Message Passing in Distributed Systems

Distributed memory machines and communication
Shared Memory Systems

- **Advantages:** Easy to parallelize, all data available nearby
- **Limitations:** Complex and expensive to build, restricted to certain system sizes
Distributed Memory Systems

- Locality of data is exposed, cheap to build
- But what are the negative points?
Message passing

• Exemplified by MPI: (Message Passing Interface)
• Work unit: Processes
• Data units:
  • Decomposed, so that each process has its own data unit
  • No shared data
  • Coordination by: exchanging “messages” via send/recv calls
  • Analogy: mail
Anatomy of message passing

• Typical clusters today:
  • Ethernet or more sophisticated network card and a interconnect
  • Messages are sent as packets over the network

• Co-processors
  • Network Interface Card (NIC) is an example
  • Offload work of communication to co-processors
Message Passing
Basic Message Passing

• We will describe a hypothetical message passing system
  • With just a few calls that define the model
  • Later, we will look at real message passing models (e.g. MPI), with a more complex sets of calls

• Basic calls:
  • send(int proc, int tag, int size, char *buf);
  • recv(int proc, int tag, int size, char *buf);
    • recv may return the actual number of bytes received in some systems
  • tag and proc may be wildcarded in a recv:
    • recv(ANY, ANY, 1000, &buf);

• Broadcast:

• Other global operations (reductions)
int count, c1, i;
main() {
    Seed s = makeSeed(myProcessor);
    for (i=0; i<100000/P; i++) {
        x = random(s);
        y = random(s);
        if (x*x + y*y < 1.0)
            count++;
    }
    send(0, 1, 4, &count);
    if (myProcessorNum() == 0) {
        globalCount = 0.0;
        for (i=0; i<maxProcessors(); i++) {
            recv(i, 1, 4, c);
            globalCount += c;
        }
        printf("pi=%f\n", 4*globalCount/100000);
    }
} /* end function main */
Collective calls

• Message passing is often, but not always, used for SPMD style of programming:
  • SPMD: Single process multiple data
  • All processors execute essentially the same program, and same steps, but not in lockstep

• All communication is *almost in lockstep*

• **Collective calls:**
  • global reductions (such as max or sum)
  • syncBroadcast (often just called broadcast):
    • syncBroadcast(whoAmI, dataSize, dataBuffer);
    • whoAmI: sender or receiver
Basic MPI

Sending and Receiving Messages
Standardization of message passing

• Historically:
  • nxlib (On Intel hypercubes)
  • ncube variants
  • PVM
  • Everyone had their own variants

• MPI standard:
  • Vendors, ISVs, and academics got together
  • with the intent of standardizing current practice
  • Ended up with a large standard
  • Popular, due to vendor support
  • Support for
    • communicators: avoiding tag conflicts, ..
    • Data types:
      • ..
A Simple subset of MPI

• These six functions allow you to write many programs:
  • MPI_Init
  • MPI_Finalize
  • MPI_Comm_size
  • MPI_Comm_rank
  • MPI_Ssend
  • MPI_Recv
MPI Init and Finalize

• MPI_Init( int argc, char **argv )
• Initializes the MPI library.
• MPI_Finalize()
• Terminates use of MPI library.

All MPI calls must occur between these two, temporally.
MPI Process Identification

MPI_Comm_size( comm, &size )
   Determines the number of processes.
MPI_Comm_rank( comm, &pid )
   Pid is the process identifier of the caller.
A simple MPI program

#include "mpi.h"
#include <stdio.h>

int main(int argc, char *argv) {
    int rank, size;
    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);
    printf("Hello world! I'm %d of %d\n", rank, size);
    MPI_Finalize();
    return 0;
}
How to Install MPI(CH)

• **Mac**: brew install mpich

• **WSL/Linux**: sudo apt-get install mpich

• [https://www.mpich.org/downloads/](https://www.mpich.org/downloads/)
MPI Basic Send

