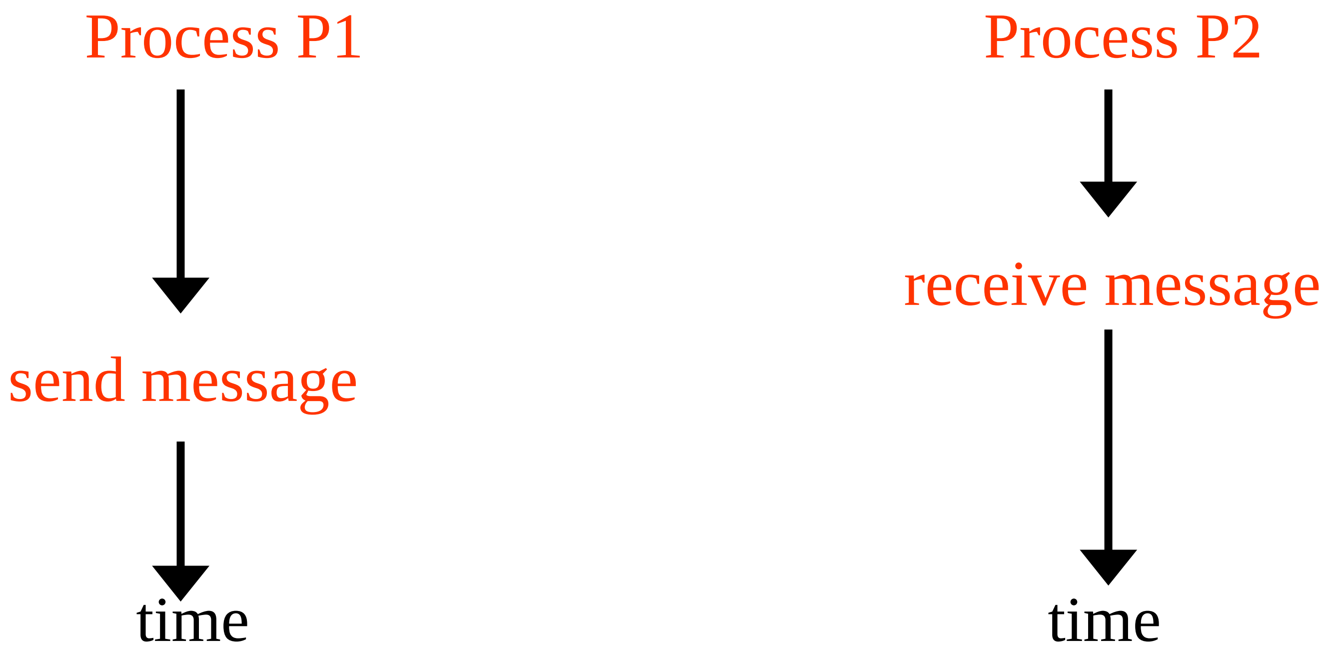
MESSAGE-BASED SYNCHRONISATION AND COMMUNICATION

Goals

- To understand the requirements for communication and synchronisation based on message passing
- To understand:
  – the Ada extended rendezvous
  – selective waiting
  – POSIX message queues
  – Remote procedure calls

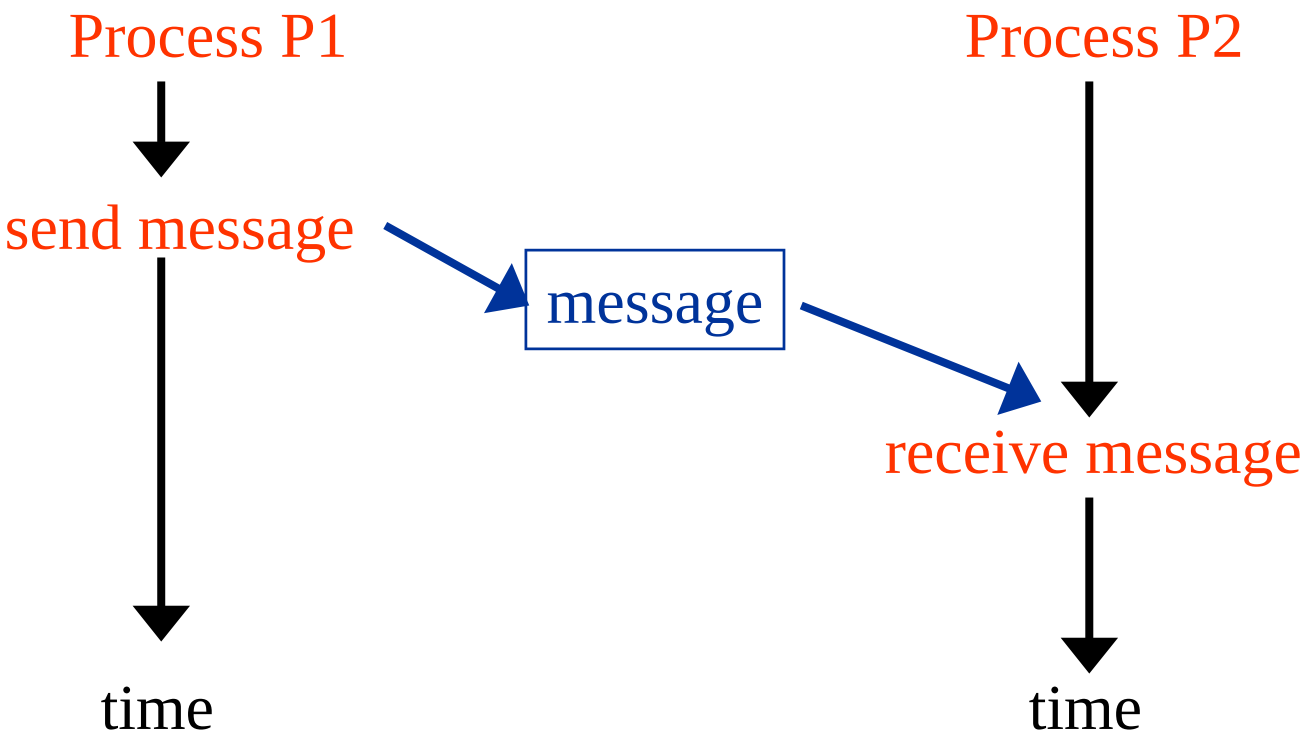
Message-Based Communication and Synchronisation

- Use of a single construct for both synchronisation and communication
- Three issues:
  - the model of synchronisation
  - the method of process naming
  - the message structure



