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Systems, Networks & Concurrency 2020

Language refresher / introduction course

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References for this chapter

[Ada 2012 Language Reference Manual]
see course pages or http://www.ada-auth.org/standards/ada12.html

[Chapel 1.13 Language Specification Version 0.981]
see course pages or
http://chapel.cray.com/docs/latest/_downloads/chapelLanguageSpec.pdf
released on 7. April 2016

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Languages explicitly supporting concurrency: e.g. Ada

Ada is an ISO standardized (ISO/IEC 8652:201x(E)) 'general purpose' language with focus on "program reliability and maintenance, programming as a human activity, and efficiency".

It provides core language primitives for:

- Strong typing, contracts, separate compilation (specification and implementation), abstract data types, generics, object-orientation.
- Concurrency, message passing, synchronization, monitors, rpcs, timeouts, scheduling, priority ceiling locks, hardware mappings, fully typed network communication.
- Strong run-time environments (incl. stand-alone execution).

… as well as standardized language-annexes for:

- Additional real-time features, distributed programming, system-level programming, numeric, informations systems, safety and security issues.

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Ada

A crash course

… refreshing for some, x'th-language introduction for others:

- **Specification** and **implementation** (body) parts, basic types
- **Exceptions**
- Information hiding in specifications ('**private**')
- **Contracts**
- **Generic** programming (polymorphism)
- **Tasking**
- Monitors and synchronisation ('**protected**', '**entries**', '**selects**', '**accepts**')
- **Abstract** types and **dispatching**

Not mentioned here: general object orientation, dynamic memory management, foreign language interfaces, marshalling, basics of imperative programming, …

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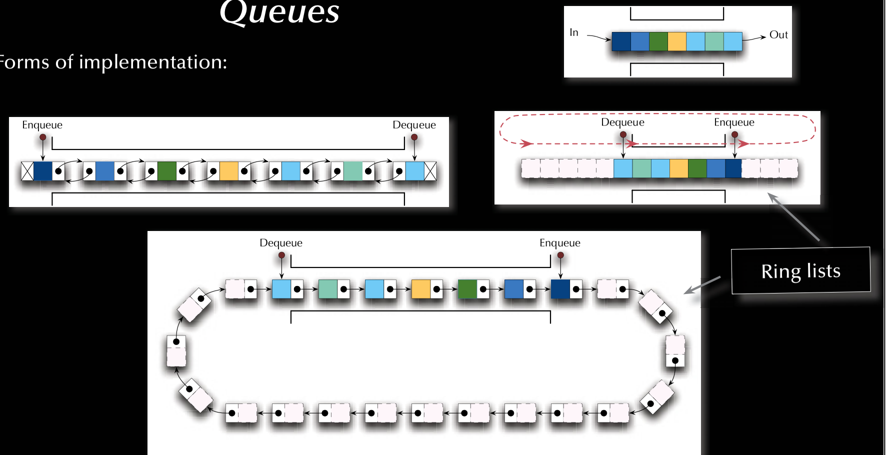
Data structure example

Queues

Forms of implementation:



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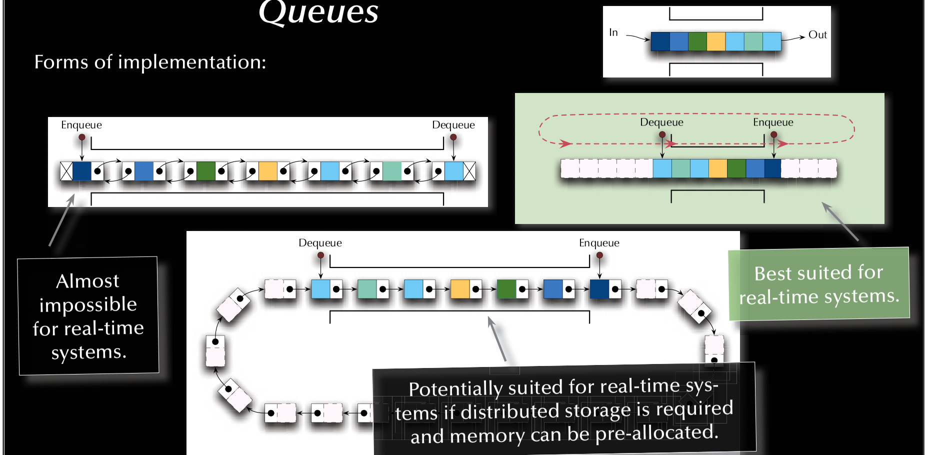
Data structure example

Queues

Forms of implementation:



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Ada

Basics

... introducing:

- **Specification** and **implementation** (body) parts
- **Constants**
- Some **basic types** (integer specifics)
- Some **type attributes**
- **Parameter** specification

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A simple queue specification

```
package Queue_Pack_Simple is
   QueueSize : constant Positive := 10;
   type Element    is new Positive range 1_000..40_000;
   type Marker     is mod QueueSize;
   type List       is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
end Queue_Pack_Simple;
```

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A simple queue specification

```ada
package Queue_Pack_Simple is
   QueueSize : constant Positive := 10;
   type Element    is new Positive range 1_000..40_000;
   type Marker     is mod QueueSize;
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      Top, Free : Marker  := Marker'First;
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      Elements  : List;
   end record;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
end Queue_Pack_Simple;
```

Specifications define an interface to provided types and operations.
Syntactically enclosed in a package block.

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A simple queue specification

```ada
package Queue_Pack_Simple is
   QueueSize : constant Positive := 10;
   type Element    is new Positive range 1_000..40_000;
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      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
end Queue_Pack_Simple;
```

Variables should be initialized.
Constants must be initialized.

Assignments are denoted by the ":=" symbol.
… leaving the "=" symbol for comparisons.

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A simple queue specification

```ada
package Queue_Pack_Simple is
   QueueSize : constant Positive := 10;
   type Element    is new Positive range 1_000..40_000;
   type Marker     is mod QueueSize;
   type List       is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
end Queue_Pack_Simple;
```

Default initializations can be selected to be:
as is (random memory content),
initialized to **invalids**, e.g. 999
or **valid, predicable values**, e.g. 1_000

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A simple queue specification

```ada
package Queue_Pack_Simple is
   QueueSize : constant Positive := 10;
   type Element    is new Positive range 1_000..40_000;
   type Marker     is mod QueueSize;
   type List       is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
end Queue_Pack_Simple;
```

Numerical types can be specified by:
range, modulo,
number of **digits** (☞ floating point)
or **delta** increment (☞ fixed point).

Always be **as specific as the language allows.**
… and don't repeat yourself!

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A simple queue specification

```
package Queue_Pack_Simple is
   QueueSize : constant Positive := 10;
   type Element    is new Positive range 1_000..40_000;
   type Marker     is mod QueueSize;
   type List       is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
end Queue_Pack_Simple;
```

All types come with a long list of built-in **attributes**.

Let the compiler fill in what you already (implicitly) specified!

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A simple queue specification

```
package Queue_Pack_Simple is
   QueueSize : constant Positive := 10;
   type Element    is new Positive range 1_000..40_000;
   type Marker     is mod QueueSize;
   type List       is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
end Queue_Pack_Simple;
```

Parameters can be passed as 'in' (default), 'out' or 'in out'.

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A simple queue specification

```
package Queue_Pack_Simple is
   QueueSize : constant Positive := 10;
   type Element    is new Positive range 1_000..40_000;
   type Marker     is mod QueueSize;
   type List       is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
end Queue_Pack_Simple;
```

All specifications are used in

Code optimizations (optional),
Compile time checks (mandatory)
Run-time checks (suppressible).

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A simple queue specification

```
package Queue_Pack_Simple is
   QueueSize : constant Positive := 10;
   type Element    is new Positive range 1_000..40_000;
   type Marker     is mod QueueSize;
   type List       is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
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      Elements  : List;
   end record;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
end Queue_Pack_Simple;
```

… anything on this slide still not perfectly clear?

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A simple queue implementation

```ada
package body Queue_Pack_Simple is

   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := Queue.Free + 1;
      Queue.Is_Empty              := False;
   end Enqueue;

   procedure Dequeue (Item: out Element; Queue: in out Queue_Type) is
   begin
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Queue.Top + 1;
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;

   function Is_Empty (Queue : Queue_Type) return Boolean is
     (Queue.Is_Empty);

   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);

end Queue_Pack_Simple;
```


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A simple queue implementation

```ada
package body Queue_Pack_Simple is

   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := Queue.Free + 1;
      Queue.Is_Empty              := False;
   end Enqueue;

   procedure Dequeue (Item: out Element; Queue: in out Queue_Type) is
   begin
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Queue.Top + 1;
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;

   function Is_Empty (Queue : Queue_Type) return Boolean is
     (Queue.Is_Empty);

   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);

end Queue_Pack_Simple;
```

Implementations are defined in a **separate** file. Syntactically enclosed in a package body block.

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A simple queue implementation

```ada
package body Queue_Pack_Simple is

   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := Queue.Free + 1;
      Queue.Is_Empty              := False;
   end Enqueue;

   procedure Dequeue (Item: out Element; Queue: in out Queue_Type) is
   begin
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Queue.Top + 1;
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;

   function Is_Empty (Queue : Queue_Type) return Boolean is
     (Queue.Is_Empty);

   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);

end Queue_Pack_Simple;
```

Modulo type, hence no index checks required.

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A simple queue implementation

```ada
package body Queue_Pack_Simple is

   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := Queue.Free + 1;
      Queue.Is_Empty              := False;
   end Enqueue;

   procedure Dequeue (Item: out Element; Queue: in out Queue_Type) is
   begin
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Queue.Top + 1;
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;

   function Is_Empty (Queue : Queue_Type) return Boolean is
     (Queue.Is_Empty);

   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);

end Queue_Pack_Simple;
```

Boolean expressions

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A simple queue implementation

```
package body Queue_Pack_Simple is
   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := Queue.Free + 1;
      Queue.Is_Empty              := False;
   end Enqueue;
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type) is
   begin
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Queue.Top + 1;
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
   function Is_Empty (Queue : Queue_Type) return Boolean is
     (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);
end Queue_Pack_Simple;
```

Side-effect free, **single expression functions** can be expressed without begin-end blocks.

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A simple queue implementation

```
package body Queue_Pack_Simple is
   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := Queue.Free + 1;
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   end Enqueue;
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   begin
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Queue.Top + 1;
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
   function Is_Empty (Queue : Queue_Type) return Boolean is
     (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);
end Queue_Pack_Simple;
```

… anything on this slide still not perfectly clear?

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A simple queue test program

```
with Queue_Pack_Simple; use Queue_Pack_Simple;
procedure Queue_Test_Simple is

   Queue : Queue_Type;
   Item  : Element;

begin
   Enqueue (2000, Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue);
end Queue_Test_Simple;
```


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A simple queue test program

```
with Queue_Pack_Simple; use Queue_Pack_Simple;
procedure Queue_Test_Simple is

   Queue : Queue_Type;
   Item  : Element;

begin
   Enqueue (2000, Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue);
end Queue_Test_Simple;
```

Importing items from other packages is done with with-clauses.

use-clauses allow to use names with qualifying them with the package name.

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A simple queue test program

```
with Queue_Pack_Simple; use Queue_Pack_Simple;
procedure Queue_Test_Simple is

   Queue : Queue_Type;
   Item  : Element;

begin
   Enqueue (2000, Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue);
end Queue_Test_Simple;
```

A top level procedure is read as the code which needs to be executed.

