
GNAT SAS Tutorial

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INTRODUCTION

This document provides a guide through the major capabilities of GNAT SAS inside the GNAT Studio IDE by working on a code example: *sdc*, a simple desktop calculator. The tutorial uses messages and annotations generated by Inspector analysis engine, which is one of four analysis engines integrated to GNAT SAS.

Notice this is the same example as the one used in the GNAT Studio Tutorial (available in the *Help* → *GNAT Studio* → *Tutorial* menu), so you might want to go through the GNAT Studio tutorial first to get familiar with this environment.

Copy the *sdc* directory and its subdirectories in a local (writable) area, and start GNAT Studio from the *sdc* directory, so that GNAT Studio will load the right context.

By default, the tutorial sources can be found under *<prefix>/share/examples/gnatsas/sdc*, where *<prefix>* is the prefix directory of the GNAT SAS installation.

RUNNING GNAT SAS

Select the menu *GNATSAS* → *Analyze All* in the menu bar at the top. This will run GNAT SAS, which first generates SCIL files, then runs the GNAT SAS analysis engines, and finally displays a summary of the problems found in the GNAT SAS Report Window.

Here, GNAT SAS reports a few medium and low messages.

Notice the different kinds of filters that are available on the right side of the window. Clicking on each of these filters will show/hide the corresponding messages in the Locations View at the bottom.

Uncheck the box **medium** in Message ranking. This clears the location view.

Check the box **low** in Message ranking. The location view now reports the low messages only.

Undo these changes to recover medium messages only. During all these changes, the GNAT SAS Report Window was not affected as it reports all problems found. The filters only apply to the Locations View.

UNDERSTANDING MESSAGES

3.1 Checks

In the location view, click in the tree on the + sign (or triangle) at the left of `tokens.adb`. Click on the message reported at line 26. This opens the file `tokens.adb` at line 26.

The message gives 3 different pieces of information:

- Ranking

Can be **high**, **medium** or **low**. It is an indication of the severity and certainty of the associated message. The higher the ranking, the more interesting the message, and the greater the likelihood the indicated line of code would fail when executed.

Here, it is a **medium** message.

- Check

A short description of the problem.

Here, it says that the array index check might fail.

- Explanation

Some messages have a more detailed explanation to help you understand the problem.

Here, it says that it requires the first index in `Input.Next_Word` to be less than its last index, which is the same as saying `Input.Next_Word` should not be empty.

Indeed, the expression at line 26 is accessing at the first index in local variable `Word`, which happens to be initialized at line 18 with a call to `Input.Next_Word`. So it will raise a `Constraint_Error` if `Input.Next_Word` returns the empty string.

Now go to the definition of function `Input.Next_Word`. This can be achieved either by clicking on the right mouse button on `Next_Word` on line 18 and selecting `Goto body of Next_Word` or by clicking on the middle mouse button while holding `Control` key and moving the mouse over `Next_Word` on line 18. To do so, you first need to go to `Scenario` and in the `Build Mode`, select `gnatsas` from the drop down list.

The annotations generated by GNAT SAS' Inspector are displayed before the definition of function `Next_Word` on line 184. You can hide these annotations by clicking on the right mouse button and selecting `GNATSAS → Hide annotations`. Re-display these annotations by clicking on the right mouse button and selecting `GNATSAS → Show annotations`.

In the postconditions generated by GNAT SAS' Inspector, you can see that Inspector computed a possible range of `1..1_024` for the application of attribute `First` to the result of calling `Next_Word`, which is displayed as `input.next_word'Result'First`, and a possible range of `0..1_023` for the application of attribute `Last` to the same value. This includes the case where `Result'First` is 1 and `Result'Last` is 0, so the result may be an empty string.

Looking at the body of function `Next_Word`, it appears that an empty string is indeed returned when the first character read on line 191 is not in the range of `Printable_Character`.

To protect against this error, return to file `tokens.adb` at line 26, and insert the following code before the case-statement:

```
if Word = "" then
  raise Except.User_Error;
end if;
```

Re-run GNAT SAS by selecting the menu *GNATSAS* → *Analyze All*. Notice that the error on `tokens.adb` has disappeared.

3.2 Warnings

This refers to messages reported by GNAT SAS that do not correspond to checks, but rather to potential logic errors: dead code, test or condition predetermined, unused assignment, etc. Like checks, these messages have an associated ranking, they are introduced by the keyword **warning** which is appended after the **high**, **medium** or **low** markers, e.g **medium warning**.

In the Locations View, click on the message reported at line 41 of `stack.adb`. It says that the precondition computed by GNAT SAS' Inspector for variable *Last* is suspicious, because it is not a continuous range of values.

Indeed, looking at the preconditions generated by Inspector, we see the following lines:

```
-- Preconditions:
-- Last in (2..199, 201)
```

It is indeed the case that the range of values allowed for variable *Last* has a 'hole', because value 200 is not allowed while values 199 and 201 are allowed.

