
MLH localhost
Workshop
Bug-free Coding with SPARK Ada
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1

Using your Web Browser,
Open this URL:

http://mlhlocal.host/lhd-resources

2

Click on the workshop you're attending, and find:

- Setup Instructions
- The Code Samples
- A demo project
- A Workshop FAQ
- These Workshop Slides
- More Learning Resources

Our Mission is to Empower Hackers.

65,000+
HACKERS

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We hope you learn something awesome today!
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What will you learn today?

1. What makes the Ada programming language special & why you should use it.

2. How to write bug-free code with a provable subset called SPARK Ada.

3. How to implement the Stack Data Structure in SPARK Ada.

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Meet the Ada programming language!

Ada is a general purpose, modern programming language like Java, C, or C++.

- Ada's creation was sponsored by the USA's Dept. of Defense (DoD) in the 1970s and 1980s.
- The goal of the Ada programming language is to give developers the tools necessary to write safer, more maintainable code.

Ada vs. C, C++, & Java

In high reliability software, you are usually choosing between C, C++, Java, and Ada. So, why Ada?

What is Ada good at?

Ada is a mature language that enables you to write efficient code on a variety of platforms. It's known for its:

- Reliability
- Maintainability
- Testability
- Formal Proofs (Bug-Free!)
- Human-Friendliness

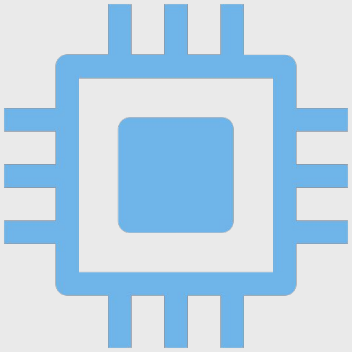
Ada's Key Value

Unlike C, C++, and Java, Ada can actually help you write **more** reliable and maintainable code.

When would you want to use Ada?

You could use Ada for just about anything, but it's especially useful for writing...

High-Integrity Embedded Systems



Planes, trains, spaceships, boats, etc.

Long-Lived Applications

Applications that need to last for 20+ years.

Apps where Human Lives are at Stake

Autonomous cars, railroad signals, etc.

Who uses Ada?

Ada is used by both big & small organizations to write mission critical software that is bug-free!



And so many more...

What is AdaCore?

AdaCore creates tools for developers to write safe and secure software.
http://www.adacore.com/

- AdaCore was founded in 1994.
- AdaCore has over 100 employees in the US, France, UK, and Estonia.
- AdaCore's products are used in many "high integrity" industries (Military, Space, Railroad, Automotive, Aviation, etc.)
- AdaCore loves empowering hackers & sponsoring these workshops!

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Let's take a quick tour of SPARK Ada.

We're going to cover the language at a high level:

- If you're familiar with C, C++, or Java, Ada will look very familiar.
- Our goal is to enable you to write your first Ada program!
- We'll also cover some useful SPARK specific features.

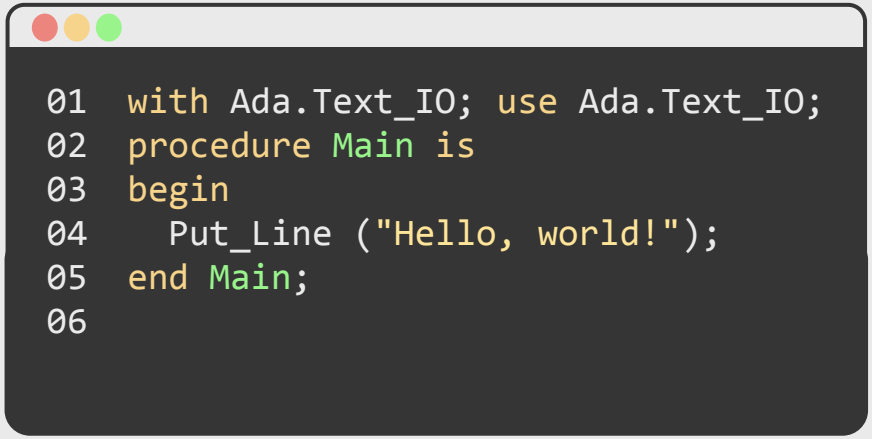
Fun Fact: Ada was named after Ada Lovelace, the first programmer!

Hello World.

The first program we usually write in a new language is “Hello World”, which just prints those words.

So, what is this code doing?

- **Line 1:** Import the Ada.Text_IO package then make its namespace immediately visible.
- **Line 2 - 3:** Define a new procedure called “Main”.
- **Line 4:** Print the string “Hello, world!” to the console.
- **Line 5:** Close the procedure.
    - Ada uses keywords rather than symbols (‘{ }’) to define scope.



```
01  with Ada.Text_IO; use Ada.Text_IO;
02  procedure Main is
03  begin
04    Put_Line ("Hello, world!");
05  end Main;
06
```

Data Types.

Your programs will need to interact with data.
What types does Ada have to offer?

Built-in Types:

Ada has a number of built-in data types that you can use in your programs. Today we'll be using:

- Integer
- Character
- String
- Boolean

Custom Types:

You can also create your own types.

```
01  type My_Integer is range 1 .. 10;
02
03  type RGB is (Red, Green, Blue);
04
05
06
```

Variables & Assignment.

You're going to need some place to store data in your programs. Variables hold data & allow you to access it.

Assignment

Assignment statements are written as `name := value`. For example, `X := 10;` sets the variable `X` to `10`.

Initialization

Variable initializations use the following format:

```
[NAME] : [TYPE] := [VALUE];
```

For example: `A : Integer := 10;`

Naming

In Ada, variable names are case insensitive. `HELLO` is the same as `Hello` is the same as `hello`.

Note: = vs. :=

In Ada, the `=` (single equal) is for comparison and `:=` is for assignment.

Strong Types.

Ada is a strongly typed language which means that variable types are predefined and do not change.

Declaring Variables.

Since Ada is strongly typed, we need to declare variables up front.

```
01  declare
02    X : Integer := 10;
03  begin
04    Do_Something (X);
05  end;
06
```

Mixing Types.

Since Ada is strongly typed, you can't combine objects of different types without explicit conversions.

```
01  Len_1 : Miles := 5.0;
02  Len_2 : Kilometers := 10.0;
03
04  -- This would cause an error!
05  D : Kilometers := Len_1 + Len_2;
06
```

Control Flow.

Ada comes with a variety of control flow structures. The two we'll be looking at today are `if` statements and `for` loops.

If Statements.

If statements are useful for logical branching of code.

```
01  if condition then
02    statement;
03  elsif condition2 then
04    statement2;
05  else
06    statement3;
07  end if;
```

For Loops.

You can use for loops to iterate over ranges of objects or arrays.

```
01  for I in Integer range 1 .. 10 loop
02       statement;
03  end loop;
04
05
06
```

Procedures vs. Functions.

Functions & procedures group code together to perform a task. For example, you could write a function to add numbers:

```
01  with Ada.Text_IO; use Ada.Text_IO;
02
03  procedure Main is
04
05    function Add (A : Integer; B : Integer) return Integer is
06    begin
07      return A + B;
08    end Add;
09
10  begin
11    Put_Line ("3 + 5 = " & Add(3, 5)'Image);
12  end Main;
```

Procedures are functions that don't return any value (like C void functions). They can alter the parameters that are passed in though.

Ada is so much more...

This is just the tip of the iceberg. Ada is a very mature, modern language with lots of useful features.

Ada also includes...

1. Object Oriented Programming
2. Generics (Templates)
3. Concurrency/Multitasking
4. Packages
5. And so much more!

Meet SPARK Ada.

Key Term

SPARK Ada: A subset of the Ada programming language, designed for program verification. In this workshop we'll be using SPARK Ada.

Key Term

Program Verification: How to check that source code is well formed, performs as intended, and is bug free.

SPARK Ada can prove...