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A simple queue test program

```
with Queue_Pack_Simple; use Queue_Pack_Simple;
procedure Queue_Test_Simple is

   Queue : Queue_Type;
   Item  : Element;

begin
   Enqueue (2000, Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue);
end Queue_Test_Simple;
```

Variables are declared Algol style: "Item is of type Element".

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A simple queue test program

```
with Queue_Pack_Simple; use Queue_Pack_Simple;
procedure Queue_Test_Simple is

   Queue : Queue_Type;
   Item  : Element;

begin
   Enqueue (2000, Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue);
end Queue_Test_Simple;
```

Will produce a result according to the chosen initialization:

Raises an "invalid data" exception if initialized to invalids.

… hmm, ok … so this was rubbish …

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A simple queue test program

```
with Queue_Pack_Simple; use Queue_Pack_Simple;
procedure Queue_Test_Simple is

   Queue : Queue_Type;
   Item  : Element;

begin
   Enqueue (2000, Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue);
end Queue_Test_Simple;
```

… anything on this slide still not perfectly clear?

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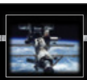

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Ada

Exceptions

... introducing:

- **Exception** handling
- **Enumeration** types
- **Type attributed operators**

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A queue specification with proper exceptions

```
package Queue_Pack_Exceptions is
   QueueSize : constant Positive := 10;

   type Element     is (Up, Down, Spin, Turn);
   type Marker      is mod QueueSize;
   type List        is array (Marker) of Element;

   type Queue_Type  is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;

   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);

   function Is_Empty (Queue : Queue_Type) return Boolean is (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);

   Queue_overflow, Queue_underflow : exception;
end Queue_Pack_Exceptions;
```

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A queue specification with proper exceptions

```
package Queue_Pack_Exceptions is
   QueueSize : constant Positive := 10;

   type Element     is (Up, Down, Spin, Turn);
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      Top, Free : Marker  := Marker'First;
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   end record;

   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);

   function Is_Empty (Queue : Queue_Type) return Boolean is (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);

   Queue_overflow, Queue_underflow : exception;
end Queue_Pack_Exceptions;
```

> **Enumeration** types are first-class types and can be used e.g. as array indices.
> The representation values can be controlled and do not need to be continuous (e.g. for purposes like interfacing with hardware).

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A queue specification with proper exceptions

```
package Queue_Pack_Exceptions is
   QueueSize : constant Positive := 10;

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   type Marker      is mod QueueSize;
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      Top, Free : Marker  := Marker'First;
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   end record;

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   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);

   function Is_Empty (Queue : Queue_Type) return Boolean is (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);

   Queue_overflow, Queue_underflow : exception;
end Queue_Pack_Exceptions;
```

> Nothing else changes in the specifications.

> **Exceptions** need to be declared.

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A queue *specification* with proper exceptions

```
package Queue_Pack_Exceptions is
   QueueSize : constant Positive := 10;

   type Element     is (Up, Down, Spin, Turn);
   type Marker      is mod QueueSize;
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      Top, Free : Marker  := Marker'First;
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   end record;

   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);

   function Is_Empty (Queue : Queue_Type) return Boolean is (Queue.Is_Empty);
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     (not Queue.Is_Empty and then Queue.Top = Queue.Free);

   Queue_overflow, Queue_underflow : exception;

end Queue_Pack_Exceptions;
```

… anything on this slide still not perfectly clear?

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A queue *implementation* with proper exceptions

```
package body Queue_Pack_Exceptions is
   procedure Enqueue (Item : Element; Queue : in out Queue_Type) is
   begin
      if Is_Full (Queue) then
         raise Queue_overflow;
      end if;
      Queue.Elements (Queue.Free) := Item;
      Queue.Free      := Marker'Succ (Queue.Free);
      Queue.Is_Empty := False;
   end Enqueue;

   procedure Dequeue (Item : out Element; Queue : in out Queue_Type) is
   begin
      if Is_Empty (Queue) then
         raise Queue_underflow;
      end if;
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Marker'Succ (Queue.Top);
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
end Queue_Pack_Exceptions;
```


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A queue *implementation* with proper exceptions

```
package body Queue_Pack_Exceptions is
   procedure Enqueue (Item : Element; Queue : in out Queue_Type) is
   begin
      if Is_Full (Queue) then
         raise Queue_overflow;
      end if;
      Queue.Elements (Queue.Free) := Item;
      Queue.Free      := Marker'Succ (Queue.Free);
      Queue.Is_Empty := False;
   end Enqueue;

   procedure Dequeue (Item : out Element; Queue : in out Queue_Type) is
   begin
      if Is_Empty (Queue) then
         raise Queue_underflow;
      end if;
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Marker'Succ (Queue.Top);
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
end Queue_Pack_Exceptions;
```

Raised **exceptions** break the control flow and "propagate" to the closest "exception handler" in the call-chain.

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A queue *implementation* with proper exceptions

```
package body Queue_Pack_Exceptions is
   procedure Enqueue (Item : Element; Queue : in out Queue_Type) is
   begin
      if Is_Full (Queue) then
         raise Queue_overflow;
      end if;
      Queue.Elements (Queue.Free) := Item;
      Queue.Free      := Marker'Succ (Queue.Free);
      Queue.Is_Empty := False;
   end Enqueue;

   procedure Dequeue (Item : out Element; Queue : in out Queue_Type) is
   begin
      if Is_Empty (Queue) then
         raise Queue_underflow;
      end if;
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Marker'Succ (Queue.Top);
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
end Queue_Pack_Exceptions;
```

All Types come with a long list of built-in operators.

Syntactically expressed as **attributes**.

Type attributes often make code more *generic*: 'Succ works for instance on enumeration types as well … "+ 1" does not.

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A queue implementation with proper exceptions

```
package body Queue_Pack_Exceptions is
   procedure Enqueue (Item : Element; Queue : in out Queue_Type) is
   begin
      if Is_Full (Queue) then
         raise Queue_overflow;
      end if;
      Queue.Elements (Queue.Free) := Item;
      Queue.Free     := Marker'Succ (Queue.Free);
      Queue.Is_Empty := False;
   end Enqueue;

   procedure Dequeue (Item : out Element; Queue : in out Queue_Type) is
   begin
      if Is_Empty (Queue) then
         raise Queue_underflow;
      end if;
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Marker'Succ (Queue.Top);
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
end Queue_Pack_Exceptions;
```

… anything on this slide still not perfectly clear?

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A queue test program with proper exceptions

```
with Queue_Pack_Exceptions; use Queue_Pack_Exceptions;
with Ada.Text_IO          ; use Ada.Text_IO;
procedure Queue_Test_Exceptions is
   Queue : Queue_Type;
   Item  : Element;
begin
   Enqueue (Turn, Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- will produce a Queue_underflow exception
exception
   when Queue_underflow => Put ("Queue underflow");
   when Queue_overflow  => Put ("Queue overflow");
end Queue_Test_Exceptions;
```

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A queue test program with proper exceptions

```
with Queue_Pack_Exceptions; use Queue_Pack_Exceptions;
with Ada.Text_IO          ; use Ada.Text_IO;
procedure Queue_Test_Exceptions is
   Queue : Queue_Type;
   Item  : Element;
begin
   Enqueue (Turn, Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- will produce a Queue_underflow exception
exception
   when Queue_underflow => Put ("Queue underflow");
   when Queue_overflow  => Put ("Queue overflow");
end Queue_Test_Exceptions;
```

An **exception handler** has a choice to **handle, pass,** or **re-raise** the same or a different exception.

Raised **exceptions** break the control flow and "propagate" to the closest "exception handler" in the call-chain.

Control flow is continued after the **exception handler** in case of a handled exception.

59

A queue test program with proper exceptions

```
with Queue_Pack_Exceptions; use Queue_Pack_Exceptions;
with Ada.Text_IO          ; use Ada.Text_IO;
procedure Queue_Test_Exceptions is
   Queue : Queue_Type;
   Item  : Element;
begin
   Enqueue (Turn, Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- will produce a Queue_underflow exception
exception
   when Queue_underflow => Put ("Queue underflow");
   when Queue_overflow  => Put ("Queue overflow");
end Queue_Test_Exceptions;
```

… anything on this slide still not perfectly clear?

60

A queue specification with proper exceptions

```
package Queue_Pack_Exceptions is
   QueueSize : constant Positive := 10;

   type Element    is (Up, Down, Spin, Turn);
   type Marker     is mod QueueSize;
   type List       is array (Marker) of Element;
   type Queue_Type  is record
      Top, Free : Marker   := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;

   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);

   function Is_Empty (Queue : Queue_Type) return Boolean is (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);

   Queue_overflow, Queue_underflow : exception;

end Queue_Pack_Exceptions;
```

This package provides access to 'internal' structures which can lead to inconsistent access.

61

Language refresher / introduction course

Ada

Information hiding

... introducing:

- **Private** declarations
  ☞ needed to compile specifications,
  yet not accessible for a user of the package.
- **Private** types ☞ assignments and comparisons are allowed
- **Limited private** types ☞ entity cannot be assigned or compared

62

A queue specification with proper information hiding

```
package Queue_Pack_Private is
   QueueSize : constant Integer := 10;

   type Element is new Positive range 1..1000;
   type Queue_Type is limited private;

   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;

   Queueoverflow, Queueunderflow : exception;

private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;

end Queue_Pack_Private;
```

63

A queue specification with proper information hiding

```
package Queue_Pack_Private is
   QueueSize : constant Integer := 10;

   type Element is new Positive range 1..1000;
   type Queue_Type is limited private;

   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;

   Queueoverflow, Queueunderflow : exception;

private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;

end Queue_Pack_Private;
```

private splits the specification into a **public** and a **private** section.

The private section is only here so that the specifications can be separately compiled.

64

A queue specification with proper information hiding

```
package Queue_Pack_Private is
   QueueSize : constant Integer := 10;
   type Element is new Positive range 1..1000;
   type Queue_Type is limited private;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
   Queueoverflow, Queueunderflow : exception;
private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker   := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Private;
```

Queue_Type can now be used outside this package **without any way to access its internal structure.**

`limited` **disables assignments and comparisons** for this type.
A user of this package would now e.g. not be able to make a copy of a Queue_Type value.

65

A queue specification with proper information hiding

```
package Queue_Pack_Private is
   QueueSize : constant Integer := 10;
   type Element is new Positive range 1..1000;
   type Queue_Type is limited private;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
   Queueoverflow, Queueunderflow : exception;
private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker   := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Private;
```

Queue_Type can now be used outside this package **without any way to access its internal structure.**

Alternatively '=' and ':=' operations can be replaced with type-specific versions (overloaded) or default operations can be allowed.

66

A queue specification with proper information hiding

```
package Queue_Pack_Private is
   QueueSize : constant Integer := 10;
   type Element is new Positive range 1..1000;
   type Queue_Type is limited private;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
   Queueoverflow, Queueunderflow : exception;
private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker   := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Private;
```

... anything on this slide still not perfectly clear?

