G52CON: Concepts of Concurrency

Lecture 15: Message Passing

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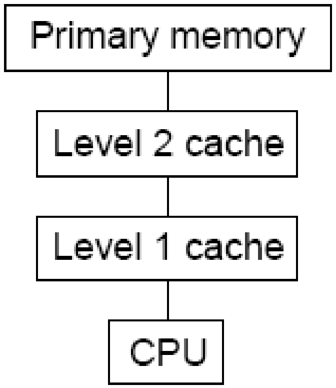
Content

- Introduction and transition
  - Recapitulation on hardware architectures
  - Overview of shared memory synchronisation
  - The need for synchronisation mechanisms that are less centralised (suitable for distributed computing)
- Message passing (one-way communication) using *channels*
  - Asynchronous communications
    - Example: Producers and consumers paradigm: Filter processes
  - Synchronous communications

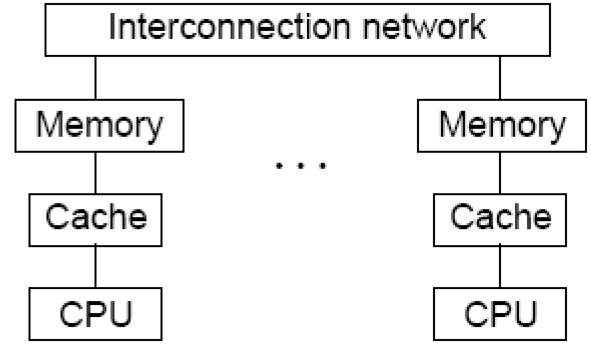
Hardware

Figures from (Andrews, 2000) Chapter 1

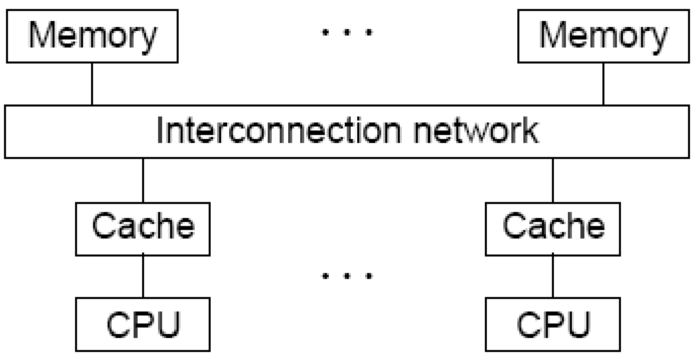


Single processor

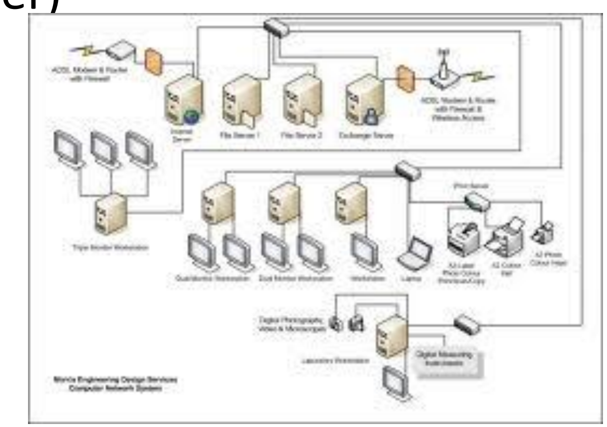
Concurrent programming models exist as an abstraction above hardware and memory architectures



Multicomputer - separate memories (Physically close to each other)