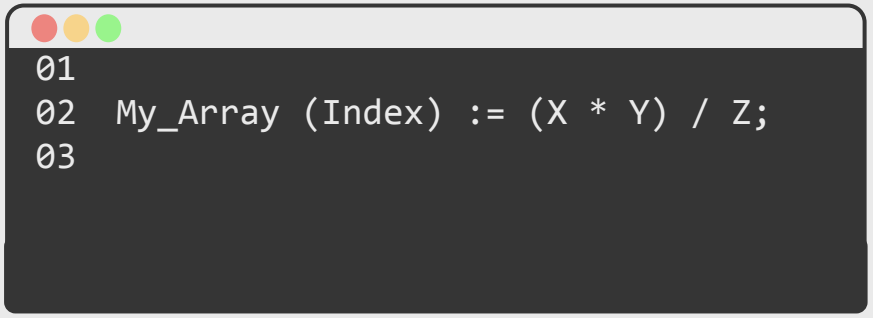
- **There are No Syntax Errors** - Is the code properly formatted & will it compile?
- **There are No Run-time Errors** - No exceptions, no buffer overflows, no division by zero, etc.
- **Your Theories** - True or False expressions that you write and the compiler verifies.

How does SPARK find bugs?

SPARK Ada's tools analyze your code for exceptions & erroneous behavior.

Questions SPARK asks...

- Are `My_Array`, `Index`, `X`, `Y`, and `Z` initialized?
- Is `Index` in the bounds of `My_Array`?
- Could `(X * Y) / Z` be potentially out of range?
- Could `(X * Y) / Z` potentially cause an overflow?
- Is `Z` potentially equal to `0`?



A SPARK Ada example.

Here is a procedure called `Inc` that takes in a “small int” and increments it by `+1`.

`inc.adb:`

```
01  package body Inc
02    with SPARK_Mode => On
03  is
04
05    procedure Inc (X: in out Small_Int) is
06    begin
07      X := X + 1;
08    end Inc;
09
10  end Inc;
```

What does this code do?

- **Line 1:** Define the package body for `Inc`.
- **Line 2:** Enable SPARK mode for program verification.
- **Line 5:** Define a procedure called `Inc` that takes a `Small_Int` called `X` & updates it.
- **Lines 6 - 8:** Update the variable `X` to equal itself plus `1`.

A SPARK Ada example.

What about the package specification for the Inc package?

inc.ads:

```
01  package Inc
02    with SPARK_Mode => On
03  is
04
05    type Small_Int is range -128 .. 127;
06
07    procedure Inc (X: in out Small_Int)
08      with Pre  => (X < Small_Int'Last),
09           Post => (X = X'Old + 1);
10
11  end Inc;
```

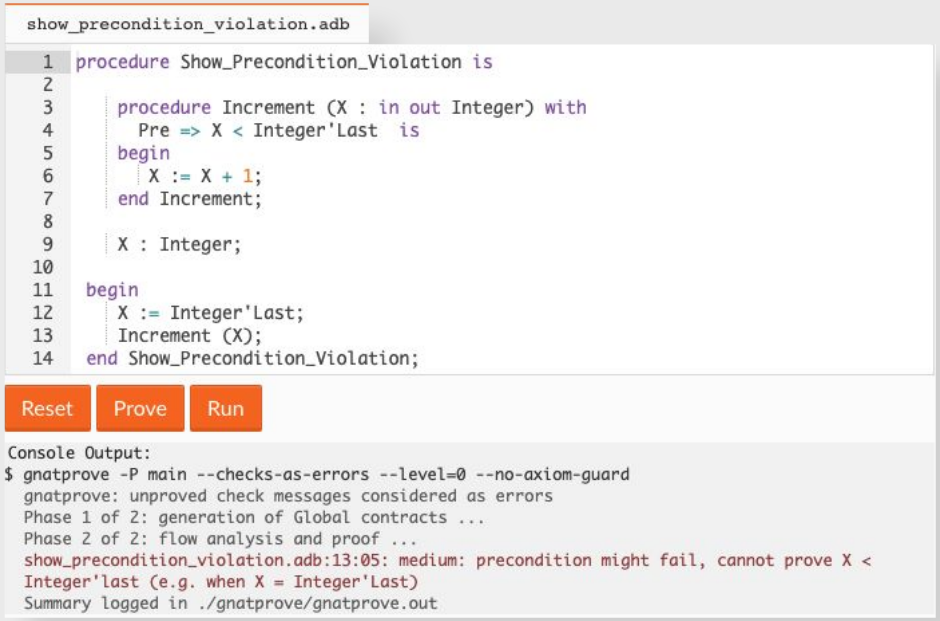
(*) Lines 8 & 9 use SPARK's proof of properties feature.

What does this code do?

- **Line 1:** Define the package specification for `Inc`.
- **Line 2:** Enable SPARK mode for program verification.
- **Line 5:** Define a new type called `Small_Int` that is an Integer between `-128` and `+127`.
- **Line 7:** Define a specification for calling `Inc`, a procedure that takes a `Small_Int` called `X` and updates it.
- **Line 8:** Verify that `X` is always less than `+127` before the procedure is called.
- **Line 9:** Verify that `X`'s new value is equal to `X`'s old value plus `1` after the procedure completes.

Running the SPARK Prover.

When you run the SPARK prover, it will identify the specific lines in your code that could cause bugs.



For example, here we are calling `Increment` with an argument that will cause the `Pre` check to fail.

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Let's Go to mlhlocal.host/learn-ada

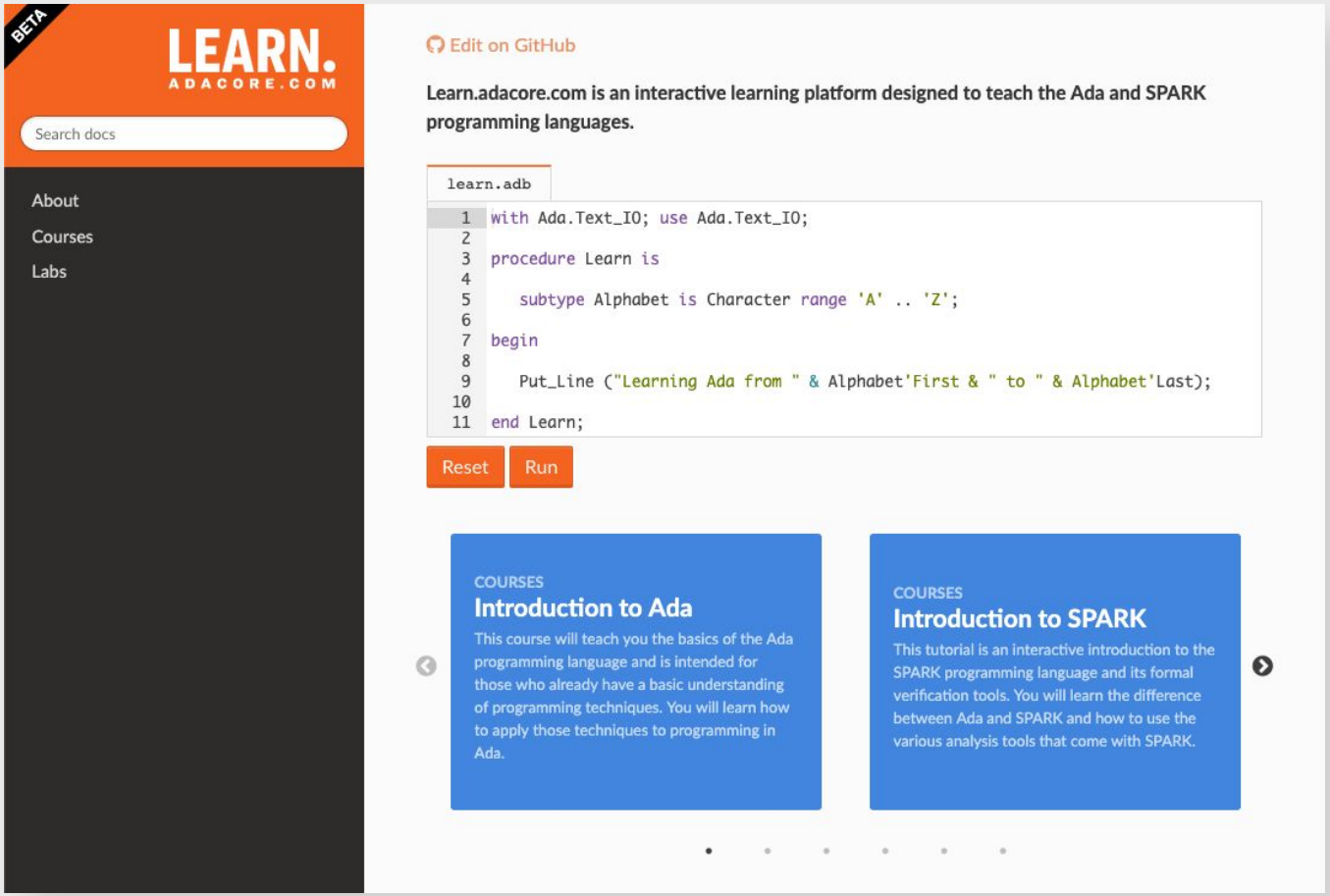
Navigate to mlhlocal.host/learn-ada in your browser and go to Labs->Major League Hacking->Let's Build a Stack

