What You Always Wanted to Know About Exceptions But Were Afraid to "Raise"

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So What Are Exceptions?

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Overview

- Introduction
- Major Benefits of Exceptions
- Ada 95 RM View of Exceptions (with Ada 83 deltas)
- Designing Software With Exceptions
  - Design Considerations
  - Ada 95 Quality and Style Guide
  - Design Examples
  - Planning for Exceptions
- Issues Using Exceptions - Exception Gotchas
- Future of Ada Exceptions (Exception Workshop)
- Conclusion

Introduction
Ada Exceptions

Support fault tolerance and safety critical requirements

Hardware faults

Network errors

Capacity faults

Error conditions

Ada predefined exceptions &
User defined exceptions

Handled by an exception handler

Allows user to identify what to do when things go wrong and return to some known safe state

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Introduction
Ada Exceptions

- Exceptions are
  - *Declared*, like types, variables, etc.; there are also some predefined exceptions
  - *Raised*, explicitly (by a raise statement) or implicitly (by Ada runtime)
  - *Caught*, explicitly (by name) or implicitly ("when others =>")
  - *Propagated*, from called subprogram to calling subprogram
- In general, exceptions are an excellent feature
  - Reliability enhancing feature designed to help specify program behavior in the presence of unexpected events
  - Allows separation of error-handling code from normal code
- However, good design and coding guidelines are essential
  - Cannot infer from a subprogram specification what exceptions the subprogram may propagate
- And automated checking for conformance to guidelines is beneficial

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Introduction
Simple Example of Exceptions in Ada

```
procedure Quadratic (A, B, C : in Float ; R1, R2 : out Float) is
   D : Float ;
begin
   D := B**2 - 4.0*A*C ;
   R1 := (-B - Sqrt (D) ) / (2. 0*A) ;
   R2 := (-B + Sqrt (D) ) / (2.0*A) ;
exception
   when Negative_Sqrt =>
      R1 := 0.0; R2 := 0.0; raise No_real_solutions ;   -- Setting legitimate values for R1 & R2.
                                                         -- Raising meaningful exception to calling
                                                            -- subprogram.
   when others =>
      Put_Line ("Problem in Quadratic") ;
      raise ;                                            -- Re-Raising other exceptions.
end Quadratic ;

function Sqrt (X : Float) return Float is
begin
   if X < 0.0 then
      raise Negative_Sqrt ;
   end if ;
   ...
end Sqrt;
```


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Benefits of Using Ada Exceptions

- Provides a reliability-enhancing language feature designed to help specify program behavior in the presence of errors or unexpected events
- Supports the logical differentiation of normal and exceptional control paths, which can lead to clarity and ease of understanding
- Avoids "overloading" a parameter with multiple layers of abstraction (i.e., products of computation and status of that computation), which can cause confusion
- Supports the notion of error status that should not be ignored (a notorious practice in, e.g., much C software)
- Intuitive way of dealing with results of interactions among asynchronous independent activities
  - No amount of precondition testing can avoid chance of encountering error condition (e.g., jammed cable)
- Supports the return to some known safe state

Ada 95 RM
Clause 11 Exceptions

11.1 Exception Declarations

11.2 Exception Handlers

11.3 Raise Statements

11.4 Exception Handling

11.4.1 The Package Ada.Exceptions

11.5 Suppressing Checks

11.6 Exceptions and Optimization

Ada 83 code is fully upward compatible to Ada 95

Major Changes for Ada 83 => Ada 95

- Numeric_Error is a renaming of Constraint_Error and is obsolete.
- Notion of Exception_Occurrence is introduced (Ada.Exceptions).
- Interaction between exceptions and optimization is clarified.
- Accept statement may now have a handler.

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Ada 95 RM
11.1 Exception Declarations

Predefined exceptions declared in package Standard:

- Constraint_Error,
- Program_Error,
- Storage_Error, and
- Tasking_Error;

Numeric_Error from Ada 83 is obsolete

Declaration of name for a user-defined exception:

exception_declaration ::= defining_identifier_list : exception;

Examples of user-defined exception declarations:

```
Node_Not_Defined    : exception;
My_Error            : exception;
Overflow, Underflow : exception;
```

Also declared in other packages

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Ada 95 RM

11.2 Exception Handlers - 1

Response to exceptions is specified by exception_handler:

```
handled_sequence_of_statements ::= sequence_of_statements
                                   [exception
                                      exception_handler
                                      {exception_handler}]

exception_handler ::=
      when [choice_parameter_specification:]
            exception_choice {| exception_choice} =>
            sequence_of_statements

choice_parameter_specification ::= defining_identifier
exception_choice ::= exception_name | others
```

Found in Frames -
Different from Ada 83

Ada 95 RM
11.2 Exception Handlers - 2

handled_sequence_of_statements found in Frames,
i.e., block_statement, subprogram_body, package_body,
task_body, accept_statement, entry_body

Simplifies syntax of all frames for Ada 95, e.g.,

Ada 95:

```
subprogram_body ::=
    subprogram_specification is
        declarative_part
   begin
      handled_sequence_of_statements
   end [designator];
```

However, no change in source from Ada 83 => Ada 95 :-)

Different in Ada 83:

```
subprogram_body ::=
    subprogram_specification is
        [declarative_part]
   begin
        sequence_of_statements
  [exception
        exception_handler
       {exception_handler}]
   end [designator];
```

Ada 95 RM
11.2 Exception Handlers - 3

Example: [in Frame, have Frame_Name:= “My_Procedure”;]

```
begin
    Open(File, In_File, "input.txt");   -- Ada.Sequential_IO
exception
    when E : Name_Error =>
        Put("Cannot open input file in  ");
        Put(Frame_Name); -- Should be provided with Information
        Put_Line(Exception_Occurrence(E)); -- fully qualified name
        Put_Line(Exception_Message(E)); -- short message
        Put_Line(Exception_Information(E)); -- implementation defined
                        -- see package Ada.Exceptions
        raise;
  end;
```

E is Defining_Identifier for Exception_Occurrence

Ada.IO_Exceptions contains:
Status_Error, Mode_Error, Name_Error, Use_Error, Device_Error, End_Error, Data_Error, Layout_Error.

Ada 95 RM

11.2 Exception Handlers - 4

- When an exception occurrence is raised by the execution of a given construct, the rest of the execution of that construct is abandoned; i.e., Control is transferred to the handler.

Then:

- If the construct is the sequence_of_statements of a handled_sequence_of_statements that has a handler with a choice covering the exception, the occurrence is handled by that handler;

Handler replaces abandoned portion of handled_sequence_of_statements

- If the construct is a task_body or main program, the exception does not propagate further; The task dies; ditto for main program.
- Otherwise, the occurrence is propagated to the innermost dynamically enclosing execution, i.e., the occurrence is raised again in that context.

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Ada 95 RM
11.2 Exception Handlers - 5

Exception Propagation Flow of Control

```
procedure A is
begin
 X;
 B;
 Y;
exception
 when My_Exception =>
  Log_Error;
end A;
```

```
procedure B is
begin
 P;
 C;
 Q;
exception
 when others =>
  raise;
end B;
```

```
procedure C is
begin
 R;
 raise My_Exception;
 S;
exception
 when My_Exception =>
  Log_Error;
  raise;
end C;
```

Calls to Y, Q, and S are not executed

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Ada 95 RM
11.3 Raise Statements

Raise Statements “raise” an exception:

raise_statement ::= raise [exception_name];

Examples of raise statements:

```
raise Node_Not_Defined;
raise My_Error;
raise Overflow;
raise;       -- called a re-raise (only allowed in a handler)
```

Ada 95 RM

11.4 Package Ada.Exceptions - 1

New for Ada 95

```
package Ada.Exceptions is
    type Exception_Id is private;
    -- Attribute E'Identity returns the unique identity of the exception.

    Null_Id : constant Exception_Id; -- Default initial value of objects of Exception_Id

    type Exception_Occurrence is limited private;
    -- Each occurrence of an exception is represented by a value of Exception_Occurrence

    type Exception_Occurrence_Access is access all Exception_Occurrence;
    Null_Occurrence : constant Exception_Occurrence;

    function Exception_Identity(X : Exception_Occurrence) return Exception_Id;
    -- Returns full expanded name of the exception in upper case
    --   starting with a root library unit.
    -- Implementation-defined if exception declared in an unnamed block_statement

    function Exception_Name(Id : Exception_Id) return String;

    function Exception_Name(X : Exception_Occurrence) return String;
    -- Same as Exception_Name(Exception_Identity(X)).
```

