What's New in Ada 2022

Maxim Reznik

LEARN.
ADACORE.COM

What's New in Ada 2022

Release 2025-05

Maxim Reznik

May 31, 2025

CONTENTS:

1 Introduction **3**
- 1.1 References . . . 3

2 'Image attribute for any type **5**
- 2.1 'Image attribute for a value . . . 5
- 2.2 'Image attribute for any type . . . 5
- 2.3 References . . . 6

3 Redefining the 'Image attribute **7**
- 3.1 What's the Root_Buffer_Type? . . . 8
- 3.2 Outdated draft implementation . . . 8
- 3.3 References . . . 8

4 User-Defined Literals **9**
- 4.1 Turn Ada into JavaScript . . . 10
- 4.2 References . . . 11

5 Advanced Array Aggregates **13**
- 5.1 Square brackets . . . 13
- 5.2 Iterated Component Association . . . 14
- 5.3 References . . . 15

6 Container Aggregates **17**
- 6.1 References . . . 21

7 Delta Aggregates **23**
- 7.1 Delta aggregate for records . . . 23
- 7.2 Delta aggregate for arrays . . . 23
- 7.3 References . . . 24

8 Target Name Symbol (@) **25**
- 8.1 Alternatives . . . 27
- 8.2 References . . . 27

9 Enumeration representation **29**
- 9.1 Literal positions . . . 29
- 9.2 Representation values . . . 30
- 9.3 Before Ada 2022 . . . 31
- 9.4 References . . . 32

10 Big Numbers **33**
- 10.1 Big Integers . . . 33
- 10.2 Tiny RSA implementation . . . 33
- 10.3 Big Reals . . . 35
- 10.4 References . . . 35

11 Interfacing C variadic functions **37**
11.1 References 38

This course presents an overview of the new features of the latest Ada 2022 standard.

This document was written by Maxim Reznik and reviewed by Richard Kenner.

Note

The code examples in this course use an 80-column limit, which is a typical limit for Ada code. Note that, on devices with a small screen size, some code examples might be difficult to read.

Note

Each code example from this book has an associated "code block metadata", which contains the name of the "project" and an MD5 hash value. This information is used to identify a single code example.

You can find all code examples in a zip file, which you can download from the learn website[2]. The directory structure in the zip file is based on the code block metadata. For example, if you're searching for a code example with this metadata:

- Project: Courses.Intro_To_Ada.Imperative_Language.Greet
- MD5: cba89a34b87c9dfa71533d982d05e6ab

you will find it in this directory:

```
projects/Courses/Intro_To_Ada/Imperative_Language/Greet/
cba89a34b87c9dfa71533d982d05e6ab/
```

In order to use this code example, just follow these steps:

1. Unpack the zip file;
2. Go to target directory;
3. Start GNAT Studio on this directory;
4. Build (or compile) the project;
5. Run the application (if a main procedure is available in the project).

[1] http://creativecommons.org/licenses/by-sa/4.0
[2] https://learn.adacore.com/zip/learning-ada_code.zip

CHAPTER

ONE

INTRODUCTION

This is a collection of short code examples demonstrating new features of the Ada 2022 Standard[3] as they are implemented in GNAT Ada compiler.

To use some of these features, you may need to use a compiler command line switch or pragma. Compilers starting with GNAT Community Edition 2021[4] or GCC 11[5] use `pragma Ada_2022;` or the `-gnat2022` switch. Older compilers use `pragma Ada_2020;` or `-gnat2020`. To use the square brackets syntax or `'Reduce` expressions, you need `pragma Extensions_Allowed (On);` or the `-gnatX` switch.

1.1 References

- Draft Ada 2022 Standard[6]
- Ada 202x support in GNAT[7] blog post

[3] http://www.ada-auth.org/standards/22aarm/html/AA-TTL.html
[4] https://blog.adacore.com/gnat-community-2021-is-here
[5] https://gcc.gnu.org/gcc-11/
[6] http://www.ada-auth.org/standards/22aarm/html/AA-TTL.html
[7] https://blog.adacore.com/ada-202x-support-in-gnat

CHAPTER

TWO

'IMAGE ATTRIBUTE FOR ANY TYPE

Note

Attribute 'Image for any type is supported by

- GNAT Community Edition 2020 and latter
- GCC 11

2.1 'Image attribute for a value

Since the publication of the Technical Corrigendum 1[8] in February 2016, the 'Image attribute can now be applied to a value. So instead of My_Type'Image (Value), you can just write Value'Image, as long as the Value is a name[9]. These two statements are equivalent:

```
Ada.Text_IO.Put_Line (Ada.Text_IO.Page_Length'Image);

Ada.Text_IO.Put_Line
  (Ada.Text_IO.Count'Image (Ada.Text_IO.Page_Length));
```

2.2 'Image attribute for any type

In Ada 2022, you can apply the 'Image attribute to any type, including records, arrays, access types, and private types. Let's see how this works. We'll define array, record, and access types and corresponding objects and then convert these objects to strings and print them:

Listing 1: main.adb

```
with Ada.Text_IO;

procedure Main is
   type Vector is array (Positive range <>) of Integer;

   V1 : aliased Vector := [1, 2, 3];

   type Text_Position is record
      Line, Column : Positive;
   end record;

   Pos : constant Text_Position := (Line => 10, Column => 3);
```

(continues on next page)

8 https://reznikmm.github.io/ada-auth/rm-4-NC/RM-0-1.html

9 https://reznikmm.github.io/ada-auth/rm-4-NC/RM-4-1.html#S0091

(continued from previous page)

```

   type Vector_Access is access all Vector;

   V1_Ptr : constant Vector_Access := V1'Access;

begin
   Ada.Text_IO.Put_Line (V1'Image);
   Ada.Text_IO.Put_Line (Pos'Image);
   Ada.Text_IO.New_Line;
   Ada.Text_IO.Put_Line (V1_Ptr'Image);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Image_Attribute
MD5: c58d3133c45d780305a2b5c88d159764
```

Runtime output

```

[ 1,  2,  3]

(LINE =>  10,
 COLUMN =>  3)

(access 7ffd50938768)
```

```
$ gprbuild -q -P main.gpr
  Build completed successfully.
$ ./main
  [ 1,  2,  3]
  (LINE =>  10,
   COLUMN =>  3)
  (access 7fff64b23988)
```

Note the square brackets in the array image output. In Ada 2022, array aggregates could be written *this way* (page 13)!

