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

- Languages
  - Python
  - Java
  - Fortran
  - struct
  - if/then/else

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

Message-Passing Parallel Programming

- Concepts
  - Processes
  - SPMD
  - Groups
  - Send/Receive
  - Collectives

- Libraries
  - MPI
  - MPI_Init()

- Implementations
  - Intel MPI
  - MPICH2
  - OpenMPI
  - Cray MPI
  - 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

Diagram showing the relationship between Memory (M), Processor (P), and Process.
Parallel Paradigm

Processes

Message Passing Interface

Communication Network
Distributed-Memory Architectures
Process Communication

Process 1
- \( a = 23 \)
- Send\((2, a)\)

Process 2
- \( \text{Recv}(1, b) \)
- \( a = b + 1 \)

Data

Program

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<thead>
<tr>
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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
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 *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

```c
if (x < 0)
    print("Error");
exit;
```