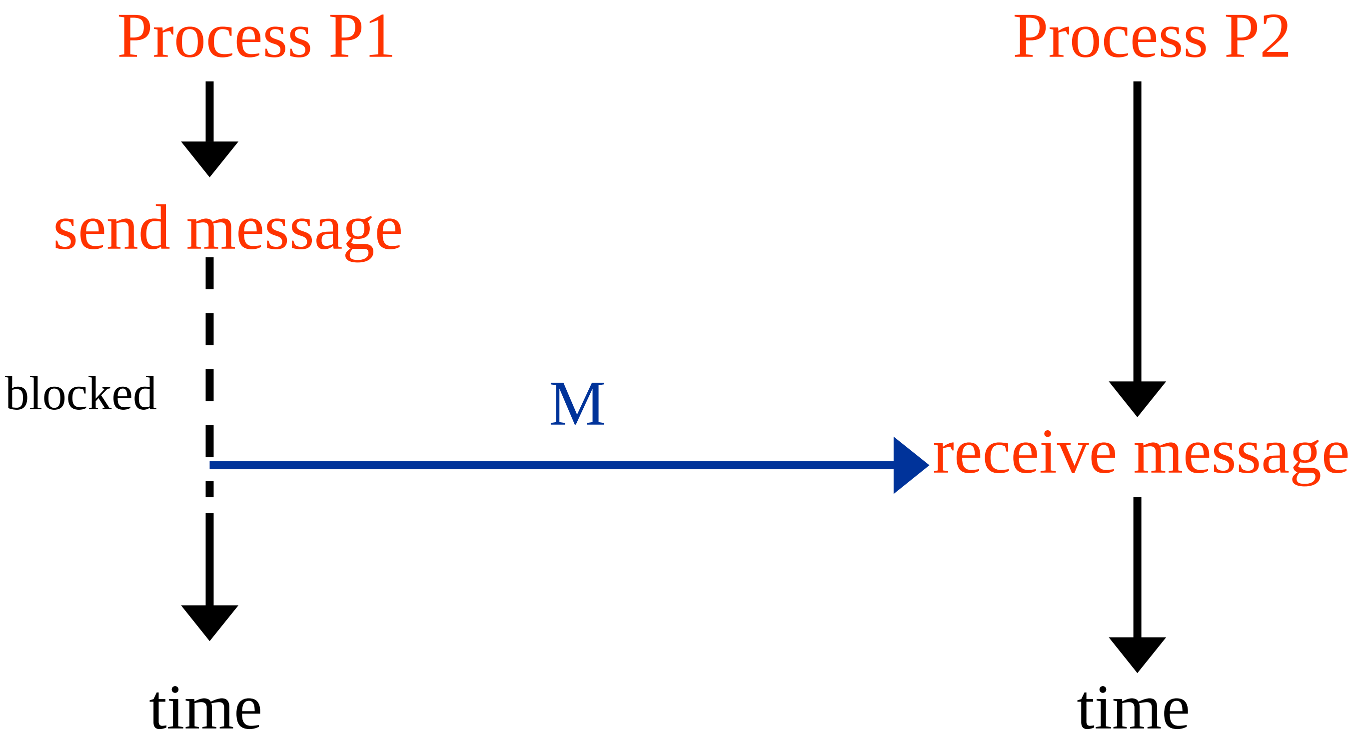
Process Synchronisation

- Variations in the process synchronisation model arise from the semantics of the send operation
- Asynchronous (or no-wait) (e.g. POSIX)
  - Requires buffer space. What happens when the buffer is full?



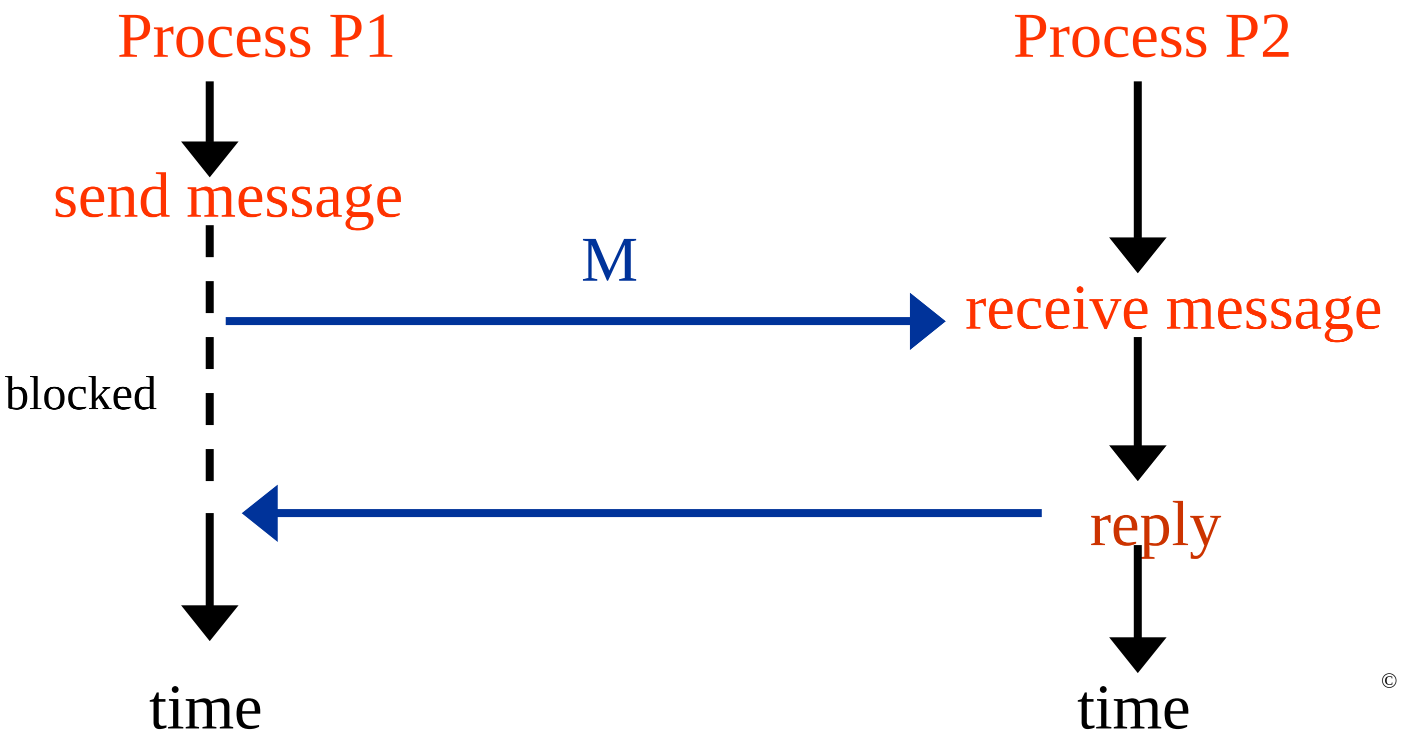
Process Synchronisation

- Synchronous (e.g. CSP, occam2)
  - No buffer space required
  - Known as a rendezvous



Process Synchronisation

- Remote invocation (e.g. Ada)
  - Known as an extended rendezvous
- Analogy:
  - The posting of a letter is an asynchronous send
  - A telephone is a better analogy for synchronous communication



Asynchronous and Synchronous Sends

- Asynchronous communication can implement synchronous communication:

P1	P2
asyn_send (M)	wait (M)
wait (ack)	asyn_send (ack)

- Two synchronous communications can be used to construct a remote invocation:

P1	P2
syn_send (message)	wait (message)
wait (reply)	...
	construct reply
	...
	syn_send (reply)

Disadvantages of Asynchronous Send

- Potentially infinite buffers are needed to store unread messages
- Asynchronous communication is out-of-date; most sends are programmed to expect an acknowledgement
- More communications are needed with the asynchronous model, hence programs are more complex
- It is more difficult to prove the correctness of the complete system
- Where asynchronous communication is desired with synchronised message passing then buffer processes can easily be constructed; however, this is not without cost