mlhlocal.host/MLHLearnAda

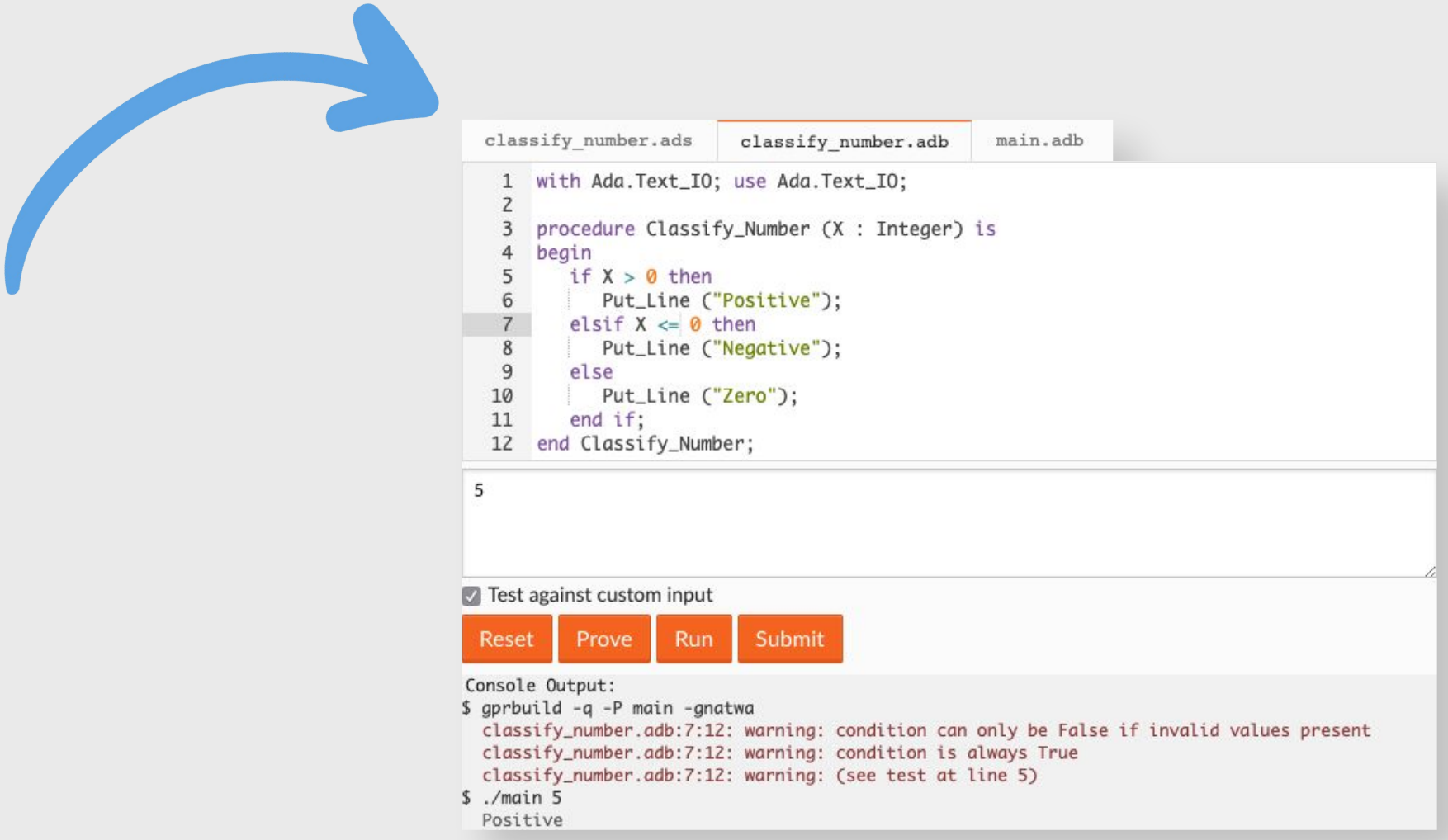
Raise your hand if you're having any trouble!

Meet mlhlocal.host/learn-ada

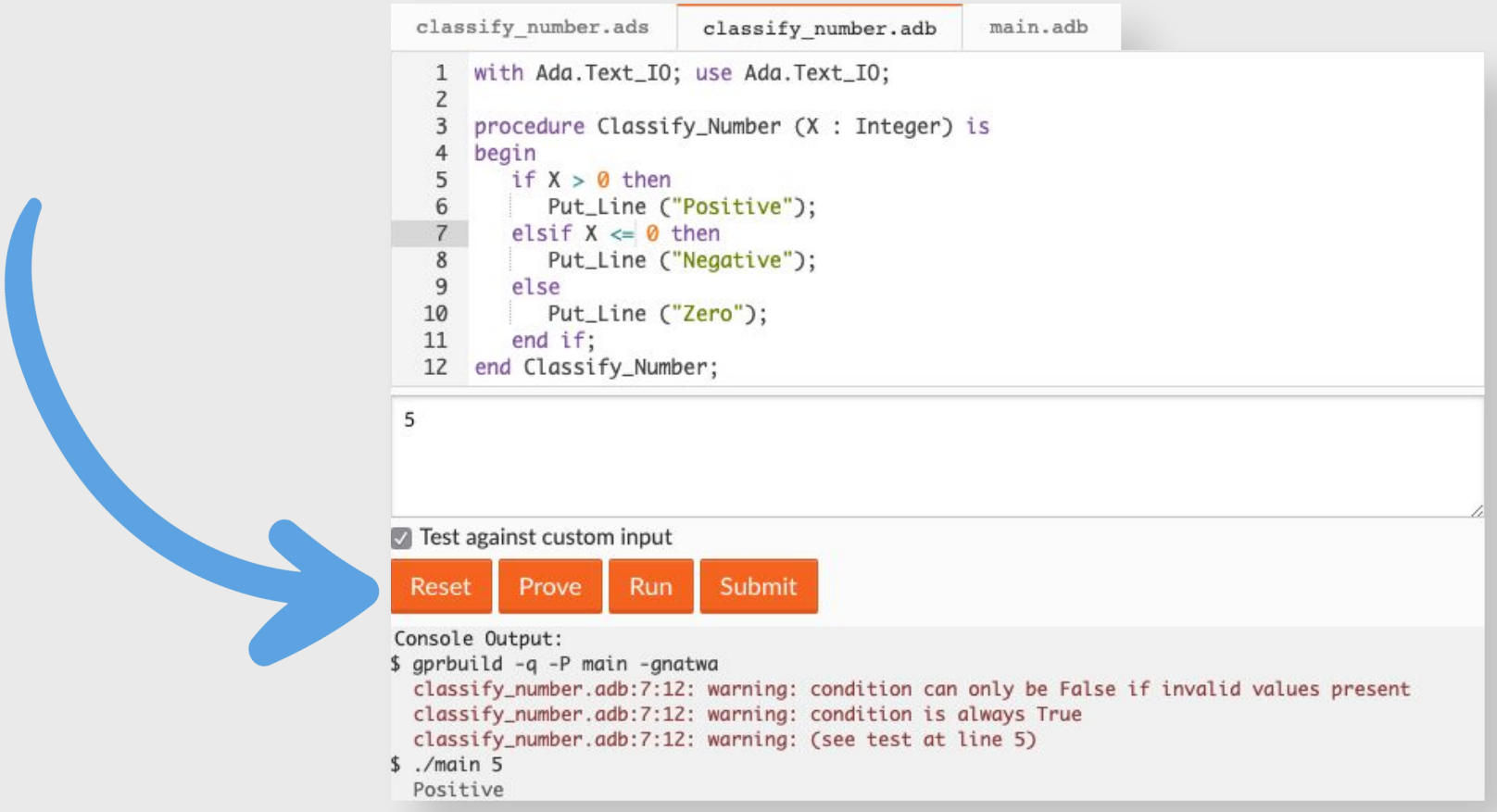
Learn Adacore is an interactive learning website designed to help you get started with Ada without installing any software.