67

A queue implementation with proper information hiding

```
package body Queue_Pack_Private is
   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      if Is_Full (Queue) then
         raise Queueoverflow;
      end if;
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := Marker'Pred (Queue.Free);
      Queue.Is_Empty              := False;
   end Enqueue;
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type) is
   begin
      if Is_Empty (Queue) then raise Queueunderflow; end if;
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Marker'Pred (Queue.Top);
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
   function Is_Empty (Queue : Queue_Type) return Boolean is (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);
end Queue_Pack_Private;
```

Identical

68

A queue implementation with proper information hiding

Identical

```
package body Queue_Pack_Private is
   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      if Is_Full (Queue) then
         raise Queueoverflow;
      end if;
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := Marker'Pred (Queue.Free);
      Queue.Is_Empty              := False;
   end Enqueue;
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type) is
   begin
      if Is_Empty (Queue) then raise Queueunderflow; end if;
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Marker'Pred (Queue.Top);
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
   function Is_Empty (Queue : Queue_Type) return Boolean is (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);
end Queue_Pack_Private;
```

… besides the implementation of the two functions which has been moved to the implementation section.

69

A queue implementation with proper information hiding

Identical

```
package body Queue_Pack_Private is
   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      if Is_Full (Queue) then
         raise Queueoverflow;
      end if;
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := Marker'Pred (Queue.Free);
      Queue.Is_Empty              := False;
   end Enqueue;
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type) is
   begin
      if Is_Empty (Queue) then raise Queueunderflow; end if;
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := Marker'Pred (Queue.Top);
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
   function Is_Empty (Queue : Queue_Type) return Boolean is (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);
end Queue_Pack_Private;
```

… anything on this slide still not perfectly clear?

70

A queue test program with proper information hiding

```
with Queue_Pack_Private; use Queue_Pack_Private;
with Ada.Text_IO       ; use Ada.Text_IO;
procedure Queue_Test_Private is
   Queue, Queue_Copy : Queue_Type;
   Item              : Element;
begin
   Queue_Copy := Queue;
      -- compiler-error: "left hand of assignment must not be limited type"
   Enqueue (Item => 1, Queue => Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- would produce a "Queue underflow"
exception
   when Queueunderflow => Put ("Queue underflow");
   when Queueoverflow  => Put ("Queue overflow");
end Queue_Test_Private;
```

71

A queue test program with proper information hiding

```
with Queue_Pack_Private; use Queue_Pack_Private;
with Ada.Text_IO       ; use Ada.Text_IO;
procedure Queue_Test_Private is
   Queue, Queue_Copy : Queue_Type;
   Item              : Element;
begin
   Queue_Copy := Queue;
      -- compiler-error: "left hand of assignment must not be limited type"
   Enqueue (Item => 1, Queue => Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- would produce a "Queue underflow"
exception
   when Queueunderflow => Put ("Queue underflow");
   when Queueoverflow  => Put ("Queue overflow");
end Queue_Test_Private;
```

Illegal operation on a limited type.

72

A queue test program with proper information hiding

```
with Queue_Pack_Private; use Queue_Pack_Private;
with Ada.Text_IO       ; use Ada.Text_IO;
procedure Queue_Test_Private is
   Queue, Queue_Copy : Queue_Type;
   Item              : Element;
begin
   Queue_Copy := Queue;
      -- compiler-error: “left hand of assignment must not be limited type”
   Enqueue (Item => 1, Queue => Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- would produce a “Queue underflow”
exception
   when Queueunderflow => Put (“Queue underflow”);
   when Queueoverflow  => Put (“Queue overflow”);
end Queue_Test_Private;
```

Parameters can be named or passed by order of definition.
(Named parameters do not need to follow the definition order.)

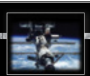
73

A queue test program with proper information hiding

```
with Queue_Pack_Private; use Queue_Pack_Private;
with Ada.Text_IO       ; use Ada.Text_IO;
procedure Queue_Test_Private is
   Queue, Queue_Copy : Queue_Type;
   Item              : Element;
begin
   Queue_Copy := Queue;
      -- compiler-error: “left hand of assignment must not be limited type”
   Enqueue (Item => 1, Queue => Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- would produce a “Queue underflow”
exception
   when Queueunderflow => Put (“Queue underflow”);
   when Queueoverflow  => Put (“Queue overflow”);
end Queue_Test_Private;
```

… anything on this slide still not perfectly clear?

74



Language refresher / introduction course

Ada

Contracts

… introducing:

- **Pre- and Post-Conditions** on methods
- **Invariants** on types
- **For all, For any** predicates

75

A contracting queue specification

```
package Queue_Pack_Contract is
   Queue_Size : constant Positive := 10;
   type Element is new Positive range 1 .. 1000;
   type Queue_Type is private;

   procedure Enqueue (Item :     Element; Q : in out Queue_Type) with
     Pre  => not Is_Full (Q),
     Post => not Is_Empty (Q) and then Length (Q) = Length (Q'Old) + 1
                and then Lookahead (Q, Length (Q)) = Item
                and then (for all ix in 1 .. Length (Q'Old)
                            => Lookahead (Q, ix) = Lookahead (Q'Old, ix));

   procedure Dequeue (Item : out Element; Q : in out Queue_Type) with
     Pre  => not Is_Empty (Q),
     Post => not Is_Full (Q) and then Length (Q) = Length (Q'Old) - 1
                and then (for all ix in 1 .. Length (Q)
                        => Lookahead (Q, ix) = Lookahead (Q'Old, ix + 1));

   function Is_Empty  (Q : Queue_Type) return Boolean;
   function Is_Full   (Q : Queue_Type) return Boolean;
   function Length    (Q : Queue_Type) return Natural;
   function Lookahead (Q : Queue_Type; Depth : Positive) return Element;
```

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A contracting queue specification

```
package Queue_Pack_Contract is
   Queue_Size : constant Positive := 10;
   type Element is new Positive range 1 .. 1000;
   type Queue_Type is private;

   procedure Enqueue (Item :     Element; Q : in out Queue_Type) with
     Pre  => not Is_Full (Q),
     Post => not Is_Empty (Q) and then Length (Q) = Length (Q'Old) + 1
                and then Lookahead (Q, Length (Q)) = Item
                and then (for all ix in 1 .. Length (Q'Old)
                            => Lookahead (Q, ix) = Lookahead (Q'Old, ix));

   procedure Dequeue (Item : out Element; Q : in out Queue_Type) with
     Pre  => not Is_Empty (Q),
     Post => not Is_Full (Q) and then Length (Q) = Length (Q'Old) - 1
                and then (for all ix in 1 .. Length (Q)
                            => Lookahead (Q, ix) = Lookahead (Q'Old, ix + 1));

   function Is_Empty  (Q : Queue_Type) return Boolean;
   function Is_Full   (Q : Queue_Type) return Boolean;
   function Length    (Q : Queue_Type) return Natural;
   function Lookahead (Q : Queue_Type; Depth : Positive) return Element;
```

Pre- and **Post-predicates** are checked before and after each execution resp.

Original (Pre) values can still be referred to.

∀ and ∃ quantifiers are expressed as "for all" and "for some" expressions resp.

77

A contracting queue specification

```
package Queue_Pack_Contract is
   Queue_Size : constant Positive := 10;
   type Element is new Positive range 1 .. 1000;
   type Queue_Type is private;

   procedure Enqueue (Item :     Element; Q : in out Queue_Type) with
     Pre  => not Is_Full (Q),
     Post => not Is_Empty (Q) and then Length (Q) = Length (Q'Old) + 1
                and then Lookahead (Q, Length (Q)) = Item
                and then (for all ix in 1 .. Length (Q'Old)
                            => Lookahead (Q, ix) = Lookahead (Q'Old, ix));

   procedure Dequeue (Item : out Element; Q : in out Queue_Type) with
     Pre  => not Is_Empty (Q),
     Post => not Is_Full (Q) and then Length (Q) = Length (Q'Old) - 1
                and then (for all ix in 1 .. Length (Q)
                            => Lookahead (Q, ix) = Lookahead (Q'Old, ix + 1));

   function Is_Empty  (Q : Queue_Type) return Boolean;
   function Is_Full   (Q : Queue_Type) return Boolean;
   function Length    (Q : Queue_Type) return Natural;
   function Lookahead (Q : Queue_Type; Depth : Positive) return Element;
```

... anything on this slide still not perfectly clear?

78

A contracting queue specification (cont.)

```
private
   type Marker is mod Queue_Size;
   type List is array (Marker) of Element;

   type Queue_Type is record
      Top, Free : Marker   := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List; -- will be initialized to invalids
   end record with Type_Invariant
     => (not Queue_Type.Is_Empty or else Queue_Type.Top = Queue_Type.Free)
        and then (for all ix in 1 .. Length (Queue_Type)
                    => Lookahead (Queue_Type, ix)'Valid);

   function Is_Empty (Q : Queue_Type) return Boolean is (Q.Is_Empty);
   function Is_Full (Q : Queue_Type)  return Boolean is
     (not Q.Is_Empty and then Q.Top = Q.Free);
   function Length (Q : Queue_Type) return Natural is
     (if Is_Full (Q) then Queue_Size else Natural (Q.Free - Q.Top));
   function Lookahead (Q : Queue_Type; Depth : Positive) return Element is
     (Q.Elements (Q.Top + Marker (Depth - 1)));
end Queue_Pack_Contract;
```

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A contracting queue specification (cont.)

```
private
   type Marker is mod Queue_Size;
   type List is array (Marker) of Element;

   type Queue_Type is record
      Top, Free : Marker   := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List; -- will be initialized to invalids
   end record with Type_Invariant
     => (not Queue_Type.Is_Empty or else Queue_Type.Top = Queue_Type.Free)
        and then (for all ix in 1 .. Length (Queue_Type)
                    => Lookahead (Queue_Type, ix)'Valid);

   function Is_Empty (Q : Queue_Type) return Boolean is (Q.Is_Empty);
   function Is_Full (Q : Queue_Type)  return Boolean is
     (not Q.Is_Empty and then Q.Top = Q.Free);
   function Length (Q : Queue_Type) return Natural is
     (if Is_Full (Q) then Queue_Size else Natural (Q.Free - Q.Top));
   function Lookahead (Q : Queue_Type; Depth : Positive) return Element is
     (Q.Elements (Q.Top + Marker (Depth - 1)));
end Queue_Pack_Contract;
```

Type-Invariants are checked on return from any operation defined in the public part.

80

A contracting queue specification (cont.)

```
private
   type Marker is mod Queue_Size;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List; -- will be initialized to invalids
   end record with Type_Invariant
      => (not Queue_Type.Is_Empty or else Queue_Type.Top = Queue_Type.Free)
         and then (for all ix in 1 .. Length (Queue_Type)
                                       => Lookahead (Queue_Type, ix)'Valid);
   function Is_Empty (Q : Queue_Type) return Boolean is (Q.Is_Empty);
   function Is_Full (Q : Queue_Type)  return Boolean is
     (not Q.Is_Empty and then Q.Top = Q.Free);
   function Length (Q : Queue_Type) return Natural is
     (if Is_Full (Q) then Queue_Size else Natural (Q.Free - Q.Top));
   function Lookahead (Q : Queue_Type; Depth : Positive) return Element is
     (Q.Elements (Q.Top + Marker (Depth - 1)));
end Queue_Pack_Contract;
```

... anything on this slide still not perfectly clear?