Multiprocessor - shared memory

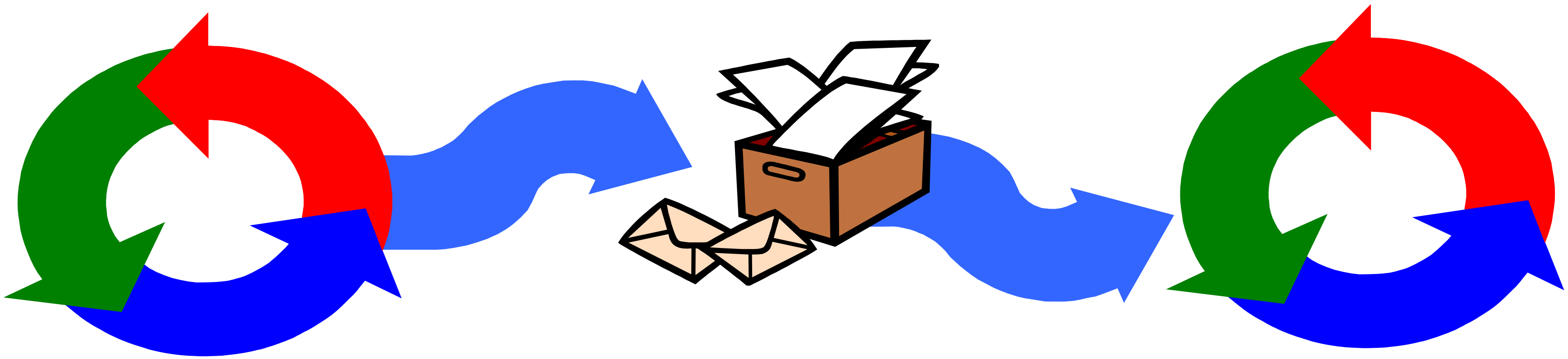


Network o or cluster of workstations

Overview of shared memory synchronisation

- Semaphores and monitors are the most important constructs found in concurrent programming languages
- They are the tools we need to use for *shared memory* synchronisation
- Both the semaphore and the monitor are highly centralised constructs. They maintain queues of blocked process and encapsulate data
- As multi-computers and distributed architectures become more popular, there is a need for synchronisation constructs that are less synchronised

Message passing



- These synchronisation constructs are based upon *communication (message passing)*, rather than upon sharing
- Synchronisation is achieved by using communication between ***sending*** processes and ***receiving*** processes
- As before, we will be dealing with an abstraction, and not with the underlying implementation
- The interleaving model will continue to be used

Message passing

- In message-passing programs, processes interact by sending and receiving messages
- Process that interact by message passing, do not need access to shared memory
- Therefore, mutual exclusion is not an issue in message passing protocols
- Processes can be located in different computers connected by a communication network
- However, message passing is also used when processes are indented to run within a single computer

Models for communication

- Fundamental to message passing are the operations to ***send*** and ***receive*** a message
- Two basic models of message passing
  - ***Synchronous***: the sender of a message waits until it has been received. Example: telephone call
  - ***Asynchronous*** : the sender does not wait and messages that have been set but not yet received are buffered. Example: text messages, or e-mail
- These are both *one-way* forms of communication: the messages are transmitted in one direction only, from sender to receiver
- Two-ways message protocol: rendezvous (next lecture)

Asynchronous message passing

- Provided by communication channels
- Channels are FIFO queues of pending messages
- Accessed by means of two primitives: **`send`** and **`receive`**
- To initiate a communication, a process send a message to a channel; another process acquires the message by receiving from the channel
- Channels are like semaphores that carry data.
  - **`send`** corresponds to ***P***
  - **`receive`** corresponds to ***V***
- Different notations have been proposed for asynchronous message passing, we follow here the notation used in Andrews (2000), Chapter 7

Asynchronous message passing

Process 1 → channel → *Process 2*
send receive

Channel: unbounded queue of messages

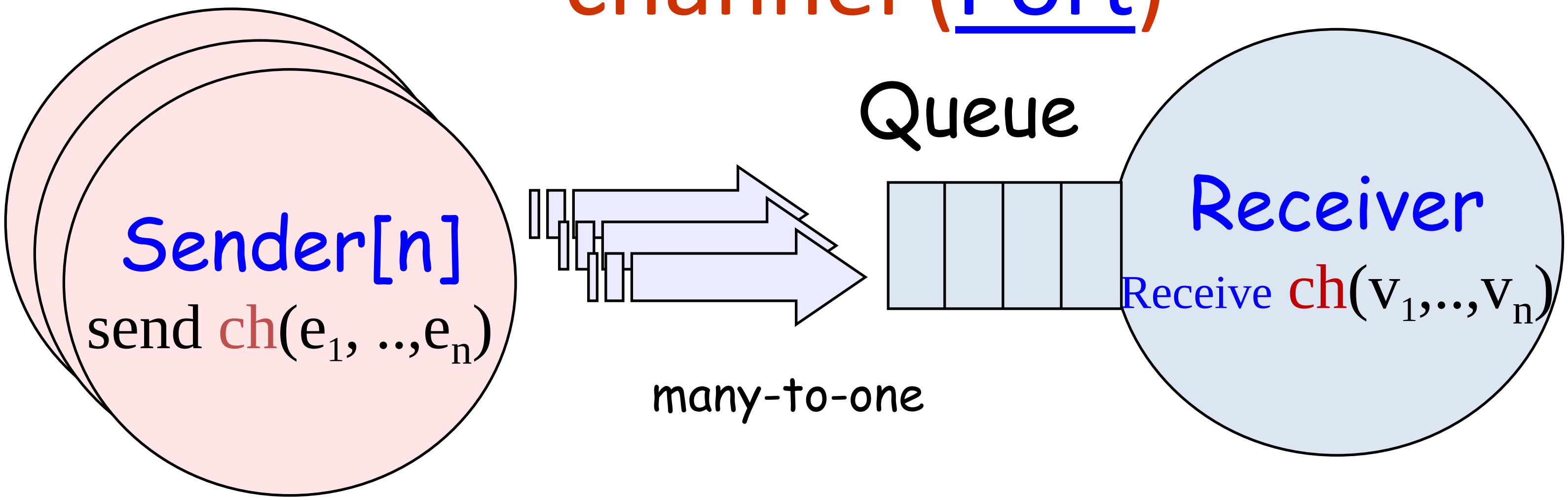
- A channel declaration has the form:
  - **`chan name(id1: type1; ...; idN: typeN);`**
- Examples
  - **`chan input(char)`**: used to transmit a single character
  - **`chan disk_access(int cylinder,int block, int count,char *buffer)`**: four fields with names indicating their roles
- Arrays of channels can be declared
  - **`chan result[n] (int);`**