Use tabs to navigate between source files

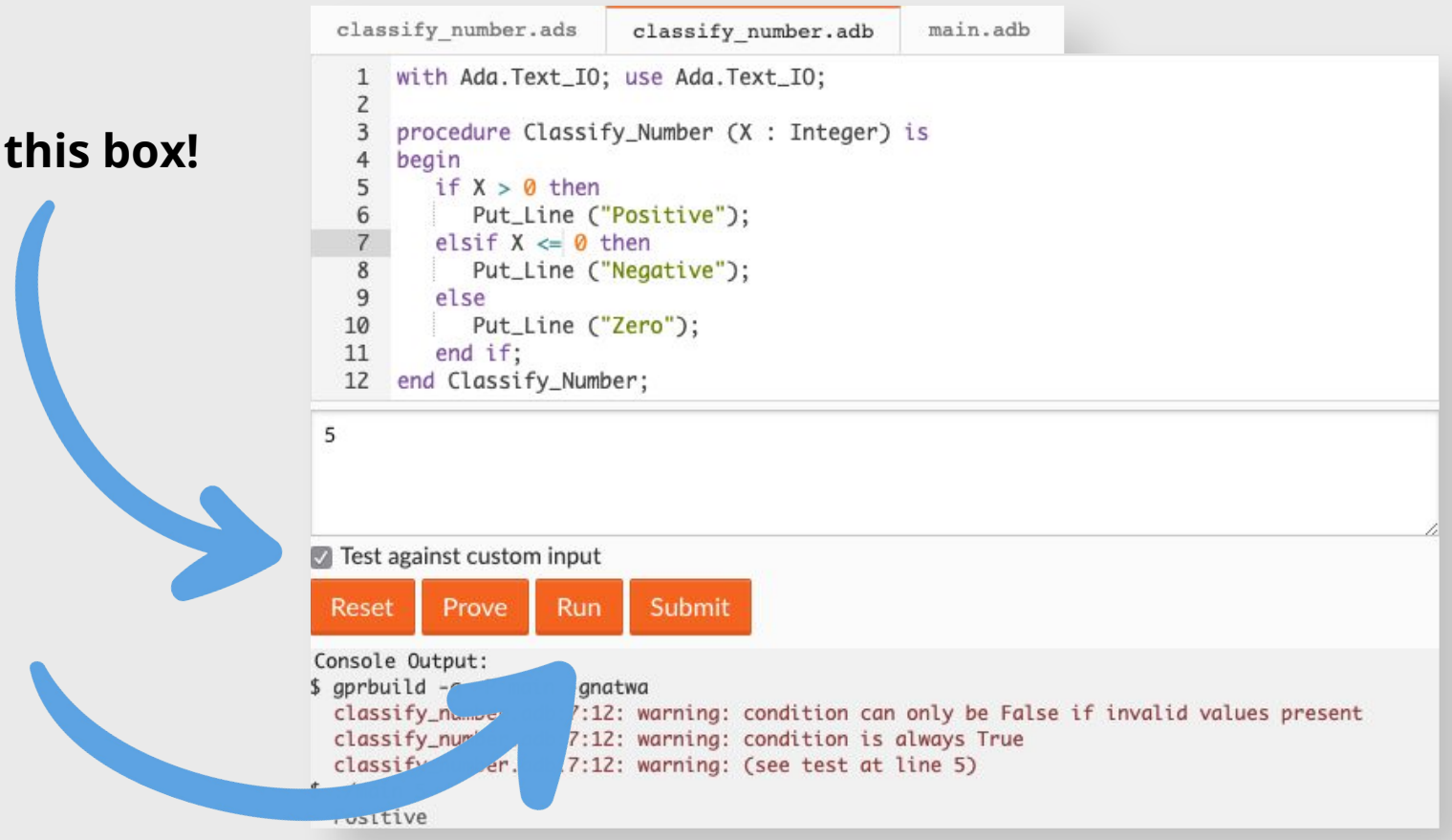


The Reset button resets the editor back to the initial code

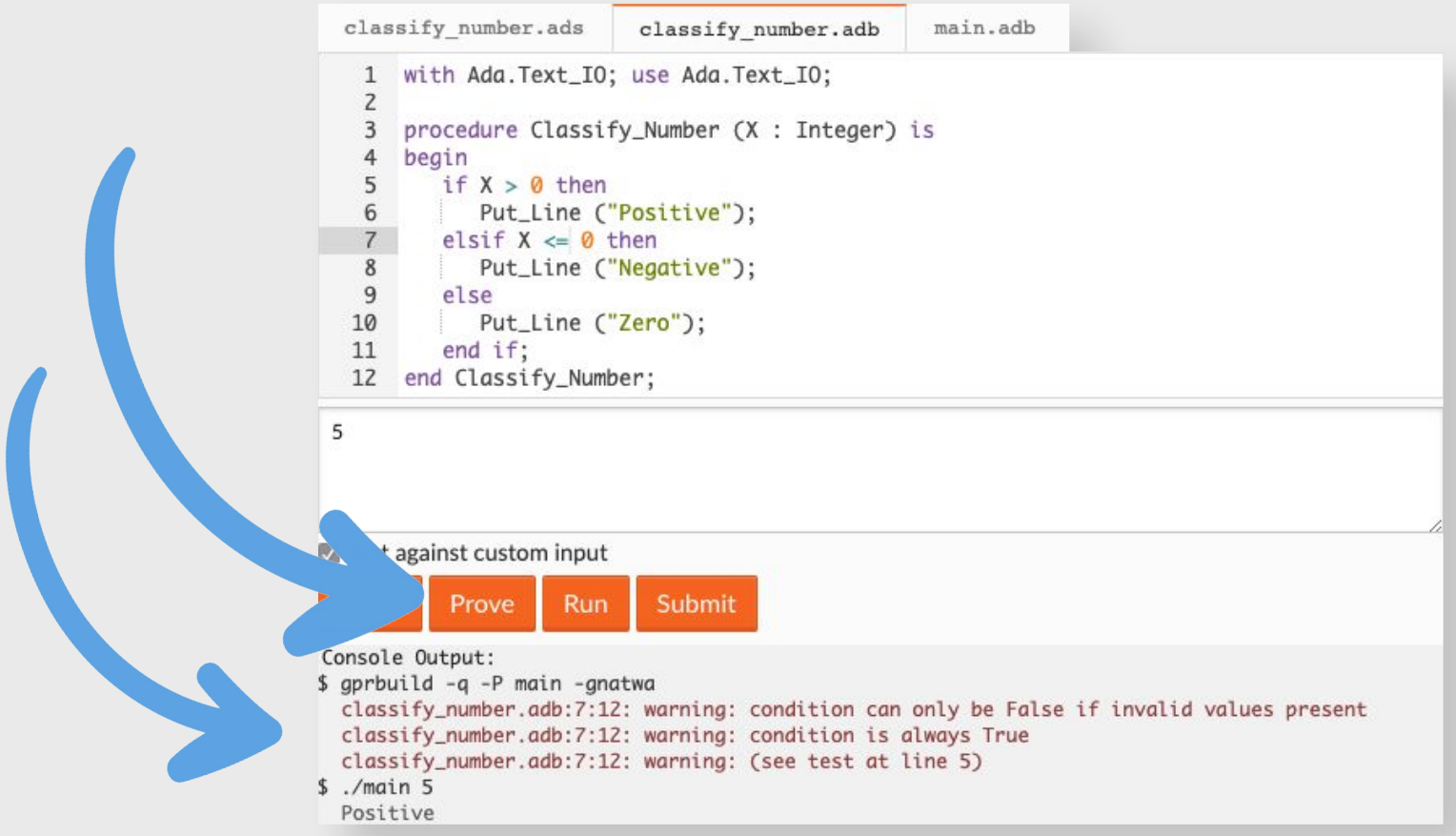


The Run button will run your code with the custom input as command line arguments

