Parallel Computing

Message Passing

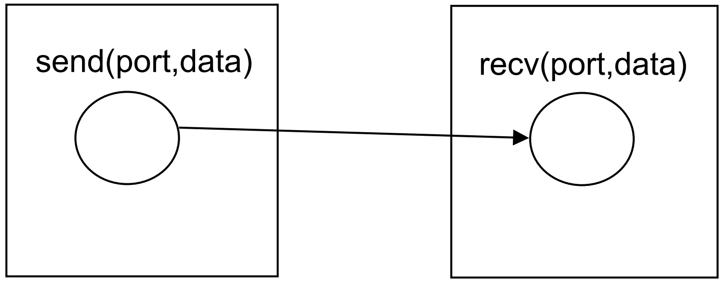
João Luís Ferreira Sobral
Departamento do Informática
Universidade do Minho

November 2018

Message Passing

Basic concepts

- Specification of parallel activities through processes with disjoint address spaces
  - No shared memory among processes => message passing parallelism
  - Processes can be identical (Single Process Multiple data, SPMD, e.g., MPI) or not (Multiple Instructions Multiple Data, MIMD, e.g., PVM)
- Parallel activities communicate through ports or channels
  - Message send and reception is explicit (from/to a port or channel)



- Data must be explicitly marshalled into messages
- There are more sophisticated communication primitives (broadcast, reduction, barrier)

Message Passing

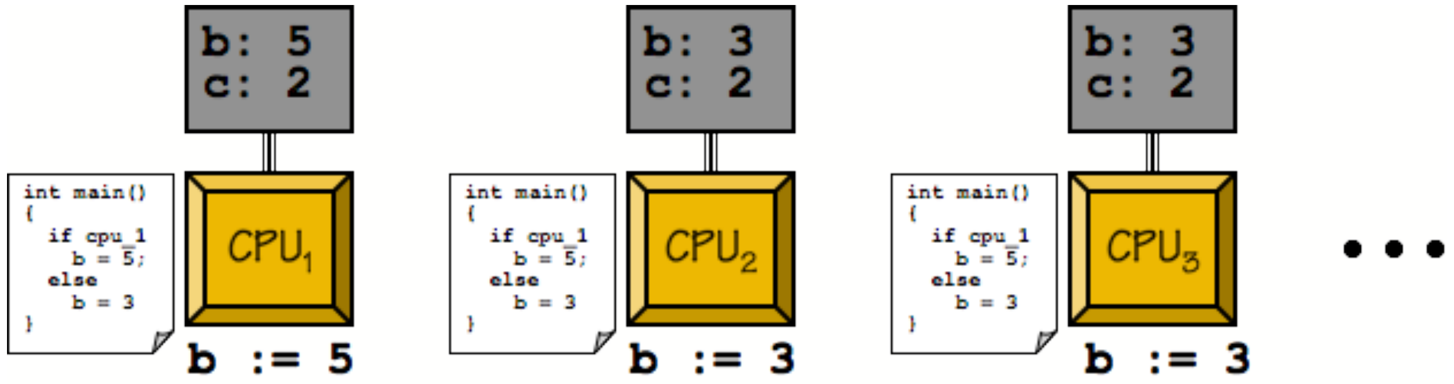
MPI (Message Passing Interface) http://www.mpi-forum.org

- **Standard** for message passing, outcome of an effort to provide a way to develop **portable** parallel applications (based on distributed memory)
- Based on the SPMD model (the same process is executed on all machines)
  - Message passing with in order message delivery
- Implemented as a library of functions
- Common Libraries (Open Source): OpenMPI, MPICH and LamMPI
- Main features:
  - Several modes of message passing
    - Synchronous / asynchronous
  - Communication groups / topologies
  - Large set of collective operations
    - Broadcast, Scatter/gather, reduce, all-to-all, barrier
  - MPI-2
    - Dynamic processes, parallel I/O, Remote memory access, RMA (put/get)

Message Passing

Single Program Multiple Data model (SPMD)

- **The same executable is launched on a given set of machines**
  - Asynchronous execution of the same program
  - Each process has a unique identifier
- The rank of each process is used to define each process-specific behaviour
  - Process control flow
  - Data processing and inter-process communication
- **Example with 3 processes**



- **Easy to write a program that works with a arbitrary number of process**

Message Passing

Structure of a MPI program

- **Initialize the library**
  - **MPI_Init -** Initializes the library
- **Get information for process**
  - **MPI_Comm_size**
    - Gets total number of process
  - **MPI_Comm_rank**
    - Get the id of current process
- **Execute the body of the program**
  - **MPI_Send / MPI_Recv**
    - Do processing and send/recv data
- **And cleanup**
  - **MPI_Finalize**

```
#include <mpi.h>
#include <stdio.h>
int main( int argc, char *argv[]) {
    int rank, msg;
    MPI_Status status;
    MPI_Init(&argc, &argv);
    MPI_Comm_rank( MPI_COMM_WORLD, &rank );

    /* Process 0 sends and Process 1 receives */
    if (rank == 0) {
        msg = 123456;
        MPI_Send( &msg, 1, MPI_INT, 1, 0, MPI_COMM_WORLD);
    }
    else if (rank == 1) {
        MPI_Recv( &msg, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, &status );
        printf( “Received %d\n”, msg);
    }

    MPI_Finalize();
    return 0;
}
```

Compile and execute the program

- **compile:** mpicc or mpicxx
- **execute:** mpirun –np <*number of processes*> a.out

Message Passing

MPI (Functionalities – cont.)