81

A contracting queue implementation

```
package body Queue_Pack_Contract is
   procedure Enqueue (Item : Element; Q : in out Queue_Type) is
   begin
      Q.Elements (Q.Free) := Item;
      Q.Free              := Q.Free + 1;
      Q.Is_Empty          := False;
   end Enqueue;
   procedure Dequeue (Item : out Element; Q : in out Queue_Type) is
   begin
      Item       := Q.Elements (Q.Top);
      Q.Top      := Q.Top + 1;
      Q.Is_Empty := Q.Top = Q.Free;
   end Dequeue;
end Queue_Pack_Contract;
```

Identical

No checks in the implementation part, as all required conditions have been guaranteed via the specifications.

82

A contracting queue test program

```
with Ada.Text_IO;         use Ada.Text_IO;
with Exceptions;          use Exceptions;
with Queue_Pack_Contract; use Queue_Pack_Contract;
with System.Assertions;   use System.Assertions;
procedure Queue_Test_Contract is
   Queue : Queue_Type;
   Item  : Element;
begin
   Enqueue (Item => 1, Q => Queue);
   Enqueue (Item => 2, Q => Queue);
   Dequeue (Item, Queue); Put (Element'Image (Item));
   Dequeue (Item, Queue); Put (Element'Image (Item));
   Dequeue (Item, Queue); -- will produce an Assert_Failure
   Put (Element'Image (Item));
   Put ("Queue is empty on exit: "); Put (Boolean'Image (Is_Empty (Queue)));
exception
   when Exception_Id : Assert_Failure => Show_Exception (Exception_Id);
end Queue_Test_Contract;
```

83

A contracting queue test program

```
with Ada.Text_IO;         use Ada.Text_IO;
with Exceptions;          use Exceptions;
with Queue_Pack_Contract; use Queue_Pack_Contract;
with System.Assertions;   use System.Assertions;
procedure Queue_Test_Contract is
   Queue : Queue_Type;
   Item  : Element;
begin
   Enqueue (Item => 1, Q => Queue);
   Enqueue (Item => 2, Q => Queue);
   Dequeue (Item, Queue); Put (Element'Image (Item));
   Dequeue (Item, Queue); Put (Element'Image (Item));
   Dequeue (Item, Queue); -- will produce an Assert_Failure
   Put (Element'Image (Item));
   Put ("Queue is empty on exit: "); Put (Boolean'Image (Is_Empty (Queue)));
exception
   when Exception_Id : Assert_Failure => Show_Exception (Exception_Id);
end Queue_Test_Contract;
```

Violated Pre-condition will raise an assert failure exception.

84

A contracting queue test program

```
with Ada.Text_IO;           use Ada.Text_IO;
with Exceptions;            use Exceptions;
with Queue_Pack_Contract;   use Queue_Pack_Contract;
with System.Assertions;     use System.Assertions;

procedure Queue_Test_Contract is
   Queue : Queue_Type;
   Item  : Element;
begin
   Enqueue (Item => 1, Q => Queue);
   Enqueue (Item => 2, Q => Queue);
   Dequeue (Item, Queue); Put (Element'Image (Item));
   Dequeue (Item, Queue); Put (Element'Image (Item));
   Dequeue (Item, Queue); -- will produce an Assert_Failure
   Put (Element'Image (Item));
   Put ("Queue is empty on exit: "); Put (Boolean'Image (Is_Empty (Queue)));
exception
   when Exception_Id : Assert_Failure => Show_Exception (Exception_Id);
end Queue_Test_Contract;
```

… anything on this slide still not perfectly clear?

85

A contracted queue

Exceptions are commonly preferred to handle rare, yet valid situations.

Contracts are commonly used to test program correctness with respect to its specifications.

```
package Queue_Pack_Contract is
  (…)
  procedure Enqueue (Item : Element; Q : in out Queue_Type) with
    Pre  => not Is_Full  (Q), -- could also be "=> True" according to specifications
    Post => not Is_Empty (Q) and then Length (Q) = Length (Q'Old) + 1
              and then Lookahead (Q, Length (Q)) = Item
              and then (for all ix in 1 .. Length (Q'Old)
                 => Lookahead (Q, ix) = Lookahead (Q'Old, ix));

  procedure Dequeue (Item : out Element; Q : in out Queue_Type) with
    Pre  => not Is_Empty (Q), -- could also be "=> True" according to specifications
    Post => not Is_Full  (Q) and then Length (Q) = Length (Q'Old) - 1
              and then (for all ix in 1 .. Length (Q)
                 => Lookahead (Q, ix) = Lookahead (Q'Old, ix + 1));
  (…)
  type Queue_Type is record
    Top, Free : Marker   := Marker'First;

  end record with Type_Invariant =>
     (not Queue_Type.Is_Empty or else Queue_Type.Top = Queue_Type.Free)
     and then (for all ix in 1 .. Length (Queue_Type)
                    => Lookahead (Queue_Type, ix)'Valid);
  (…)
```

Those contracts can be used to fully specify operations and types. Specifications should be complete, consistent and canonical, while using as little implementation details as possible.

86

Language refresher / introduction course

Ada

Generic (polymorphic) packages

… introducing:

- Specification of **generic** packages
- Instantiation of **generic** packages

87

A generic queue specification

```
generic
   type Element is private;

package Queue_Pack_Generic is
   QueueSize: constant Integer := 10;
   type Queue_Type is limited private;

   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
   Queueoverflow, Queueunderflow : exception;
private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Generic;
```

88

A generic queue *specification*

```
generic
   type Element is private;
package Queue_Pack_Generic is
   QueueSize: constant Integer := 10;
   type Queue_Type is limited private;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
   Queueoverflow, Queueunderflow : exception;
private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Generic;
```

The type of Element now becomes a parameter of a generic package.

No restrictions (private) have been set for the type of Element.

Haskell syntax:
`enqueue :: a -> Queue a -> Queue a`

89

A generic queue *specification*

```
generic
   type Element is private;
package Queue_Pack_Generic is
   QueueSize: constant Integer := 10;
   type Queue_Type is limited private;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
   Queueoverflow, Queueunderflow : exception;
private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Generic;
```

Generic aspects can include:

- Type categories
- Incomplete types
- Constants
- Procedures and functions
- Other packages
- Objects (interfaces)

Default values can be provided (making those parameters optional)

90

A generic queue *specification*

```
generic
   type Element is private;
package Queue_Pack_Generic is
   QueueSize: constant Integer := 10;
   type Queue_Type is limited private;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
   Queueoverflow, Queueunderflow : exception;
private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Generic;
```

... anything on this slide still not perfectly clear?

91

A generic queue *implementation*

```
package body Queue_Pack_Generic is
   procedure Enqueue (Item: Element; Queue: in out Queue_Type) is
   begin
      if Is_Full (Queue) then
         raise Queueoverflow;
      end if;
      Queue.Elements (Queue.Free) := Item;
      Queue.Free                  := [illegible]ueu[illegible]Free);
      Queue.Is_Empty              := False;
   end Enqueue;
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type) is
   begin
      if Is_Empty (Queue) then raise Queueunderflow; end if;
      Item           := Queue.Elements (Queue.Top);
      Queue.Top      := [illegible] (Queue.Top);
      Queue.Is_Empty := Queue.Top = Queue.Free;
   end Dequeue;
   function Is_Empty (Queue : Queue_Type) return Boolean is (Queue.Is_Empty);
   function Is_Full  (Queue : Queue_Type) return Boolean is
     (not Queue.Is_Empty and then Queue.Top = Queue.Free);
end Queue_Pack_Generic;
```

Identical

92

A generic queue test program

```
with Queue_Pack_Generic; -- cannot apply 'use' clause here
with Ada.Text_IO       ; use Ada.Text_IO;
procedure Queue_Test_Generic is
   package Queue_Pack_Positive is
      new Queue_Pack_Generic (Element => Positive);
   use Queue_Pack_Positive; -- 'use' clause can be applied to instantiated package
   Queue : Queue_Type;
   Item  : Positive;
begin
   Enqueue (Item => 1, Queue => Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- will produce a "Queue underflow"
exception
   when Queueunderflow => Put ("Queue underflow");
   when Queueoverflow  => Put ("Queue overflow");
end Queue_Test_Generic;
```

93

A generic queue test program

```
with Queue_Pack_Generic; -- cannot apply 'use' clause here
with Ada.Text_IO       ; use Ada.Text_IO;
procedure Queue_Test_Generic is
   package Queue_Pack_Positive is
      new Queue_Pack_Generic (Element => Positive);
   use Queue_Pack_Positive; -- 'use' clause can be applied to instantiated package
   Queue : Queue_Type;
   Item  : Positive;
begin
   Enqueue (Item => 1, Queue => Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- will produce a "Queue underflow"
exception
   when Queueunderflow => Put ("Queue underflow");
   when Queueoverflow  => Put ("Queue overflow");
end Queue_Test_Generic;
```

Instantiate generic package

94

A generic queue test program

```
with Queue_Pack_Generic; -- cannot apply 'use' clause here
with Ada.Text_IO       ; use Ada.Text_IO;
procedure Queue_Test_Generic is
   package Queue_Pack_Positive is
      new Queue_Pack_Generic (Element => Positive);
   use Queue_Pack_Positive; -- 'use' clause can be applied to instantiated package
   Queue : Queue_Type;
   Item  : Positive;
begin
   Enqueue (Item => 1, Queue => Queue);
   Dequeue (Item, Queue);
   Dequeue (Item, Queue); -- will produce a "Queue underflow"
exception
   when Queueunderflow => Put ("Queue underflow");
   when Queueoverflow  => Put ("Queue overflow");
end Queue_Test_Generic;
```

… anything on this slide still not perfectly clear?

95

A generic queue specification

```
generic
   type Element is private;
package Queue_Pack_Generic is
   QueueSize: constant Integer := 10;
   type Queue_Type is limited private;
   procedure Enqueue (Item:     Element; Queue: in out Queue_Type);
   procedure Dequeue (Item: out Element; Queue: in out Queue_Type);
   function Is_Empty (Queue : Queue_Type) return Boolean;
   function Is_Full  (Queue : Queue_Type) return Boolean;
   Queueoverflow, Queueunderflow : exception;
private
   type Marker is mod QueueSize;
   type List is array (Marker) of Element;
   type Queue_Type is record
      Top, Free : Marker  := Marker'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Generic;
```

None of the packages so far can be used in a concurrent environment.

96

Language refresher / introduction course

Ada

Access routines for concurrent systems

… introducing:

- **Protected objects**
- **Entry guards**
- **Side-effecting (mutually exclusive) entry and procedure calls**
- **Side-effect-free (concurrent) function calls**

97

A generic protected queue specification

```
generic
   type Element is private;
   type Index   is mod <>;   -- Modulo defines size of the queue.
package Queue_Pack_Protected_Generic is
   type Queue_Type is limited private;
   protected type Protected_Queue is
      entry Enqueue (Item :     Element);
      entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   type List is array (Index) of Element;
   type Queue_Type is record
      Top, Free : Index   := Index'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Protected_Generic;
```


98

A generic protected queue specification

```
generic
   type Element is private;
   type Index   is mod <>;   -- Modulo defines size of the queue.
package Queue_Pack_Protected_Generic is
   type Queue_Type is limited private;
   protected type Protected_Queue is
      entry Enqueue (Item :     Element);
      entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   type List is array (Index) of Element;
   type Queue_Type is record
      Top, Free : Index   := Index'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Protected_Generic;
```

> Generic components of the package:
> Element can be anything while the Index need to be a modulo type.