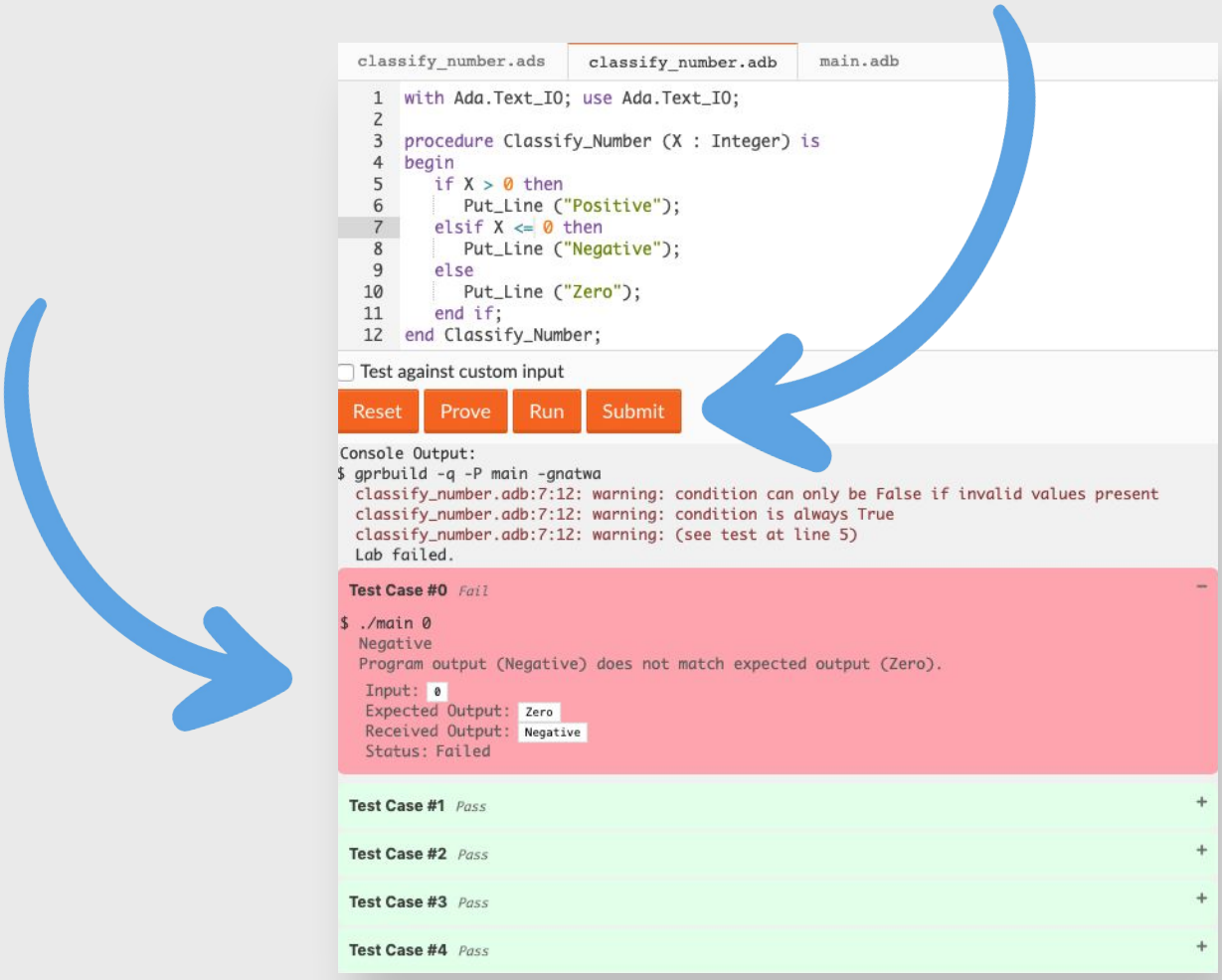
Check this box!



The Prove button runs the SPARK provers. Warnings and errors will appear in the output window.



Submit your lab for grading using the Submit button. Your test results will appear below.



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What are we building today?

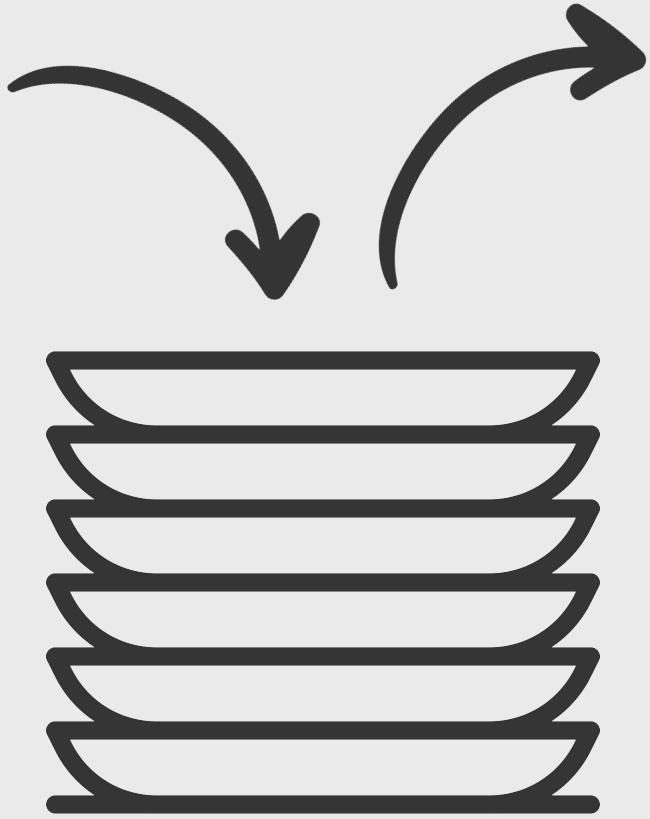
We're building a Stack!

- *We're going to build a common data structure called a "Stack".*
- *You'll receive some sample code that's mostly working with a few bugs.*
- *We'll use some of SPARK Ada's cool features to find and fix the issues.*

So, what is a Stack?

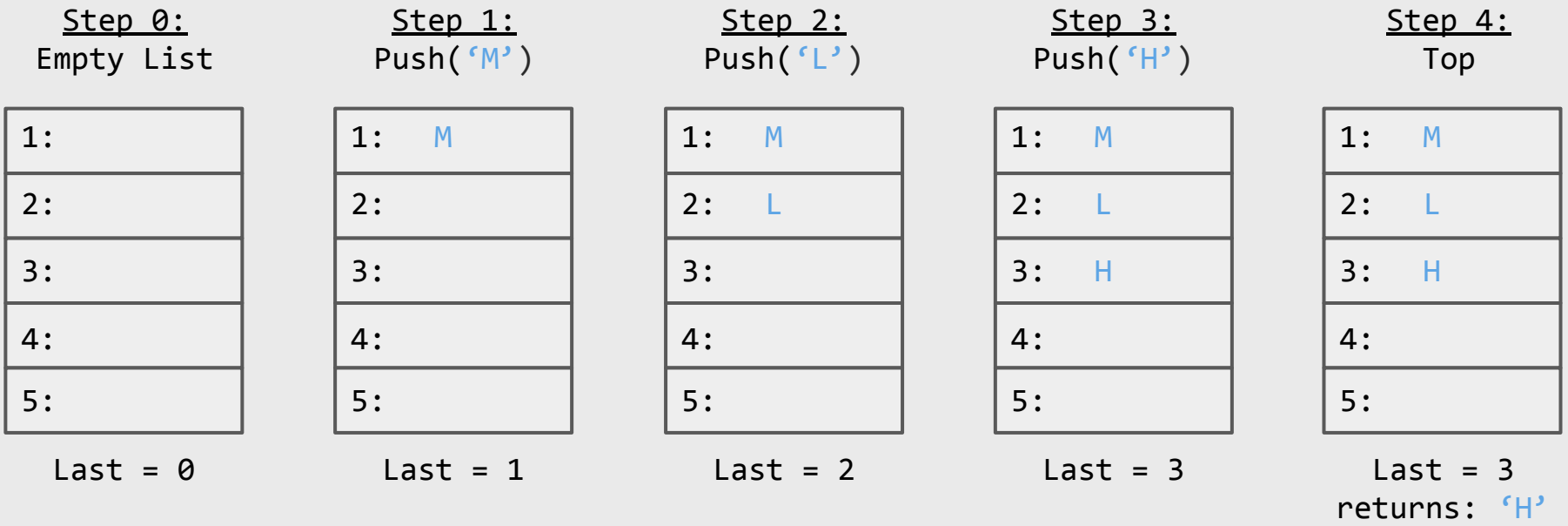
A Stack is like a pile of dishes...