Message passing primitives

- **`send name(expr1, ..., exprN)`**
  - types and number of fields must match with channel declaration
  - **effect**: evaluate the expressions and produce a message *M*, and atomically append *M* to the end of the named channel
  - send is *nonblocking* (asynchronous) (queue is unbounded)

- **`receive name(var1, ..., varN)`**
  - variables types and number must match with channel declaration
  - **effect**: wait for a message on the named channel, atomically remove first message (at the front of the queue) and put the fields of the message into the variables .
  - Receive is a *blocking* primitive since it might cause delay

Asynchronous Message Passing – channel (Port)



♦ ch(e_1, ..,e_n) - send the value of the expressions e_1, ..,e_n to channel ch. The process calling the send operation is not blocked. The message is queued at the channel if the receiver is not waiting.

♦ Receive ch(v_1,..,v_n) - receive a value into local variable v_1, ..,v_n from channel ch. The process calling the receive operation is blocked if there are no messages queued to the channel.

Asynchronous message passing

- Access to he contents of each channel is atomic
- Message delivery us realiable and error free
- Every message sent to the channel is eventually delivered
- Channels are FIFO queues. So, messages will be received in the order in which they were appended to the channel
- Example:

```
                 chan ch(int)
// process A                  // process B
  send ch(1)                     receive ch(x)
  send ch(2)                     receive ch(y)
```

x will contain 1 and y will contain 2
order of messages from **SAME** source is the order of the sends

Another simple example

```
chan ch1(int), ch2(int)

// process A
  send ch1(1)
  send ch2(2)

// process B
  receive ch1(x)
  receive ch1(y)

// process C
  send ch1(3)
  send ch2(4)

// process D
  receive ch2(u)
  receive ch2(v)
```

- what is received now? x will get 1 or 3 and y will get 3 or 1 u will get 2 or 4 and v will get 4 or 2

Example 1: filter process to assemble line of characters

- A *Filter* is a process that receives messages from one or more input channels and send messages to one or more output channels
- Consider a simple filter process that
  - receives a stream of characters from channel **`input`**,
  - Assembles the characters into lines, and
  - Sends the resulting lines to channel **`ouptut`**
- Symbolic constants
  - **`CR`**: carriage-return character
  - **`MAXLINE`**: maximum length of a line
  - **`EOL`**: appended to the output to indicate the of of a line

Example 1: filter process to assemble line of characters

```
chan input(char), output(char [MAXLINE]);
process Char_to_Line {
  char line[MAXLINE]; int i = 0;
  while (true) {
    receive input(line[i]);
    while (line[i] != CR and i < MAXLINE) {
      # line[0:i-1] contains the last i input characters
      i = i+1;
      receive input(line[i]);
    }
    line[i] = EOL;
    send output(line);
    i = 0;
  }
}
```

More on Channels

- Common terminology
  - ***Mailbox*:** a channel that have several process sending and several process receiving;
  - ***Port***: a channel that has exactly one receiver, it may have several senders
  - ***Link***: a channel with just one sender and one receiver
- To determine whether a channel's queue is currently empty, a process can call the Boolean-valued function
  - **`empty(ch):`** This function is true if a channel **`ch`** contains no messages, otherwise, it is false

