Lecture 4

Programming Using the Message-Passing Paradigm I

Principles of Message-Passing Programming

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Contents

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- Some links; Scientific Applications on Linux, Parallel Programming Laboratory.

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  - for dynamic and/or unstructured interactions, the *complexity of the code* can be very high,
  - primary advantage of explicit two-way interactions is that the programmer is fully aware of all the costs of non-local interactions
  - more likely to think about algorithms (and mappings) that minimize interactions.

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- The programmer is responsible for analyzing the underlying serial algorithm/application.
- Identifying ways by which he or she can decompose the computations and extract concurrency.
- As a result, programming using the message-passing paradigm tends to be hard and intellectually demanding.
- However, on the other hand, **properly written** message-passing programs can often *achieve very high performance* and *scale to a very large* number of processes.

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- In its most general form, the message-passing paradigm supports execution of a different program on each of the p processes.
- This provides the ultimate flexibility in parallel programming, but makes the job of writing parallel programs effectively unscalable.

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- But except for this degenerate case, most processes execute the same code.
- SPMD programs can be loosely synchronous or completely asynchronous.

The Building Blocks: Send and Receive Operations I

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- Process P_0 sends a message to process P_1 which receives and prints the message.

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- It may seem that it is quite straightforward to ensure the semantics of the send and receive operations.
- However, based on how the send and receive operations are implemented this may not be the case.

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- Network interfaces allow the transfer of messages from buffer memory to desired location *without CPU intervention*.
- Similarly, DMA allows copying of data from one memory location to another (e.g., communication buffers) *without CPU support* (once they have been programmed).
- As a result, *if the send operation programs the communication hardware and returns before the communication operation has been accomplished*, process P_1 might receive the value 0 in a instead of 100!

Blocking Message Passing Operations I

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- There are two mechanisms by which this can be achieved.

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1. Blocking Non-Buffered Send/Receive
2. Blocking Buffered Send/Receive

Blocking Message Passing Operations II

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Blocking Message Passing Operations II

1 Blocking Non-Buffered Send/Receive

- The send operation does not return until the matching receive has been encountered at the receiving process.
- When this happens, the message is sent and the send operation returns upon completion of the communication operation.
- Typically, this process involves a *handshake* between the sending and receiving processes (see Fig. 1).

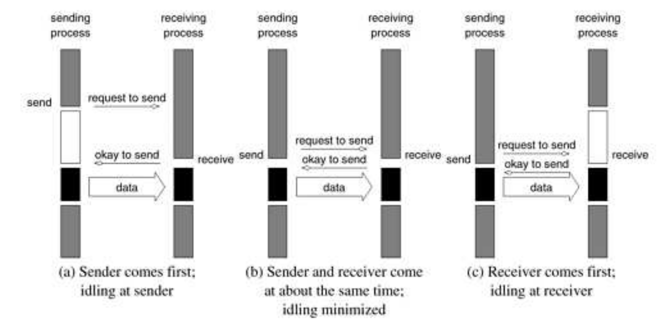

Figure: Handshake for a blocking non-buffered send/receive operation.

Blocking Message Passing Operations III

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- However, in an asynchronous environment, this may be impossible to predict.
- This idling overhead is one of the major drawbacks of this protocol.

Blocking Message Passing Operations IV

- *Deadlocks in Blocking Non-Buffered Operations:* Consider the following simple exchange of messages that can lead to a deadlock:

```
  P0                            P1

send(&a, 1, 1);            send(&a, 1, 0);
receive(&b, 1, 1);        receive(&b, 1, 0);
```

- The code fragment makes the values of *a* available to both processes P_0 and P_1.
- However, if the send and receive operations are implemented using a blocking non-buffered protocol,
  - the send at P_0 waits for the matching receive at P_1
  - whereas the send at process P_1 waits for the corresponding receive at P_0,
  - resulting in an infinite wait.
- Deadlocks are very easy in blocking protocols and care must be taken to break cyclic waits.

Blocking Message Passing Operations V

2 Blocking Buffered Send/Receive

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- A simple solution to the *idling* and *deadlocking* problems outlined above is to rely on **buffers** at the sending and receiving ends.

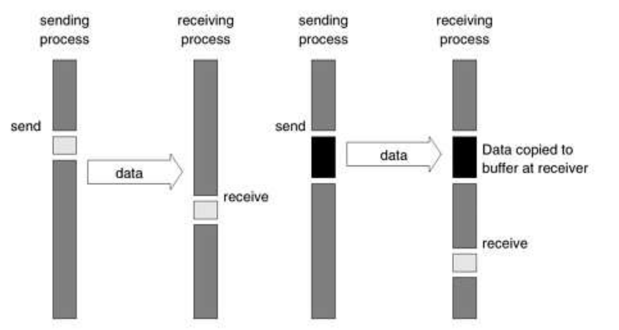

Figure: Blocking buffered transfer protocols: *Left:* in the presence of communication hardware with buffers at send and receive ends; and *Right:* in the absence of communication hardware, sender interrupts receiver and deposits data in buffer at receiver end.