2.3 References

- ARM 4.10 Image Attributes[10]
- AI12-0020-1[11]

[10] http://www.ada-auth.org/standards/22aarm/html/AA-4-10.html
[11] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/ai12s/ai12-0020-1.txt

CHAPTER

THREE

REDEFINING THE 'IMAGE ATTRIBUTE

In Ada 2022, you can redefine 'Image attribute for your type, though the syntax to do this has been changed several times. Let's see how it works in GNAT Community 2021.

Note

Redefining attribute 'Image is supported by

- GNAT Community Edition 2021 (using Text_Buffers)
- GNAT Community Edition 2020 (using Text_Output.Utils)
- GCC 11 (using Text_Output.Utils)

In our example, let's redefine the 'Image attribute for a location in source code. To do this, we provide a new Put_Image aspect for the type:

Listing 1: main.adb

```
with Ada.Text_IO;
with Ada.Strings.Text_Buffers;

procedure Main is

   type Source_Location is record
      Line   : Positive;
      Column : Positive;
   end record
     with Put_Image => My_Put_Image;

   procedure My_Put_Image
     (Output : in out Ada.Strings.Text_Buffers.Root_Buffer_Type'Class;
      Value  : Source_Location);

   procedure My_Put_Image
     (Output : in out Ada.Strings.Text_Buffers.Root_Buffer_Type'Class;
      Value  : Source_Location)
   is
      Line   : constant String := Value.Line'Image;
      Column : constant String := Value.Column'Image;
      Result : constant String :=
        Line (2 .. Line'Last) & ':' & Column (2 .. Column'Last);
   begin
       Output.Put (Result);
   end My_Put_Image;

   Line_10 : constant Source_Location := (Line => 10, Column => 1);

begin
```

(continues on next page)

(continued from previous page)

```
   Ada.Text_IO.Put_Line (Line_10'Image);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Image_Redefine
MD5: 4c77a3589eaba3a4c1b70200913ad6b8
```

Runtime output

```
10:1
```

3.1 What's the Root_Buffer_Type?

Let's see how it's defined in the `Ada.Strings.Text_Buffers` package.

```
type Root_Buffer_Type is abstract tagged limited private;

procedure Put
  (Buffer : in out Root_Buffer_Type;
   Item   : in     String) is abstract;
```

In addition to `Put`, there are also `Wide_Put`, `Wide_Wide_Put`, `Put_UTF_8`, `Wide_Put_UTF_16`. And also `New_Line`, `Increase_Indent`, `Decrease_Indent`.

3.2 Outdated draft implementation

GNAT Community Edition 2020 and GCC 11 both provide a draft implementation that's incompatible with the Ada 2022 specification. For those versions, `My_Put_Image` looks like:

```
procedure My_Put_Image
  (Sink  : in out Ada.Strings.Text_Output.Sink'Class;
   Value : Source_Location)
is
   Line   : constant String := Value.Line'Image;
   Column : constant String := Value.Column'Image;
   Result : constant String :=
     Line (2 .. Line'Last) & ':' & Column (2 .. Column'Last);
begin
    Ada.Strings.Text_Output.Utils.Put_UTF_8 (Sink, Result);
end My_Put_Image;
```

3.3 References

- ARM 4.10 Image Attributes[12]
- AI12-0020-1[13]
- AI12-0384-2[14]

[12] http://www.ada-auth.org/standards/22aarm/html/AA-4-10.html
[13] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0020-1.TXT
[14] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/ai12s/AI12-0384-2.TXT

CHAPTER

FOUR

USER-DEFINED LITERALS

Note

User-defined literals are supported by

- GNAT Community Edition 2020
- GCC 11

In Ada 2022, you can define string, integer, or real literals for your types. The compiler will convert such literals to your type at run time using a function you provide. To do so, specify one or more new aspects:

- `Integer_Literal`
- `Real_Literal`
- `String_Literal`

For our example, let's define all three for a simple type and see how they work. For simplicity, we use a `Wide_Wide_String` component for the internal representation:

Listing 1: main.adb

```
with Ada.Wide_Wide_Text_IO;
with Ada.Characters.Conversions;

procedure Main is

   type My_Type (Length : Natural) is record
      Value : Wide_Wide_String (1 .. Length);
   end record
     with String_Literal => From_String,
       Real_Literal      => From_Real,
       Integer_Literal   => From_Integer;

   function From_String (Value : Wide_Wide_String) return My_Type is
      ((Length => Value'Length, Value => Value));

   function From_Real (Value : String) return My_Type is
      ((Length => Value'Length,
        Value  => Ada.Characters.Conversions.To_Wide_Wide_String (Value)));

   function From_Integer (Value : String) return My_Type renames From_Real;

   procedure Print (Self : My_Type) is
   begin
      Ada.Wide_Wide_Text_IO.Put_Line (Self.Value);
   end Print;
```

(continues on next page)

(continued from previous page)

```ada

begin
   Print ("Test ""string""");
   Print (123);
   Print (16#DEAD_BEEF#);
   Print (2.99_792_458e+8);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.User_Defined_Literals
MD5: 755732418174c841bd88a8330cdc3e01
```

Runtime output

```
Test "string"
123
16#DEAD_BEEF#
2.99_792_458e+8
```

As you see, real and integer literals are converted to strings while preserving the formatting in the source code, while string literals are decoded: `From_String` is passed the specified string value. In all cases, the compiler translates these literals into function calls.