1. The pile starts out empty.
2. You add ("`push`") a new plate ("`data`") onto the Stack by placing it on the top of the pile.
3. To get plates ("`data`") out, you take the topmost one off the pile ("`pop`").
4. Our stack has a maximum height ("`size`") of 9 dishes.



Pushing items onto the stack.

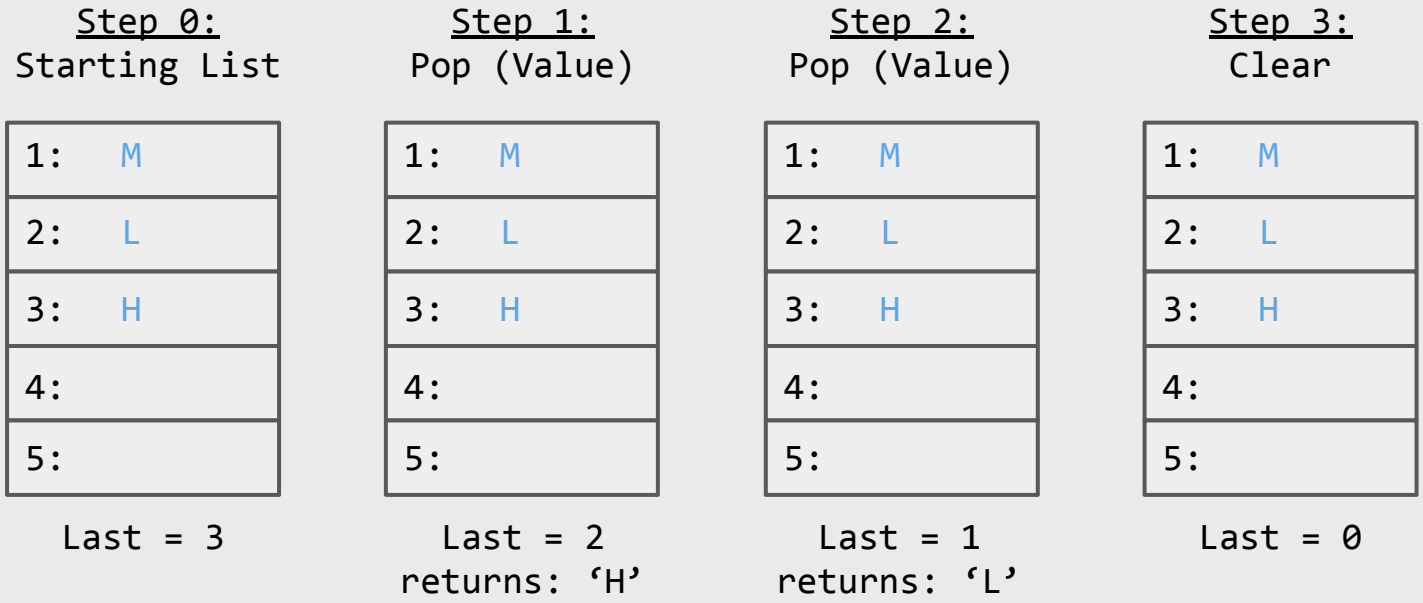
Here's what should happen if we pushed the string "MLH" onto the stack.



The list starts out empty. Each time we push a character onto the stack, `Last` increments by 1.

Popping items from the stack.

Here's what should happen if we popped 2 characters off our stack & then clear it.



Note that `Pop` & `Clear` don't unset the array's elements, they just change the value of `Last`.

Let's Try the Program

The program is supposed to push values onto the stack, print the stack, and pop some values off the stack.

- We can print the stack using the 'd' character.
- We can pop a value off the stack using the 'p' character.
- If we use any other character, it will be pushed onto the stack.

Consider the sequence: "M L H d p d"

This will:

1.) Push 'M'
2.) Push 'L'
3.) Push 'H'
4.) Print the stack "M L H"
5.) Pop the top item off the stack 'H'
6.) Print the stack "M L"

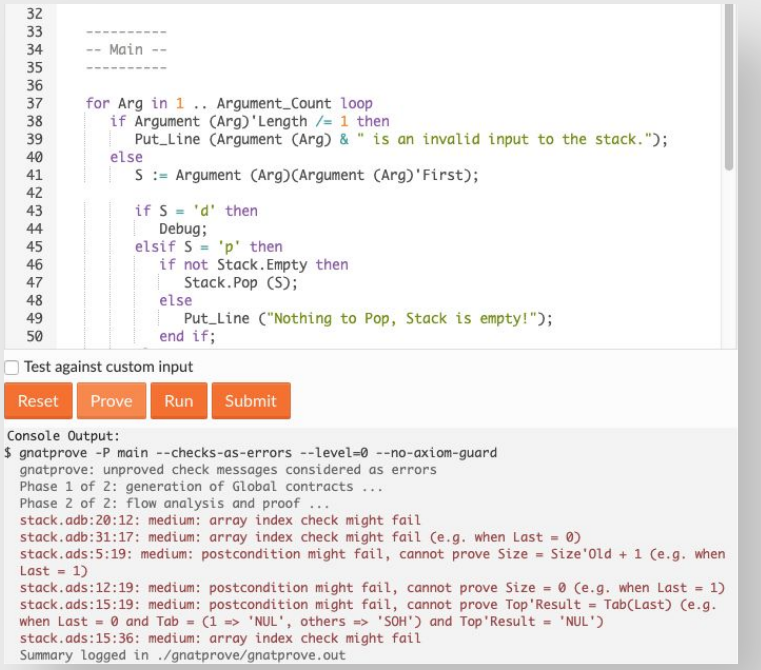
Let's Try the Program

The program is supposed to push values onto the Stack. *What happens when you try to submit the lab?*

As you can see, the program crashes.
SPARK Ada can actually warn us before we compile though!

Using the Prover

If you press the Prove button, you'll see the SPARK Prover identifies 6 issues with our code that may cause bugs or unexpected behavior.



Click on any item in the list to go to the relevant section of the code.

Fixing our first bug.

