Course Outline

• Introduction in algorithms and applications
• Parallel machines and architectures
  Overview of parallel machines, trends in top-500, clusters, many-cores
• Programming methods, languages, and environments
  Message passing (SR, MPI, Java)
  Higher-level language: HPF
• Applications
  N-body problems, search algorithms
• Many-core (GPU) programming
  (Rob van Nieuwpoort)
Approaches to Parallel Programming

- Sequential language + library
  - MPI, PVM
- Extend sequential language
  - C/Linda, Concurrent C++, HPF
- New languages designed for parallel or distributed programming
  - SR, occam, Ada, Orca
Paradigms for Parallel Programming

- Processes + shared variables
- Processes + message passing
- Concurrent object-oriented languages
- Concurrent functional languages
- Concurrent logic languages
- Data-parallelism (SPMD model)

- SR and MPI
- Java
- HPF, CUDA
Interprocess Communication and Synchronization based on Message Passing

Henri Bal
Overview

• Message passing
  – Naming the sender and receiver
  – Explicit or implicit receipt of messages
  – Synchronous versus asynchronous messages

• Nondeterminism
  – Select statement

• Example language: SR (Synchronizing Resources)
• Example library: MPI (Message Passing Interface)
Point-to-point Message Passing

- Basic primitives: send & receive
  - As library routines:
    - `send(destination, & MsgBuffer)`
    - `receive(source, &MsgBuffer)`
  - As language constructs
    - `send MsgName(arguments) to destination`
    - `receive MsgName(arguments) from source`
Direct naming

• Sender and receiver directly name each other
  – S: send M to R
  – R: receive M from S

• Asymmetric direct naming (more flexible):
  – S: send M to R
  – R: receive M

• Direct naming is easy to implement
  – Destination of message is know in advance
  – Implementation just maps logical names to machine addresses
Indirect naming

- Indirect naming uses extra indirection level
  - R: send M to P  -- P is a port name
  - S: receive M from P
- Sender and receiver need not know each other
- Port names can be moved around in a message
  - send ReplyPort(P) to U  -- P is name of reply port
- Most languages allow only a single process at a time to receive from any given port
- Some languages allow multiple receivers that service messages on demand -> called a mailbox
Explicit Message Receipt

- Explicit receive by an existing process
  - Receiving process only handles message when it is willing to do so

```c
process main()
{
  // regular computation here

  receive M( ....);  // explicit message receipt

  // code to handle message

  // more regular computations

  ....
}
```
Implicit message receipt

- Receipt by a new thread of control, created for handling the incoming message

```plaintext
int X;
process main( )
{
    // just regular computations, this code can access X
}
message-handler M( ) // created whenever a message M arrives
{
    // code to handle the message, can also access X
}
```
Threads

- Threads run in (pseudo-) parallel on the same node
- Each thread has its own program counter and local variables
- Threads share global variables
Implicit receipt is used if it’s unknown when a message will arrive; example: global bound in TSP

```java
int Minimum;
process main() {
  int Minimum;
  while (true) {
    if (there is a message Update) {
      receive Update(m);
      if (m<Minimum) Minimum = m
    }
    // regular computations
  }
}
message-handler
  Update(m: int) {
    if (m<Minimum) Minimum = m
  }
```
Differences (2)

• Explicit receive gives more control over when to accept which messages; e.g., SR allows:
  – receive ReadFile(file, offset, NrBytes) by NrBytes
  – // sorts messages by (increasing) 3rd parameter, i.e. small reads go first
• MPI has explicit receive (+ polling for implicit receive)
• Java has implicit receive: Remote Method Invocation (RMI)
• SR has both
Synchronous vs. asynchronous Message Passing

• Synchronous message passing:
  – Sender is blocked until receiver has accepted the message
  – Too restrictive for many parallel applications

• Asynchronous message passing:
  – Sender continues immediately
  – More efficient
  – Ordering problems
  – Buffering problems
Message ordering

• Ordering with asynchronous message passing

  SENDER:  
  • send message(1)  
  • send message(2)  

  RECEIVER:  
  receive message(N); print N  
  receive message(M); print M

• Messages may be received in any order, depending on the protocol
Example: AT&T crash

P1 crashes → P2 is dead

P1 is dead

I’m back → Regular message

Something’s wrong, I’d better crash!

Are you still alive?

P2 is dead

P1 crashes
Message buffering

• Keep messages in a buffer until the receive( ) is done
• What if the buffer overflows?
  – Continue, but delete some messages (e.g., oldest one), or
  – Use flow control: block the sender temporarily
• Flow control changes the semantics since it introduces synchronization
  – S: send zillion messages to R; receive messages
  – R: send zillion messages to S; receive messages
    • -> deadlock!
Nondeterminism

• Interactions may depend on run-time conditions
  – e.g.: wait for a message from either A or B, whichever comes first

• Need to express and control nondeterminism
  – specify when to accept which message

• Example (bounded buffer):
  – do simultaneously
    • when buffer not full: accept request to store message
    • when buffer not empty: accept request to fetch message
Select statement

• several alternatives of the form:
  – WHEN condition => RECEIVE message DO statement

• Each alternative may
  – succeed, if condition=true & a message is available
  – fail, if condition=false
  – suspend, if condition=true & no message available yet

• Entire select statement may
  – succeed, if any alternative succeeds -> pick one nondeterministically
  – fail, if all alternatives fail
  – suspend, if some alternatives suspend and none succeeds yet
Example: bounded buffer

select
  when not FULL(BUFFER) =>
    receive STORE_ITEM(X: INTEGER) do
      'store X in buffer'
    end;
  or
  when not EMPTY(BUFFER) =>
    receive FETCH_ITEM(X: out INTEGER) do
      X := 'first item from buffer'
    end;
end select;
Synchronizing Resources (SR)

- Developed at University of Arizona
- Goals of SR:
  - Expressiveness
    - Many message passing primitives
  - Ease of use
    - Minimize number of underlying concepts
    - Clean integration of language constructs
  - Efficiency
    - Each primitive must be efficient
Overview of SR

• Multiple forms of message passing
  – Asynchronous message passing
  – Rendezvous (synchronous send, explicit receipt)
  – Remote Procedure Call (synchronous send, implicit receipt)
  – Multicast (many receivers)

• Powerful receive-statement
  – Conditional & ordered receive, based on contents of message
  – Select statement

• Resource = module run on 1 node (uni/multiprocessor)
  – Contains multiple threads that share variables
Orthogonality in SR

- The send and receive primitives can be combined in all 4 possible ways.

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<th>Synchronous call</th>
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Example

body S  #sender
  send R.m1  #asynchr. mp
  send R.m2  # fork
  call  R.m1  # rendezvous
  call  R.m2  # RPC
end S

body R  #receiver
  proc M2( )  # implicit receipt
    # code to handle M2
  end

initial  # main process of R
  do true ->  #infinite loop
    in m1( )  # explicit receive
      # code to handle m1
    ni
  od
end

end R