4.1 Turn Ada into JavaScript

Do you know that '*5*'+*3* in JavaScript is *53*?

```
> '5'+3
'53'
```

Now we can get the same result in Ada! But before we do, we need to define a custom `+` operator:

Listing 2: main.adb

```ada
with Ada.Wide_Wide_Text_IO;
with Ada.Characters.Conversions;

procedure Main is

   type My_Type (Length : Natural) is record
      Value : Wide_Wide_String (1 .. Length);
   end record
     with String_Literal => From_String,
       Real_Literal      => From_Real,
       Integer_Literal   => From_Integer;

   function "+" (Left, Right : My_Type) return My_Type is
     (Left.Length + Right.Length, Left.Value & Right.Value);

   function From_String (Value : Wide_Wide_String) return My_Type is
      ((Length => Value'Length, Value => Value));

   function From_Real (Value : String) return My_Type is
      ((Length => Value'Length,
        Value  => Ada.Characters.Conversions.To_Wide_Wide_String (Value)));

   function From_Integer (Value : String) return My_Type renames From_Real;
```

(continues on next page)

(continued from previous page)

```

   procedure Print (Self : My_Type) is
   begin
      Ada.Wide_Wide_Text_IO.Put_Line (Self.Value);
   end Print;

begin
   Print ("5" + 3);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.User_Defined_Literals_JS
MD5: 2d6eaf2d1b5bf560a90d4c6e491a2495
```

Runtime output

```
53
```

Jokes aside, this feature is very useful. For example it allows a "native-looking API" for *big integers* (page 33).

4.2 References

- ARM 4.2.1 User-Defined Literals[15]
- AI12-0249-1[16]
- AI12-0342-1[17]

[15] http://www.ada-auth.org/standards/22rm/html/RM-4-2-1.html
[16] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0249-1.TXT
[17] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0342-1.TXT

CHAPTER

FIVE

ADVANCED ARRAY AGGREGATES

Note

These array aggregates are supported by

- GNAT Community Edition 2020
- GCC 11

5.1 Square brackets

In Ada 2022, you can use square brackets in array aggregates. Using square brackets simplifies writing both empty aggregates and single-element aggregates. Consider this:

Listing 1: show_square_brackets.ads

```
package Show_Square_Brackets is

   type Integer_Array is array (Positive range <>) of Integer;

   Old_Style_Empty : Integer_Array := (1 .. 0 => <>);
   New_Style_Empty : Integer_Array := [];

   Old_Style_One_Item : Integer_Array := (1 => 5);
   New_Style_One_Item : Integer_Array := [5];

end Show_Square_Brackets;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Square_Brackets
MD5: 2914b9435684a1eecd2567548969a3ed
```

Short summary for parentheses and brackets

- Record aggregates use parentheses
- *Container aggregates* (page 17) use square brackets
- Array aggregates can use both square brackets and parentheses, but parentheses usage is obsolescent

5.2 Iterated Component Association

There is a new kind of component association:

```
Vector : Integer_Array := [for J in 1 .. 5 => J * 2];
```

This association starts with **for** keyword, just like a quantified expression. It declares an index parameter that you can use in the computation of a component.

Iterated component associations can nest and can be nested in another association (iterated or not). Here we use this to define a square matrix:

```
Matrix : array (1 .. 3, 1 .. 3) of Positive :=
 [for J in 1 .. 3 =>
   [for K in 1 .. 3 => J * 10 + K]];
```

Iterated component associations in this form provide both element indices and values, just like named component associations:

```
Data : Integer_Array (1 .. 5) :=
  [for J in 2 .. 3 => J, 5 => 5, others => 0];
```

Here `Data` contains `(0, 2, 3, 0, 5)`, not `(2, 3, 5, 0, 0)`.

Another form of iterated component association corresponds to a positional component association and provides just values, but no element indices:

```
Vector_2 : Integer_Array := [for X of Vector => X / 2];
```

You cannot mix these forms in a single aggregate.

It's interesting that such aggregates were originally proposed more than 25 years ago!

Complete code snippet:

Listing 2: show_iterated_component_association.adb

```
with Ada.Text_IO;

procedure Show_Iterated_Component_Association is

   type Integer_Array is array (Positive range <>) of Integer;

   Old_Style_Empty : Integer_Array := (1 .. 0 => <>);
   New_Style_Empty : Integer_Array := [];

   Old_Style_One_Item : Integer_Array := (1 => 5);
   New_Style_One_Item : Integer_Array := [5];

   Vector : constant Integer_Array := [for J in 1 .. 5 => J * 2];

   Matrix : constant array (1 .. 3, 1 .. 3) of Positive :=
     [for J in 1 .. 3 =>
       [for K in 1 .. 3 => J * 10 + K]];

   Data : constant Integer_Array (1 .. 5) :=
     [for J in 2 .. 3 => J, 5 => 5, others => 0];

   Vector_2 : constant Integer_Array := [for X of Vector => X / 2];
begin
   Ada.Text_IO.Put_Line (Vector'Image);
   Ada.Text_IO.Put_Line (Matrix'Image);
   Ada.Text_IO.Put_Line (Data'Image);
```

(continues on next page)

(continued from previous page)

```
   Ada.Text_IO.Put_Line (Vector_2'Image);
end Show_Iterated_Component_Association;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Iterated_Component_Association
MD5: 9bc822b59c2c423019917728aab75c69
```