MPI_Send(buf, count, datatype, dest, tag, comm)

- buf: address of send buffer
- count: number of elements
- datatype: data type of send buffer elements
- dest: process id of destination process
- tag: message tag (ignore for now)
- comm: communicator (ignore for now)
MPI Basic Receive

MPI_Recv(buf, count, datatype, source, tag, comm, &status)

buf: address of receive buffer
count: size of receive buffer in elements
datatype: data type of receive buffer elements
source: source process id or MPI_ANY_SOURCE
tag and comm: ignore for now
status: status object
Running a MPI Program

- Example: `mpirun -np 2 hello`
- Interacts with a daemon process on the hosts.
- Causes a process to be run on each of the hosts.
Other Operations

• Collective Operations
  • Broadcast
  • Reduction
  • Scan
  • All-to-All
  • Gather/Scatter

• Support for Topologies

• Buffering issues: optimizing message passing

• Data-type support
Example: Jacobi relaxation

Red and blue boundaries held at fixed values (say temperature)

Discretization: divide the space into a grid of cells.

For all cells except those on the boundary: iteratively compute temperature as average of their neighboring cells’

Pseudocode:
A, Anew: NxN 2D-array of (FP) nos.
Begin Loop (how many times?)
  for each I = 1, N
    for each J between 1, N
      Anew[I,J] = average of 4 neighbors and itself.
    Swap Anew and A
End Loop
How to parallelize?

• Decide to decompose data:
  • What options are there? (e.g. 16 processors)
    • Vertically
    • Horizontally
    • In square chunks
  • Pros and cons:

• Identify communication needed
  • Let us assume we will run for a fixed number of iterations
  • What data do I need from others?
  • From whom specifically?
  • Reverse the question: Who needs my data?
  • Express this with sends and recvs..
Ghost cells: a common apparition

• The data I need from neighbors
  • But that I don’t modify (therefore “don’t own”)

• Can be stored in my data structures
  • So that my inner loops don’t have to know about communication at all..
  • They can be written as if they are sequential code.
Ghost Cells

5 Point Stencil
Assume P ranks gridded as p1 x p2
For each rank proc, tag, size, buf
myx = myrank / p2; myy = myrank % p2;

Begin Loop
  if(myx != 0) send(RANK(myx-1, myy), 0, N, northData)
  if(myx != p1-1) send(RANK(myx+1, myy), 1, N, southData)
  if(myy != 0) send(RANK(myx, myy-1), 2, N, eastData)
  if(myy != p2-1) send(RANK(myx, myy+1), 3, N, westData)

  if(myx != p1-1) recv(RANK(myx+1, myy), 0, N, newSouthData)
  if(myx != 0) recv(RANK(myx-1, myy), 1, N, newNorthData)
  if(myy != p2-1) recv(RANK(myx, myy+1), 2, N, newWestData)
  if(myy != 0) recv(RANK(myx, myy-1), 3, N, newEastData)

  For data on me
    update Anew using A and received data
  End For
End For

Exercise: code this with MPI
Comparing the decomposition options

• What issues?
  • Communication cost is the main one here
  • How many messages? How many bytes?

• Options:
  1. Each process owns a block of rows
  2. Each process owns a tile

• Compare the options:
  • Communication volume (number of bytes)
  • Number of messages: 2 vs 4
  • Restrictions of machine configuration: tile decomposition needs a square number of processors
  • Ease of coding
  • Cache performance for copying
Send/Receive Variants

Buffers, copies, and waits
Implementation and efficiency issues

• It is useful to understand some of these to see the motivation for the variety of send/recv call variants

• Issues:
  • Data copying cost
  • Buffer availability and allocation
  • Packetization
  • Tag matching
  • Progress engine
Recall: Message Passing

Involves copying data from user’s data space on the source processor to user’s data space on the other processor.
Recall: Message Passing