99

A generic protected queue specification

```
generic
   type Element is private;
   type Index   is mod <>;   -- Modulo defines size of the queue.
package Queue_Pack_Protected_Generic is
   type Queue_Type is limited private;
   protected type Protected_Queue is
      entry Enqueue (Item :     Element);
      entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   type List is array (Index) of Element;
   type Queue_Type is record
      Top, Free : Index   := Index'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Protected_Generic;
```

> Queue is protected for safe concurrent access.
> Three categories of a access routines are distinguished by the keywords:
> entry, procedure, function

100

A generic protected queue *specification*

```
generic
   type Element is private;
   type Index   is mod <>;  -- Modulo defines size of the queue.
package Queue_Pack_Protected_Generic is
   type Queue_Type is limited private;
   protected type Protected_Queue is
      entry Enqueue (Item :     Element);
      entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   type List is array (Index) of Element;
   type Queue_Type is record
      Top, Free : Index   := Index'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Protected_Generic;
```

Procedures are **mutually exclusive** to all other access routines.

Rationale:

Procedures can modify the protected data.

Hence they need a guarantee for exclusive access.

101

A generic protected queue *specification*

```
generic
   type Element is private;
   type Index   is mod <>;  -- Modulo defines size of the queue.
package Queue_Pack_Protected_Generic is
   type Queue_Type is limited private;
   protected type Protected_Queue is
      entry Enqueue (Item :     Element);
      entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   type List is array (Index) of Element;
   type Queue_Type is record
      Top, Free : Index   := Index'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Protected_Generic;
```

Functions are **mutually exclusive** to procedures and entries, yet **concurrent** to other functions.

Rationale:

The compiler enforces those functions to be side-effect-free with respect to the protected data.

Hence concurrent access can be granted among functions without risk.

102

A generic protected queue *specification*

```
generic
   type Element is private;
   type Index   is mod <>;  -- Modulo defines size of the queue.
package Queue_Pack_Protected_Generic is
   type Queue_Type is limited private;
   protected type Protected_Queue is
      entry Enqueue (Item :     Element);
      entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   type List is array (Index) of Element;
   type Queue_Type is record
      Top, Free : Index   := Index'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Protected_Generic;
```

Entries are **mutually exclusive** to all other access routines and also provide one **guard** per entry which need to evaluate to True before entry is granted.

The **guard expressions** are defined in the implementation part.

Rationale:

Entries can be blocking even if the protected object itself is unlocked.

Hence a separate task waiting queue is provided per entry.

103

A generic protected queue *specification*

```
generic
   type Element is private;
   type Index   is mod <>;  -- Modulo defines size of the queue.
package Queue_Pack_Protected_Generic is
   type Queue_Type is limited private;
   protected type Protected_Queue is
      entry Enqueue (Item :     Element);
      entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   type List is array (Index) of Element;
   type Queue_Type is record
      Top, Free : Index   := Index'First;
      Is_Empty  : Boolean := True;
      Elements  : List;
   end record;
end Queue_Pack_Protected_Generic;
```

… anything on this slide still not perfectly clear?

104

A generic protected queue *implementation*

```
package body Queue_Pack_Protected_Generic is
   protected body Protected_Queue is
      entry Enqueue (Item : Element) when not Is_Full is
      begin
         Queue.Elements (Queue.Free) := Item; Queue.Free := Index'Succ (Queue.Free);
         Queue.Is_Empty := False;
      end Enqueue;
      entry Dequeue (Item : out Element) when not Is_Empty is
      begin
         Item := Queue.Elements (Queue.Top); Queue.Top := Index'Succ (Queue.Top);
         Queue.Is_Empty := Queue.Top = Queue.Free;
      end Dequeue;
      procedure Empty_Queue is
      begin
         Queue.Top := Index'First; Queue.Free := Index'First; Queue.Is_Empty := True;
      end Empty_Queue;
      function Is_Empty return Boolean is (Queue.Is_Empty);
      function Is_Full  return Boolean is
        (not Queue.Is_Empty and then Queue.Top = Queue.Free);
   end Protected_Queue;
end Queue_Pack_Protected_Generic;
```


105

A generic protected queue *implementation*

```
package body Queue_Pack_Protected_Generic is
   protected body Protected_Queue is
      entry Enqueue (Item : Element) when not Is_Full is
      begin
         Queue.Elements (Queue.Free) := Item; Queue.Free := Index'Succ (Queue.Free);
         Queue.Is_Empty := False;
      end Enqueue;
      entry Dequeue (Item : out Element) when not Is_Empty is
      begin
         Item := Queue.Elements (Queue.Top); Queue.Top := Index'Succ (Queue.Top);
         Queue.Is_Empty := Queue.Top = Queue.Free;
      end Dequeue;
      procedure Empty_Queue is
      begin
         Queue.Top := Index'First; Queue.Free := Index'First; Queue.Is_Empty := True;
      end Empty_Queue;
      function Is_Empty return Boolean is (Queue.Is_Empty);
      function Is_Full  return Boolean is
        (not Queue.Is_Empty and then Queue.Top = Queue.Free);
   end Protected_Queue;
end Queue_Pack_Protected_Generic;
```

Guard expressions follow after when in the implementation of entries.

Tasks are automatically blocked or released depending on the state of the guard.
Guard expressions are re-evaluated on exiting an entry or procedure
(no point to re-check them at any other time).
Exactly one waiting task on one entry is released.

106

A generic protected queue *implementation*

```
package body Queue_Pack_Protected_Generic is
   protected body Protected_Queue is
      entry Enqueue (Item : Element) when not Is_Full is
      begin
         Queue.Elements (Queue.Free) := Item; Queue.Free := Index'Succ (Queue.Free);
         Queue.Is_Empty := False;
      end Enqueue;
      entry Dequeue (Item : out Element) when not Is_Empty is
      begin
         Item := Queue.Elements (Queue.Top); Queue.Top := Index'Succ (Queue.Top);
         Queue.Is_Empty := Queue.Top = Queue.Free;
      end Dequeue;
      procedure Empty_Queue is
      begin
         Queue.Top := Index'First; Queue.Free := Index'First; Queue.Is_Empty := True;
      end Empty_Queue;
      function Is_Empty return Boolean is (Queue.Is_Empty);
      function Is_Full  return Boolean is
        (not Queue.Is_Empty and then Queue.Top = Queue.Free);
   end Protected_Queue;
end Queue_Pack_Protected_Generic;
```

… anything on this slide still not perfectly clear?

107

A generic protected queue test *program*

```
with Ada.Task_Identification;     use Ada.Task_Identification;
with Ada.Text_IO;                 use Ada.Text_IO;
with Queue_Pack_Protected_Generic;
procedure Queue_Test_Protected_Generic is
   type Queue_Size is mod 3;
   package Queue_Pack_Protected_Character is
      new Queue_Pack_Protected_Generic (Element => Character, Index => Queue_Size);
   use Queue_Pack_Protected_Character;
   Queue : Protected_Queue;
   type Task_Index is range 1 .. 3;
   task type Producer;
   task type Consumer;
   Producers : array (Task_Index) of Producer;
   Consumers : array (Task_Index) of Consumer;
(…)
begin
   null;
end Queue_Test_Protected_Generic;
```

108

A generic protected queue test program

```ada
with Ada.Task_Identification;      use Ada.Task_Identification;
with Ada.Text_IO;                  use Ada.Text_IO;
with Queue_Pack_Protected_Generic;
procedure Queue_Test_Protected_Generic is
   type Queue_Size is mod 3;
   package Queue_Pack_Protected_Character is
      new Queue_Pack_Protected_Generic (Element => Character, Index => Queue_Size);
   use Queue_Pack_Protected_Character;
   Queue : Protected_Queue;
   type Task_Index is range 1 .. 3;
   task type Producer;
   task type Consumer;
   Producers : array (Task_Index) of Producer;
   Consumers : array (Task_Index) of Consumer;
(…)
begin
   null;
end Queue_Test_Protected_Generic;
```

If more than one instance of a specific task is to be run then a **task type** (as opposed to a concrete task) is declared.

109

A generic protected queue test program

```ada
with Ada.Task_Identification;      use Ada.Task_Identification;
with Ada.Text_IO;                  use Ada.Text_IO;
with Queue_Pack_Protected_Generic;
procedure Queue_Test_Protected_Generic is
   type Queue_Size is mod 3;
   package Queue_Pack_Protected_Character is
      new Queue_Pack_Protected_Generic (Element => Character, Index => Queue_Size);
   use Queue_Pack_Protected_Character;
   Queue : Protected_Queue;
   type Task_Index is range 1 .. 3;
   task type Producer;
   task type Consumer;
   Producers : array (Task_Index) of Producer;
   Consumers : array (Task_Index) of Consumer;
(…)
begin
   null;
end Queue_Test_Protected_Generic;
```

Multiple instances of a task can be instantiated e.g. by declaring an array of this task type.

Tasks are started right when such an array is created.

110

A generic protected queue test program

```ada
with Ada.Task_Identification;      use Ada.Task_Identification;
with Ada.Text_IO;                  use Ada.Text_IO;
with Queue_Pack_Protected_Generic;
procedure Queue_Test_Protected_Generic is
   type Queue_Size is mod 3;
   package Queue_Pack_Protected_Character is
      new Queue_Pack_Protected_Generic (Element => Character, Index => Queue_Size);
   use Queue_Pack_Protected_Character;
   Queue : Protected_Queue;
   type Task_Index is range 1 .. 3;
   task type Producer;
   task type Consumer;
   Producers : array (Task_Index) of Producer;
   Consumers : array (Task_Index) of Consumer;
(…)
begin
   null;
end Queue_Test_Protected_Generic;
```

These declarations spawned off all the production code.

Often there are no statements for the "main task" (here explicitly stated by a `null` statement).

This task is prevented from terminating though until all tasks inside its scope terminated.

111

A generic protected queue test program

```ada
with Ada.Task_Identification;      use Ada.Task_Identification;
with Ada.Text_IO;                  use Ada.Text_IO;
with Queue_Pack_Protected_Generic;
procedure Queue_Test_Protected_Generic is
   type Queue_Size is mod 3;
   package Queue_Pack_Protected_Character is
      new Queue_Pack_Protected_Generic (Element => Character, Index => Queue_Size);
   use Queue_Pack_Protected_Character;
   Queue : Protected_Queue;
   type Task_Index is range 1 .. 3;
   task type Producer;
   task type Consumer;
   Producers : array (Task_Index) of Producer;
   Consumers : array (Task_Index) of Consumer;
(…)
begin
   null;
end Queue_Test_Protected_Generic;
```

… anything on this slide still not perfectly clear?