Blocking Message Passing Operations VI

Figure 2Left

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Blocking Message Passing Operations VI

Figure 2Left

- On a send operation, the sender simply *copies the data into* the designated buffer and *returns after the copy operation has been completed*.
- The sender process can now continue with the program knowing that any changes to the data will not impact program semantics.
- If the hardware supports asynchronous communication (independent of the CPU), then a network transfer can be initiated after the message has been copied into the buffer.

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- On a send operation, the sender simply *copies the data into* the designated buffer and *returns after the copy operation has been completed*.
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- Instead, the data is copied into a buffer at the receiver as well.
- When the receiving process encounters a receive operation, it checks to see if the message is available in its receive buffer. If so, the data is copied into the target location.

Blocking Message Passing Operations VII

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- In general, if the parallel program is highly synchronous, non-buffered sends may perform better than buffered sends.
- However, generally, this is not the case and buffered sends are desirable unless buffer capacity becomes an issue.

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- Impact of finite buffers in message passing; consider the following code fragment:

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   P0                                        P1

for (i = 0; i < 1000; i++)          for (i = 0; i < 1000; i++)
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- In general, it is a good idea to write programs that have bounded buffer requirements.

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- However, deadlocks are caused only by waits on receive operations in this case.

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  - to provide a fast send/receive operation that incurs little overhead.
- This class of **non-blocking protocols** returns from the send or receive operation before it is semantically safe to do so.
- Consequently, the user must be careful not to alter data that may be potentially participating in communication.

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- Non-blocking operations can be buffered or non-buffered.

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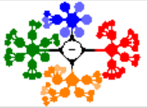

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- This is illustrated in Fig. 3Right.

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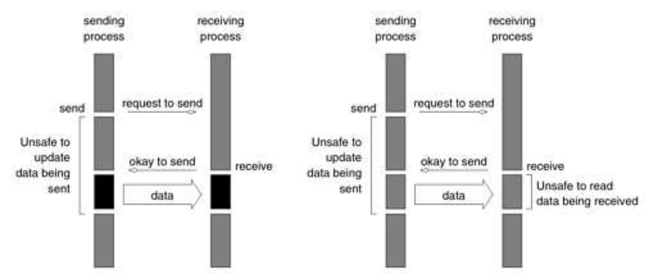

Figure: Non-blocking non-buffered send and receive operations *Left:* in absence of communication hardware; *Right:* in presence of communication hardware.

- Comparing Figures 3Left and 1a, it is easy to see that the idling time when the process is waiting for the corresponding receive in a blocking operation can now be utilized for computation (provided it does not update the data being sent).

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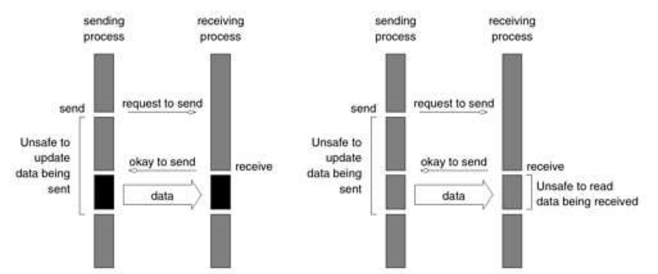

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- Comparing Figures 3Left and 1a, it is easy to see that the idling time when the process is waiting for the corresponding receive in a blocking operation can now be utilized for computation (provided it does not update the data being sent).
- This removes the major bottleneck associated with the former at the expense of some program restructuring.

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- Typical message-passing libraries such as Message Passing Interface (MPI) and Parallel Virtual Machine (PVM) implement both blocking and non-blocking operations.
- Blocking operations facilitate safe and easier programming.
- Non-blocking operations are useful for performance optimization by masking communication overhead.
- One must, however, be careful using non-blocking protocols since errors can result from unsafe access to data that is in the process of being communicated.

Non-Blocking Message Passing Operations VI

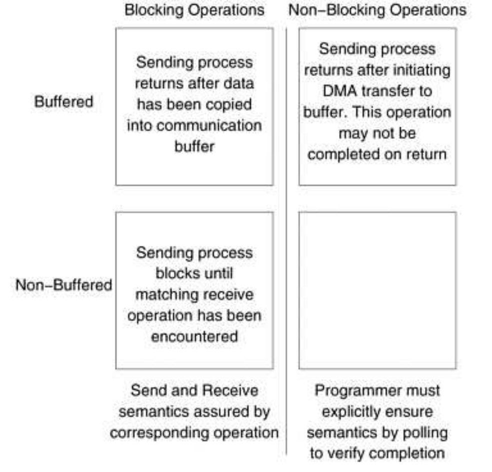

Figure: Space of possible protocols for send and receive operations.