Example 2: A sorting Network

- A *Filter* is a process that receives messages from one or more input channels and send messages to one or more output channels
- Consider the problem of sorting a list of **`n`** numbers into ascending order
- There are many kinds of sorting networks, just as there are many different internal sorting algorithms
- *Merge network*: repeatedly and in parallel, merge two sorted lists into a longer sorted list
- The network is constructed out of **`Merge`** filters

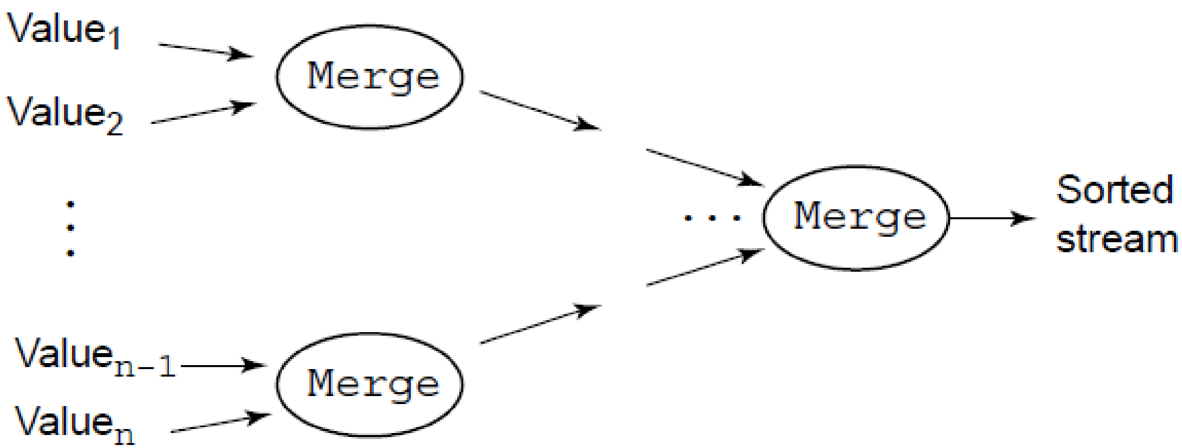
Example 2: A sorting Network

- Each Merge filter receives values from two ordered input streams **`in1`** and **`in2`**, and produces and ordered output out.
- The ends of the input stream are marked by a sentinel **`EOS`**
- **`Merge`** appends **`EOS`** and the end of the output stream
- **`Merge`** is implemented by repeatedly comparing the next two values received from **`in1`** and **`in2`** (stored in **`v1`** and **`v2`**), and sending the smaller to **`out`**
- The next slide shows the implementation of the filter process

```
chan in1(int), in2(int), out(int);
process Merge {
  int v1, v2;
  receive in1(v1);  # get first two input values
  receive in2(v2);
  # send smaller value to output channel and repeat
  while (v1 != EOS and v2 != EOS) {
    if (v1 <= v2)
      { send out(v1); receive in1(v1); }
    else   # (v2 < v1)
      { send out(v2); receive in2(v2); }
  }
  # consume the rest of the non-empty input channel
  if (v1 == EOS)
    while (v2 != EOS)
      { send out(v2); receive in2(v2); }
  else   # (v2 == EOS)
    while (v1 != EOS)
      { send out(v1); receive in1(v1); }
  # append a sentinel to the output channel
  send out(EOS);
}
```