112

A generic protected queue test program

```
subtype Some_Characters is Character range 'a' .. 'f';

task body Producer is

begin
   for Ch in Some_Characters loop
      Put_Line ("Task " & Image (Current_Task) & " finds the queue to be " &
                (if Queue.Is_Empty then "EMPTY" else "not empty") &
                  " and " &
                (if Queue.Is_Full  then "FULL" else "not full") &
                  " and prepares to add: " & Character'Image (Ch) &
                  " to the queue.");
      Queue.Enqueue (Ch); -- task might be blocked here!
   end loop;
   Put_Line ("<---- Task " & Image (Current_Task) & " terminates.");
end Producer;
```


113

A generic protected queue test program

```
subtype Some_Characters is Character range 'a' .. 'f';

task body Producer is

begin
   for Ch in Some_Characters loop
      Put_Line ("Task " & Image (Current_Task) & " finds the queue to be " &
                (if Queue.Is_Empty then "EMPTY" else "not empty") &
                  " and " &
                (if Queue.Is_Full  then "FULL" else "not full") &
                  " and prepares to add: " & Character'Image (Ch) &
                  " to the queue.");
      Queue.Enqueue (Ch); -- task might be blocked here!
   end loop;
   Put_Line ("<---- Task " & Image (Current_Task) & " terminates.");
end Producer;
```

The executable code for a task is provided in its body.

114

A generic protected queue test program

```
subtype Some_Characters is Character range 'a' .. 'f';

task body Producer is

begin
   for Ch in Some_Characters loop
      Put_Line ("Task " & Image (Current_Task) & " finds the queue to be " &
                (if Queue.Is_Empty then "EMPTY" else "not empty") &
                  " and " &
                (if Queue.Is_Full  then "FULL" else "not full") &
                  " and prepares to add: " & Character'Image (Ch) &
                  " to the queue.");
      Queue.Enqueue (Ch); -- task might be blocked here!
   end loop;
   Put_Line ("<---- Task " & Image (Current_Task) & " terminates.");
end Producer;
```

There are three of those tasks and they are all 'hammering' the queue at full CPU speed.

115

A generic protected queue test program

```
subtype Some_Characters is Character range 'a' .. 'f';

task body Producer is

begin
   for Ch in Some_Characters loop
      Put_Line ("Task " & Image (Current_Task) & " finds the queue to be " &
                (if Queue.Is_Empty then "EMPTY" else "not empty") &
                  " and " &
                (if Queue.Is_Full  then "FULL" else "not full") &
                  " and prepares to add: " & Character'Image (Ch) &
                  " to the queue.");
      Queue.Enqueue (Ch); -- task might be blocked here!
   end loop;
   Put_Line ("<---- Task " & Image (Current_Task) & " terminates.");
end Producer;
```

Tasks automatically terminate once they reach their end declaration (and once all inner tasks are terminated).

116

A generic protected queue test program

```
subtype Some_Characters is Character range 'a' .. 'f';

task body Producer is

begin
   for Ch in Some_Characters loop
      Put_Line ("Task " & Image (Current_Task) & " finds the queue to be " &
                (if Queue.Is_Empty then "EMPTY" else "not empty") &
                  " and " &
                (if Queue.Is_Full  then "FULL" else "not full") &
                  " and prepares to add: " & Character'Image (Ch) &
                  " to the queue.");
      Queue.Enqueue (Ch); -- task might be blocked here!
   end loop;
   Put_Line ("<---- Task " & Image (Current_Task) & " terminates.");
end Producer;
```

... anything on this slide still not perfectly clear?

117

A generic protected queue test program

```
task body Consumer is
   Item    : Character;
   Counter : Natural := 0;
begin
   loop
      Queue.Dequeue (Item); -- task might be blocked here!
      Counter := Natural'Succ (Counter);
      Put_Line ("Task " & Image (Current_Task) &
                  " received: " & Character'Image (Item) &
                  " and the queue appears to be " &
                (if Queue.Is_Empty then "EMPTY" else "not empty") &
                  " and " &
                (if Queue.Is_Full  then "FULL" else "not full") &
                  " afterwards.");
      exit when Item = Some_Characters'Last;
   end loop;
   Put_Line ("<---- Task " & Image (Current_Task) &
               " terminates and received" & Natural'Image (Counter) & " items.");
end Consumer;
```


118

A generic protected queue test program

```
task body Consumer is
   Item    : Character;
   Counter : Natural := 0;
begin
   loop
      Queue.Dequeue (Item); -- task might be blocked here!
      Counter := Natural'Succ (Counter);
      Put_Line ("Task " & Image (Current_Task) &
                  " received: " & Character'Image (Item) &
                  " and the queue appears to be " &
                (if Queue.Is_Empty then "EMPTY" else "not empty") &
                  " and " &
                (if Queue.Is_Full  then "FULL" else "not full") &
                  " afterwards.");
      exit when Item = Some_Characters'Last;
   end loop;
   Put_Line ("<---- Task " & Image (Current_Task) &
               " terminates and received" & Natural'Image (Counter) & " items.");
end Consumer;
```

Another three tasks and are all 'hammering' the queue at this end and at full CPU speed.

119

A generic protected queue test program

```
task body Consumer is
   Item    : Character;
   Counter : Natural := 0;
begin
   loop
      Queue.Dequeue (Item); -- task might be blocked here!
      Counter := Natural'Succ (Counter);
      Put_Line ("Task " & Image (Current_Task) &
                  " received: " & Character'Image (Item) &
                  " and the queue appears to be " &
                (if Queue.Is_Empty then "EMPTY" else "not empty") &
                  " and " &
                (if Queue.Is_Full  then "FULL" else "not full") &
                  " afterwards.");
      exit when Item = Some_Characters'Last;
   end loop;
   Put_Line ("<---- Task " & Image (Current_Task) &
               " terminates and received" & Natural'Image (Counter) & " items.");
end Consumer;
```

... anything on this slide still not perfectly clear?

120

A generic protected queue test program

```
Task producers(1) finds the queue to be EMPTY and not full and prepares to add: 'a' to the queue.
Task producers(1) finds the queue to be not empty and not full and prepares to add: 'b' to the queue.
Task producers(1) finds the queue to be not empty and not full and prepares to add: 'c' to the queue.
Task producers(1) finds the queue to be not empty and FULL and prepares to add: 'd' to the queue.
Task producers(2) finds the queue to be not empty and FULL and prepares to add: 'a' to the queue.
Task producers(3) finds the queue to be not empty and FULL and prepares to add: 'a' to the queue.
Task consumers(1) received: 'a' and the queue appears to be not empty and FULL afterwards.
Task consumers(1) received: 'b' and the queue appears to be not empty and FULL afterwards.
Task consumers(1) received: 'c' and the queue appears to be not empty and FULL afterwards.
Task consumers(1) received: 'd' and the queue appears to be not empty and not full afterwards.
Task consumers(1) received: 'a' and the queue appears to be not empty and not full afterwards.
..
<---- Task producers(1) terminates.
..
Task consumers(3) received: 'b' and the queue appears to be EMPTY and not full afterwards.
<---- Task consumers(2) terminates and received 1 items.
..
<---- Task producers(2) terminates.
..
<---- Task producers(3) terminates.
..
<---- Task consumers(1) terminates and received 12 items.
<---- Task consumers(3) terminates and received 5 items.
```

What is going on here?

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121

A generic protected queue test program

```
Task producers(1) finds the queue to be EMPTY and not full and prepares to add: 'a' to the queue.
Task producers(2) finds the queue to be EMPTY and not full and prepares to add: 'a' to the queue.
Task producers(1) finds the queue to be not empty and not full and prepares to add: 'b' to the queue.
Task consumers(1) received: 'a' and the queue appears to be EMPTY and not full afterwards.
Task producers(3) finds the queue to be EMPTY and not full and prepares to add: 'a' to the queue.
Task producers(1) finds the queue to be EMPTY and not full and prepares to add: 'c' to the queue.
Task producers(2) finds the queue to be EMPTY and not full and prepares to add: 'b' to the queue.
Task consumers(2) received: 'a' and the queue appears to be EMPTY and not full afterwards.
Task consumers(3) received: 'b' and the queue appears to be EMPTY and not full afterwards.
..
<---- Task producers(1) terminates.
Task producers(2) finds the queue to be not empty and FULL and prepares to add: 'f' to the queue.
Task consumers(2) received: 'f' and the queue appears to be not empty and not full afterwards.
Task consumers(3) received: 'e' and the queue appears to be EMPTY and not full afterwards.
Task producers(3) finds the queue to be not empty and not full and prepares to add: 'f' to the queue.
Task consumers(1) received: 'd' and the queue appears to be not empty and not full afterwards.
<---- Task producers(2) terminates.
<---- Task consumers(2) terminates and received 5 items.
Task consumers(3) received: 'e' and the queue appears to be not empty and not full afterwards.
<---- Task producers(3) terminates.
Task consumers(1) received: 'f' and the queue appears to be not empty and not full afterwards.
Task consumers(3) received: 'f' and the queue appears to be EMPTY and not full afterwards.
<---- Task consumers(1) terminates and received 6 items.
<---- Task consumers(3) terminates and received 7 items.
```

Does this make any sense?

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122

Language refresher / introduction course

Ada

Abstract types & dispatching

... introducing:

- **Abstract tagged types & subroutines (Interfaces)**
- Concrete implementation of abstract types
- **Dynamic dispatching** to different packages, tasks, protected types or partitions.
- **Synchronous message passing.**

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Language refresher / introduction course

Ada

Abstract types & dispatching

... introducing:

- **Abstract tagged types & subroutines (Interfaces)**
- Concrete implementation of abstract types
- **Dynamic dispatching** to different packages, tasks, protected types or partitions.
- **Synchronous message passing.**

– Advanced topic –

Proceed with caution!

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124

An abstract queue specification

```
generic
   type Element is private;
package Queue_Pack_Abstract is
   type Queue_Interface is synchronized interface;
   procedure Enqueue (Q : in out Queue_Interface; Item :     Element) is abstract;
   procedure Dequeue (Q : in out Queue_Interface; Item : out Element) is abstract;
end Queue_Pack_Abstract;
```

125

An abstract queue specification

```
generic
   type Element is private;
package Queue_Pack_Abstract is
   type Queue_Interface is synchronized interface;
   procedure Enqueue (Q : in out Queue_Interface; Item :     Element) is abstract;
   procedure Dequeue (Q : in out Queue_Interface; Item : out Element) is abstract;
end Queue_Pack_Abstract;
```

Motivation:
Different, derived implementations (potentially on different computers) can be passed around and referred to with the same common interface as defined here.

126

An abstract queue specification

```
generic
   type Element is private;
package Queue_Pack_Abstract is
   type Queue_Interface is synchronized interface;
   procedure Enqueue (Q : in out Queue_Interface; Item :     Element) is abstract;
   procedure Dequeue (Q : in out Queue_Interface; Item : out Element) is abstract;
end Queue_Pack_Abstract;
```

synchronized means that this interface can only be implemented by **synchronized entities** like **protected objects** (as seen above) or **synchronous message passing**.

Abstract, empty type definition which serves to define interface templates.

127

An abstract queue specification

```
generic
   type Element is private;
package Queue_Pack_Abstract is
   type Queue_Interface is synchronized interface;
   procedure Enqueue (Q : in out Queue_Interface; Item :     Element) is abstract;
   procedure Dequeue (Q : in out Queue_Interface; Item : out Element) is abstract;
end Queue_Pack_Abstract;
```

Abstract methods need to be **overridden** with concrete methods when a new type is derived from it.

128

An abstract queue specification

```
generic
   type Element is private;
package Queue_Pack_Abstract is
   type Queue_Interface is synchronized interface;
   procedure Enqueue (Q : in out Queue_Interface; Item :     Element) is abstract;
   procedure Dequeue (Q : in out Queue_Interface; Item : out Element) is abstract;
end Queue_Pack_Abstract;
```

… this does not require an implementation package (as all procedures are abstract)

… anything on this slide still not perfectly clear?