Since 200 is the value of *Tab*'*Last*, having *Last* equal to 200 means that the stack is full. So it is expected that we should not call *Push* on a stack when *Last* equals 200.

What's surprising is that *Last* can be equal to 201 in the precondition computed by Inspector. This means that we could call *Push* on a stack which is more than full!

Let's simulate what happens when we call *Push* with *Last* being equal to 201. The test on line 43 is false, so execution continues on line 47, then on line 49 *Last* is assigned the value 200 (201 - 1) and finally on line 50 we replace the last item in array *Tab* with the value *V*.

What's wrong here?

The problem is on line 49: instead of decrementing the value of *Last*, it should be incremented. This bug is also found by debugging during the GNAT Studio tutorial.

Notice that it also causes the message at line 11 in file `values.adb`, because function *Stack.Push* is called in function *Values.Process*, so the precondition generated for *Stack.Push* causes a similar precondition to be generated for *Values.Process*.

This kind of logic error typically results in a precondition with a 'hole' like the one reported here. This is why GNAT SAS reports warnings when it encounters such preconditions.

After correcting line 49, re-run GNAT SAS. The two messages in files `stack.adb` and `values.adb` are no longer present.

3.3 False Positive

Some messages reported by GNAT SAS are not actual errors. These messages which are called *false positive* are a necessary evil when performing static analysis of complex properties of code.

First, allow low messages to be displayed by checking the box **low** in Message ranking.

In the location view, click on the message reported on the code you were asked to insert before line 26 of `tokens.adb`. It says that an exception might be raised, which is precisely the intention of the inserted code when `Input.Next_Word` returns an empty string.

Likewise, click on the message reported at line 191 of `input.adb`. It says that `First_Char` might be greater than `Line_Size` (1024).

This cannot happen, as the call to `Input.Skip_Spaces` ensures that `First_Char` points within the bounds of `Line` to a printable character, and the loop between lines 191 and 193 cannot increase `First_Char` beyond `Line_Size` because the procedure `Input.Read_New_Line` which updates `Line` ensures that the line is terminated by a character `ASCII.CR` which is not printable. So the loop will exit at most when `First_Char` is the index of this last character.

You can choose to ignore such false positive, or else mark them as reviewed so that they do not show up in future runs of GNAT SAS. To do that, click on the *Edit* icon displayed in front of GNAT SAS messages in the Locations View. This opens a window where you can enter a manual analysis of the message and e.g. change its *New status* to **Not a bug**.

Notice that the reasoning above, for the value of `First_Char`, depends on subtle invariants maintained by the code on the `Line` data structure. This may reveal brittle code which would deserve refactoring. A good way to realize this is to try to understand how `Input.Skip_Spaces` ensures that `First_Char` points within the bounds of `Line`. This is not as easy as it seems!

UNDERSTANDING INSPECTOR'S ANNOTATIONS

In addition to messages, GNAT SAS' Inspector analysis also generates annotations on your source code. Annotations express properties and assumptions of the code, and can be used to help reviewing the code manually and spot inconsistencies, and also to help understand messages generated by Inspector.

4.1 Basic Annotations

Open file `stack.adb` and look at the annotations for procedure `Push`.

The preconditions of `Push` correspond to constraints that should be respected prior to calling `Push` in order to avoid errors. The third precondition states that `Last` should be less than 200, so that the stack is not full. The other preconditions state that parameter `V` should not be null and `V.E` should be initialized:

```
-- Preconditions:
--   Last <= 199
--   V /= null
--   V.E'Initialized
```

While some preconditions can be traced to checks inside the current procedure, others originate in functions or procedures directly or indirectly (through a chain of other functions or procedures) called by the current procedure. Here, the last precondition can be traced to the increment on `Last` at line 49 and the access to `Tab (Last)` that follows on line 50, while the preconditions on `V` are propagated from the precondition of function `Values.To_String` called on line 47.

The postconditions of `Push` correspond to constraints that will be satisfied after calling `Push`. The first postcondition states that the output value for `Last` will be its input value plus one. Notice the use of Ada 2012 attribute `'Old` to denote the input value of `Last`. The second postcondition states that the output value of `Last` will be in the range 1..200:

```
-- Postconditions:
--   Last = Last'Old + 1
--   Last in 1..200
--   Tab(1..200) = One-of{V, Tab(1..200)'Old}
```

We will explain the last postcondition in the next section.