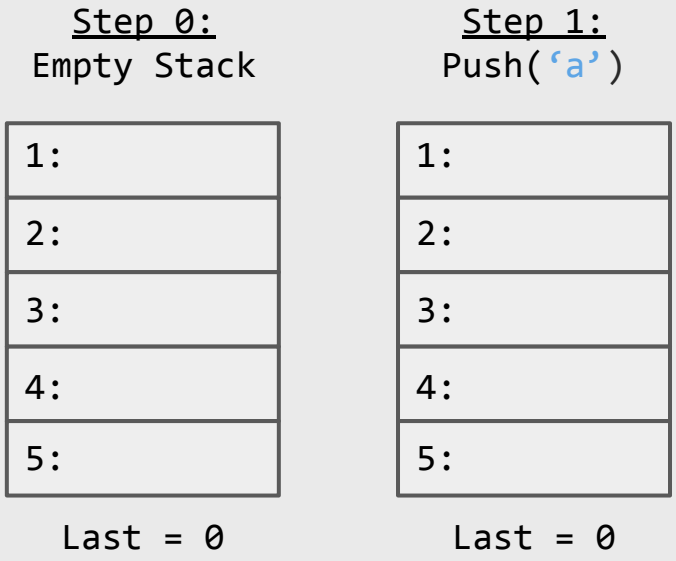
Click on the warning from line 20 of stack.adb.
This is the code that handles “pushing” values onto the stack.

```
12
13  ----------
14  -- Push --
15  ----------
16
17  procedure Push (V : Character)
18  is
19  begin
20    Tab (Last) := V;
21  end Push;
22
```

Can anyone spot the bug in this code?
*(**Hint**: It’s a logical bug, not a syntax bug)*

Fixing our first bug.

Let's draw out what happens when we `push` a value onto the stack.



Look, `Last` never changes! We try to insert `'a'` at index `0` of the `Tab` array, which raises an index out of bounds exception.

Fixing our first bug.

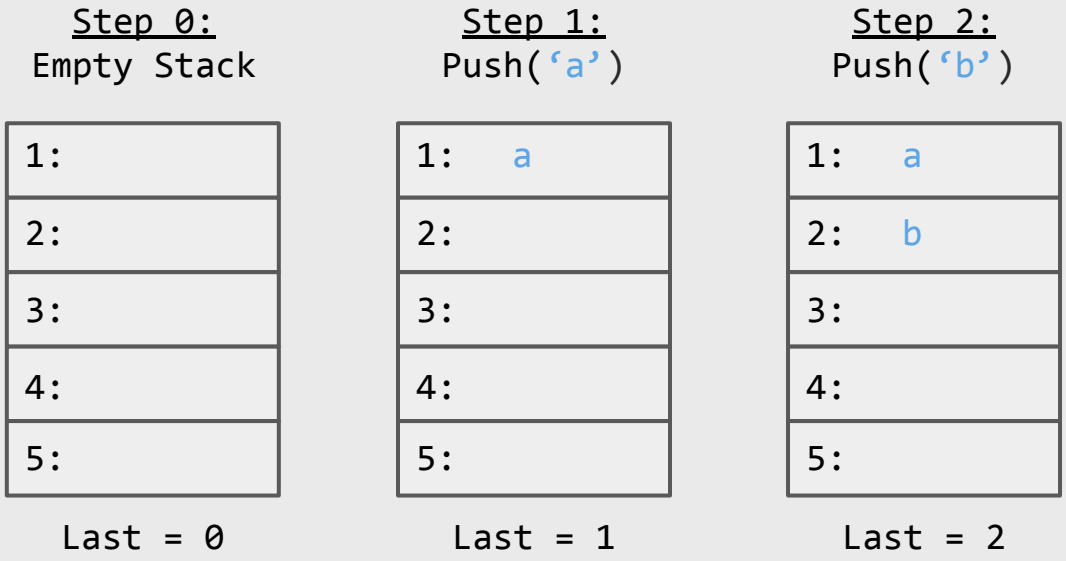
To fix the bug, we need to increment `Last` by `1` *before* adding `V` to the `Tab` array.

```
12
13  ----------
14  -- Push --
15  ----------
16
17  procedure Push (V : Character)
18  is
19  begin
>>  20    Last := Last + 1;
21    Tab (Last) := V;
22  end Push;
23
```

Going forward, line numbers will assume you've made the changes as we identify them.

Fixing our first bug.

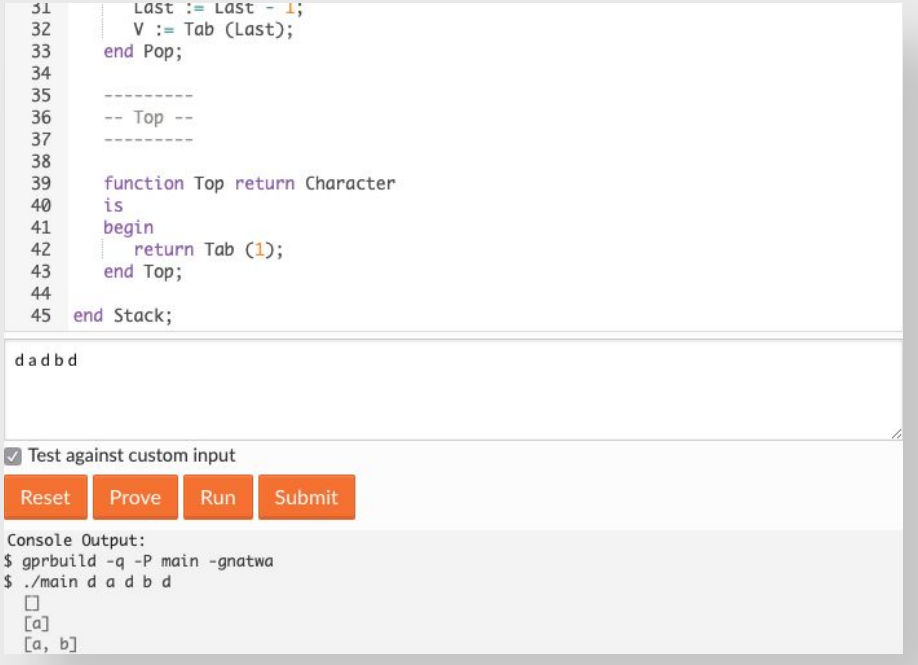
Now let's draw out what happens when we `push` a few values onto the stack with our new code.



As we push new values, `Last` increments to refer to the slot in the `Tab` array with the most recent value.

Fixing our first bug.

If you run the program again, you can now push new values onto the stack without any issue.



While you're at it, run the SPARK prover again to verify that our total warning count has gone down to 5.

Fixing the Pop procedure.

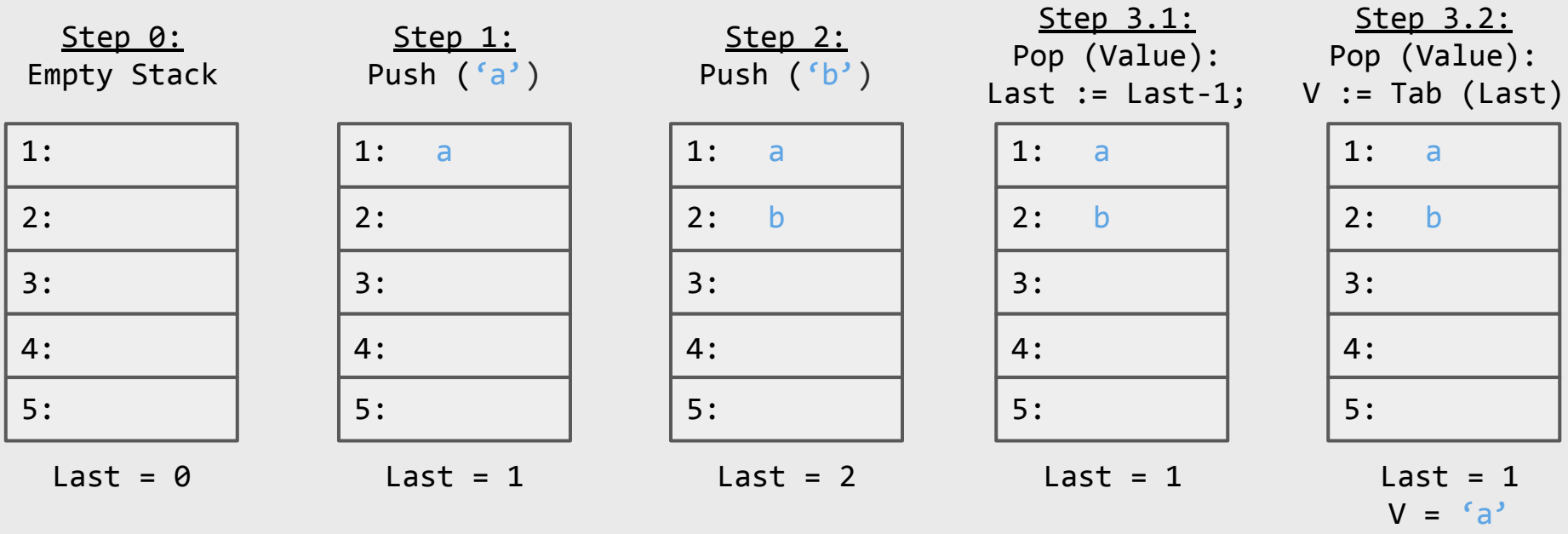
Next, let's look at the warning on line 32 of the Pop procedure.
The warning is "array index check might fail".

```
23
24  ---------
25  -- Pop --
26  ---------
27
28  procedure Pop (V : out Character)
29  is
30  begin
31    Last := Last - 1;
32    V := Tab (Last);
33  end Pop;
34
```

Can anyone spot the bug in this code?
*(**Hint**: It's a logical bug, not a syntax bug)*

Fixing the Pop procedure.