129

A concrete queue specification

```
with Queue_Pack_Abstract;
generic
   with package Queue_Instance is new Queue_Pack_Abstract (<>);
   type Index is mod <>; -- Modulo defines size of the queue.
package Queue_Pack_Concrete is
   use Queue_Instance;
   type Queue_Type is limited private;
   protected type Protected_Queue is new Queue_Interface with
      overriding entry Enqueue (Item :     Element);
      overriding entry Dequeue (Item : out Element);
      not overriding procedure Empty_Queue;
      not overriding function Is_Empty return Boolean;
      not overriding function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   (...) -- as all previous private queue declarations
end Queue_Pack_Concrete;
```

130

A concrete queue specification

```
with Queue_Pack_Abstract;
generic
   with package Queue_Instance is new Queue_Pack_Abstract (<>);
   type Index is mod <>; -- Modulo defines size of the queue.
package Queue_Pack_Concrete is
   use Queue_Instance;
   type Queue_Type is limited private;
   protected type Protected_Queue is new Queue_Interface with
      overriding entry Enqueue (Item :     Element);
      overriding entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   (...) -- as all previous private queue declarations
end Queue_Pack_Concrete;
```

A generic package which takes another **generic package as a parameter.**

131

A concrete queue specification

```
with Queue_Pack_Abstract;
generic
   with package Queue_Instance is new Queue_Pack_Abstract (<>);
   type Index is mod <>; -- Modulo defines size of the queue.
package Queue_Pack_Concrete is
   use Queue_Instance;
   type Queue_Type is limited private;
   protected type Protected_Queue is new Queue_Interface with
      overriding entry Enqueue (Item :     Element);
      overriding entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   (...) -- as all previous private queue declarations
end Queue_Pack_Concrete;
```

A synchronous implementation of the abstract type `Queue_Interface`

All abstract methods are **overridden** with concrete implementations.

132

A concrete queue specification

```
with Queue_Pack_Abstract;
generic
   with package Queue_Instance is new Queue_Pack_Abstract (<>);
   type Index is mod <>; -- Modulo defines size of the queue.
package Queue_Pack_Concrete is
   use Queue_Instance;
   type Queue_Type is limited private;
   protected type Protected_Queue is new Queue_Interface with
      overriding entry Enqueue (Item :     Element);
      overriding entry Dequeue (Item : out Element);
      not overriding procedure Empty_Queue;
      not overriding function Is_Empty return Boolean;
      not overriding function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   (...) -- as all previous private queue declarations
end Queue_Pack_Concrete;
```

Other (not-overriding) methods can be added.

133

A concrete queue specification

```
with Queue_Pack_Abstract;
generic
   with package Queue_Instance is new Queue_Pack_Abstract (<>);
   type Index is mod <>; -- Modulo defines size of the queue.
package Queue_Pack_Concrete is
   use Queue_Instance;
   type Queue_Type is limited private;
   protected type Protected_Queue is new Queue_Interface with
      overriding entry Enqueue (Item :     Element);
      overriding entry Dequeue (Item : out Element);
      procedure Empty_Queue;
      function Is_Empty return Boolean;
      function Is_Full  return Boolean;
   private
      Queue : Queue_Type;
   end Protected_Queue;
private
   (...) -- as all previous private queue declarations
end Queue_Pack_Concrete;
```

... anything on this slide still not perfectly clear?

134

A concrete queue implementation

```
package body Queue_Pack_Concrete is
   protected body Protected_Queue is
      entry Enqueue (Item : Element) when not Is_Full is
      begin
         Queue.Elements (Queue.Free) := Item; Queue.Free := Index'Succ (Queue.Free);
         Queue.Is_Empty := False;
      end Enqueue;
      entry Dequeue (Item : out Element) when not Is_Empty is
      begin
         Item := Queue.Elements (Queue.Top); Queue.Top := Index'Succ (Queue.Top);
         Queue.Is_Empty := Queue.Top = Queue.Free;
      end Dequeue;
      procedure Empty_Queue is
      begin
         Queue.Top := Index'First; Queue.Free := Index'First; Queue.Is_Empty := True;
      end Empty_Queue;
      function Is_Empty return Boolean is (Queue.Is_Empty);
      function Is_Full  return Boolean is
        (not Queue.Is_Empty and then Queue.Top = Queue.Free);
   end Protected_Queue;
end Queue_Pack_Concrete;
```

Identical

135

A dispatching test program

```
with Ada.Text_IO;          use Ada.Text_IO;
with Queue_Pack_Abstract;
with Queue_Pack_Concrete;
procedure Queue_Test_Dispatching is
   package Queue_Pack_Abstract_Character is
      new Queue_Pack_Abstract (Character);
   use Queue_Pack_Abstract_Character;
   type Queue_Size is mod 3;
   package Queue_Pack_Character is
      new Queue_Pack_Concrete (Queue_Pack_Abstract_Character, Queue_Size);
   use Queue_Pack_Character;
   type Queue_Class is access all Queue_Interface'class;
   task Queue_Holder; -- could be on an individual partition / separate computer
   task Queue_User is -- could be on an individual partition / separate computer
      entry Send_Queue (Remote_Queue : Queue_Class);
   end Queue_User;
(...)
begin
   null;
end Queue_Test_Dispatching;
```

A dispatching test *program*

```
with Ada.Text_IO;          use Ada.Text_IO;
with Queue_Pack_Abstract;
with Queue_Pack_Concrete;
procedure Queue_Test_Dispatching is
   package Queue_Pack_Abstract_Character is
      new Queue_Pack_Abstract (Character);
   use Queue_Pack_Abstract_Character;
   type Queue_Size is mod 3;
   package Queue_Pack_Character is
      new Queue_Pack_Concrete (Queue_Pack_Abstract_Character, Queue_Size);
   use Queue_Pack_Character;
   type Queue_Class is access all Queue_Interface'class;
   task Queue_Holder; -- could be on an individual partition / separate computer
   task Queue_User is -- could be on an individual partition / separate computer
      entry Send_Queue (Remote_Queue : Queue_Class);
   end Queue_User;
(...)
begin
   null;
end Queue_Test_Dispatching;
```

Sequence of instantiations

A dispatching test *program*

```
with Ada.Text_IO;          use Ada.Text_IO;
with Queue_Pack_Abstract;
with Queue_Pack_Concrete;
procedure Queue_Test_Dispatching is
   package Queue_Pack_Abstract_Character is
      new Queue_Pack_Abstract (Character);
   use Queue_Pack_Abstract_Character;
   type Queue_Size is mod 3;
   package Queue_Pack_Character is
      new Queue_Pack_Concrete (Queue_Pack_Abstract_Character, Queue_Size);
   use Queue_Pack_Character;
   type Queue_Class is access all Queue_Interface'class;
   task Queue_Holder; -- could be on an individual partition / separate computer
   task Queue_User is -- could be on an individual partition / separate computer
      entry Send_Queue (Remote_Queue : Queue_Class);
   end Queue_User;
(...)
begin
   null;
end Queue_Test_Dispatching;
```

Type which can refer to any instance of Queue_Interface

A dispatching test *program*

```
with Ada.Text_IO;          use Ada.Text_IO;
with Queue_Pack_Abstract;
with Queue_Pack_Concrete;
procedure Queue_Test_Dispatching is
   package Queue_Pack_Abstract_Character is
      new Queue_Pack_Abstract (Character);
   use Queue_Pack_Abstract_Character;
   type Queue_Size is mod 3;
   package Queue_Pack_Character is
      new Queue_Pack_Concrete (Queue_Pack_Abstract_Character, Queue_Size);
   use Queue_Pack_Character;
   type Queue_Class is access all Queue_Interface'class;
   task Queue_Holder; -- could be on an individual partition / separate computer
   task Queue_User is -- could be on an individual partition / separate computer
      entry Send_Queue (Remote_Queue : Queue_Class);
   end Queue_User;
(...)
begin
   null;
end Queue_Test_Dispatching;
```

Declaring two concrete tasks.
(Queue_User has a synchronous message passing entry)

A dispatching test *program*

```
with Ada.Text_IO;          use Ada.Text_IO;
with Queue_Pack_Abstract;
with Queue_Pack_Concrete;
procedure Queue_Test_Dispatching is
   package Queue_Pack_Abstract_Character is
      new Queue_Pack_Abstract (Character);
   use Queue_Pack_Abstract_Character;
   type Queue_Size is mod 3;
   package Queue_Pack_Character is
      new Queue_Pack_Concrete (Queue_Pack_Abstract_Character, Queue_Size);
   use Queue_Pack_Character;
   type Queue_Class is access all Queue_Interface'class;
   task Queue_Holder; -- could be on an individual partition / separate computer
   task Queue_User is -- could be on an individual partition / separate computer
      entry Send_Queue (Remote_Queue : Queue_Class);
   end Queue_User;
(...)
begin
   null;
end Queue_Test_Dispatching;
```

… anything on this slide still not perfectly clear?

140

A dispatching test program (cont.)

```
task body Queue_Holder is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   Queue_User.Send_Queue (Local_Queue);
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (Holder): " & Character'Image (Item));
end Queue_Holder;

task body Queue_User is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   accept Send_Queue (Remote_Queue : Queue_Class) do
      Remote_Queue.all.Enqueue ('r'); -- potentially a remote procedure call!
      Local_Queue.all.Enqueue  ('l');
   end Send_Queue;
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (User)   : " & Character'Image (Item));
end Queue_User;
```


141

A dispatching test program (cont.)

```
task body Queue_Holder is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   Queue_User.Send_Queue (Local_Queue);
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (Holder): " & Character'Image (Item));
end Queue_Holder;

task body Queue_User is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   accept Send_Queue (Remote_Queue : Queue_Class) do
      Remote_Queue.all.Enqueue ('r'); -- potentially a remote procedure call!
      Local_Queue.all.Enqueue  ('l');
   end Send_Queue;
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (User)   : " & Character'Image (Item));
end Queue_User;
```

Declaring local queues in each task.

142

A dispatching test program (cont.)

```
task body Queue_Holder is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   Queue_User.Send_Queue (Local_Queue);
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (Holder): " & Character'Image (Item));
end Queue_Holder;

task body Queue_User is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   accept Send_Queue (Remote_Queue : Queue_Class) do
      Remote_Queue.all.Enqueue ('r'); -- potentially a remote procedure call!
      Local_Queue.all.Enqueue  ('l');
   end Send_Queue;
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (User)   : " & Character'Image (Item));
end Queue_User;
```

Handing over the Holder's queue via synchronous message passing.

143

A dispatching test program (cont.)

```
task body Queue_Holder is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   Queue_User.Send_Queue (Local_Queue);
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (Holder): " & Character'Image (Item));
end Queue_Holder;

task body Queue_User is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   accept Send_Queue (Remote_Queue : Queue_Class) do
      Remote_Queue.all.Enqueue ('r'); -- potentially a remote procedure call!
      Local_Queue.all.Enqueue  ('l');
   end Send_Queue;
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (User)   : " & Character'Image (Item));
end Queue_User;
```

Adding to both queues

144

A dispatching test program (cont.)