Ada 95 RM
11.4 Package Ada.Exceptions - 2

```
procedure Raise_Exception(E : in Exception_Id; Message : in String := "");
  -- Raises new occurrence. Default message is "Raise_Exception"

procedure Reraise_Occurrence(X : in Exception_Occurrence);
-- Similar to Raise_Exception, but reraises original Exception_Occurrence

function Exception_Message(X : Exception_Occurrence) return String;
 -- Returns a one line nameless message associated with Exception_Occurrence

function Exception_Information(X : Exception_Occurrence) return String;
-- Returns implementation-defined information about the exception.

procedure Save_Occurrence(Target : out Exception_Occurrence;
                          Source : in Exception_Occurrence);
 -- Copies Source to Target; Target can be used in Reraise_Occurrence later

function Save_Occurrence(Source : Exception_Occurrence)
                        return Exception_Occurrence_Access;
-- Creates new object, copies Source to object, returns access value designating
--    new object; result can be deallocated using _Unchecked_Deallocation
private
      ... -- not specified by the language
end Ada.Exceptions;
```


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Ada 95 RM
11.5 Suppressing Checks - 1

pragma Suppress gives *permission* to an implementation to omit certain language-defined checks

```
pragma Suppress(identifier [, [On =>] name]);
```

- Allowed only immediately within a declarative_part, immediately within a package_specification, or as a configuration pragma.
- For use within a package_specification, the name shall denote an entity (or several overloaded subprograms) declared immediately within the package_specification.

If a given check has been suppressed, and the corresponding error situation occurs, the execution of the program is erroneous.

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Ada 95 RM
11.5 Suppressing Checks - 2

- **Identifiers identify checks:**
  - **Constraint_Error checks:** Access_Check, Discriminant_Check, *Division_Check*, Index_Check, Length_Check, *Overflow_Check*, Range_Check, Tag_Check
  - **Program_Error checks:** Elaboration_Check, Accessibility_Check
  - **Storage_Error checks:** Storage_Check
  - **Suppress all checks:** All_Checks
- **Examples:**

```
pragma Suppress(Range_Check);
pragma Suppress(Index_Check, On => Table);
pragma Suppress(All_Checks);
```

Ada 83:
Checks for Numeric_Error
Check N/A
Note Upward Compatible

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Ada 95 RM

11.6 Exceptions and Optimization (The fine print)

The following additional permissions are granted to the implementation:

- An implementation need not always raise an exception when a language-defined check fails. Instead, the operation that failed the check can simply yield an undefined result. The exception need be raised by the implementation only if, in the absence of raising it, the value of this undefined result would have some effect on the external interactions of the program. In determining this, the implementation shall not presume that an undefined result has a value that belongs to its subtype, nor even to the base range of its type, if scalar. Having removed the raise of the exception, the canonical semantics will in general allow the implementation to omit the code for the check, and some or all of the operation itself.
- If an exception is raised due to the failure of a language-defined check, then upon reaching the corresponding exception_handler (or the termination of the task, if none), the external interactions that have occurred need reflect only that the exception was raised somewhere within the execution of the sequence_of_statements with the handler (or the task_body), possibly earlier (or later if the interactions are independent of the result of the checked operation) than that defined by the canonical semantics, but not within the execution of some abort-deferred operation or independent subprogram that does not dynamically enclose the execution of the construct whose check failed. An independent subprogram is one that is defined outside the library unit containing the construct whose check failed, and has no Inline pragma applied to it. Any assignment that occurred outside of such abort-deferred operations or independent subprograms can be disrupted by the raising of the exception, causing the object or its parts to become abnormal, and certain subsequent uses of the object to be erroneous, as explained in 13.9.1.
- The permissions granted by this clause can have an effect on the semantics of a program only if the program fails a language-defined check.

Design Considerations Overview

- Thoughts on Exception Use Impacting Design
- Alternative Ways to Handle Exceptions
- Ada 95 Quality and Style Guide Recommendations
- Examples for Systems Design

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Thoughts on Exception Use Impacting Design

- **Unhandled exceptions will propagate all the way up the calling sequence, causing termination of the task or program**
- **Exception propagation can violate abstractions, forcing clients of abstractions to handle implementation details**
- ***Anonymous* exceptions can result from the interaction of exception propagation (dynamic) with Ada scoping rules (static)**
- **Analysis of exception propagation can be difficult in large systems due to the mixture of dynamic and static aspects**
- **Subtle interactions with other language features, e.g., propagation can be arbitrarily delayed waiting on termination of dependent tasks in a frame, propagation can expose parameter-passing mechanisms, etc.**

Proper Design Can Result in Highly Effective Results

Design Considerations
Alternative Ways To Handle Exceptions

- How is the exception caught?
  - Explicitly ("when My_Exception =>")
  - Implicitly ("when others =>")
  - Not at all
- What is propagated out of the handler?
  - Nothing (stops)
  - Same exception (passes)
  - Different exception (maps)

Ada 95 Quality & Style Guide – Section 3.2.7
Naming Conventions for Exceptions

Guideline:

- Use a name that indicates the kind of problem the exception represents.

Example:

```
Invalid_Name: exception;
Stack_Overflow: exception;
```

Rationale:

- Naming exceptions according to the kind of problem they are detecting enhances the readability of the code.

Ada 95 Quality & Style Guide – Section 3.3.2
File Headers for Exceptions

Guideline:

- Describe the complete interface to the program unit, including any exceptions it can raise and any global effects it can have.

Example:

```
-- Exceptions:
--       Node_Not_Defined – A node must be defined …
```

Rationale:

- The purpose of a header comment on the specification of a program unit is to help the user understand how to use the program unit.
- None of this information can be determined from the Ada specification of the program unit.

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Ada 95 Quality & Style Guide – Section 3.3.5
Comments for Exceptions

Guideline:

- Comment on all data types, objects, and exceptions unless their names are self-explanatory.
  - The conditions under which an exception is raised should be commented.

Example:

```
Node_Already_Defined : exception;
                     --| Raised when an attempt is made to define
                     --| a node with an identifier which already
                     --| defines a node.
```

Rationale:

- The reader has no other way to find out the exact meaning of the exception (without reading the code in the package body).

Ada 95 Quality & Style Guide – Section 4.3.1
Using Exceptions to Help Define an Abstraction - 1

Guidelines:

- For unavoidable internal errors for which no user recovery is possible, declare a single user-visible exception. Inside the abstraction, provide a way to distinguish between the different internal errors.
- Do not borrow an exception name from another context.
- Export (declare visibly to the user) the names of all exceptions that can be raised.
- In a package, document which exceptions can be raised by each subprogram and task entry.
- Do not raise exceptions for internal errors that can be avoided or corrected within the unit.
- Do not raise the same exception to report different kinds of errors that are distinguishable by the user of the unit.

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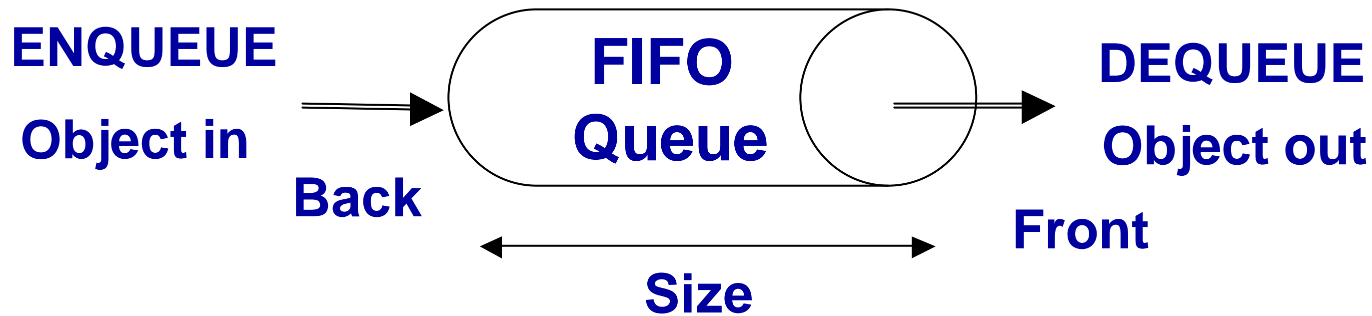
Ada 95 Quality & Style Guide – Section 4.3.1
Using Exceptions to Help Define an Abstraction - 2

Guidelines (continued):

- Provide interrogative functions that allow the user of a unit to avoid causing exceptions to be raised.
- When possible, avoid changing state information in a unit before raising an exception.
- Catch and convert or handle all predefined and compiler-defined exceptions at the earliest opportunity.
- Do not explicitly raise predefined or implementation-defined exceptions.
- Never let an exception propagate beyond its scope.