Runtime output

```

[ 2,  4,  6,  8,  10]

[
 [ 11,  12,  13],

 [ 21,  22,  23],

 [ 31,  32,  33]]

[ 0,  2,  3,  0,  5]

[ 1,  2,  3,  4,  5]
```

5.3 References

- ARM 4.3.3 Array Aggregates[18]
- AI12-0212-1[19]
- AI12-0306-1[20]

[18] http://www.ada-auth.org/standards/22aarm/html/AA-4-3-3.html
[19] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0212-1.TXT
[20] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0306-1.TXT

CHAPTER

SIX

CONTAINER AGGREGATES

> **Note**
>
> Container aggregates are supported by
>
> - GNAT Community Edition 2021
> - GCC 11

Ada 2022 introduces container aggregates, which can be used to easily create values for vectors, lists, maps, and other aggregates. For containers such as maps, the aggregate must use named associations to provide keys and values. For other containers it uses positional associations. Only square brackets are allowed. Here's an example:

Listing 1: main.adb

```
with Ada.Text_IO;
with Ada.Containers.Vectors;
with Ada.Containers.Ordered_Maps;

procedure Main is

   package Int_Vectors is new Ada.Containers.Vectors
     (Positive, Integer);

   X : constant Int_Vectors.Vector := [1, 2, 3];

   package Float_Maps is new Ada.Containers.Ordered_Maps
     (Integer, Float);

   Y : constant Float_Maps.Map := [-10 => 1.0, 0 => 2.5, 10 => 5.51];
begin
   Ada.Text_IO.Put_Line (X'Image);
   Ada.Text_IO.Put_Line (Y'Image);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Container_Aggregates_1
MD5: 317c252582f75f248a154bd843388aaa
```

Runtime output

```
[ 1,  2,  3]

[-10 =>  1.00000E+00,  0 =>  2.50000E+00,  10 =>  5.51000E+00]
```

At run time, the compiler creates an empty container and populates it with elements one by one. If you define a new container type, you can specify a new `Aggregate` aspect to enable container aggregates for your container and let the compiler know what subprograms to use to construct the aggregate:

Listing 2: main.adb

```
procedure Main is

   package JSON is
      type JSON_Value is private
        with Integer_Literal => To_JSON_Value;

      function To_JSON_Value (Text : String) return JSON_Value;

      type JSON_Array is private
        with Aggregate => (Empty       => New_JSON_Array,
                           Add_Unnamed => Append);

      function New_JSON_Array return JSON_Array;

      procedure Append
        (Self  : in out JSON_Array;
         Value : JSON_Value) is null;

   private
      type JSON_Value is null record;
      type JSON_Array is null record;

      function To_JSON_Value (Text : String) return JSON_Value
        is (null record);

      function New_JSON_Array return JSON_Array is (null record);
   end JSON;

   List : JSON.JSON_Array := [1, 2, 3];
   ------------------------------------
begin
   --  Equivalent old initialization code
   List := JSON.New_JSON_Array;
   JSON.Append (List, 1);
   JSON.Append (List, 2);
   JSON.Append (List, 3);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Container_Aggregates_2
MD5: d930702be4e6b4836afab082e8abe633
```

The equivalent for maps is:

Listing 3: main.adb

```
procedure Main is

   package JSON is
      type JSON_Value is private
        with Integer_Literal => To_JSON_Value;

      function To_JSON_Value (Text : String) return JSON_Value;

```

(continues on next page)

(continued from previous page)

```
      type JSON_Object is private
        with Aggregate => (Empty     => New_JSON_Object,
                           Add_Named => Insert);

      function New_JSON_Object return JSON_Object;

      procedure Insert
        (Self  : in out JSON_Object;
         Key   : Wide_Wide_String;
         Value : JSON_Value) is null;

   private
      type JSON_Value is null record;
      type JSON_Object is null record;

      function To_JSON_Value (Text : String) return JSON_Value
        is (null record);

      function New_JSON_Object return JSON_Object is (null record);
   end JSON;

   Object : JSON.JSON_Object := ["a" => 1, "b" => 2, "c" => 3];
   ------------------------------------------------------------
begin
   --  Equivalent old initialization code
   Object := JSON.New_JSON_Object;
   JSON.Insert (Object, "a", 1);
   JSON.Insert (Object, "b", 2);
   JSON.Insert (Object, "c", 3);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Container_Aggregates_3
MD5: c39c651e3e2f48c515c87c4cc6b979e9
```

You can't specify both Add_Named and Add_Unnamed subprograms for the same type. This prevents you from defining JSON_Value with both array and object aggregates present. But we can define conversion functions for array and object and get code almost as dense as the same code in native JSON. For example:

Listing 4: main.adb

```
procedure Main is

   package JSON is
      type JSON_Value is private
        with Integer_Literal => To_Value, String_Literal => To_Value;

      function To_Value (Text : String) return JSON_Value;
      function To_Value (Text : Wide_Wide_String) return JSON_Value;

      type JSON_Object is private
        with Aggregate => (Empty     => New_JSON_Object,
                           Add_Named => Insert);

      function New_JSON_Object return JSON_Object;

      procedure Insert
        (Self  : in out JSON_Object;
         Key   : Wide_Wide_String;
```

(continues on next page)