Tasks could run on separate computers

```
task body Queue_Holder is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   Queue_User.Send_Queue (Local_Queue);
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (Holder): " & Character'Image (Item));
end Queue_Holder;

task body Queue_User is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   accept Send_Queue (Remote_Queue : Queue_Class) do
      Remote_Queue.all.Enqueue ('r'); -- potentially a remote procedure call!
      Local_Queue.all.Enqueue  ('l');
   end Send_Queue;
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (User)   : " & Character'Image (Item));
end Queue_User;
```

These two calls can be very different in nature:

The first call is potentially **tunneled through a network** to another computer and thus uses a **remote data structure**.

The second call is always a **local call** and using a **local data-structure**.

145

A dispatching test program (cont.)

```
task body Queue_Holder is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   Queue_User.Send_Queue (Local_Queue);
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (Holder): " & Character'Image (Item));
end Queue_Holder;

task body Queue_User is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   accept Send_Queue (Remote_Queue : Queue_Class) do
      Remote_Queue.all.Enqueue ('r'); -- potentially a remote procedure call!
      Local_Queue.all.Enqueue  ('l');
   end Send_Queue;
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (User)   : " & Character'Image (Item));
end Queue_User;
```

Reading out 'r'

Reading out 'l'

146

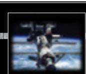
A dispatching test program (cont.)

```
task body Queue_Holder is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   Queue_User.Send_Queue (Local_Queue);
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (Holder): " & Character'Image (Item));
end Queue_Holder;

task body Queue_User is
   Local_Queue : constant Queue_Class := new Protected_Queue;
   Item        : Character;
begin
   accept Send_Queue (Remote_Queue : Queue_Class) do
      Remote_Queue.all.Enqueue ('r'); -- potentially a remote procedure call!
      Local_Queue.all.Enqueue  ('l');
   end Send_Queue;
   Local_Queue.all.Dequeue (Item);
   Put_Line ("Local dequeue (User)   : " & Character'Image (Item));
end Queue_User;
```

… anything on this slide still not perfectly clear?

147



Language refresher / introduction course

Ada

Ada language status

Boeing 787 cockpit (press release photo)

- Established language standard with free and professionally supported compilers available for all major OSs and platforms.
- Emphasis on maintainability, high-integrity and efficiency.
- Stand-alone runtime environments for embedded systems.
- High integrity, real-time profiles part of the standard ☞ e.g. Ravenscar profile.

☞ Used in many large scale and/or high integrity projects

- Commonly used in aviation industry, high speed trains, metro-systems, space programs and military programs.
- … also increasingly on small platforms / micro-controllers.

TGV, Renaud Chodkowski 2012

148

Language refresher / introduction course

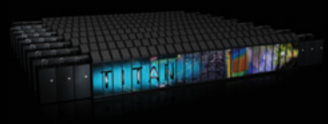
Chapel

Currently under development at Cray.
(originally for the DARPA High Productivity Computing Systems initiative.)

☞ Targeted at massively parallel computers

Language primitives for ...

- Data parallelism:
  - ☞ Distributed data storage with fine grained control ("domains").
  - ☞ Concurrent map operations (`forall`).
  - ☞ Concurrent fold operations (`scan, reduce`).
- Task parallelism:
  - ☞ concurrent loops and blocks (`cobegin, coforall`).
- Synchronization:
  - ☞ Task synchronization, synchronized variables, atomic sections.



149

A data-parallel stencil program

```
config const n              = 100,
             max_iterations = 50,
             epsilon        = 1.0E-5,
             initial_border = 1.0;
const Matrix_w_Borders = {0 .. n + 1, 0 .. n + 1, 0 .. n + 1},
      Matrix           = Matrix_w_Borders [1 .. n, 1 .. n, 1 .. n],
      Single_Border    = Matrix.exterior (1, 0, 0);
var Field      : [Matrix_w_Borders] real,
    Next_Field : [Matrix]           real;
proc Stencil (M : [/* Matrix_w_Borders */] real, (i, j, k) : index (Matrix)) : real {
  return (M [i - 1, j, k]
        + M [i + 1, j, k]
        + M [i, j - 1, k]
        + M [i, j + 1, k]
        + M [i, j, k + 1]
        + M [i, j, k - 1]) / 6;
}
```

150

A data-parallel stencil program

```
config const n              = 100,
             max_iterations = 50,
             epsilon        = 1.0E-5,
             initial_border = 1.0;
const Matrix_w_Borders = {0 .. n + 1, 0 .. n + 1, 0 .. n + 1},
      Matrix           = Matrix_w_Borders [1 .. n, 1 .. n, 1 .. n],
      Single_Border    = Matrix.exterior (1, 0, 0);
var Field      : [Matrix_w_Borders] real,
    Next_Field : [Matrix]           real;
proc Stencil (M : [/* Matrix_w_Borders */] real, (i, j, k) : index (Matrix)) : real {
  return (M [i - 1, j, k]
        + M [i + 1, j, k]
        + M [i, j - 1, k]
        + M [i, j + 1, k]
        + M [i, j, k + 1]
        + M [i, j, k - 1]) / 6;
}
```

Configuration constants can be set via command line options:
`./Stencil --n=500`

151

A data-parallel stencil program

```
config const n              = 100,
             max_iterations = 50,
             epsilon        = 1.0E-5,
             initial_border = 1.0;
const Matrix_w_Borders = {0 .. n + 1, 0 .. n + 1, 0 .. n + 1},
      Matrix           = Matrix_w_Borders [1 .. n, 1 .. n, 1 .. n],
      Single_Border    = Matrix.exterior (1, 0, 0);
var Field      : [Matrix_w_Borders] real,
    Next_Field : [Matrix]           real;
proc Stencil (M : [/* Matrix_w_Borders */] real, (i, j, k) : index (Matrix)) : real {
  return (M [i - 1, j, k]
        + M [i + 1, j, k]
        + M [i, j - 1, k]
        + M [i, j + 1, k]
        + M [i, j, k + 1]
        + M [i, j, k - 1]) / 6;
}
```

Defining **domains** to be used for multi-dimensional array declarations and assignments.

152

A data-parallel stencil program

```
config const n              = 100,
             max_iterations = 50,
             epsilon        = 1.0E-5,
             initial_border = 1.0;
const Matrix_w_Borders = {0 .. n + 1, 0 .. n + 1, 0 .. n + 1},
      Matrix           = Matrix_w_Borders [1 .. n, 1 .. n, 1 .. n],
      Single_Border    = Matrix.exterior (1, 0, 0);
var Field      : [Matrix_w_Borders] real,
    Next_Field : [Matrix]           real;
proc Stencil (M : [/* Matrix_w_Borders */] real, (i, j, k) : index (Matrix)) : real {
  return (M [i - 1, j, k]
        + M [i + 1, j, k]
        + M [i, j - 1, k]
        + M [i, j + 1, k]
        + M [i, j, k + 1]
        + M [i, j, k - 1]) / 6;
}
```

Declaring matrices of different, yet related dimensions.

153

A data-parallel stencil program

```
config const n              = 100,
             max_iterations = 50,
             epsilon        = 1.0E-5,
             initial_border = 1.0;
const Matrix_w_Borders = {0 .. n + 1, 0 .. n + 1, 0 .. n + 1},
      Matrix           = Matrix_w_Borders [1 .. n, 1 .. n, 1 .. n],
      Single_Border    = Matrix.exterior (1, 0, 0);
var Field      : [Matrix_w_Borders] real,
    Next_Field : [Matrix]           real;
proc Stencil (M : [/* Matrix_w_Borders */] real, (i, j, k) : index (Matrix)) : real {
  return (M [i - 1, j, k]
        + M [i + 1, j, k]
        + M [i, j - 1, k]
        + M [i, j + 1, k]
        + M [i, j, k + 1]
        + M [i, j, k - 1]) / 6;
}
```

Note the index type

Function which calculates a "stencil" value at a spot inside a given matrix

154

A data-parallel stencil program

```
config const n              = 100,
             max_iterations = 50,
             epsilon        = 1.0E-5,
             initial_border = 1.0;
const Matrix_w_Borders = {0 .. n + 1, 0 .. n + 1, 0 .. n + 1},
      Matrix           = Matrix_w_Borders [1 .. n, 1 .. n, 1 .. n],
      Single_Border    = Matrix.exterior (1, 0, 0);
var Field      : [Matrix_w_Borders] real,
    Next_Field : [Matrix]           real;
proc Stencil (M : [/* Matrix_w_Borders */] real, (i, j, k) : index (Matrix)) : real {
  return (M [i - 1, j, k]
        + M [i + 1, j, k]
        + M [i, j - 1, k]
        + M [i, j + 1, k]
        + M [i, j, k + 1]
        + M [i, j, k - 1]) / 6;
}
```

… anything on this slide still not perfectly clear?

155

A data-parallel stencil program (cont.)

```
Field [Single_Border] = initial_border;

for l in 1 .. max_iterations {

  forall Matrix_Indices in Matrix do
    Next_Field (Matrix_Indices) = Stencil (Field, Matrix_Indices);

  const delta = max reduce abs (Field [Matrix] - Next_Field);

  Field [Matrix] = Next_Field;

  if delta < epsilon then break;
}
```

156

A data-parallel stencil program (cont.)

```
Field [Single_Border] = initial_border;

for l in 1 .. max_iterations {

  forall Matrix_Indices in Matrix do
    Next_Field (Matrix_Indices) = Stencil (Field, Matrix_Indices);

  const delta = max reduce abs (Field [Matrix] - Next_Field);

  Field [Matrix] = Next_Field;

  if delta < epsilon then break;
}
```

Scalar to 2-d array-slice assignment
(Technically a 3-d domain with two degenerate dimensions)

3-d array to 3-d array-slice assignment

157

A data-parallel stencil program (cont.)

```
Field [Single_Border] = initial_border;

for l in 1 .. max_iterations {

  forall Matrix_Indices in Matrix do
    Next_Field (Matrix_Indices) = Stencil (Field, Matrix_Indices);

  const delta = max reduce abs (Field [Matrix] - Next_Field);

  Field [Matrix] = Next_Field;

  if delta < epsilon then break;
}
```

Data parallel application of the `Stencil` function to the whole 3-d matrix

158

A data-parallel stencil program (cont.)

```
Field [Single_Border] = initial_border;

for l in 1 .. max_iterations {

  forall Matrix_Indices in Matrix do
    Next_Field (Matrix_Indices) = Stencil (Field, Matrix_Indices);

  const delta = max reduce abs (Field [Matrix] - Next_Field);

  Field [Matrix] = Next_Field;

  if delta < epsilon then break;
}
```

Data parallel (divide-and-conquer) application of the `max` function to the component-wise differences.

"3-d data-parallel version" of (Haskell):
`foldr max minBound $ zipWith (-) field next_field`

159

A data-parallel stencil program (cont.)

```
Field [Single_Border] = initial_border;

for l in 1 .. max_iterations {

  forall Matrix_Indices in Matrix do
    Next_Field (Matrix_Indices) = Stencil (Field, Matrix_Indices);

  const delta = max reduce abs (Field [Matrix] - Next_Field);

  Field [Matrix] = Next_Field;

  if delta < epsilon then break;
}
```

… anything on this slide still not perfectly clear?

Summary

Language refresher / introduction course

- Specification and implementation (body) parts, basic types
- Exceptions & Contracts
- Information hiding in specifications (‘private’)
- Generic programming
- Tasking
- Monitors and synchronisation (‘protected’, ‘entries’, ‘selects’, ‘accepts’)
- Abstract types and dispatching
- Data parallel operations