Ada 95 Quality & Style Guide – Section 4.3.1
Using Exceptions to Help Define an Abstraction - 3



Abstraction Using Ada Package Specification & Exceptions

```
package QUEUE is
    procedure DEQUEUE (Object : out Object_type);
    procedure ENQUEUE (Object : in   Object_type);
    function Is_Empty return Boolean;
    function Is_Full return Boolean;
    OVERFLOW, UNDERFLOW : exception;
end QUEUE;
```

From application:

```
ENQUEUE(Object);
DEQUEUE(Object);
```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Ada 95 Quality & Style Guide – Section 5.4.5
Data Structures – Dynamic Data

Guideline:

- **Provide handlers for Storage_Error.**

Example:

```
when Storage_Error =>
          Do_Some_Garbage_Collection;
           raise; -- Allowing subprogram to be called again in loop.
```

Rationale:

- **Prepare handlers for the exception Storage_Error, and consider carefully what alternatives you may be able to include in the program for each such situation.**

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Ada 95 Quality & Style Guide – Section 5.6.9
Statements – Blocks

Guideline:

- **Use blocks to define local exception handlers.**

Example:

```
for I in 1 .. Sample_Limit loop
   Get_Samples_And_Ignore_Invalid_Data:
      declare
         -- declarations
      begin
         Get_Value(Current);
      exception
         when Constraint_Error =>
            null; -- Continue trying
         when Accelerometer_Device.Failure =>
            raise Accelerometer_Device_Failed;
      end Get_Samples_And_Ignore_Invalid_Data;
   exit when Current <= 0.0; -- Slowing down
end loop;
```

Rationale:

Local exception handlers can catch exceptions close to the point of origin and allow them to be either handled, propagated, or converted.

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Ada 95 Quality & Style Guide – Section 5.8
Using Exceptions – Programming Practices

"Ada exceptions are a reliability-enhancing language feature designed to help specify program behavior in the presence of errors or unexpected events.

"Exceptions are **not** intended to provide a general purpose control construct."

"Further, liberal use of exceptions should **not** be considered sufficient for providing full software fault tolerance (Melliar-Smith and Randell 1987)."

Sections =>

5.8.1 Handling Versus Avoiding Exceptions

5.8.2 Handlers for Others

5.8.3 Propagation

5.8.4 Localizing the Cause of an Exception

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Ada 95 Quality & Style Guide – Section 5.8.1
Handling Versus Avoiding Exceptions - 1

Guidelines:

- When it is easy and efficient to do so, avoid causing exceptions to be raised.
- Provide handlers for exceptions that cannot be avoided.
- Use exception handlers to enhance readability by separating fault handling from normal execution.
- Do not use exceptions and exception handlers as `goto` statements.
- Do not evaluate the value of an object (or a part of an object) that has become abnormal because of the failure of a language-defined check.

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Ada 95 Quality & Style Guide – Section 5.8.1
Handling Versus Avoiding Exceptions - 2

Example:

- Test an integer for 0 before dividing by it
- Call an interrogative function Stack_Is_Empty before invoking the pop procedure of a stack package
- Use exceptions where such a
  - test is too expensive [Entry_Exists before each call to the procedure Modify_Entry simply to avoid raising the exception Entry_Not_Found] or
  - or too unreliable [Concurrent Operations]

Rationale:

- In many cases, it is possible to detect easily and efficiently that an operation you are about to perform would raise an exception.
- When fault handling and only fault handling code is included in exception handlers, the separation makes the code easier to read.

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Ada 95 Quality & Style Guide – Section 5.8.2
Handlers for Others - 1

Guidelines:

- When writing an exception handler for *when others*, capture and return additional information about the exception through the Exception_Name, Exception_Message, or Exception_Information subprograms declared in the predefined package Ada.Exceptions.
- Use others only to catch exceptions you cannot enumerate explicitly, preferably only to flag a potential abort.
- During development, trap others, capture the exception being handled, and consider adding an explicit handler for that exception.

Rationale:

- Writing a handler without these subprograms limits the amount of error information you may see.
- Programming a handler for others requires caution. You should name the exception in the handler.

Ada 95 Quality & Style Guide – Section 5.8.2
Handlers for Others - 2

Example

```
with Ada.Exceptions; …
function Valid_Choice return Positive is
   subtype Choice_Range is Positive range 1..3;
   Choice : Choice_Range;
begin
    Put ("Please enter your choice: 1, 2, or 3: ");
   Ada.Integer_Text_IO.Get (Choice);
    if Choice in Choice_Range then   -- else garbage returned
       return Choice;
    end if;
 exception
    when Out_of_Bounds : Constraint_Error =>
       Put_Line ("Input choice not in range: ");
       Put_Line (Ada.Exceptions.Exception_Name (Out_of_Bounds));
       Skip_Line;
     when The_Error : others =>
       Put_Line ("Unexpected error: ");
       Put_Line (Ada.Exceptions.Exception_Information (The_Error));
       Skip_Line;
end Valid_Choice;
```

Input choice not in range: Constraint_Error

Unexpected error: Program_Error

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Ada 95 Quality & Style Guide – Section 5.8.3
Propagation

Guidelines:

- Handle all exceptions, both user and predefined.
- For every exception that might be raised, provide a handler in suitable frames to protect against undesired propagation outside the abstraction.

Rationale:

- The statement that "it can never happen" is not an acceptable programming approach.
- You must assume it can happen and be in control when it does. You should provide defensive code routines for the "cannot get here" conditions.
- You should catch the exception and propagate it or a substitute only if your handler is at the wrong abstraction level to effect recovery.

Ada 95 Quality & Style Guide – Section 5.8.4
Localizing the Cause of an Exception

Guidelines:

- Do not rely on being able to identify the fault-raising, predefined, or implementation-defined exceptions.
- Use the facilities defined in Ada.Exceptions to capture as much information as possible about an exception.
- Use blocks to associate localized sections of code with their own exception handlers.

Rationale:

- In an exception handler, it is very difficult to determine exactly which statement and which operation within that statement raised an exception.
- The predefined exceptions are candidates for conversion and propagation to higher abstraction levels for handling there.
- User-defined exceptions, being more closely associated with the application, are better candidates for recovery within handlers.

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Ada 95 Quality & Style Guide – Section 5.9.5
Suppression of Exception Check

Section 5.9 is: ERRONEOUS EXECUTION AND BOUNDED ERRORS

Guidelines:

- **Do not suppress exception checks during development.**
- **Minimize suppression of exception checks during operation.**
- **If necessary, during operation, introduce blocks that encompass the smallest range of statements that can safely have exception checking removed.**

Rationale:

- **If you disable exception checks and program execution results in a condition in which an exception would otherwise occur, the program execution is erroneous. The results are unpredictable.**
- **Further, you must still be prepared to deal with the suppressed exceptions if they are raised in and propagated from the bodies of subprograms, tasks, and packages you call.**
- **By minimizing the code that has exception checking removed, you increase the reliability of the program.**

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Ada 95 Quality & Style Guide – Section 5.9.8
Exception Propagation

Section 5.9 is: ERRONEOUS EXECUTION AND BOUNDED ERRORS

Guideline:

- **Prevent exceptions from propagating outside any user-defined Finalize or Adjust procedure by providing handlers for all predefined and user-defined exceptions at the end of each procedure.**

Rationale:

- **Using Finalize or Adjust to propagate an exception results in a bounded error (Ada Reference Manual 1995, §7.6.1). Either the exception will be ignored or a Program_Error exception will be raised.**

[For Controlled Types - See RM §7.6 for Ada.Finalization]

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Ada 95 Quality & Style Guide – Section 6.2.2
Concurrency – Defensive Task Communications - 1

Guidelines:

- **Provide a handler for exception Program_Error whenever you cannot avoid a selective accept statement whose alternatives can all be closed (Honeywell 1986).**
- **Make systematic use of handlers for Tasking_Error.**
- **Be prepared to handle exceptions during a rendezvous.**
- **Consider using a *when others* exception handler.**

Example:

```
Accelerate:
 begin
    Throttle.Increase(Step);
 exception
    when Tasking_Error     =>     ...
    when Program_Error  =>        ...
    when Throttle_Too_Wide =>     ...
    ...
    when others =>   ...
end Accelerate;
```


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Ada 95 Quality & Style Guide – Section 6.2.2
Concurrency – Defensive Task Communications - 2

Rationale:

- The exception Program_Error is raised if a selective accept statement is reached, all of whose alternatives are closed (i.e., the guards evaluate to False and there are no alternatives without guards), unless there is an else part. When all alternatives are closed, the task can never again progress, so there is by definition an error in its programming.
- Because an else part cannot have a guard, it can never be closed off as an alternative action; thus, its presence prevents Program_Error. However, an else part, a delay alternative, and a terminate alternative are all mutually exclusive, so you will not always be able to provide an else part.