(continued from previous page)

```ada
        Value : JSON_Value) is null;

      function From_Object (Self : JSON_Object) return JSON_Value;

      type JSON_Array is private
        with Aggregate => (Empty       => New_JSON_Array,
                           Add_Unnamed => Append);

      function New_JSON_Array return JSON_Array;

      procedure Append
        (Self  : in out JSON_Array;
         Value : JSON_Value) is null;

      function From_Array (Self : JSON_Array) return JSON_Value;

   private
      type JSON_Value is null record;
      type JSON_Object is null record;
      type JSON_Array is null record;

      function To_Value (Text : String) return JSON_Value is
        (null record);
      function To_Value (Text : Wide_Wide_String) return JSON_Value is
        (null record);
      function New_JSON_Object return JSON_Object is
        (null record);
      function New_JSON_Array return JSON_Array is
        (null record);
      function From_Object (Self : JSON_Object) return JSON_Value is
        (null record);
      function From_Array (Self : JSON_Array) return JSON_Value is
        (null record);
   end JSON;

   function "+" (X : JSON.JSON_Object) return JSON.JSON_Value
     renames JSON.From_Object;
   function "-" (X : JSON.JSON_Array) return JSON.JSON_Value
     renames JSON.From_Array;

   Offices : JSON.JSON_Array :=
     [+["name"   => "North American Office",
        "phones" => -[1_877_787_4628,
                      1_866_787_4232,
                      1_212_620_7300],
        "email"  => "info@adacore.com"],
      +["name"   => "European Office",
        "phones" => -[33_1_49_70_67_16,
                      33_1_49_70_05_52],
        "email"  => "info@adacore.com"]];
   -----------------------------------------------------------------
begin
   --  Equivalent old initialization code is too long to print it here
   null;
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Container_Aggregates_4
MD5: a2770961eab00ee297fffa280cd9a481
```

The `Offices` variable is supposed to contain this value:

```
[{"name"  : "North American Office",
  "phones": [18777874628,
             18667874232,
             12126207300],
  "email" : "info@adacore.com"},
 {"name"  : "European Office",
  "phones": [33149706716,
             33149700552],
  "email" : "info@adacore.com"}]
```

6.1 References

- ARM 4.3.5 Container Aggregates[21]
- AI12-0212-1[22]

[21] http://www.ada-auth.org/standards/22aarm/html/AA-4-3-5.html
[22] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0212-1.TXT

CHAPTER

SEVEN

DELTA AGGREGATES

Note

Delta aggregates are supported by

- GNAT Community Edition 2019
- GCC 9

Sometimes you need to create a copy of an object, but with a few modifications. Before Ada 2022, doing this involves a dummy object declaration or an aggregate with associations for each property. The dummy object approach doesn't work in contract aspects or when there are limited components. On the other hand, re-listing properties in an large aggregate can be very tedious and error-prone. So, in Ada 2022, you can use a *delta aggregate* instead.

7.1 Delta aggregate for records

The delta aggregate for a record type looks like this:

```
type Vector is record
   X, Y, Z : Float;
end record;

Point_1 : constant Vector := (X => 1.0, Y => 2.0, Z => 3.0);

Projection_1 : constant Vector := (Point_1 with delta Z => 0.0);
```

The more components you have, the more you will like the delta aggregate.

7.2 Delta aggregate for arrays

You can also use delta aggregates for arrays to change elements, but not bounds. Moreover, it only works for one-dimensional arrays of non-limited components.

```
type Vector_3D is array (1 .. 3) of Float;

Point_2 : constant Vector_3D := [1.0, 2.0, 3.0];
Projection_2 : constant Vector_3D := [Point_2 with delta 3 => 0.0];
```

You can use parentheses for array aggregates, but you can't use square brackets for record aggregates.

Here is the complete code snippet:

Listing 1: main.adb

```
with Ada.Text_IO;

procedure Main is

   type Vector is record
      X, Y, Z : Float;
   end record;

   Point_1 : constant Vector := (X => 1.0, Y => 2.0, Z => 3.0);
   Projection_1 : constant Vector := (Point_1 with delta Z => 0.0);

   type Vector_3D is array (1 .. 3) of Float;

   Point_2 : constant Vector_3D := [1.0, 2.0, 3.0];
   Projection_2 : constant Vector_3D := [Point_2 with delta 3 => 0.0];
begin
   Ada.Text_IO.Put (Float'Image (Projection_1.X));
   Ada.Text_IO.Put (Float'Image (Projection_1.Y));
   Ada.Text_IO.Put (Float'Image (Projection_1.Z));
   Ada.Text_IO.New_Line;
   Ada.Text_IO.Put (Float'Image (Projection_2 (1)));
   Ada.Text_IO.Put (Float'Image (Projection_2 (2)));
   Ada.Text_IO.Put (Float'Image (Projection_2 (3)));
   Ada.Text_IO.New_Line;
end Main;
```

7.3 References

- ARM 4.3.4 Delta Aggregates[23]
- AI12-0127-1[24]

[23] http://www.ada-auth.org/standards/22aarm/html/AA-4-3-4.html
[24] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0127-1.TXT

CHAPTER

EIGHT

TARGET NAME SYMBOL (@)

Note

Target name symbol is supported by

- GNAT Community Edition 2019
- GCC 9

Ada 2022 introduces a new symbol, @, which can only appear on the right hand side of an assignment statement. This symbol acts as the equivalent of the name on the left hand side of that assignment statement. It was introduced to avoid code duplication: instead of retyping a (potentially long) name, you can use @. This symbol denotes a constant, so you can't pass it into [**in**] **out** arguments of a subprogram.