Process Naming

- Two distinct sub-issues
  - direction versus indirection
  - symmetry
- With direct naming, the sender explicitly names the receiver:

  send <message> to <process-name>
- With indirect naming, the sender names an intermediate entity (e.g. a channel, mailbox, link or pipe):

  send <message> to <mailbox>
- With a mailbox, message passing can still be synchronous
- Direct naming has the advantage of simplicity, whilst indirect naming aids the decomposition of the software; a mailbox can be seen as an interface between parts of the program

Process Naming

- A naming scheme is symmetric if both sender and receiver name each other (directly or indirectly)

  send <message> to <process-name>

  wait <message> from <process-name>

  send <message> to <mailbox>

  wait <message> from <mailbox>

- It is asymmetric if the receiver names no specific source but accepts messages from any process (or mailbox)

  wait <message>

- Asymmetric naming fits the client-server paradigm
- With indirect the intermediary could have:
  - a many-to-one structure
  - a one-to-one structure
  - a many-to-many structure
  - a one-to-many

Message Structure

- A language usually allows any data object of any defined type (predefined or user) to be transmitted in a message
- Need to convert to a standard format for transmission across a network in a heterogeneous environment
- OS allow only arrays of bytes to be sent

The Ada Model

- Ada supports a form of message-passing between tasks
- Based on a client/server model of interaction
- The server declares a set of services that it is prepared to offer other tasks (its clients)
- It does this by declaring one or more public entries in its task specification
- Each entry identifies the name of the service, the parameters that are required with the request, and the results that will be returned

Entries

```
entry_declaration ::=
  entry defining_identifier[(discrete_subtype_definition)]
    parameter_profile;
```

```
entry Syn;
entry Send(V : Value_Type);
entry Get(V : out Value_Type);
entry Update(V : in out Value_Type);
entry Mixed(A : Integer; B : out Float);
entry Family(Boolean)(V : Value_Type);
```

Example

```
task type Telephone_Operator is
  entry Directory_Enquiry(
    Person : in Name;
    Addr : Address;
    Num : out Number);
  -- other services possible
end Telephone_Operator;

An_Op : Telephone_Operator;

-- client task executes
An_Op.Directory_Enquiry ("Stuart_Jones",
                         "11 Main, Street, York"
                         Stuarts_Number);
```

Accept Statement

```
accept_statement ::=
  accept entry_direct_name[(entry_index)]
    parameter_profile [do
      handled_sequence_of_statements
  end [entry_identifier]];
```

```
accept Family(True)(V : Value_Type) do
  -- sequence of statements
exception
  -- handlers
end Family;
```

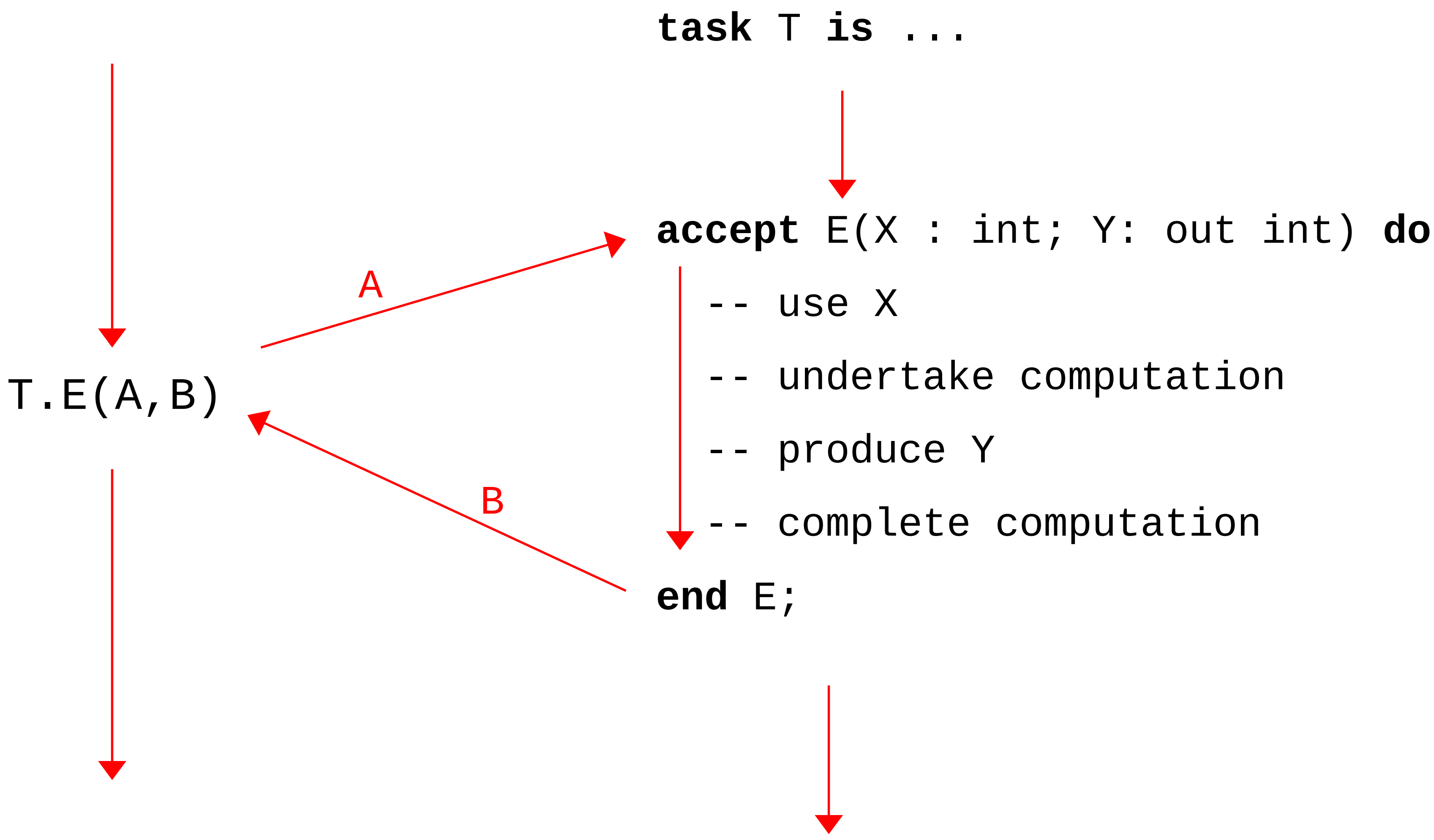
Server Task

```
task body Telephone_Operator is
begin
  ...
  loop
    --prepare to accept next call
    accept Directory_Enquiry (...) do
      -- look up telephone number
    exception
      when Illegal_Number =>
        -- propagate error to client
    end Directory_Enquiry;
    -- undertake housekeeping
  end loop;
  ...
end Telephone_Operator;
```

Client Task

```
task type Subscriber;
task body Subscriber is
begin
   ...
   loop
     ...
     An_Op.Directory_Enquiry(...);
     ...
   end loop;
   ...
end Subscriber;
```

Protocol


task T is ...
accept E(X : int; Y: out int) do
-- use X
-- undertake computation
-- produce Y
-- complete computation
end E;
T.E(A,B)
A
B