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Ada 95 Quality & Style Guide – Section 6.2.2
Concurrency – Defensive Task Communications - 3

Rationale (continued):

- The exception Tasking_Error can be raised in the calling task whenever it attempts to communicate. There are many situations permitting this. Few of them are preventable by the calling task.
- If an exception is raised during a rendezvous and not handled in the accept statement, it is propagated to both tasks and must be handled in two places.
- The handling of the others exception can be used to avoid propagating unexpected exceptions to callers (when this is the desired effect) and to localize the logic for dealing with unexpected exceptions in the rendezvous. After handling, an unknown exception should normally be raised again because the final decision of how to deal with it might need to be made at the outermost scope of the task body.

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Ada 95 Quality & Style Guide – Section 6.3.1
Avoiding Undesired Task Termination - 1

Guideline:

- Consider using an exception handler for a rendezvous within the main loop inside each task.

Rationale:

- Allowing a task to terminate might not support the requirements of the system. Without an exception handler for the rendezvous within the main task loop, the functions of the task might not be performed.
- The use of an exception handler is the only way to guarantee recovery from an entry call to an abnormal task. Use of the 'Terminated attribute to test a task's availability before making the entry call can introduce a race condition where the tested task fails after the test but before the entry call.

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Ada 95 Quality & Style Guide – Section 6.3.1
Avoiding Undesired Task Termination - 2

Example:

```
loop                                   -- CPP = Current_Position_Primary
   Recognize_Degraded_Mode:            -- CPB = Current_Position_Backup
      begin
         case Mode is
            when Primary =>
               select
                  CPP.Request_New_Coordinates (X, Y);
               or
                  delay 0.25;
                  -- Decide whether to switch modes;
               end select;
            when Degraded =>
               CPB.Request_New_Coordinates (X, Y);
         end case;
         ...
      exception
         when Tasking_Error | Program_Error =>
            Mode := Degraded;
      end Recognize_Degraded_Mode;
end loop;
```


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Ada 95 Quality & Style Guide – Section 6.3.4
Abnormal Task Termination - 1

Guidelines:

- Place an exception handler for others at the end of a task body.
- Consider having each exception handler at the end of a task body report the task's demise.
- Do not rely on the task status to determine whether a rendezvous can be made with the task.

Rationale:

- A task will terminate if an exception is raised within it for which it has no handler. In such a case, the exception is not propagated outside of the task (unless it occurs during a rendezvous). The task simply dies with no notification to other tasks in the program. Therefore, providing exception handler for others, ensures that a task can regain control after an exception occurs.

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Ada 95 Quality & Style Guide – Section 6.3.4
Abnormal Task Termination - 2

Example:

```
 task type Track (My_Index : Track_Index) is
   ...
end Track;
------------------------------------------------------------
task body Track is
    Neutral : Boolean := True;
begin  -- Track
   select
      accept ...
          ...
      or
     terminate;
   end select;
   ...
   exception
     when others =>
         if not Neutral then Station(My_Index).Status := Dead;
     end if;
end Track;
```

Should the task terminate due to an exception, it signals the fact in one of its parent's data structures, "Station".

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Ada 95 Quality & Style Guide – Section 7.1
Portability - Ada 83 Obsolescent Features

Guideline:

- Avoid using the exception Numeric_Error

Rationale:

- Ten years of reflection on the use of Ada 83 led to the conclusion that some features of the original language are not as useful as originally intended.
- It would have been desirable to remove the obsolescent features completely, but that would have prevented the upward compatible transition from Ada 83 to Ada 95.
- Thus, the obsolescent features remain in the language and are explicitly labeled as such in Annex J of the Ada Reference Manual (1995). The features listed in Annex J are candidates for removal from the language during its next revision.

Ada 95 Quality & Style Guide – Section 7.5
Portability - Exceptions

Guidelines:

- Do not depend on the exact locations at which predefined exceptions are raised.
- Do not rely on the behavior of Ada.Exceptions beyond the minimum defined in the language.
- Do not raise implementation-specific exceptions.
- Convert implementation-specific exceptions within interface packages to visible user-defined exceptions.

Rationale:

- Predefined exceptions may be raised from different locations. Predefined exceptions are associated with a variety of conditions.
- No exception defined specifically by an implementation can be guaranteed to be portable to other implementations.

Do not allow yourself to be forced to find and change the name of every handler you have written for these exceptions when the program is ported.

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Ada 95 Quality & Style Guide – Section 8.2.7
Reusability - Exceptions

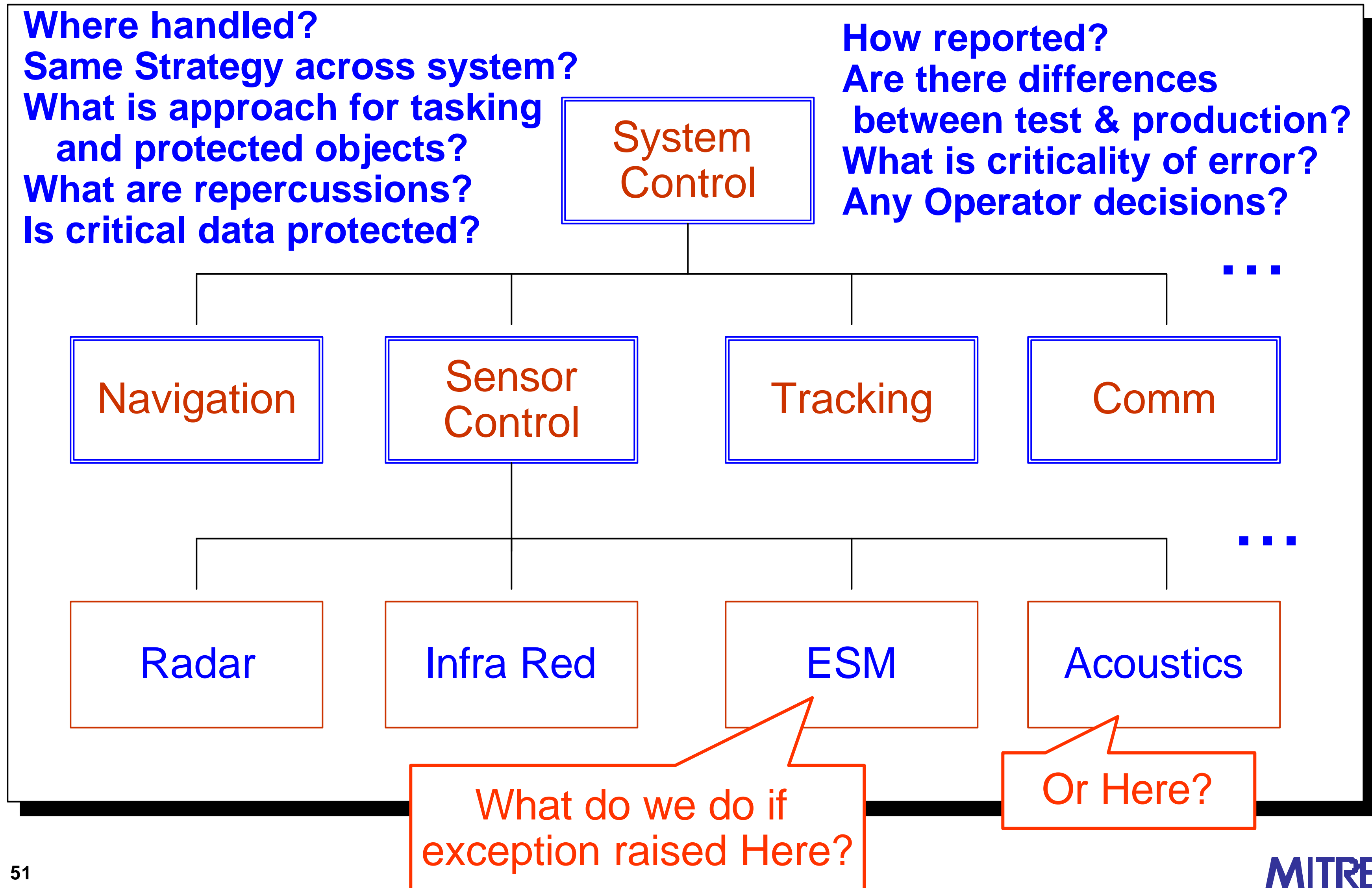
Guideline:

- Propagate exceptions out of reusable parts. Handle exceptions within reusable parts only when you are certain that the handling is appropriate in all circumstances.
- Propagate exceptions raised by generic formal subprograms after performing any cleanup necessary to the correct operation of future invocations of the generic instantiation.
- Leave state variables in a valid state when raising an exception.
- Leave parameters unmodified when raising an exception.