As an example, let's calculate some statistics for My_Data array:

Listing 1: statistics.ads

```
package Statistics is

   type Statistic is record
      Count : Natural := 0;
      Total : Float := 0.0;
   end record;

   My_Data : array (1 .. 5) of Float := [for J in 1 .. 5 => Float (J)];

   Statistic_For_My_Data : Statistic;

end Statistics;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Assignment_Tagged_Intro
MD5: 8ca75d894ed8ddbdb459aee0ce0c427d
```

To do this, we loop over My_Data elements:

Listing 2: main.adb

```
with Ada.Text_IO;

procedure Main is

   type Statistic is record
      Count : Natural := 0;
      Total : Float := 0.0;
```

(continues on next page)

(continued from previous page)

```
   end record;

   My_Data : constant array (1 .. 5) of Float :=
     [for J in 1 .. 5 => Float (J)];

   Statistic_For_My_Data : Statistic;

begin
   for Data of My_Data loop
      Statistic_For_My_Data.Count := @ + 1;
      Statistic_For_My_Data.Total := @ + Data;
   end loop;

   Ada.Text_IO.Put_Line (Statistic_For_My_Data'Image);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Assignment_Tagged_2
MD5: b116e7a172d43547b227eb27fb994366
```

Runtime output

```
(COUNT =>  5,
 TOTAL =>  1.50000E+01)
```

Each right hand side is evaluated only once, no matter how many @ symbols it contains. Let's verify this by introducing a function call that prints a line each time it's called:

Listing 3: main.adb

```
with Ada.Text_IO;

procedure Main is

   My_Data : array (1 .. 5) of Float := [for J in 1 .. 5 => Float (J)];

   function To_Index (Value : Positive) return Positive is
   begin
      Ada.Text_IO.Put_Line ("To_Index is called.");
      return Value;
   end To_Index;

begin
   My_Data (To_Index (1)) := @ ** 2 - 3.0 * @;
   Ada.Text_IO.Put_Line (My_Data'Image);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Assignment_Tagged_3
MD5: ed946d4e1b90df28fbd358d17033279d
```

Runtime output

```
To_Index is called.

[-2.00000E+00,  2.00000E+00,  3.00000E+00,  4.00000E+00,  5.00000E+00]
```

This use of @ may look a bit cryptic, but it's the best solution that was found. Unlike other languages (e.g., `sum += x;` in C), this approach lets you use @ an arbitrary number of times within the right hand side of an assignment statement.

8.1 Alternatives

In C++, the previous statement could be written with a reference type (one line longer!):

```
auto& a = my_data[to_index(1)];
a = a * a - 3.0 * a;
```

In Ada 2022, you can use a similar renaming:

```
declare
   A renames My_Data (To_Index (1));
begin
   A := A ** 2 - 3.0 * A;
end;
```

Here we use a new short form of the rename declaration, but this still looks too heavy, and even worse, it can't be used for discriminant-dependent components.

8.2 References

- ARM 5.2.1 Target Name Symbols[25]
- AI12-0125-3[26]

[25] http://www.ada-auth.org/standards/22aarm/html/AA-5-2-1.html
[26] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0125-3.TXT

CHAPTER

NINE

ENUMERATION REPRESENTATION

Note

Enumeration representation attributes are supported by

- GNAT Community Edition 2019
- GCC 9

Enumeration types in Ada are represented as integers at the machine level. But there are actually two mappings from enumeration to integer: a literal position and a representation value.

9.1 Literal positions

Each enumeration literal has a corresponding position in the type declaration. We can easily obtain it from the `Type'Pos (Enum)` attribute.

Listing 1: main.adb

```
with Ada.Text_IO;
with Ada.Integer_Text_IO;

procedure Main is
begin
   Ada.Text_IO.Put ("Pos(False) =");
   Ada.Integer_Text_IO.Put (Boolean'Pos (False));
   Ada.Text_IO.New_Line;
   Ada.Text_IO.Put ("Pos(True)  =");
   Ada.Integer_Text_IO.Put (Boolean'Pos (True));
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Enum_Val.Pos
MD5: de7c39f83f7df231dd648606579996a8
```

Runtime output

```
Pos(False) =          0
Pos(True)  =          1
```

For the reverse mapping, we use `Type'Val (Int)`:

Listing 2: main.adb

```
with Ada.Text_IO;

procedure Main is
begin
   Ada.Text_IO.Put_Line (Boolean'Val (0)'Image);
   Ada.Text_IO.Put_Line (Boolean'Val (1)'Image);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Enum_Val.Val
MD5: 43f712d25552970bccc4c0c84089d927
```

Runtime output

```
FALSE
TRUE
```

9.2 Representation values

The representation value defines the *internal* code, used to store enumeration values in memory or CPU registers. By default, enumeration representation values are the same as the corresponding literal positions, but you can redefine them. Here, we created a copy of `Boolean` type and assigned it a custom representation.

In Ada 2022, we can get an integer value of the representation with `Type'Enum_Rep(Enum)` attribute:

Listing 3: main.adb

```
with Ada.Text_IO;
with Ada.Integer_Text_IO;

procedure Main is
   type My_Boolean is new Boolean;
   for My_Boolean use (False => 3, True => 6);
begin
   Ada.Text_IO.Put ("Enum_Rep(False) =");
   Ada.Integer_Text_IO.Put (My_Boolean'Enum_Rep (False));
   Ada.Text_IO.New_Line;
   Ada.Text_IO.Put ("Enum_Rep(True)  =");
   Ada.Integer_Text_IO.Put (My_Boolean'Enum_Rep (True));
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Enum_Val.Enum_Rep
MD5: 384ad9de7124c8131aa83ab71da58964
```

Runtime output

```
Enum_Rep(False) =          3
Enum_Rep(True)  =          6
```

And, for the reverse mapping, we can use `Type'Enum_Val (Int)`:

Listing 4: main.adb

```
with Ada.Text_IO;
with Ada.Integer_Text_IO;

procedure Main is
   type My_Boolean is new Boolean;
   for My_Boolean use (False => 3, True => 6);
begin
   Ada.Text_IO.Put_Line (My_Boolean'Enum_Val (3)'Image);
   Ada.Text_IO.Put_Line (My_Boolean'Enum_Val (6)'Image);

   Ada.Text_IO.Put ("Pos(False) =");
   Ada.Integer_Text_IO.Put (My_Boolean'Pos (False));
   Ada.Text_IO.New_Line;
   Ada.Text_IO.Put ("Pos(True)  =");
   Ada.Integer_Text_IO.Put (My_Boolean'Pos (True));
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Enum_Val.Enum_Val
MD5: 6e06202472d4cf0ea7c68461ac7afcb1
```

Runtime output

```
FALSE
TRUE
Pos(False) =          0
Pos(True)  =          1
```

Note that the 'Val(X)/'Pos(X) behaviour still is the same.