- **Point to point communication between processes**

```
int MPI_Send(void *buf, int count, MPI_Datatype datatype, int dest, int tag, MPI_Comm comm)

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

- **Message data content:** void *buf, int count, MPI_Datatype datatype
  - Requires the specification of the data type (MPI_INT, MPI_DOUBLE, etc)

- **Each process is identified by its rank in the group**
  - *dest* / *source* provide the destination / source of the message
  - By default there is a group comprising all processes: MPI_COMM_WORLD

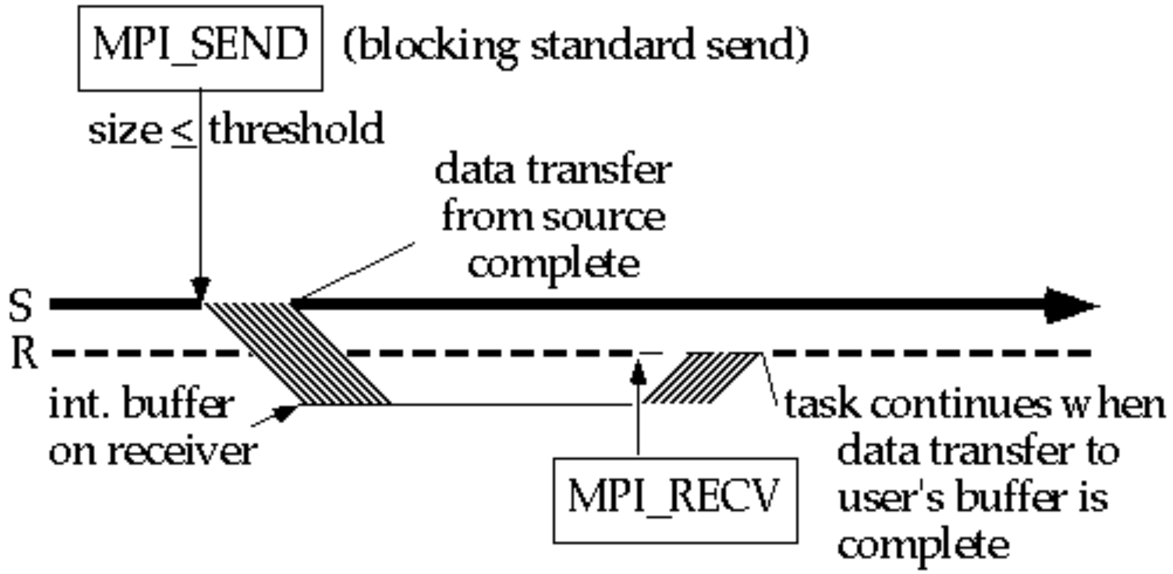
- **The tag can be used to make distinction among messages**

- **MPI_Recv:** waits for the arrival of a message with the required characteristics
  - MPI_ANY_SOURCE and MPI_ANY_TAG can be used to identify any source / any tag

Message Passing

MPI – Modes of point-to-point communication

- **Message passing overhead**
  - Message transfer time (copy into the network, network transmission, deliver at the receptor buffer)


MPI_SEND
(blocking standard send)
size ≤ threshold
data transfer from source complete
S
R
int. buffer on receiver
MPI_RECV
task continues when data transfer to user's buffer is complete

Message Passing

MPI – Modes of point-to-point communication

- **“standard” MPISend my be implemented on a variety of ways**
  - **MPI_Send:** will not return until you can use the send buffer. It may or may not block (it is allowed to buffer, either on the sender or receiver side, or to wait for the matching receive).

- **MPI_Ssend (blocking synchronous send)**
  - the sender waits until the message is received (w/ MPI_Recv)

- **MPI_Bsend (Buffered send)**
  - Returns as soon as the message has been placed on a buffer on the sender side
  - **Does not suffers from the overhead of receptor synchronization, but may copy to a local buffer**

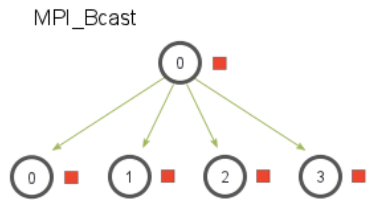
- **MPI_Rsend (Ready send)**
  - Returns as soon as the message has been placed in the network