Rationale:

- When an exception is raised by a generic formal subprogram, the generic unit is in no position to understand why or to know what corrective action to take.
- The generic unit must first clean up after itself, restoring its internal data structures to a correct state so that future calls may be made to it after the caller has dealt with the current exception.

Design Considerations
Example 1: System Example



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Design Considerations
Example 1: Planning For Exceptions - 1

Microsoft Excel - Airborne Operational Program Error Planning.xls

Error Description

Exception	Type of Error	Located in System	Located in Module	Impact of Error	Notes on Method of Detection
INS_1_Timeout_Error	Inertial 1 Failed	AOP	Navigation	Navigation Degraded	Timeout = 50 milliseconds
INS_2_Timeout_Error	Inertial 1 Failed	AOP	Navigation	Navigation Degraded	Timeout = 50 milliseconds
INS_3_Timeout_Error	Inertial 1 Failed	AOP	Navigation	Navigation Degraded	Timeout = 50 milliseconds
Voting_Plane_INS_1_Bad_Error	Inertial 1 Computation Bad	AOP	Navigation	Only 2 INS's agree	Threshold = .0000001 Seconds
Voting_Plane_INS_2_Bad_Error	Inertial 2 Computation Bad	AOP	Navigation	Only 2 INS's agree	Threshold = .0000001 Seconds
Voting_Plane_INS_3_Bad_Error	Inertial 3 Computation Bad	AOP	Navigation	Only 2 INS's agree	Threshold = .0000001 Seconds
INS_1_Out_To_Lunch_Error	Inertial 1 Computation Bad 10 Times	AOP	Navigation	INS_1 Needs Initialization	Raised by Voting_Plane_INS_1_Bad_Error
INS_2_Out_To_Lunch_Error	Inertial 2 Computation Bad 10 Times	AOP	Navigation	INS_2 Needs Initialization	Raised by Voting_Plane_INS_2_Bad_Error
INS_3_Out_To_Lunch_Error	Inertial 3 Computation Bad 10 Times	AOP	Navigation	INS_3 Needs Initialization	Raised by Voting_Plane_INS_3_Bad_Error
Voting_Plane_No_Agree_Error	No vote of INSs within Threshold	AOP	Navigation	INS to use =???	Threshold = .0000001 Seconds
FTP_Invalid_Error	Operator entered Fly To Point Invalid	AOP	Navigation	Operator Must Reenter	FTP not within 500 nm of current position
Navigation_Subsystem_Error	Variety of Error Conditions	AOP	Navigation	All Nav Reinitialized	Variety of Error Conditions enumerate

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Design Considerations
Example 1: Planning For Exceptions - 2

Microsoft Excel - Airborne Operational Program Error Planning.xls

Exception-Handler Description

Exception	Log	Alert Operator	Local Recovery Action	Propogate To Caller	Caller Recovery Action
INS_1_Timeout_Error	Yes	Warning	Disable INS_1; Request INS_1 Reinitialize	No	Null
INS_2_Timeout_Error	Yes	Warning	Disable INS_2; Request INS_2 Reinitialize	No	Null
INS_3_Timeout_Error	Yes	Warning	Disable INS_3; Request INS_3 Reinitialize	No	Null
Voting_Plane_INS_1_Bad_Error	Yes	No	Increment Counter, Bad 10 times Raise OTLE	Conditional	Disable INS_1; Request INS_1 Reinitialize
Voting_Plane_INS_2_Bad_Error	Yes	No	Increment Counter, Bad 10 times Raise OTLE	Conditional	Disable INS_2; Request INS_2 Reinitialize
Voting_Plane_INS_3_Bad_Error	Yes	No	Increment Counter, Bad 10 times Raise OTLE	Conditional	Disable INS_3; Request INS_3 Reinitialize
INS_1_Out_To_Lunch_Error	Yes	Warning	Disable INS_1; Request INS_1 Reinitialize	No	Null
INS_2_Out_To_Lunch_Error	Yes	Warning	Disable INS_2; Request INS_2 Reinitialize	No	Null
INS_3_Out_To_Lunch_Error	Yes	Warning	Disable INS_3; Request INS_3 Reinitialize	No	Null
Voting_Plane_No_Agree_Error	Yes	Severe	Disable all 3 INSs;Dead Reckon; Reinitialize	Yes	Disable all 3 INSs;Dead Reckon; Reinitialize all 3
FTP_Invalid_Error	No	Yes	None	Yes	Error Message to User; Ask to Renter FTP
Navigation_Subsystem_Error	Yes	Severe	Null	To Nav Main	Main: Reinitialize Navigation Subsystem

Perhaps Other Columns for:

- Propogate to Subsystem Main Loop
- Main Loop Recovery Action
- Module/Package Declared
- Tasking Actions
- Exception Messages Used

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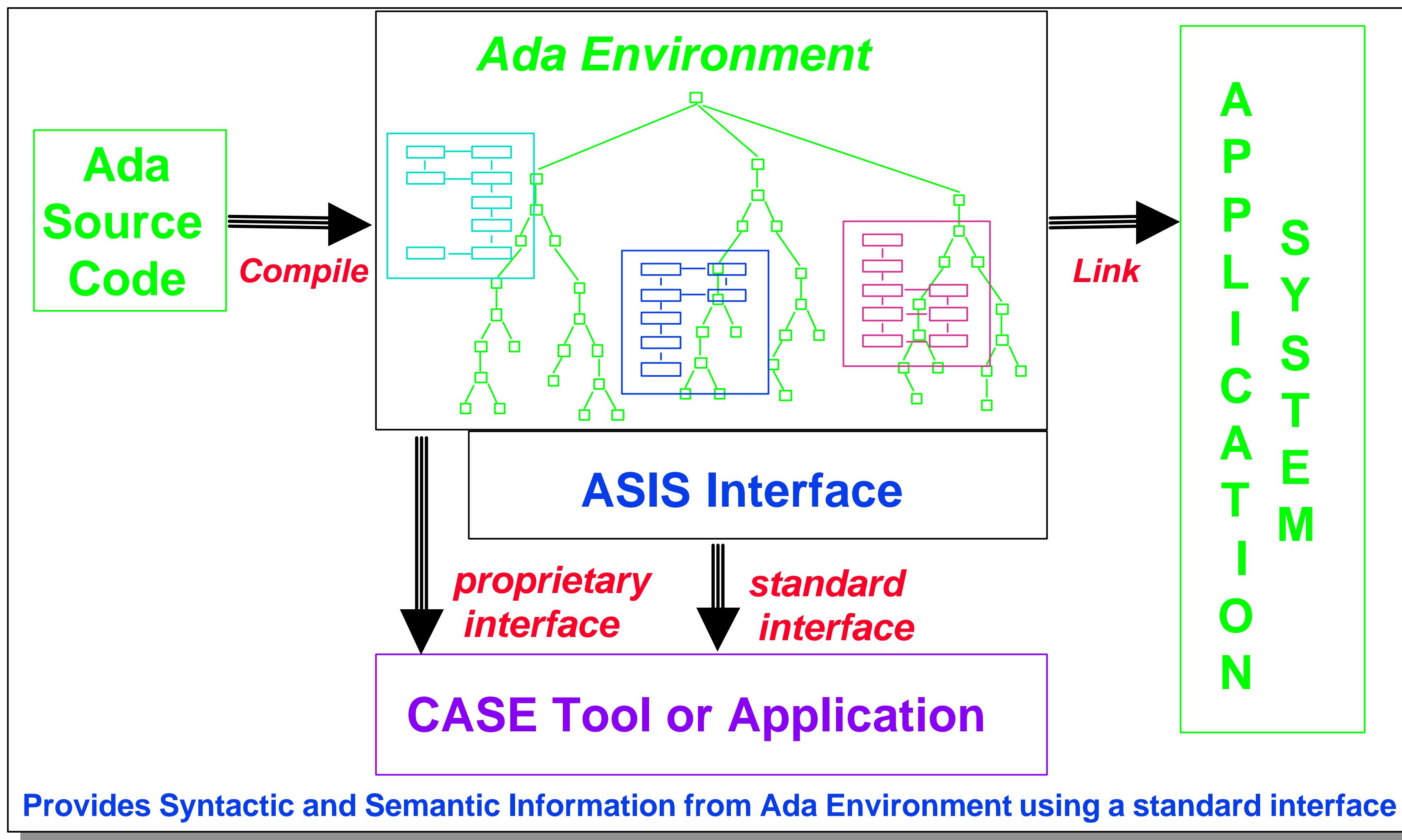
Design Considerations
Example 2: ASIS Client - Server Example

- **The Ada Semantic Interface Specification (ASIS) exception handling mechanism is a good example demonstrating the types of things useful to do in a design.**

  The Ada Semantic Interface Specification (ASIS) is an interface between an Ada environment (as defined by ISO/IEC 8652:1995) and any tool or application requiring information from it. An Ada environment includes valuable semantic and syntactic information. ASIS is an open and published callable interface which gives CASE tool and application developers access to this information. ASIS has been designed to be independent of underlying Ada environment implementations, thus supporting portability of software engineering tools while relieving tool developers from needing to understand the complexities of an Ada environment's proprietary internal representation. In short, ASIS can provide the foundation for your code analysis activities.