Synchronisation

- Both tasks must be prepared to enter into the communication
- If one is ready and the other is not, then the ready one waits for the other
- Once both are ready, the client's parameters are passed to the server
- The server then executes the code inside the accept statement
- At the end of the accept, the results are returned to the client
- Both tasks are then free to continue independently

Bus Driver Example

```
task type Bus_Driver (Num : Natural) is
  entry Get_Ticket (R: in Request, M: in Money;
                    G : out Ticket) ;
  -- money given with request, no change given!
end Bus_Driver;
task body Bus_Driver is
begin
  loop
    accept Get_Ticket (R: Request,
                       M: Money; G : out Ticket) do
      -- take money
      G := Next_Ticket(R);
    end Get_Ticket;
  end loop;
end Bus_Driver;
```

Bus

```
type Bus_T (N : Natural) is
  record
    ....
    Driver : Bus_Driver(N);
  end record;

Number31 : Bus_T(31);
Number60 : Bus_T(60);
Number70 : Bus_T(70);
```

Shop Keeper Example

```
task Shopkeeper is
  entry Serve(X : Request; A: out Goods);
  entry Get_Money(M : Money; Change : out Money);
end Shopkeeper;

task body Shopkeeper is
begin
  loop
    accept Serve(X : Request; A: out Goods) do
      A := Get_Goods;
    end Serve;
    accept Get_Money(M : Money; Change : out Money) do
      -- take money return change
    end Get_Money;
  end loop;
end Shopkeeper;
```

What is wrong with this algorithm?

Customer

```
task Customer;
task body Customer is
begin
  -- go to shop
  Shopkeeper.Serve(Weekly_Shoping, Trolley);
  -- leave shop in a hurry!
end Customer;
```

Rider

```
task type Rider;
task body Rider is
begin
  ...
  -- go to bus stop and wait for bus
  while Bus /= Number31 loop
    -- moan about bus service
  end loop;
  Bus.Bus_Driver.Get_Ticket(Heslington, Fiftyp, Ticket);
     -- get in line
  -- board bus, notice three more number 31 buses
  ...
end Rider;
```

Other Facilities

- `'Count` gives number of tasks queued on an entry
- Entry families allow the programmer to declare, in effect, a single dimension array of entries
- Nested accept statements allow more than two tasks to communicate and synchronise
- A task executing inside an accept statement can also execute an entry call
- Exceptions not handled in a rendezvous are propagated to both the caller and the called tasks
- An accept statement can have exception handlers

Restrictions

- Accept statements can only be placed in the body of a task
- Nested accept statements for the same entry are not allowed
- The `'Count` attribute can only be accessed from within the task that owns the entry
- Parameters to entries cannot be access parameters but can be parameters of an access type

Families

```
task Multiplexer is
  entry Channel(1..3)(X : Data);
end Multiplexer;

task body Multiplexer is
begin
  loop
    for I in 1..3 loop
      accept Channel(I)(X : Data) do
      -- consume input data on channel I
      end Channel;
    end loop;
  end loop;
end Multiplexer;
```

A family declaration

Tesco

```
type Counter is (Meat, Cheese, Wine);
task Tesco_Server is
  entry Serve(Counter)(Request: . . .);
end Tesco_Server;

task body Tesco_Server is
begin
  loop
    accept Serve(Meat)(. . .) do . . . end Serve;
    accept Serve(Cheese)(. . .) do . . . end Serve;
    accept Serve(Wine)(. . .) do . . . end Serve;
  end loop
end Tesco_Server;
```

- What happens if all queues are full?
- What happens if the Meat queue is empty?

Nested Accepts

```
task body Controller is
begin
  loop
    accept Doio (I : out Integer) do
      accept Start;
      accept Completed (K : Integer) do
        I := K;
      end Completed;
    end Doio;
  end loop;
end Controller;
```

Shopkeeper Example

```
task Shopkeeper is
  entry Serve_Groceries(. . .);
  entry Serve_Tobacco( . . .);
  entry Serve_Alcohol(. . .);
end Shopkeeper;

task body Shopkeeper is
begin
  . . .
  accept Serve_Groceries (. . .) do
    -- no change for a £10 note
    accept Serve_ Alcohol(. . .) do
      -- serve another Customer,
      -- get more change
    end Serve_ Alcohol
  end Serve_Groceries
  . . .
end Shopkeeper;
```

Can not have

```
accept Serve_Groceries (. . .) do
  accept Serve_Groceries(. . .) do
    . . .
  end Serve_Groceries
end Serve_Groceries
```

Entry Call within Accept Statement

```
task Car_Spares_Server is
   entry Serve_Car_Part(Number: Part_ID; . . .);
end Car_Spares_Server ;

task body Car_Spares_Server is
begin
  . . .
  accept Serve_Car_Part(Number: Part_ID; . . .) do
    -- part not is stock
    Dealer.Phone_Order(. . .);
  end Serve_Car_Part;
  . . .
end Car_Spares_Server;
```

Exceptions

```
accept Get(R : out Rec; Valid_Read : out Boolean) do
  loop
    begin
      Put("VALUE OF I?"); Get(R.I);
      Put("VALUE OF F?"); Get(R.F);
      Put("VALUE OF S?"); Get(R.S);
      Valid_Read := True;
      return;
    exception
      when Ada.Text_IO.Data_Error =>
        Put("INVALID INPUT: START AGAIN");
    end;
  end loop;
exception
  when Ada.Text_IO.Mode_Error =>
    Valid_Read := False;
end Get;
```

return from accept

exception raised

could be handled here

or here

If not handled anywhere exception raised in calling task and the ‘accept’ task

Private Entries

- Public entries are visible to all tasks which have visibility to the owning task's declaration
- Private entries are only visible to the owning task
  - if the task has several tasks declared internally; these tasks have access to the private entry
  - if the entry is to be used internally by the task for requeuing purposes
  - if the entry is an interrupt entry, and the programmer does not wish any software task to call this entry

Private Entries II

```
task type Telephone_Operator is
  entry Report_Fault(N : Number);
private
  entry Allocate_Repair_Worker(N : out Number);
end Telephone_Operator;
task body Telephone_Operator is
  Failed : Number;
  task type Repair_Worker;
  Work_Force:array (1.. Num_Workers) of Repair_Worker;
  task body Repair_Worker is
    Job : Number:
  begin
    ...
    Telephone_Operator.Allocate_Repair_Worker(Job);
    ...
  end Repair_Worker;
```

private entry

internal task

Private Entries III

```
begin
  loop
    accept Report_Fault(N : Number) do
      Failed := N;
    end Report_Fault;
    -- log faulty line

    if New_Fault(Failed) then -- new fault

      accept Allocate_Repair_Worker(N : out Number) do
        N := Failed;
      end Allocate_Repair_Worker;
    end if;
  end loop;
end Telephone_Operator;
```

Selective Waiting

- So far, the receiver of a message must wait until the specified process, or mailbox, delivers the communication
- A receiver process may actually wish to wait for any one of a number of processes to call it
- Server processes receive request messages from a number of clients; the order in which the clients call being unknown to the servers
- To facilitate this common program structure, receiver processes are allowed to wait selectively for a number of possible messages
- Based on Dijkstra’s guarded commands

Forms of Select Statement

The select statement comes in four forms:

```
select_statement ::=
          selective_accept |
          conditional_entry_call |
          timed_entry_call |
          asynchronous_select
```

