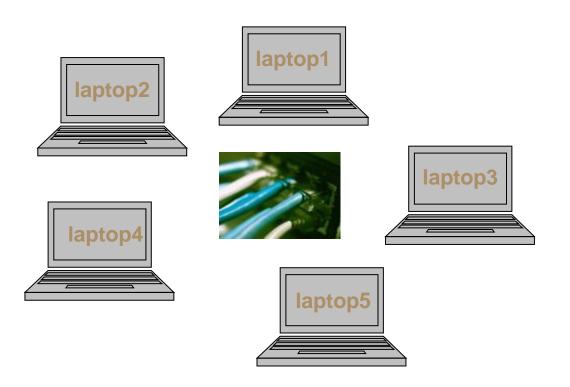
Distributed-Memory Architectures





Generic Parallel Machine

- Good conceptual model is collection of multicore laptops
 - connected together by a network



- Each laptop is called a compute node
 - each has its own operating system and network connection
- Suppose each node is a quadcore laptop
 - total system has 20 CPU-cores





Process Communication

Process 1

Process 2

Program

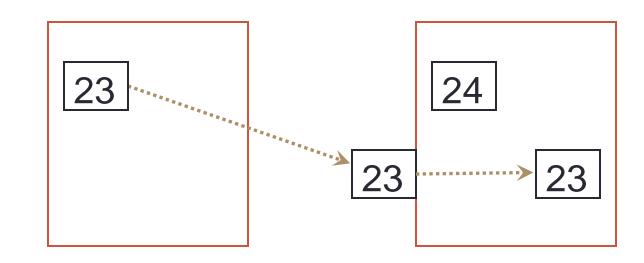
a=23

Recv(1,b)

Send(2,a)

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

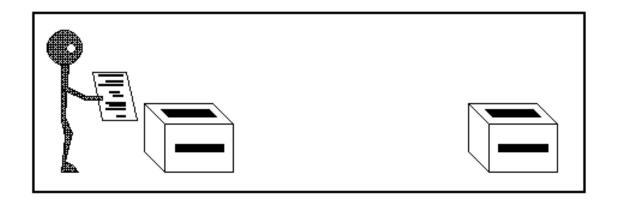
- Sending a message can either be synchronous or asynchronous
- A synchronous send is not completed until the message has started to be received
- An asynchronous send completes as soon as the message has gone
- Receives are usually synchronous the receiving process must wait until the message arrives





Synchronous send

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

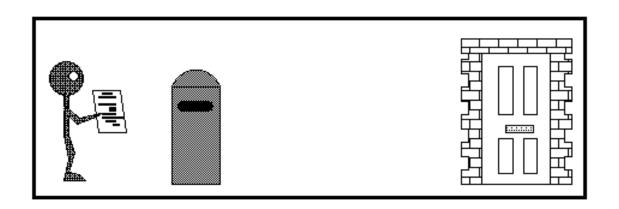






Asynchronous send

- 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

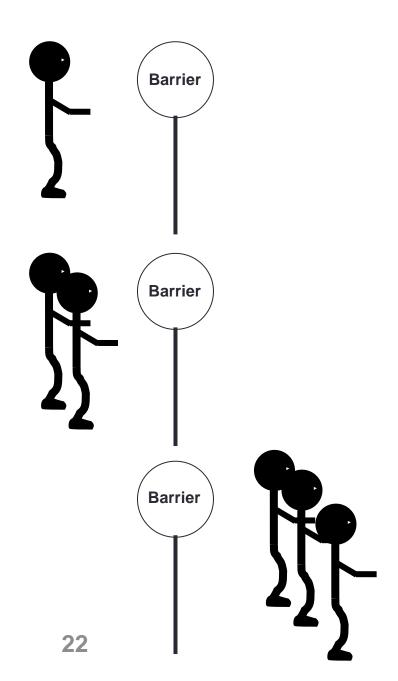
- A simple message communicates between two processes
- There are many instances where communication between groups of processes is required
- Can be built from simple messages, but often implemented separately, for efficiency