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Implementing MPI

• Data transfer plus synchronization

- Requires cooperation of sender and receiver
- Cooperation not always apparent in code

(Gropp, ~2007)
Implementation and efficiency issues

• It is useful to understand some of these to see the motivation for the variety of send/recv call variants

• Issues:
  • Data copying cost: if you copy into MPI buffers at source and destination
  • Buffer availability and allocation
  • Packetization: who will pay attention to incoming packets? Where do they go?
  • Tag matching
  • Progress engine
Messaging protocols

• Message consists of “envelope” (header) and data
  • Envelope contains tag, communicator, length, source information, plus implementation-specific private data

• MPI implementations often use different protocols for different messages,
  • for a good tradeoff between performance and buffer memory
    • Short
      • Message data (message for short) sent with envelope
    • Eager
      • Message sent assuming destination can store (by allocating memory if needed)
    • Rendezvous
      • Header sent first
      • Message not sent until destination sends an ok-to-send reply
Messaging protocol: programmer’s control

• What can you do as a programmer with the knowledge of protocols?
  • Understand why the program performs a certain way
  • Influence it by changing the threshold message size when it switches from one protocol to the other
MPI terminology

• Basic terms
  • Immediate- Operation does not wait for completion (aka nonblocking)
  • Synchronous - Completion of send requires initiation (but not completion) of receive
  • Buffered – The MPI implementation can use a buffer the user has already supplied to it for its internal copies
  • Ready - Correct send requires a matching receive already be posted
    • I.e. programmer guarantees that such a receive has been posted by the time the send call is made

• Asynchronous - communication and computation take place simultaneously, not an MPI concept (implementations may use asynchronous methods)
Basic Send/Receive modes

• MPI_Send
  • Sends data. May wait for matching receive. Depends on implementation, message size, and possibly history of computation

• MPI_Recv
  • Receives data

• MPI_Ssend (synchronous send)
  • Waits for matching receive to start

• MPI_Rsend (ready send)
  • Expects matching receive to be pre-posted
Nonblocking Modes

- **MPI_Isend**
  - Returns immediately, does not complete until send buffer available for reuse
- **MPI_Irsend**
  - Expects matching receive to be posted when called
- **MPI_Issend**
  - Does not complete until buffer available and matching receive posted
- **MPI_Irecv**
  - Does not complete until receive buffer available for use
There is a problem in both cases:

- Either the sender arrives first, or
- Receiver arrives first
Completion

• MPI_Test
  • Nonblocking test for the completion of a nonblocking operation

• MPI_Wait
  • Blocking test

• MPI_Testall, MPI_Waitall
  • For all in a collection of requests

• MPI_Testany, MPI_Waitany

• MPI_Testsome, MPI_Waitsome

• MPI_Cancel (MPI_Test_cancelled)
Persistent Communications

• MPI_Send_init
  • Creates a request (like an MPI_Isend) but doesn’t start it

• MPI_Start
  • Actually begin an operation

• MPI_Startall
  • Start all in a collection

• Also MPI_Recv_init, MPI_Rsend_init, MPI_Ssend_init, MPI_Bsend_init
Testing for Messages

• MPI_Probe
  • Blocking test for a message in a specific communicator

• MPI_Iprobe
  • Nonblocking test

• Can use wildcard tag and source for dynamic communication patterns

• No way to test in all/any communicator
Buffered Communications

• MPI_Bsend
  • May use user-defined buffer

• MPI_Buffer_attach
  • Defines buffer for all buffered sends

• MPI_Buffer_detach
  • Completes all pending buffered sends and releases buffer

• MPI_Ibsend
  • Nonblocking version of MPI_Bsend
Why so Many Forms

• Each represents a different tradeoff in ease of use, efficiency, or correctness
• Smaller sets can provide full functionality
• Need all to tune with
• What about asynchrony?
  • Implementation may be asynchronous or not
  • User may insert MPI_Test or MPI_Iprobe calls to ensure progress
References