  - **The receptor side should already posted to avoid recv “deadlocks”**

- **MPI_Ixxx (non-bloking sends) w/ MPI_wait / MPI_Test /MPI_Probe**
  - Return immediately, being the programmer responsible to verify if the operation has completed (using wait)

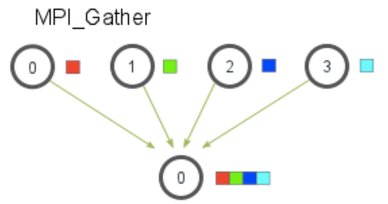
Message Passing

MPI – Collective communications

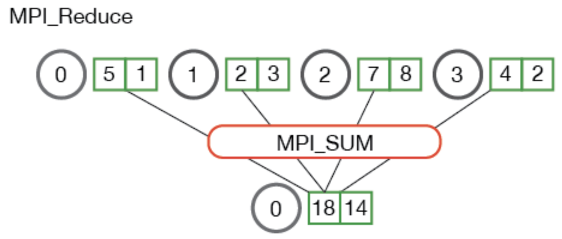
- int MPI_Barrier(MPI_Comm comm)
  - Wait until all processes arrive at the barrier
- int MPI_Bcast(void* buffer, int count, MPI_Datatype datatype, int root, MPI_Comm comm)
  - Broadcast the data from root to all other processes



- int MPI_Gather & int MPI_Scatter(void* sbuf, int scount, MPI_Datatype stype, void* rbuf, int rcount, MPI_Datatype rtype, int root, MPI_Comm comm)
  - Gather: Joints data from all processes into the root
  - Scather: scatters data from root into all other processes



- int MPI_Reduce(void* sbuf, void* rbuf, int count, MPI_Datatype stype, MPI_Op op, int root, MPI_Comm comm)
  - Combines the results from all process into the root, using the operator *MPI_Op*
- Compositions: Allgather, Alltoall , Allreduce, Reduce_scatter

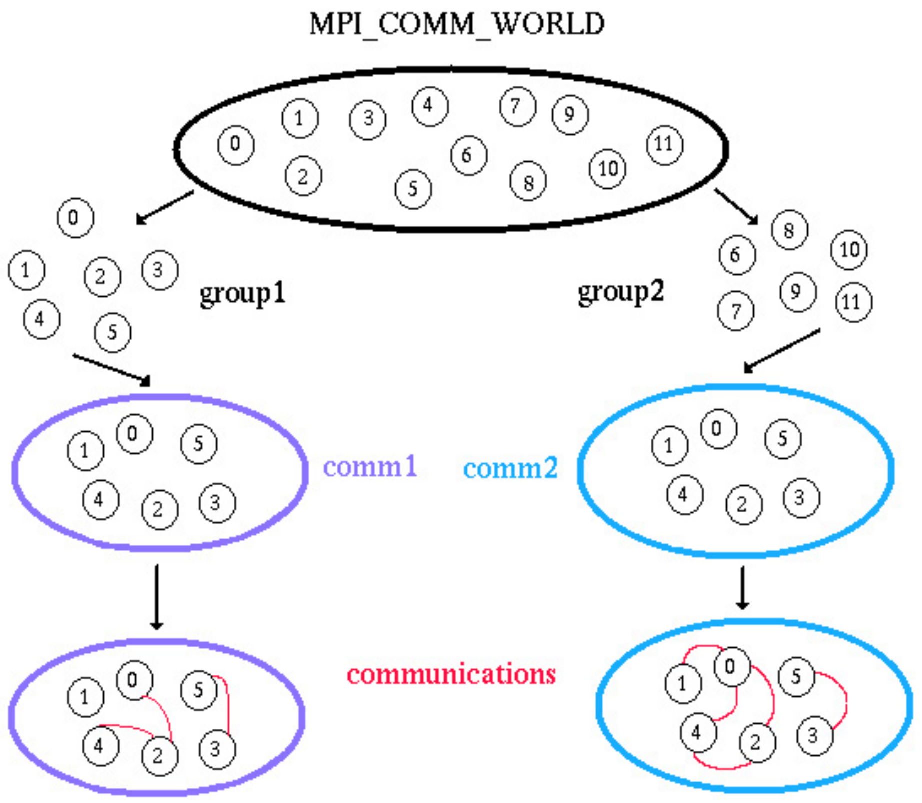


Message Passing

MPI – Groups

- Ordered group of process
  - Each process has a rank within the group

- Scope for communication on collective and point to point communications



Message Passing

MPI – C++

- **C++ Exemple**

```
#include “mpi.h”
#include <iostream>
int main( int argc, char *argv[]) {
        int rank, buf;
        MPI::Init(argv, argc);
        rank = MPI::COMM_WORLD.Get_rank();
        // Process 0 sends and Process 1 receives
        if (rank == 0) {
                buf = 123456;
                MPI::COMM_WORLD.Send( &buf, 1, MPI::INT, 1, 0 );
        }
        else if (rank == 1) {
                MPI::COMM_WORLD.Recv( &buf, 1, MPI::INT, 0, 0 );
                std::cout << “Received “ << buf << “\n”;
        }
        MPI::Finalize();
        return 0;
}
```