A filter process that merges two input streams

A sorting network of **`Merge`** processes



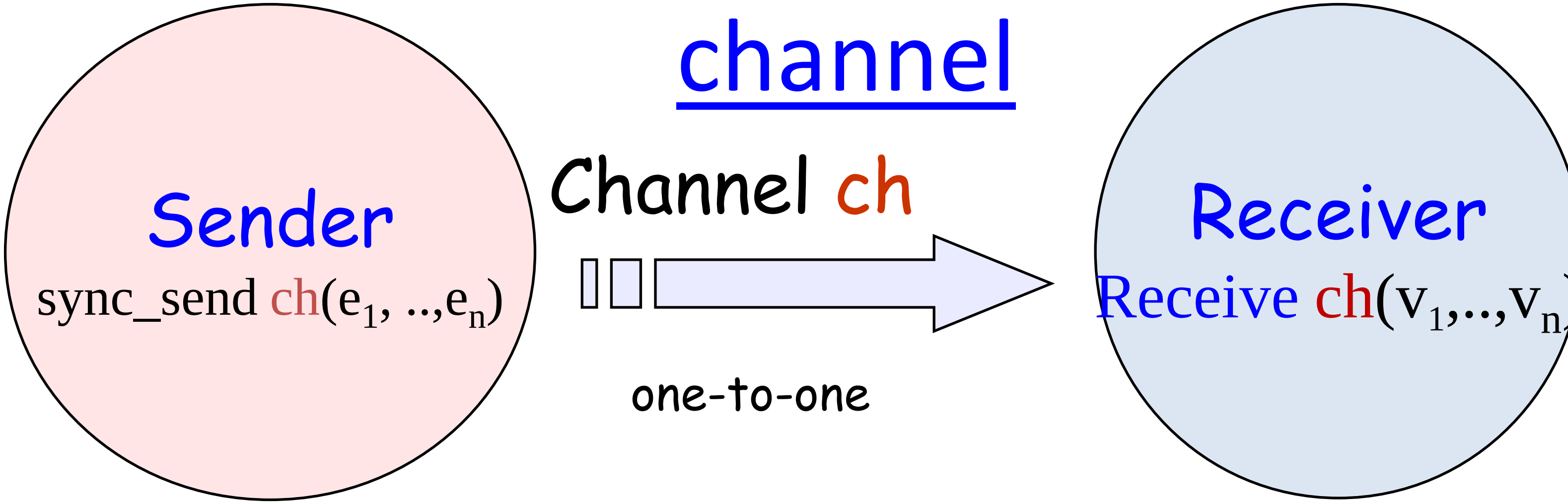
- To form a sorting network, we employ a collection of **`Merge`** processes and arrays of input and output channels.
- If the number of values n is a power of 2, the resulting communication patter forms a tree
- Information in the sorting network flows from left to right.
- Each node at the left is given two input values, which it merges to from a stream of two sorted values. The next node forms streams of four sorted values, and so on.
- The rightmost node produces the final sorted stream
- The sorting network contains **`n-1`** processes, the width of the network is log_2**`n`**

Other uses of asynchronous channels
(Examples discussed in Andrews (2000))

- We covered a **producers and consumers** example (filters): each process is a *filter* that consumes the output of its predecessors and produces outputs for its successors
- **Clients and servers**: dominant interaction patterns in distributed systems. A client process request a service, and waits for a reply. A server waits for requests from clients, then acts upon them
  - **Examples**: resource managers, self-scheduling disk servers, file servers
- **Interacting peers**: It occurs in distributed programs when there are several processes that execute the same code and exchange messages to accomplish a task.
  - **Examples**: scientific computing, matrix multiplication

SYNCHRONOUS MESSAGE PASSING

Synchronous Message Passing - channel



- sync_end ch(e_1, ..,e_n) - send the value of the expressions e_1, ..,e_n to channel ch. The process calling the send operation is blocked until the message is received from the channel.

- Receive ch(v_1,..,v_n) - receive a value into local variable v_1,..,v_n from channel ch. The process calling the receive operation is blocked waiting until a message is sent to the channel.

Synchronous Message Passing in one-way communication channels

Advantages

- There is a bound on the size of communications channels (buffer space)
- A process can have at most one message a time queued up on any channel
- Not until the message is received, can the sending process continue and send another message

Disadvantages

- Concurrency is reduced. When two processes communicate, at least one of them will have to block
- Programs are more prone to deadlock. The programmer has to be careful that all send and receive statements match up.

Asynchronous vs. Synchronous channels

- **`send`** and **`sync_send`**, are often interchangeable
- The main difference between asynchronous and synchronous message passing is the trade-off between having possibly more concurrency, and having bounded communication buffers
- Since memory is plentiful, and asynchronous send is less prone to deadlock, most programmers prefer it.

Distributed programming and Java

- Java supports concurrent programming by mean of threads, shared variables and synchronized methods
- Java can also be used to write distributed programs
- Java **does not** contain built-in primitives for message passing
- But it contains a standard package **`java.net`**
- Classes in the **`java.net`** package support
  - Low-level communications using datagrams
  - Higher-level communication using sockets
  - Internet communication using URLs (Uniform Resource Locations)

Overview and transition

- Message passing is ideally suited for programming filters and interacting peers, because these kinds of processes send information in one direction through communication channels
- Message passing can also be used to program clients and servers. However, since client-server communications is two ways, this lead to a large number of channels.
- There are other additional programming constructs
  - Remote procedure call (RPC)
  - Rendezvous
- These are two-way communication protocols, ideally suited to programming client/server interactions. (next lecture)