What is ASIS?



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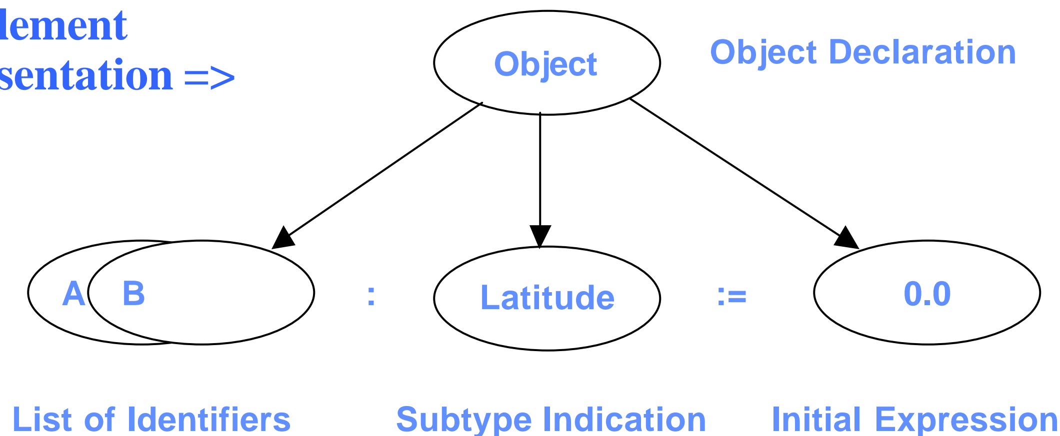
Syntactic Information

Ada syntax is summarized in Ada 95 RM, Annex P as variant of Backus-Naur Form

For example:
object_declaration ::==
defining_identifier_list : [**aliased**] [**constant**] subtype_indication [:= expression]; | ...

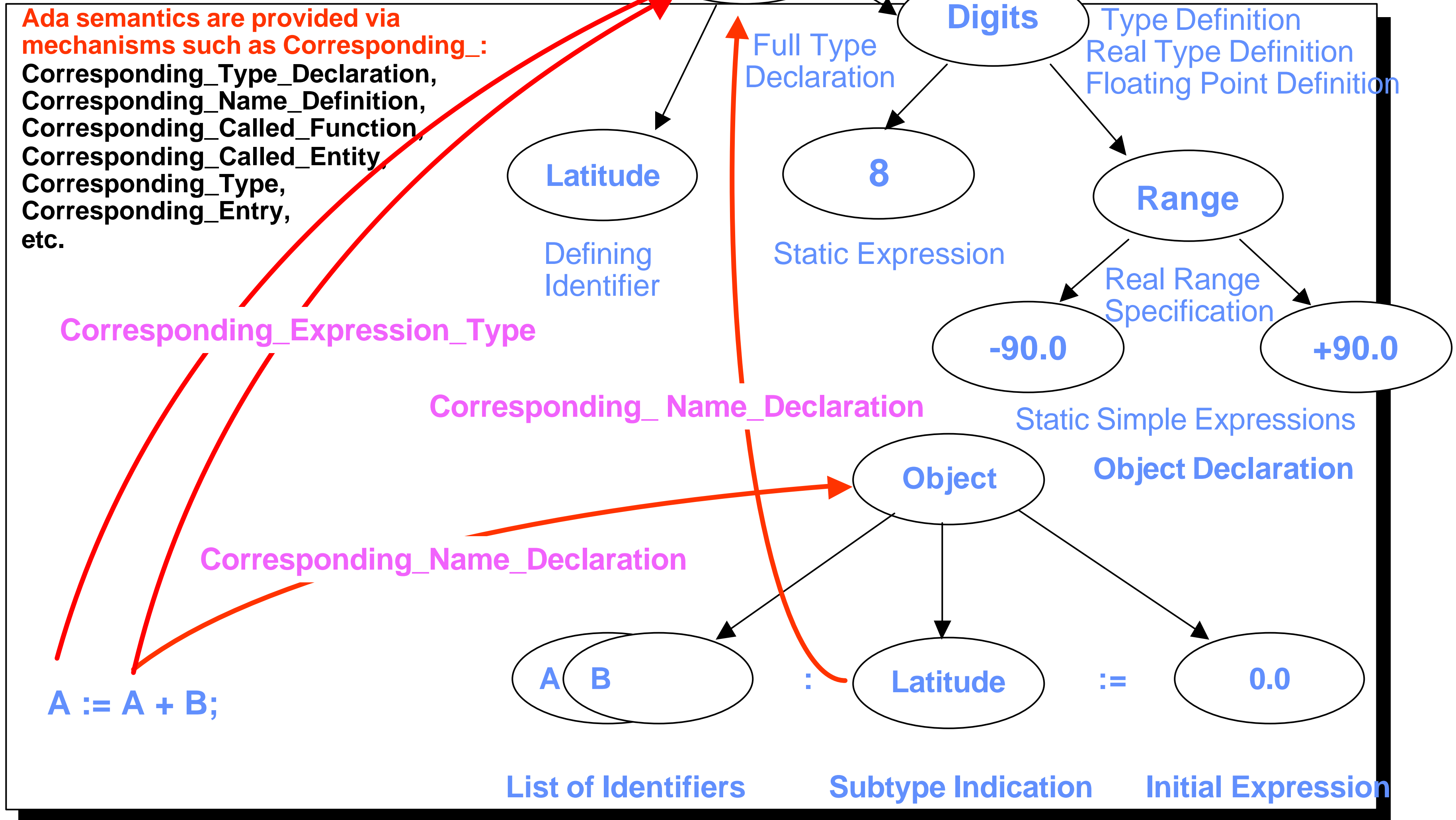
For the Ada object declaration => A,B: Latitude := 0.0;

Syntactic Element
Tree Representation =>



ASIS can extract desired syntactic information for every syntactic category
Of the 367 ASIS Queries, most support syntactic tree analysis

Semantic Information



These mechanisms allow ASIS to traverse the syntactic tree like Hypertext allows one to traverse a document

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ASIS Abstractions - Package ASIS

Ada Semantic Interface Specification (ASIS)

Package Asis provides:

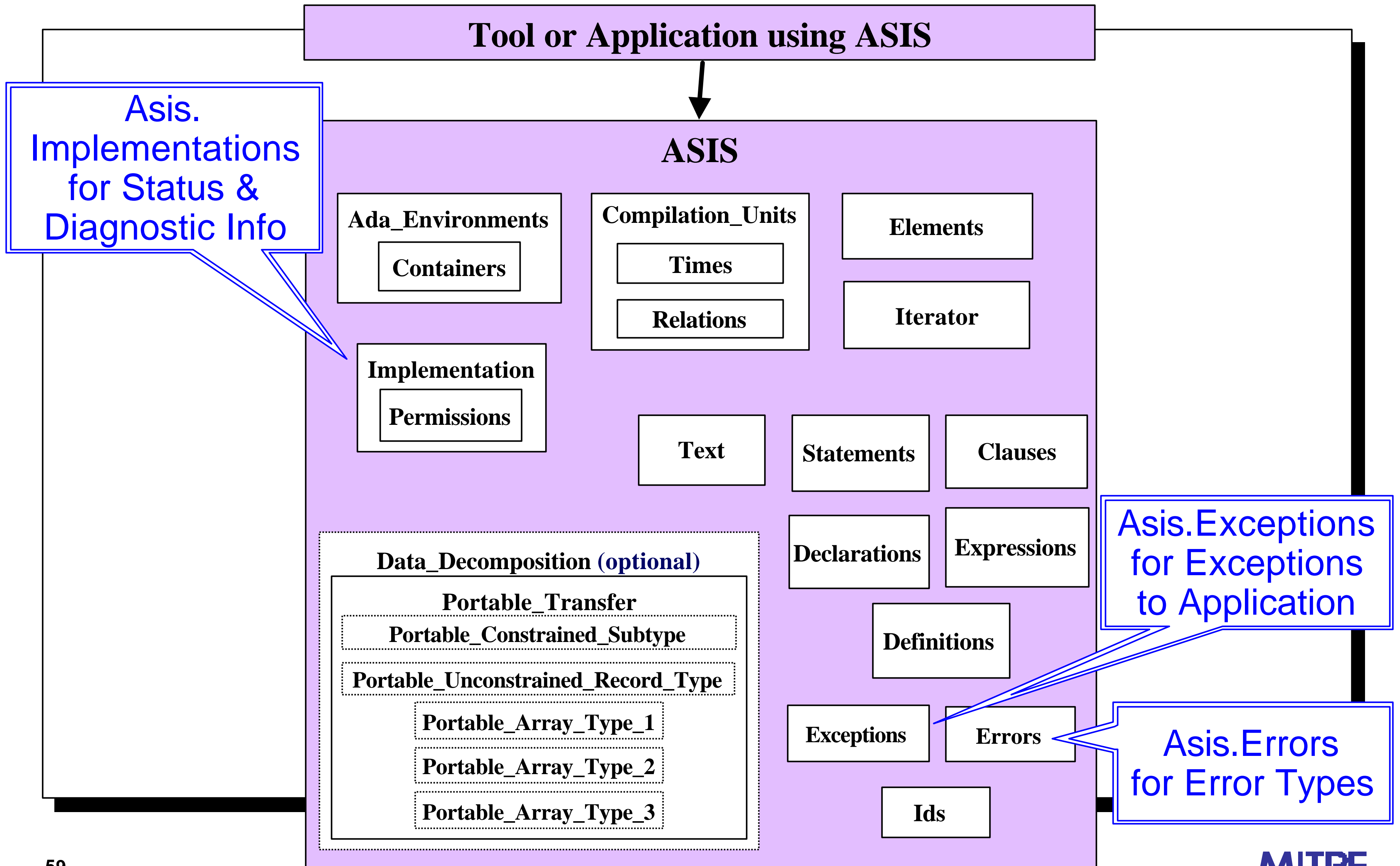
- **Common types:**
  ASIS_Integer, ASIS_Natural, ASIS_Positive,
  List_Index,
  Context,
  Element, Element_List, Element Subtypes,
  Element Kinds (collection of enumeration types)
  Compilation_Units, Compilation_Unit_List,
  Unit Kinds (collection of enumeration types),
  Traverse_Control, and
  Program_Text (subtype of Wide_String)
- **Queries via 20 visible child packages**
- **Ada Exceptions for errors with Status & Diagnostic information**

Defined mechanisms for Errors

Asis and child packages encapsulate vendor dependencies

Designed to be portable for all implementations

ASIS Package Architecture



Design Considerations
ASIS Exceptions - Example

```
package Asis.Exceptions is   -- Clause 5 in ISO/IEC 15291: 1999
ASIS_Inappropriate_Context : exception;
ASIS_Inappropriate_Container : exception;
ASIS_Inappropriate_Compilation_Unit : exception;
ASIS_Inappropriate_Element : exception;
ASIS_Inappropriate_Line : exception;
ASIS_Inappropriate_Line_Number : exception;
ASIS_Failed : exception;
-- This is a catch-all exception that may be raised for different reasons
-- in different ASIS implementations.  All ASIS routines may raise ASIS_Failed
-- whenever they cannot normally complete their operation.  This exception
-- will typically indicate a failure of the underlying ASIS implementation.
end Asis.Exceptions;
```

Those that can be raised across ASIS interface

Exceptions for all normal error conditions

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Design Considerations - Example
ASIS Exceptions used with ASIS Errors

- ASIS reports all operational errors by raising an exception.
- Whenever an ASIS implementation raises one of the exceptions declared in package Asis.Exceptions, it will previously have set the values returned by the Status and Diagnosis queries to indicate the cause of the error.
- The possible values for Status are indicated in the definition of Error_Kinds, with suggestions for the associated contents of the Diagnosis string as a comment.
- The Diagnosis and Status queries are provided in the Asis.Implementation package to supply more information about the reasons for raising any exception.
- ASIS applications are encouraged to follow this same convention whenever they explicitly raise any ASIS exception--always record a Status and Diagnosis prior to raising the exception.

Design Considerations - Example
Package ASIS Errors defines the kinds of errors

```
package Asis.Errors is                          -- Clause 4 in ISO/IEC 15291: 1999
type Error_Kinds is (
      Not_An_Error,                             -- No error is presently recorded
      Value_Error,                              -- Routine argument value invalid
      Initialization_Error,                     -- ASIS is uninitialized
      Environment_Error,                        -- ASIS could not initialize
      Parameter_Error,                          -- Bad Parameter given to Initialize
      Capacity_Error,                           -- Implementation overloaded
      Name_Error,                               -- Context/unit not found
      Use_Error,                                -- Context/unit not use/open-able
      Data_Error,                               -- Context/unit bad/invalid/corrupt
      Text_Error,                               -- The program text cannot be located
      Storage_Error,                            -- Storage_Error suppressed
      Obsolete_Reference_Error,                 -- Argument or result is invalid due to
                                                  -- and inconsistent compilation unit
      Unhandled_Exception_Error,                -- Unexpected exception suppressed
      Not_Implemented_Error,                    -- Functionality not implemented
      Internal_Error);                          -- Implementation internal failure
end Asis.Errors;
```

Design Considerations - Example
Status Reporting

```
Package Asis.Implementation  -- Clause 6 in ISO/IEC 15291: 1999

   function Status return Asis.Errors.Error_Kinds; -- Clause 6.9
      -- Returns the Error_Kinds value for the most recent error.
   function Diagnosis return Wide_String; -- Clause 6.10
     -- Returns a string value describing the most recent error.
     -- Will typically return a null string if Status = Not_An_Error.
  procedure Set_Status -- Clause 6.11
      (Status    : in  Asis.Errors.Error_Kinds := Asis.Errors.Not_An_Error;
       Diagnosis : in Wide_String        := "");
     -- Status      - Specifies the new status to be recorded
     -- Diagnosis   - Specifies the new diagnosis to be recorded
     -- Sets (clears, if the defaults are used) the Status and Diagnosis
     -- information.  Future calls to Status will return this Status (Not_An_Error)
     -- and this Diagnosis (a null string).
     -- Raises ASIS_Failed, with a Status of Internal_Error and a Diagnosis of
     -- a null string, if the Status parameter is Not_An_Error and the Diagnosis
     -- parameter is not a null string.
end Asis.Implementation;
```

Design Considerations - Example
Notional Exception Handler

```
exception
  when Asis.Exceptions.ASIS_Inappropriate_Context
     | Asis.Exceptions.ASIS_Inappropriate_Container
     | Asis.Exceptions.ASIS_Inappropriate_Compilation_Unit
     | Asis.Exceptions.ASIS_Inappropriate_Element
     | Asis.Exceptions.ASIS_Inappropriate_Line
     | Asis.Exceptions.ASIS_Inappropriate_Line_Number
     | Asis.Exceptions.ASIS_Failed
    =>
    Put (Asis.Implementation.Diagnosis);
    Put ("Status Value is ");
    Put (Asis.Errors.Error_Kinds'Wide_Image (Asis.Implementation.Status));

  when others =>
    Put_Line ("Asis Application failed because of non-ASIS reasons");
end ASIS_Call_Tree_Example:
```

Full compilable example on ASIS Home Page:

http://www.acm.org/sigada/wg/asiswg

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Design Considerations - Example Error Message