4.2 More Complex Annotations

Open file `tokens.adb` and look at the preconditions generated for procedure `Process`:

```
-- Preconditions:
--   T.Kind /= Op or StackBody.Last in 2..200
--   T.Kind /= Op or StackBody.Tab(StackBody.Last - 1) /= null
--   T.Kind /= Op or StackBody.Tab(StackBody.Last) /= null
--   T.Kind /= Op or StackBody.Tab(1..200).E'Initialized
--   T.Kind /= Op or T.Op'Initialized
--   T.Kind <= Op or StackBody.Last <= 200 or T.Instr /= Print
--   T.Kind <= Op or StackBody.Last = 0 or T.Instr /= Print or StackBody.Tab(StackBody.
↪Last) /= null
--   T.Kind <= Op or StackBody.Last = 0 or T.Instr /= Print or StackBody.Tab(1..200).E
↪'Initialized
--   T.Kind <= Op or T.Instr <= Print
--   T.Kind >= Op or StackBody.Last <= 199
--   T.Kind >= Op or T.Val /= null
--   T.Kind >= Op or T.Val.E'Initialized
```

Some preconditions are disjunctions of cases, like `T.Kind /= Op or Last in 2..200`. This conditional precondition states that, either `T.Kind` is different from `Op`, or `Last` must be in the range `2..200`. This is because the constraint on `Last` comes from a path in `Process` that is only executed when `T.Kind = Op`, so it does not apply when `T.Kind /= Op`.

Look now at the postconditions generated for procedure `Process`:

```
-- Postconditions:
--   StackBody.Last = One-of{StackBody.Last'Old + 1, StackBody.Last'Old - 2, StackBody.
↪Last'Old - 1, 0, StackBody.Last'Old}
--   StackBody.Last <= 200
--   StackBody.Tab(1..200) = One-of{T.Val, StackBody.Tab(1..200)'Old, new Value_Info(in_
↪values.operations.process)#1'Address}
--   new Value_Info(in values.operations.process)#1.<num objects> in 0..1
--   new Value_Info(in values.operations.process)#1.E'Initialized
```

Some postconditions of `Process` are of the form `Variable = One-of{Value1, Value2, ...}`. This indicates that the output value of `Variable` is either `Value1` or `Value2` or ... Look in particular at the postcondition of this form for `Last`. Inspector computed that the possible output value for `Last` is either zero, input value of `Last`, input value of `Last` plus one, input value of `Last` minus one or input value of `Last` minus two. This postcondition effectively summarizes all the possible modifications occurring to `Last` in various procedures and functions called from `Process`.

Be aware that, although annotations are displayed in an Ada-friendly syntax, they may not be legal Ada, or they may designate something different than in Ada. For example, there is no way in Ada to specify that a value should be initialized like suggested by the pseudo-Ada attribute `'Initialized`. Likewise, it is not valid in Ada to refer to the value of ‘any element of an array’ like done in Inspector annotations using the syntax of an array slice.

RUNNING GNAT SAS AGAIN

As you may have noticed already, GNAT SAS recorded the results of the first run that you made as the baseline for successive runs after possible code modifications, as shown by the top line displayed in the GNAT SAS report:

Base run: <code>sdc.baseline.sam</code>	Current run: <code>sdc.sam</code>
---	-----------------------------------

Notice the different kinds of filters which are available on the right side of the window, in panel Message ranking, in particular the *Message history* part: selecting these different filters will show/hide the corresponding messages in the Locations View at the bottom. By default, only the messages which correspond to the current run (either **added** or **unchanged**) are shown.

Uncheck the **unchanged** box in Message history. This clears the location view from all previously reported messages.

Now check the **removed** box: if `-show age+removed` is used, you will see all the messages which have disappeared since the base run (the first run in this case).

GNAT SAS defines two types of runs: regular and baseline. The runs are represented by *sam* files. A first GNAT SAS run is a baseline run and it results in a sam file `<PROJECT_NAME>.baseline.sam`. All the subsequent runs are regular runs resulting in sam file `<PROJECT_NAME>.sam` and are compared to the baseline run.

In order to bump a baseline to a current run, you can use the menu `GNATSAS → Baseline → Bump Baseline to Current Run`. You can also set a baseline to a given run via `GNATSAS → Baseline → Set Baseline to Run...`

RUNNING DEEPER ANALYSES

You can vary the thoroughness of GNAT SAS' analysis by selecting the menu *GNATSAS* → *Analyze...* and selecting *fast* or *deep* in the *Analysis mode* dropdown. In fast mode, a fast analysis is performed. In particular, GNAT SAS' Inspector analyzes each library unit separately. In deep mode GNAT SAS' Inspector performs the analysis by group of units.

Partitioning can be seen in the Messages window:

```
Partition 1 of 2.  
...  
Partition 2 of 2.  
...
```

Note: Partitioning does not occur in deep mode on our project, which is too small.

When units are analyzed separately, no information is shared between the various analyses. The results may be less precise than the ones obtained by running GNAT SAS at deep mode. But the benefit is quite clear: you can get much faster results by running GNAT SAS at fast mode, and you can later run at deep mode when more precision is required.

EPILOGUE

This terminates our tour of GNAT SAS inside the GNAT Programming Studio. We hope this tutorial gave you a good overview of the general capabilities available with GNAT SAS. A non-exhaustive list of the features not mentioned in this document includes:

- Running from the command-line
- HTML report
- Sharing GNAT SAS results in a team
- Management of manual reviews
- Capabilities of Infer, GNATcheck, and GNAT Warnings analysis engines
- Identification of race conditions

For more information, please look at the GNAT SAS User's Guide, as well as the *Help* → *GNATSAS* → *Examples* menu which gives access to many small examples with interesting messages.

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