Barrier

Global synchronisation

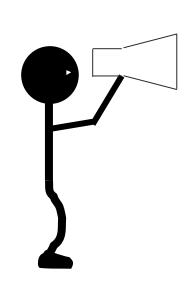


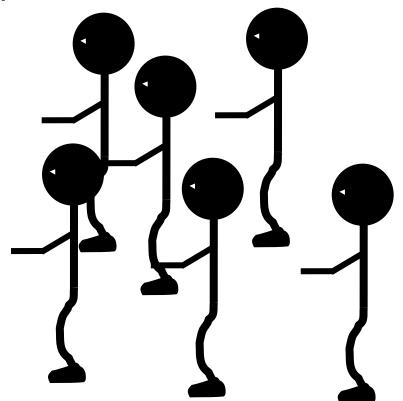




Broadcast

One to all communication



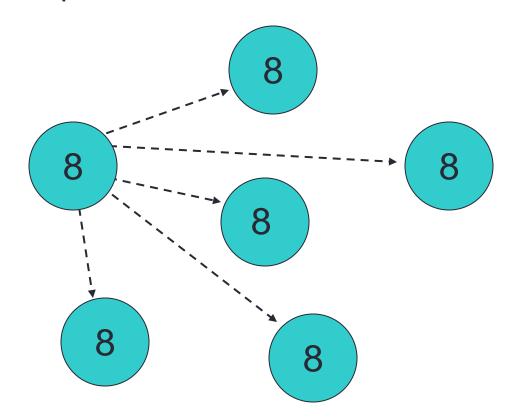






Broadcast

From one process to all others

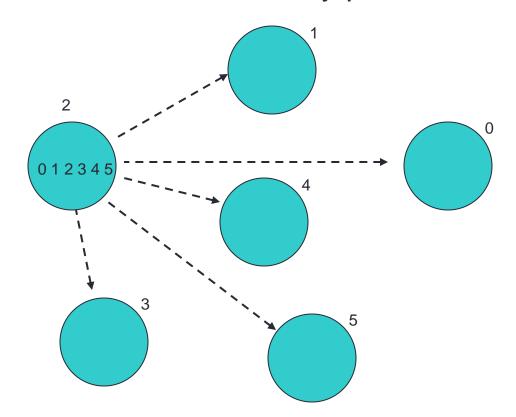






Scatter

Information scattered to many processes

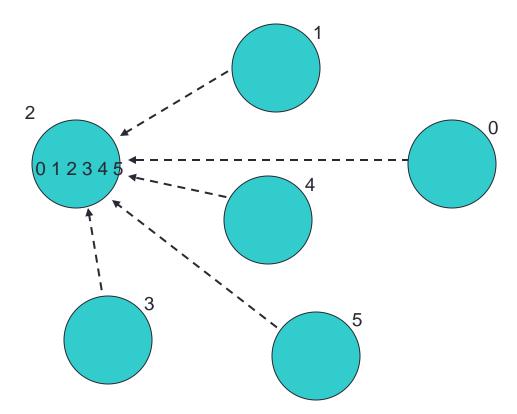






Gather

Information gathered onto one process



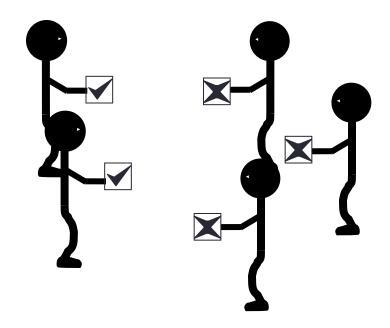




Reduction Operations

Combine data from several processes to form a single result

Strike?

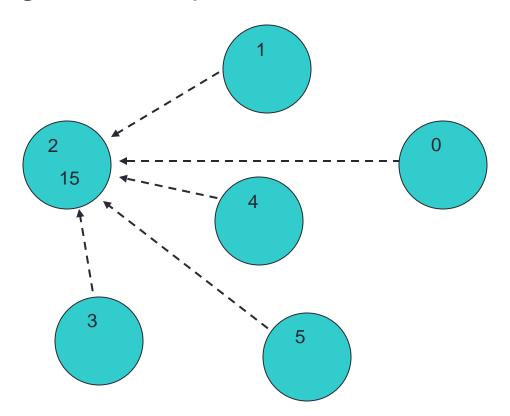






Reduction

• 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 messagepassing 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;</pre>
```