Custom representations can be useful for integration with a low level protocol or hardware.

9.3 Before Ada 2022

This doesn't initially look like an important feature, but let's see how we'd do the equivalent with Ada 2012 and earlier versions. First, we need an integer type of matching size, then we instantiate Ada.Unchecked_Conversion. Next, we call To_Int/From_Int to work with representation values. And finally an extra type conversion is needed:

Listing 5: main.adb

```
with Ada.Text_IO;
with Ada.Integer_Text_IO;
with Ada.Unchecked_Conversion;

procedure Main is

   type My_Boolean is new Boolean;
   for My_Boolean use (False => 3, True => 6);
   type My_Boolean_Int is range 3 .. 6;
   for My_Boolean_Int'Size use My_Boolean'Size;

   function To_Int is new Ada.Unchecked_Conversion
     (My_Boolean, My_Boolean_Int);

   function From_Int is new Ada.Unchecked_Conversion
     (My_Boolean_Int, My_Boolean);
```

(continues on next page)

(continued from previous page)

```

begin
   Ada.Text_IO.Put ("To_Int(False) =");
   Ada.Integer_Text_IO.Put (Integer (To_Int (False)));
   Ada.Text_IO.New_Line;
   Ada.Text_IO.Put ("To_Int(True)  =");
   Ada.Integer_Text_IO.Put (Integer (To_Int (True)));
   Ada.Text_IO.New_Line;
   Ada.Text_IO.Put ("From_Int (3)  =");
   Ada.Text_IO.Put_Line (From_Int (3)'Image);
   Ada.Text_IO.New_Line;
   Ada.Text_IO.Put ("From_Int (6)  =");
   Ada.Text_IO.Put_Line (From_Int (6)'Image);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Enum_Val.Conv
MD5: 7c7624ed024b26036389f77dbd6cb109
```

Runtime output

```
To_Int(False) =          3
To_Int(True)  =          6
From_Int (3)  =FALSE

From_Int (6)  =TRUE
```

Even with all that, this solution doesn't work for generic formal type (because `T'Size` must be a static value)!

We should note that these new attributes may already be familiar to GNAT users because they've been in the GNAT compiler for many years.

9.4 References

- ARM 13.4 Enumeration Representation Clauses[27]
- AI12-0237-1[28]

[27] http://www.ada-auth.org/standards/22aarm/html/AA-13-4.html
[28] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0237-1.TXT

CHAPTER

TEN

BIG NUMBERS

> **Note**
>
> Big numbers are supported by
>
> - GNAT Community Edition 2020
> - GCC 11
> - GCC 10 (draft, no user defined literals)

Ada 2022 introduces big integers and big real types.

10.1 Big Integers

The package `Ada.Numerics.Big_Numbers.Big_Integers` contains a type `Big_Integer` and corresponding operations such as comparison (`=`, `<`, `>`, `<=`, `>=`), arithmetic (`+`, `-`, `*`, `/`, **rem**, **mod**, **abs**, `**`), `Min`, `Max` and `Greatest_Common_Divisor`. The type also has `Integer_Literal` and `Put_Image` aspects redefined, so you can use it in a natural manner.

```
Ada.Text_IO.Put_Line (Big_Integer'Image(2 ** 256));
```

```
115792089237316195423570985008687907853269984665640564039457584007913129639936
```

10.2 Tiny RSA implementation

> **Note**
>
> Note that you shouldn't use `Big_Numbers` for cryptography because it's vulnerable to timing side-channels attacks.

We can implement the RSA algorithm[29] in a few lines of code. The main operation of RSA is (m^d) mod n. But you can't just write `m ** d`, because these are really big numbers and the result won't fit into memory. However, if you keep intermediate result **mod** n during the m^d calculation, it will work. Let's write this operation as a function:

Listing 1: power_mod.ads

```
with Ada.Numerics.Big_Numbers.Big_Integers;
use  Ada.Numerics.Big_Numbers.Big_Integers;
```

(continues on next page)

[29] https://en.wikipedia.org/wiki/RSA_(cryptosystem)

(continued from previous page)

```

--  Calculate M ** D mod N

function Power_Mod (M, D, N : Big_Integer) return Big_Integer;
```

Listing 2: power_mod.adb

```
function Power_Mod (M, D, N : Big_Integer) return Big_Integer is

   function Is_Odd (X : Big_Integer) return Boolean is
     (X mod 2 /= 0);

   Result : Big_Integer := 1;
   Exp    : Big_Integer := D;
   Mult   : Big_Integer := M mod N;
begin
   while Exp /= 0 loop
      --  Loop invariant is Power_Mod'Result = Result * Mult**Exp mod N
      if Is_Odd (Exp) then
         Result := (Result * Mult) mod N;
      end if;

      Mult := Mult ** 2 mod N;
      Exp := Exp / 2;
   end loop;

   return Result;
end Power_Mod;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Big_Integers
MD5: 8ade78366bf7c98090ae32f9a9830cf9
```

Let's check this with the example from Wikipedia[30]. In that example, the *public key* is (n = 3233, e = 17) and the message is m = 65. The encrypted message is m^e mod n = 65^{17} mod 3233 = 2790 = c.

```
Ada.Text_IO.Put_Line (Power_Mod (M => 65, D => 17, N => 3233)'Image);
```

```
2790
```

To decrypt it with the public key (n = 3233, d = 413), we need to calculate c^d mod n = 2790^{413} mod 3233:

```
Ada.Text_IO.Put_Line (Power_Mod (M => 2790, D => 413, N => 3233)'Image);
```

```
65
```

So 65 is the original message m. Easy!