Selective Accept

The selective accept allows the server to:

- wait for more than a single rendezvous at any one time
- time-out if no rendezvous is forthcoming within a specified time
- withdraw its offer to communicate if no rendezvous is available immediately
- terminate if no clients can possibly call its entries

Syntax Definition

```
selective_accept ::=
  select
    [guard]
     selective_accept_alternative
{ or
    [guard]
    selective_accept_alternative
[ else
    sequence_of_statements ]
  end select;

guard ::= when <condition> =>
```

Syntax Definition II

```
selective_accept_alternative ::=
  accept_alternative |
  delay_alternative  |
  terminate_alternative

accept_alternative ::=
   accept_statement [ sequence_of_statements ]

delay_alternative ::=
   delay_statement [ sequence_of_statements ]

terminate_alternative ::=
   terminate;
```

Overview Example

```
task Server is
  entry S1(...);
  entry S2(...);
end Server;

task body Server is
  ...
begin
  loop
    select
      accept S1(...) do
        -- code for this service
      end S1;
    or
      accept S2(...) do
        -- code for this service
      end S2;
    end select;
  end loop;
end Server;
```

Simple select with two possible actions

Example

```
task type Telephone_Operator is
  entry Directory_Enquiry (P : Name; A : Address;
                           N : out Number);
  entry Directory_Enquiry (P : Name; PC : Postal_Code;
                           N : out Number);
  entry Report_Fault(N : Number);
private
  entry Allocate_Repair_Worker (N : out Number);
end Telephone_Operator;
```

Example II

```
task body Telephone_Operator is
  Failed : Number;
  task type Repair_Worker;
  Work_Force : array(1.. Num_Workers) of
                 Repair_Worker;

  task body Repair_Worker is separate;
```

Example III

```
begin
  loop
    select
      accept Directory_Enquiry( ... ; A: Address...) do
        -- look up number based on address
      end Directory_Enquiry;
    or
      accept Directory_Enquiry( ... ;
                                  PC: Postal_Code...) do
        -- look up number based on ZIP
      end Directory_Enquiry;
    or
```

Example IV

```
    or
      accept Report_Fault(N : Number) do
        ...
      end Report_Fault;
      if New_Fault(Failed) then
        accept Allocate_Repair_Worker (N : out
               Number) do
          N := Failed;
        end Allocate_Repair_Worker;
      end if;
    end select;
  end loop;
end Telephone_Operator;
```

Note

- If no rendezvous are available, the select statement waits for one to become available
- If one is available, it is chosen immediately
- If more than one is available, the one chosen is implementation dependent (RT Annex allows order to be defined)
- More than one task can be queued on the same entry; default queuing policy is FIFO (RT Annex allows priority order to be defined)

Tesco

```
type Counter is (Meat, Cheese, Wine);
task Tesco_Server is
  entry Serve(Counter)(Request: . . .);
end Tesco_Server;

task body Tesco_Server is
begin
  loop
    select
      accept Serve(Meat)(. . .) do . . . end Serve;
    or
      accept Serve(Cheese)(. . .) do . . . end Serve;
    or
      accept Serve(Wine)(. . .) do . . . end Serve;
    end select
  end loop
end Tesco_Server;
```

- What happens if all queues are full?
- What happens if the Meat queue is empty?

What is the difference between

```
select
  accept A;
  B;
or
  accept C;
end select
```

and

```
select
  accept A do
    B;
  end A;
or
  accept C;
end select
```

Guarded Alternatives

- Each select accept alternative can have an associated guard
- The guard is a boolean expression which is evaluated when the select statement is executed
- If the guard evaluates to true, the alternative is eligible for selection
- If it is false, the alternative is not eligible for selection during this execution of the select statement (even if client tasks are waiting on the associated entry)

Example Usage

```
select
  when Boolean_Expression =>
    accept S1(...) do
      -- code for service
    end S1;
    -- sequence of statements
or
  ...
end select;
```

Example of Guard

```
task body Telephone_Operator is
begin
  ...
  select
    accept Directory_Enquiry (...) do ... end;
  or
    accept Directory_Enquiry (...) do ... end;
  or
    when Workers_Available =>        -- guard
      accept Report_Fault (...) do ... end;
  end select;
end Telephone_Operator;
```

Corner Shop

```
type Counter is (Tobacco, Alcohol, Groceries);
task Shopkeeper is
  entry Serve(Counter)(Request: . . .);
end Shopkeeper;

task body Shopkeeper is
begin
  loop
    select
      when After_7pm =>
        accept Serve(Alcohol)(. . .) do . . . end Serve;
    or
      when Customers_Age > 16 =>
        accept Serve(Tobacco)(. . .) do . . . end Serve;
    or
      accept Serve(Groceries)(. . .) do . . . end Serve;
    end select
  end loop
end Shopkeeper;
```

- Are these guards OK?

Delay Alternative

- The delay alternative of the select statement allows the server to time-out if an entry call is not received within a certain period
- The timeout is expressed using a delay statement, and therefore can be relative or absolute
- If the relative time is negative, or the absolute time has passed, the delay alternative becomes equivalent to the else alternative
- More than one delay is allowed

Example: Periodic Execution

- Consider a task which reads a sensors every 10 seconds, however, it may be required to change its periods during certain modes of operation

```
task Sensor_Monitor is
  entry New_Period(P : Duration);
end Sensor_Monitor;
```

Periodic Execution II

```
task body Sensor_Monitor is
  Current_Period : Duration := 10.0;
  Next_Cycle : Time := Clock + Current_Period;
begin
  loop
    -- read sensor value etc.
    select
      accept New_Period(P : Duration) do
        Current_Period := P;
      end New_Period;
      Next_Cycle := Clock + Current_Period;
    or
      delay until Next_Cycle;   -- delay alternative
      Next_Cycle := Next_Cycle + Current_Period;
    end select;
  end loop;
end Sensor_Monitor;
```

Delay Alternative: Error Detection

- Used to program timeouts

```
task type Watchdog is
  entry All_Is_Well;
end Watchdog;
```

Watchdog

```
task body Watchdog is
  Client_Failed : Boolean := False;
begin
  loop
    select
      accept All_Is_Well;
    or
      delay 10.0;
      -- signal alarm
      Client_Failed := True;
    end select;
    exit when Client_Failed;
  end loop;
end Watchdog;
```

The Else Part

```
task body Sensor_Monitor is
  Current_Period : Duration := 10.0;
  Next_Cycle : Time := Clock + Current_Period;
begin
  loop
    -- read sensor value etc.
    select
      accept New_Period(P : Duration) do
        Current_Period := P;
      end New_Period;
    else -- cannot be guarded
      null;
    end select;
    Next_Cycle := Clock + Current_Period;
    delay until Next_Cycle;
  end loop;
end Sensor_Monitor;
```

else part

The Delay and the Else Part

- Cannot mix else part and delay in the same select statement.
- The following are equivalent

```
select
  accept A;
or
  accept B;
else
  C;
end select;
```

```
select
  accept A;
or
  accept B;
or
  delay 0.0;
  C;
end select;
```

More on Delay

```
select
  accept A;
or
  delay 10.0;
end select;
```

```
select
  accept A;
else
  delay 10.0;
end select;
```