Error probably in code being analyzed

```
08:13:40 *** UNEXPECTED ERROR, EXCEPTION:
  ASIS.EXCEPTIONS.ASIS_INAPPROPRIATE_ELEMENT
  DIAGNOSIS: Raise location: #015407FC. Asis Diagnosis: Element is Nil.
 Internal => Asis_Declarations.Object_Declaration_Definition
  (SOL,120.0.2.1)>>STATUS: VALUE_ERROR, Version: 120.0.2.1, UNIT:
  /project/AAAV/aaav200101/gunner.ss/sun4_solaris2_ada95_3_2_0.wrk/unit
  s/battlesight_range_adjust_pkg.2.ada, On line:  541

08:12:31 *** Traversal of unit
  /project/AAAV/aaav200101/gunner.ss/sun4_solaris2_ada95_3_2_0.wrk/unit
  s/mailbox_pkg.2.ada terminated. Diagnosis: Exception:
  ADA.IO_EXCEPTIONS.DATA_ERROR (raised at #015407FC)
 Internal =>
  Asis_Elements.Traverse_Element.Pre_Operation/DN_SUBPROGRAM_BODY:
  Asis_Elements.Walk'N(2)/DN_SUBPROGRAM_BODY:
  Asis_Elements.Walk'N(1)/DN_SUBPROGRAM_BODY:
  Asis_Elements.Children/DN_ITEM_S: Asis_Elements.Walk'N(1)/DN_ITEM_S:
  Asis_Elements.Children/DN_BLOCK: Asis_Elements.Walk'N(2)/DN_BLOCK:
  Asis_Elements.Walk'N(1)/DN_BLOCK:
  Asis_Elements.Children/DN_PACKAGE_BODY:
  Asis_Elements.Walk_First/DN_PACKAGE_BODY:
  Asis_Elements.Traverse_Element
 (SOL,120.0.2.1) Status: UNHANDLED_EXCEPTION_ERROR
```

Error probably in tool

Exception Gotchas - 1

Function Handlers Must Raise Exception or Return

- Functions must either return a value or propagate an exception. Otherwise the exception Program_Error is raised. Six instances were detected where an exception handler would handle exceptions raised, but would neither return a known safe value or propagate an exception. The fact that the designer added the exception handler implied that exceptions were possible.

```
function Next_Packet return Rcv_Type is
   ...
begin
   ...
exception

  when Exception_Id: others =>
      Log_Error (Package_Id & ".Next_Packet: Unhandled
               exception: " &
    Ada.Exceptions.Exception_Information (Exception_Id));

end Next_Packet;
```

6 Violations in recent analysis

Exception Gotchas - 2

Unset Out Parameters

- When a handler does not propagate the exception, out parameters of a procedure and return values of functions should be set. In the case of a procedure, if the out parameters are not set appropriately, the calling program is likely to use them erroneously.

```
function Compute_Range return Integer is
   ...
begin
   ...
exception

  when Range_Not_Computable => return 0;
  when others =>
      Log_Error (Package_Id & ".Next_Packet: Unhandled
               exception: " &
    Ada.Exceptions.Exception_Information (Exception_Id));
    raise;
end Next_Packet;
```

Acceptable return value

Acceptable to reraise the exception

Either prevents Program_Error

Exception Gotchas - 3

Missing Storage Error Handler For Allocators

- Any allocator can exhaust the available space for the collection, the use of allocators should be limited and the "out of memory" case handled locally. An exception handler for Storage Error should be provided in the local scope for each allocator.

143 Violations in recent analysis

Exception Gotchas - 4

Exception handler with "*when others => null*"

- Use of a "when others" whose statement body is "null" may be inappropriate in that they catch all exceptions but provide no further processing of conditions that led to the exception.
- Exceptions should be used to trap expected problems and revert to some known safe state. These are normally classified as serious errors since should an exception be raised, processing continues which is likely degraded.

```
when others =>
   null;
```

13 Violations in recent analysis

Catches the exception, but erroneous problem is not resolved, resulting in erroneous execution, which some folks call "Graceful Degradation"

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Exception Gotchas - 5

Use of When Others in an Exception Handler

- Such handlers are a catchall and may be inappropriate in some cases. It prevents the opportunity to return the system to a known safe state based on the exception named. Typical action is to log the exception and to allow the system to perform in a degraded state. It is better practice to handle all potential exceptions explicitly. It should be noted that it is quite valuable to have such an exception handler within a looped block for tasks and main programs, as the absence there can result in a system crash.

659 Violations in recent analysis

```
when Exception_Id: others =>
    Log_Error (Package_Id & ".Next_Packet: Unhandled
            exception: " &
  Ada.Exceptions.Exception_Information (Exception_Id));
```

Logs the exception, but erroneous problem is not resolved allowing for "Graceful Degradation"

Useful to Have "when others" at Subsystem/System Level with operator Decision to Reinitialize Subsystem/System

Exception Gotchas - 6
Raised Exceptions Non Propagating

- Explicit raising of exceptions that are caught in the local scope is similar in nature to a Goto statement. Use of exceptions in this manner represents another form of an unstructured program jump. It makes programs harder to understand, test, and modify.
- If the problem can be resolved at the local level, perhaps the use of exceptions is the wrong abstraction.

7 Violations in recent analysis

Exception Gotchas - 7
Raise Predefined Exceptions

- Raising predefined exceptions adds confusion as to the source of the exception. The declaration of application exceptions keeps system run-time errors and application errors separate. This is considered to be a poor programming practice.

```
Raise Constraint_Error;
```

8 Violations in recent analysis all for Constraint_Error

Exception Gotchas - 8
Non-Visible Exception Declarations

- This is the declaration of an exception in a non-visible part of the program. Non-visible declarations can be very dangerous as they can be only handled within the scope of the declaration (except with a *when others*). Unintended propagation outside this scope may impact remote sections of the code and be a difficult error to find.

11 Violations in recent analysis

```
package QUEUE is
   procedure DEQUEUE (Object : out Object_type);
   procedure ENQUEUE (Object : in  Object_type);
   function Is_Empty return Boolean;
   function Is_Full return Boolean;
end QUEUE;

and in body:
 OVERFLOW, UNDERFLOW : exception;
```

Declarations of exceptions in body is not useful for desired abstractions

Exception Gotchas - 9

Exceptions that Propagate Out of Visible Scope of Subprogram

- Subprograms should not raise exceptions that are outside the visible scope of calling programs. This creates a serious problem where the exception cannot be handled by name to take the appropriate action for the raised exception. The raised exception can only be handled by a "***when others =>***" option which cannot distinguish which exception has been raised.

```
procedure Erroneous_Propagation_Demo is
   My_Exception: exception;
begin
   ...
   raise My_Exception;
exception
   when My_Exception => raise;
end Erroneous_Propagation_Demo;
```

4 Violations in recent analysis

Propagates Outside of Scope

Future of Ada Exceptions - 1

Workshop on Exception Handling for a
21st Century Programming Language
May 14, 2001, Leuven, Belgium

The aims of the workshop were:

- To share experience on how to build modern systems that have to deal with abnormal situations;
- To discuss how solutions to those needs can be developed employing standard Ada features including the current exception handling paradigm; and
- To propose new exception handling mechanisms / paradigms that can be included in future revisions of the Ada language and also fit high integrity language profiles for safety critical systems.

Future of Ada Exceptions - 2

Some of the issues addressed at Workshop:

- Exception handling model remains based on Ada 83 while Ada 95 is object oriented.
- Exceptions and concurrency are not well integrated
  - Task with an unhandled exception dies silently
  - Asynchronous transfer of control for passing exceptions asynchronously between tasks
- New fault tolerance schemes based on existing exception handling facilities have been developed in research environments
  - Higher level abstractions providing more advanced mechanisms

Future of Ada Exceptions - 3

Ideas Emerged:

- Extensions to Exception Handling should be downward compatible with Ada95
- Exceptions can be (generic) parameters
- Unhandled Exceptions must be declared in the subprogram header (signature)
- Exceptions are types
- It should be possible to know if (for a controlled type) “Finalize” is called with a pending exception
- Visibility Control should be controlled
- There should be some notification mechanism for tasks that complete by raising an exception
- And as a study topic: Instead of associating exceptions with subprograms, it would be nice to be able to associate exceptions with classes, types, objects, etc.

Future of Ada Exceptions - 4

For more Information:

Ada Letters Volume XXI, Number 1, September 2001

Special Issue -

Exception Handling for a 21st Century Programming Language Proceedings

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Conclusion

- Ada 95 Exceptions can be effective in supporting situations that might otherwise result in erroneous execution.
- Handled exceptions can be used to return the system to some known safe state or to propagate the exception to a handler that can return the system to some known safe state.
- The Ada.Exceptions package provides excellent support to help debug a program. If you are not currently using it, plan to use it.
- Exceptions must be used intelligently as improper use can result in serious errors including Program_Error.
- Sound Software Engineering includes planning for Exceptions during the Design Phase
- Code Analysis Tools can be essential.
- There are likely to be enhancements to exceptions for Ada 0X.