Here is the complete code snippet:

Listing 3: main.adb

```
with Ada.Text_IO;
with Ada.Numerics.Big_Numbers.Big_Integers;
use  Ada.Numerics.Big_Numbers.Big_Integers;
```

(continues on next page)

30 https://en.wikipedia.org/wiki/RSA_(cryptosystem)

(continued from previous page)

```

procedure Main is

   --  Calculate M ** D mod N

   function Power_Mod (M, D, N : Big_Integer) return Big_Integer is

      function Is_Odd (X : Big_Integer) return Boolean is
        (X mod 2 /= 0);

         Result : Big_Integer := 1;
         Exp    : Big_Integer := D;
         Mult   : Big_Integer := M mod N;
   begin
      while Exp /= 0 loop
         --  Loop invariant is Power_Mod'Result = Result * Mult**Exp mod N
         if Is_Odd (Exp) then
            Result := (Result * Mult) mod N;
         end if;

         Mult := Mult ** 2 mod N;
         Exp := Exp / 2;
      end loop;

      return Result;
   end Power_Mod;

begin
   Ada.Text_IO.Put_Line (Big_Integer'Image (2 ** 256));
   --  Encrypt:
   Ada.Text_IO.Put_Line (Power_Mod (M => 65, D => 17, N => 3233)'Image);
   --  Decrypt:
   Ada.Text_IO.Put_Line (Power_Mod (M => 2790, D => 413, N => 3233)'Image);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Big_Numbers_Tiny_RSA
MD5: 298c4a82ceafba9654d41b3a9762927d
```

Runtime output

```
 115792089237316195423570985008687907853269984665640564039457584007913129639936
 2790
 65
```

10.3 Big Reals

In addition to Big_Integer, Ada 2022 provides Big Reals[31].

10.4 References

- ARM A.5.6 Big Integers[32]
- ARM A.5.7 Big Reals[33]

[31] http://www.ada-auth.org/standards/22aarm/html/AA-A-5-7.html
[32] http://www.ada-auth.org/standards/22aarm/html/AA-A-5-6.html
[33] http://www.ada-auth.org/standards/22aarm/html/AA-A-5-7.html

- AI12-0208-1[34]

[34] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0208-1.TXT

CHAPTER

ELEVEN

INTERFACING C VARIADIC FUNCTIONS

Note

Variadic convention is supported by

- GNAT Community Edition 2020
- GCC 11

In C, variadic functions[35] take a variable number of arguments and an ellipsis as the last parameter of the declaration. A typical and well-known example is:

```
int printf (const char* format, ...);
```

Usually, in Ada, we bind such a function with just the parameters we want to use:

```
procedure printf_double
  (format : Interfaces.C.char_array;
   value  : Interfaces.C.double)
     with Import,
       Convention    => C,
       External_Name => "printf";
```

Then we call it as a normal Ada function:

```
printf_double (Interfaces.C.To_C ("Pi=%f"), Ada.Numerics.π);
```

Unfortunately, doing it this way doesn't always work because some ABI[36]s use different calling conventions for variadic functions. For example, the AMD64 ABI[37] specifies:

- %rax — with variable arguments passes information about the number of vector registers used;
- %xmm0–%xmm1 — used to pass and return floating point arguments.

This means, if we write (in C):

```
printf("%d", 5);
```

The compiler will place 0 into %rax, because we don't pass any float argument. But in Ada, if we write:

```
procedure printf_int
  (format : Interfaces.C.char_array;
   value  : Interfaces.C.int)
```

(continues on next page)

[35] https://en.cppreference.com/w/c/variadic
[36] https://en.wikipedia.org/wiki/Application_binary_interface
[37] https://software.intel.com/sites/default/files/article/402129/mpx-linux64-abi.pdf

(continued from previous page)

```
     with Import,
       Convention    => C,
       External_Name => "printf";

printf_int (Interfaces.C.To_C ("d=%d"), 5);
```

the compiler won't use the `%rax` register at all. (You can't include any float argument because there's no float parameter in the Ada wrapper function declaration.) As result, you will get a crash, stack corruption, or other undefined behavior.

To fix this, Ada 2022 provides a new family of calling convention names — `C_Variadic_N`:

> The convention `C_Variadic_n` is the calling convention for a variadic C function taking *n* fixed parameters and then a variable number of additional parameters.

Therefore, the correct way to bind the `printf` function is:

```
procedure printf_int
  (format : Interfaces.C.char_array;
   value  : Interfaces.C.int)
     with Import,
       Convention    => C_Variadic_1,
       External_Name => "printf";
```

And the following call won't crash on any supported platform:

```
printf_int (Interfaces.C.To_C ("d=%d"), 5);
```

Without this convention, problems cause by this mismatch can be very hard to debug. So, this is a very useful extension to the Ada-to-C interfacing facility.

Here is the complete code snippet:

Listing 1: main.adb

```
with Interfaces.C;

procedure Main is

   procedure printf_int
     (format : Interfaces.C.char_array;
      value  : Interfaces.C.int)
     with Import,
       Convention    => C_Variadic_1,
       External_Name => "printf";

begin
   printf_int (Interfaces.C.To_C ("d=%d"), 5);
end Main;
```

Code block metadata

```
Project: Courses.Ada_2022_Whats_New.Variadic_Import
MD5: 94515f55a93f27e4f4ecec31256645d9
```

11.1 References

- ARM B.3 Interfacing with C and C++[38]

[38] http://www.ada-auth.org/standards/22aarm/html/AA-B-3.html

- AI12-0028-1[39]

[39] http://www.ada-auth.org/cgi-bin/cvsweb.cgi/AI12s/AI12-0028-1.TXT