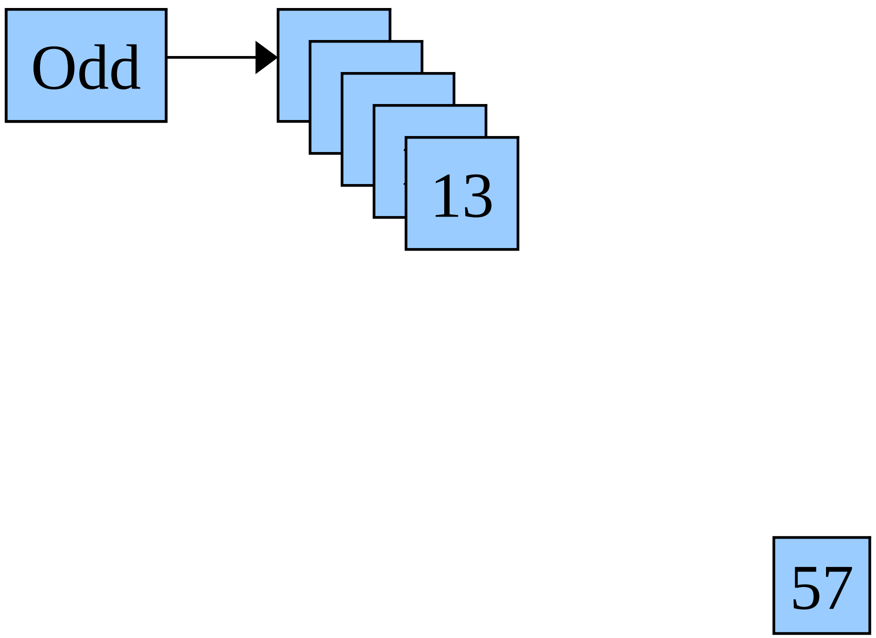
```
select
  accept A;
or
  delay 5.0;
  delay 5.0;
end select;
```

- What is the difference?

The Terminate Alternative

- In general a server task only needs to exist when there are clients to serve
- The very nature of the client server model is that the server does not know the identity of its clients
- The terminate alternative in the select statement allows a server to indicate its willingness to terminate if there are no clients that could possibly request its service
- The server terminates when a master of the server is completed and all its dependants are either already terminated or are blocked at a select with an open terminate alternative

Primes by Sieve



Primes by Sieve II

```
procedure Primes_By_Sieve is
  task type Sieve is
    entry Pass_On(Int : Integer);
  end Sieve;

  task Odd;

  type Sieve_Ptr is access Sieve;

  function Get_New_Sieve return Sieve_Ptr is
  begin
    return new Sieve;
  end Get_New_Sieve;

  task body Odd is ...
  task body Sieve is ...

begin null; end Primes_By_Sieve;
```

function needed, as a task type cannot contain a 'new' for its own type

Primes by Sieve III

```
task body Odd is
  Limit : constant Positive := ...;
  Num : Positive;
  S : Sieve_Ptr := new Sieve;
begin
  Num := 3;
  while Num < Limit loop
    S.Pass_On(Num);
    Num := Num + 2;
  end loop;
end Odd;
```

Primes by Sieve IV

```
task body Sieve is
  New_Sieve : Sieve_Ptr;
  Prime, Num : Positive;
begin
  accept Pass_On(Int : Integer) do
    Prime := Int;
  end Pass_On;
  -- Prime is a prime number, could output
  loop
    select
      accept Pass_On(Int : Integer) do
        Num := Int;
      end Pass_On;
    or
      terminate;
    end select;
    exit when Num rem Prime /= 0;
  end loop;
```

Primes by Sieve V

```
  New_Sieve := Get_New_Sieve;
  New_Sieve.Pass_On(Num);
  loop
    select
      accept Pass_On(Int : Integer) do
        Num := Int;
      end Pass_On;
    or
      terminate;
    end select;
    if Num rem Prime /= 0 then
      New_Sieve.Pass_On(Num);
    end if;
  end loop;
end Sieve;
```

Last Wishes

- Last Wishes can be programmed using controlled types
- Example: count the number of times two entries are called

```
with Ada.Finalization; use Ada;
package Counter is
 type Task_Last_Wishes is new
          Finalization.Limited_Controlled
    with record
      Count1, Count2 : Natural := 0;
    end record;
  procedure Finalize(Tlw : in out Task_Last_Wishes);
end Counter;
```

Last Wishes II

```
with Ada.Integer_Text_IO; use Ada.Integer_Text_IO;
with Ada.Text_IO; use Ada.Text_IO;
package body Counter is
  procedure Finalize(Tlw : in out Task_Last_Wishes) is
  begin
    Put("Calls on Service1:");
    Put(Tlw.Count1);
    Put(" Calls on Service2:");
    Put(Tlw.Count2);
    New_Line;
  end Finalize;
end Counter;
```

Last Wishes III

```
task body Server is
  Last_Wishes :  Counter.Task_Last_Wishes;
begin
  -- initial housekeeping
  loop
    select
      accept Service1(...) do
        ...
      end Service1;
      Last_Wishes.Count1 :=  Last_Wishes.Count1 + 1;
    or
      accept Service2(...) do
        ...
      end Service2;
      Last_Wishes.Count2 :=  Last_Wishes.Count2 + 1;
    or
      terminate;
    end select;
    -- housekeeping
  end loop;
end Server;
```

As the task terminates the finalize procedure is executed

Program Error

- If all the accept alternatives have guards then there is the possibility in certain circumstances that all the guards will be closed
- If the select statement does not contain an else clause then it becomes impossible for the statement to be executed
- The exception `Program_Error` is raised at the point of the select statement if no alternatives are open

Sample Exam Question

- A server task has the following Ada specification.

```
task Server is
  entry Service_A;
  entry Service_B;
  entry Service_C;
end Server;
```

See answer to Exercise 9.11

- Write the body of the `Server` task so that
  - If client tasks are waiting on all the entries, the `Server` should service the clients in a cyclic order, that is accept first a `Service_A` entry, and then a `Service_B` entry, and then a `Service_C`, so on
  - If not all entries have a client task waiting, the `Server` should service the other entries in a cyclic order. The `Server` tasks should not be blocked if there are clients still waiting for a service
  - If the `Server` task has no waiting clients then it should NOT busy-wait; it should block waiting for a client's request to be made
  - If all the possible clients have terminated, the `Server` should terminate
- Assume that client tasks are not aborted and issue simple entry calls only

The Selective Accept : Summary

- A selective accept must contain at least one accept alternative (each possibly guarded)

- A selective accept may contain one and only one of the following :
  - a terminate alternative (possibly guarded), or
  - one or more delay alternatives (each possibly guarded), or
  - an else part

The Selective Accept : Summary II

- A select alternative is 'open' if it does not contain a guard or if the boolean condition associated with the guard evaluates to true; otherwise the alternative is 'closed'

- On execution: all guards, open delay expressions, and open entry family expressions are evaluated

- A choice is made from the open alternatives

Non-determinism and Selective Waiting

- Concurrent languages make few assumptions about the execution order of processes
- A scheduler is assumed to schedule processes non-deterministically
- Consider a process P that will execute a selective wait construct upon which processes S and T could call

Non-determinism and Selective Waiting

- P runs first; it is blocked on the select. S (or T) then runs and rendezvous with P
- S (or T) runs, blocks on the call to P; P runs and executes the select; a rendezvous takes place with S (or T)
- S (or T) runs first and blocks on the call to P; T (or S) now runs and is also blocked on P. Finally P runs and executes the select on which T and S are waiting
- The three possible interleavings lead to P having none, one or two calls outstanding on the selective wait
- If P, S and T can execute in any order then, in latter case, P should be able to choose to rendezvous with S or T — it will not affect the programs correctness

Non-determinism and Selective Waiting

- A similar argument applies to any queue that a synchronisation primitive defines
- Non-deterministic scheduling implies all queues should release processes in a non-deterministic order
- Semaphore queues are often defined in this way; entry queues and monitor queues are specified to be FIFO
- The rationale here is that FIFO queues prohibit starvation but if the scheduler is non-deterministic then starvation can occur anyway!

Timed Entry Calls

- A timed entry call issues an entry call which is cancelled if the call is not accepted within the specified period (relative or absolute)

- Note that only one delay alternative and one entry call can be specified.

```
task type Subscriber;
```

Timed Entry Calls II

```
task body Subscriber is
  Stuarts_Number : Number;
begin
  loop
    ...
    select
      An_Op.Directory_Enquiry("Stuart Jones",
         "10 Main Street, York", Stuarts_Number);
      -- log the cost of a directory enquiry call
    or
      delay 10.0;
      -- phone up Stuart's parents and ask them;
      -- log the cost of a long distance call
    end select;
    ...
   end loop;
end Subscriber;
```

Timed Entry Calls III

```
task body Telephone_Operator is
  ...
begin
  loop
    -- prepare to accept next request
    select
      accept Directory_Enquiry(Person : Name;
         Addr   : Address; Num   : out Number) do
         delay 3600.0; -- take a lunch break
      end Directory_Enquiry; or
      ...
    end select;
    ...
   end loop;
end Telephone_Operator;
```

Time-out is on the start of the rendezvous not the finish

Shopper

```
task type Shopper;
task body Shopper is
begin
  . . .
  -- enter shop
  select
    shopkeeper.Serve_Groceries(. . .)
  or
    delay10.0;
    -- moan about queues;
  end select;
  -- leave shop
  . . .
end Shopper;
```

WARNING

```
accept Serve_Groceries(. . .) do
  -- go to lunch
end Serve_Groceries;
```

Conditional Entry Call

- The conditional entry call allows the client to withdraw the offer to communicate if the server task is not prepared to accept the call immediately
- It has the same meaning as a timed entry call where the expiry time is immediate

```
select
  Security_Op.Turn_Lights_On;
else
  null; -- assume they are on already
end select;
```

Conditional Entry Call II

- A conditional entry call should only be used when the task can genuinely do other productive work, if the call is not accepted
- Care should be taken not to program polling, or busy-wait, solutions unless they are explicitly required
- Note, the conditional entry call uses an else, the timed entry call an or

Conditional Entry Call III

- They cannot be mixed, nor can two entry call statements be included
- A client task can not therefore wait for more than one entry call to be serviced

- The asynchronous select statement allows some of these restrictions to be overcome

Dining Philosophers

```
procedure Dining_Philosophers is
  package Activities is
    procedure Think;
    procedure Eat;
  end Activities;

  N : constant := 5;  -- number of philosophers
  type Philosophers_Range is range 0..N-1;

  task type Phil(P : Philosophers_Range);
  type Philosopher is access Phil;

  task type Chopstick_Control is
    entry Pick_Up;
    entry Put_Down;
  end Chopstick_Control;
```

Dining Philosophers II

```
 task Deadlock_Prevention is
    entry Enters;
    entry Leaves;
  end Deadlock_Prevention;

  Chopsticks : array(Philosophers_Range) of Chopstick_Control;
  Philosophers : array(Philosophers_Range) of Philosopher;

  package body Activities is separate;
  task body Phil is separate;
  task body Chopstick_Control is separate;
  task body Deadlock_Prevention is separate;

begin
  for P in Philosophers_Range loop
    Philosophers(P) := new Phil(P);
  end loop;
end Dining_Philosophers;
```

Dining Philosophers III

```
separate (Dining_Philosophers)
task body Chopstick_Control is
begin
  loop
    accept Pick_Up;
    accept Put_Down;
  end loop;
end Chopstick_Control;
```

Dining Philosophers IV

```
separate (Dining_Philosophers)
task body Deadlock_Prevention is
  Max : constant Integer := N - 1;
  People_Eating : Integer range 0..Max := 0;
begin
  loop
    select
      when People_Eating < Max =>
        accept Enters;
        People_Eating := People_Eating + 1;
    or
      accept Leaves;
      People_Eating := People_Eating - 1;
    end select;
  end loop;
end Deadlock_Prevention;
```

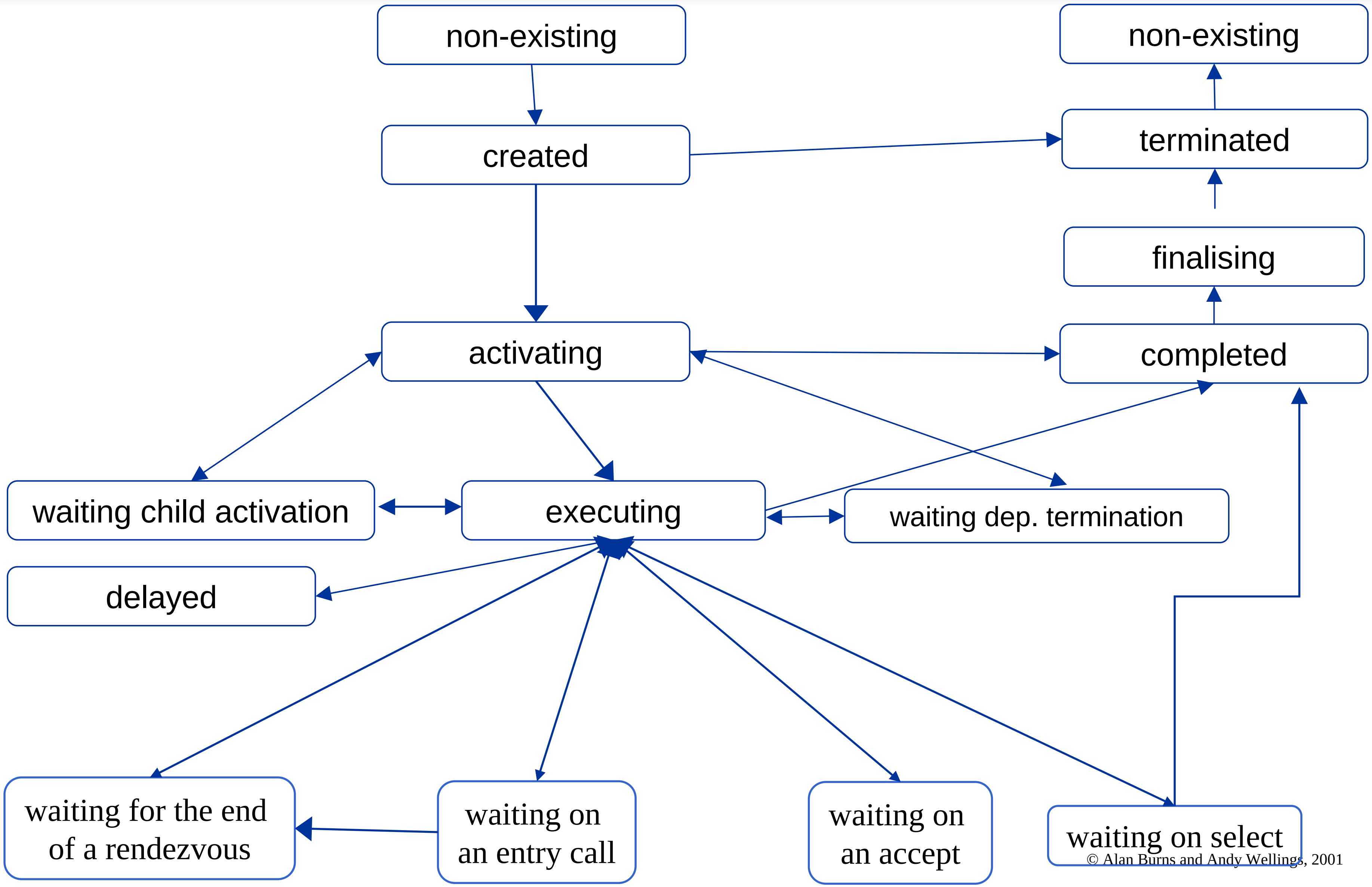
Dining Philosophers V

```
separate (Dining_Philosophers)
task body Phil is
  Chop_Stick1, Chop_Stick2 : Philosophers_Range;
begin
  Chop_Stick1 := P;
  Chop_Stick2 := (Chop_Stick1 + 1) mod N;
  loop
    Think;
    Deadlock_Prevention.Enters;
    Chopsticks(Chop_Stick1).Pick_Up;
    Chopsticks(Chop_Stick2).Pick_Up;
    Eat;
    Chopsticks(Chop_Stick1).Put_Down;
    Chopsticks(Chop_Stick2).Put_Down;
    Deadlock_Prevention.Leaves;
  end loop;
end Philosopher;
```

Exercises

- Modify the code so that the program terminates after each philosopher has taken 32 meals
- Make your solution resilient to a task failing
- Replace the control tasks with protected objects

Task States


non-existing
non-existing
created
terminated
finalising
activating
completed
waiting child activation
executing
waiting dep. termination
delayed
waiting for the end of a rendezvous
waiting on an entry call
waiting on an accept
waiting on select

POSIX Message Queues

- POSIX supports asynchronous, indirect message passing through the notion of message queues
- A message queue can have many readers and many writers
- Priority may be associated with the queue
- Intended for communication between processes (not threads)
- Message queues have attributes which indicate their maximum size, the size of each message, the number of messages currently queued etc.
- An attribute object is used to set the queue attributes when the queue is created

POSIX Message Queues

- Message queues are given a name when they are created
- To gain access to the queue, requires an `mq_open` name
- `mq_open` is used to both create and open an already existing queue (also `mq_close` and `mq_unlink`)
- Sending and receiving messages is done via `mq_send` and `mq_receive`
- Data is read/written from/to a character buffer.
- If the buffer is full or empty, the sending/receiving process is blocked unless the attribute O_NONBLOCK has been set for the queue (in which case an error return is given)
- If senders and receivers are waiting when a message queue becomes unblocked, it is not specified which one is woken up unless the priority scheduling option is specified

POSIX Message Queues

- A process can also indicate that a signal should be sent to it when an empty queue receives a message and there are no waiting receivers
- In this way, a process can continue executing whilst waiting for messages to arrive or one or more message queues
- It is also possible for a process to wait for a signal to arrive; this allows the equivalent of selective waiting to be implemented
- If the process is multi-threaded, each thread is considered to be a potential sender/receiver in its own right

Robot Arm Example

```
typedef enum {xplane, yplane, zplane} dimension;


void move_arm(int D, int P);

#define DEFAULT_NBYTES 4
int nbytes = DEFAULT_NBYTES;

#define MQ_XPLANE  "/mq_xplane" -- message queue name
#define MQ_YPLANE  "/mq_yplane" -- message queue name
#define MQ_ZPLANE  "/mq_zplane" -- message queue name
#define MODE . . . /* mode info for mq_open */
/* names of message queues */
```

Robot Arm Example

```
void controller(dimension dim) {
  int position, setting;
  mqd_t my_queue; /* message queue */
  struct mq_attr ma;  /*attributes */
  char buf[DEFAULT_NBYTES];
  ssiz_t len;

  position = 0;
  switch(dim)  { /* open appropriate message queue */
    case xplane:
      my_queue = MQ_OPEN(MQ_XPLANE,O_RDONLY,MODE,&ma);
      break;
    case yplane:  my_queue = MQ_OPEN(MQ_YPLANE,...); break;
    case zplane:  my_queue = MQ_OPEN(MQ_ZPLANE,...); break;
    default:
      return;
  };
```

Robot Arm Example

```
  while (1) {
    /* read message */
    len = mq_receive(my_queue, &buf[0], nbytes,
                                      null);
    setting = *((int *)(&buf[0]));
    position = position + setting;
    move_arm(dim, position);
  };
}
```

- Now the main program which creates the controller processes and passes the appropriate coordinates to them:

Robot Arm Example

```
void (*C)(dimension dim) = &controller;

int main(int argc, char **argv) {
  mqd_t mq_xplane, mq_yplane, mq_zplane;
  struct mq_attr ma; /* queue attributes */
  int xpid, ypid, zpid;
  char buf[DEFAULT_NBYTES];

  /* set message queues attributes*/
  ma.mq_flags = 0;    /* No special behaviour */
  ma.mq_maxmsg = 1;
  ma.mq_msgsize = nbytes;

  mq_xplane = MQ_OPEN(MQ_XPLANE,
                   O_CREAT|O_EXCL, MODE, &ma);
  mq_yplane = ...;
  mq_zplane = ...;
```

```
  /* Duplicate the process to get three controllers */
  switch (xpid = FORK()) {
    case 0: controller(xplane); exit(0); /* child */
    default:    /* parent */
      switch (ypid = FORK()) {
        case 0: controller(yplane); exit(0);
        default:    /* parent */
          switch (zpid = FORK()) {
            case 0: controller(zplane); exit(0);
            default:    /* parent */
              break;
          }
      }
  }
  while (1) {
    /* set up buffer to transmit each co-ordinate
       to the controllers, for example */
    MQ_SEND(mq_xplane, &buf[0], nbytes, 0);
  }
}
```

Summary

- The semantics of message-based communication are defined by three issues:
  - the model of synchronisation
  - the method of process naming
  - the message structure
- Variations in the process synchronisation model arise from the semantics of the send operation.
  - asynchronous, synchronous or remote invocation
  - Remote invocation can be made to appear syntactically similar to a procedure call
- Process naming involves two distinct issues; direct or indirect, and symmetry

Summary

- Ada has remote invocation with direct asymmetric naming
- Communication in Ada requires one task to define an entry and then, within its body, accept any incoming call. A rendezvous occurs when one task calls an entry in another
- Selective waiting allows a process to wait for more than one message to arrive.
- Ada's select statement has two extra facilities: an else part and a terminate alternative
- POSIX message queues allow asynchronous, many to many communication