Let's draw out what happens when we Push a few values onto the stack & then Pop them off.



Look, Last is decremented *before* we set V's value.
We always get the 2nd-to-last item back from Pop.

Fixing the Pop procedure.

Swap lines 29 & 30 to set V's value *before* we decrement Last.

```
23
24  ---------
25  -- Pop --
26  ---------
27
28  procedure Pop (V : out Character)
29  is
30  begin
>>  31    V := Tab (Last);
>>  32    Last := Last - 1;
33  end Pop;
34
```

What happens when you run the prover now?

We're down to 3 warnings!

When we run the prover now, we only get 3 warnings.
All three come from the Stack package's specification file (`stack.ads`).

```
33     end Pop;
34
35     ---------
36     -- Top --
37     ---------
38
39     function Top return Character
40     is
41     begin
42        return Tab (1);
43     end Top;
44
45  end Stack;
```

Test against custom input

Reset | Prove | Run | Submit

```
Console Output:
$ gnatprove -P main --checks-as-errors --level=0 --no-axiom-guard
  gnatprove: unproved check messages considered as errors
  Phase 1 of 2: generation of Global contracts ...
  Phase 2 of 2: flow analysis and proof ...
  stack.ads:12:19: medium: postcondition might fail, cannot prove Size = 0 (e.g. when Last = 1)
  stack.ads:15:19: medium: postcondition might fail, cannot prove Top'Result = Tab(Last) (e.g.
  when Last = 0 and Tab = (1 => 'NUL', others => 'SOH') and Top'Result = 'NUL')
  stack.ads:15:36: medium: array index check might fail
  Summary logged in ./gnatprove/gnatprove.out
```

Fixing the Clear procedure.

Click on the warning from line 12 in `stack.ads`.

`stack.ads:`

```
10
11  procedure Clear
12    with Post => Size = 0;
13
```

The SPARK Prover can't assert that `Size` will equal `0` after the `Clear` procedure has been run.

Can anyone figure out why?

Fixing the Clear procedure.

The code on line 11 of stack.ads corresponds to the code on line 7 of stack.adb.

stack.ads:

```
10
11  procedure Clear
12    with Post => Size = 0;
13
```

stack.adb:

```
03  -----------
04  -- Clear --
05  -----------
06
07  procedure Clear
08  is
09  begin
10    Last := Tab'First;
11  end Clear;
```

Fixing the Clear procedure.

The Size function is also defined in `stack.ads` on line `30`.

stack.ads:

```
10
11  procedure Clear
12    with Post => Size = 0;
13
```

stack.ads:

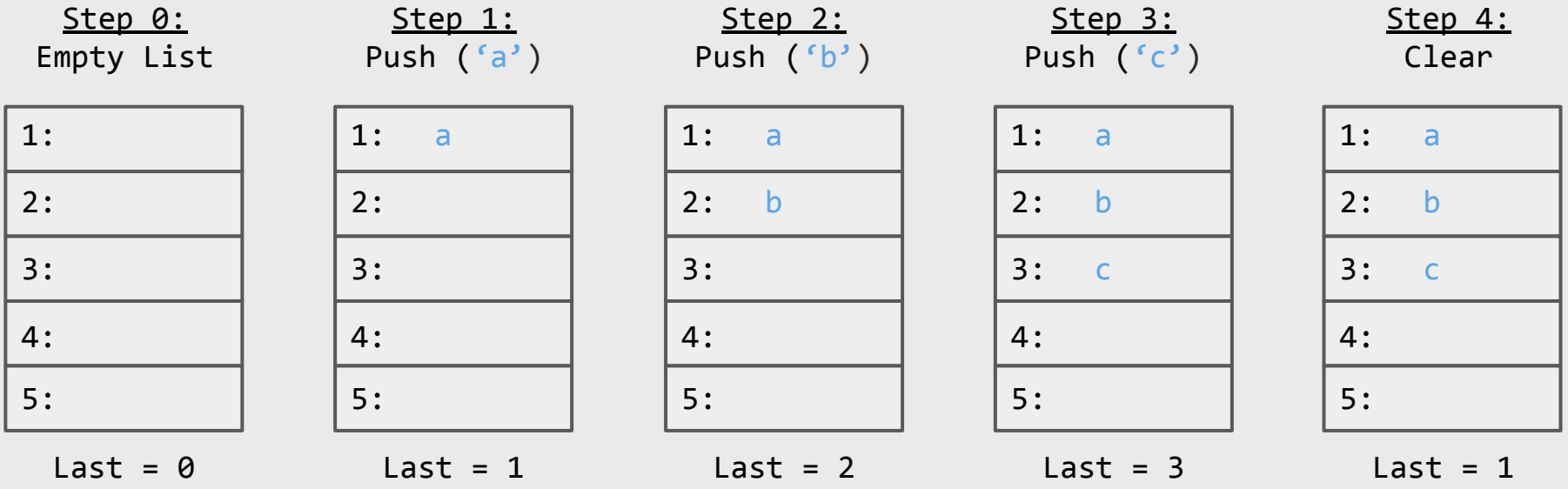
```
29
30  function Size return Integer is (Last);
31
```

It simply returns the value of `Last`.

So, when the stack is cleared, it should return `0`.

Fixing the Clear procedure.

Let's draw out what happens when we `Push` a few values onto the stack & then `Clear` it.



In Step 4, `Last` is set to `Tab'First`, which is the first index of the array - `1` not `0`!

Fixing the Clear procedure.

The code on line 11 of stack.ads corresponds to the code on line 7 of stack.adb.

stack.adb:

```
03  -----------
04  -- Clear --
05  -----------
06
07  procedure Clear
08  is
09  begin
>>  10    Last := Tab'First - 1;
11  end Clear;
```

Now Last will be set to 0 when we Clear the stack.

We're down to our last warnings!

When we run the prover now, we only get 2 warnings.
Both point to line 15 of the specification - `stack.ads`.

```
38
39      function Top return Character
40      is
41      begin
42         return Tab (1);
43      end Top;
44
45   end Stack;
```

Test against custom input

Reset | Prove | Run | Submit

```
Console Output:
$ gnatprove -P main --checks-as-errors --level=0 --no-axiom-guard
  gnatprove: unproved check messages considered as errors
  Phase 1 of 2: generation of Global contracts ...
  Phase 2 of 2: flow analysis and proof ...
  stack.ads:15:19: medium: postcondition might fail, cannot prove Top'Result = Tab(Last) (e.g.
  when Last = 0 and Tab = (1 => 'NUL', others => 'SOH') and Top'Result = 'NUL')
  stack.ads:15:36: medium: array index check might fail
  Summary logged in ./gnatprove/gnatprove.out
```

Fixing the Top function.

Top returns the item at the top of the stack without popping it.

Can anyone spot the bug?

stack.ads:

```
13
14  procedure Top
15    with Post => Top'Result = Tab(Last);
16
```

stack.adb:

```
35  -----------
36  -- Top --
37  -----------
38
39  function Top return Character
40  is
41  begin
42    return Tab (1);
43  end Top;
```

Fixing the Top function.

Although `1` is technically the top (first element) of the `Tab` *array*, the top of the *stack* is actually `Last`.

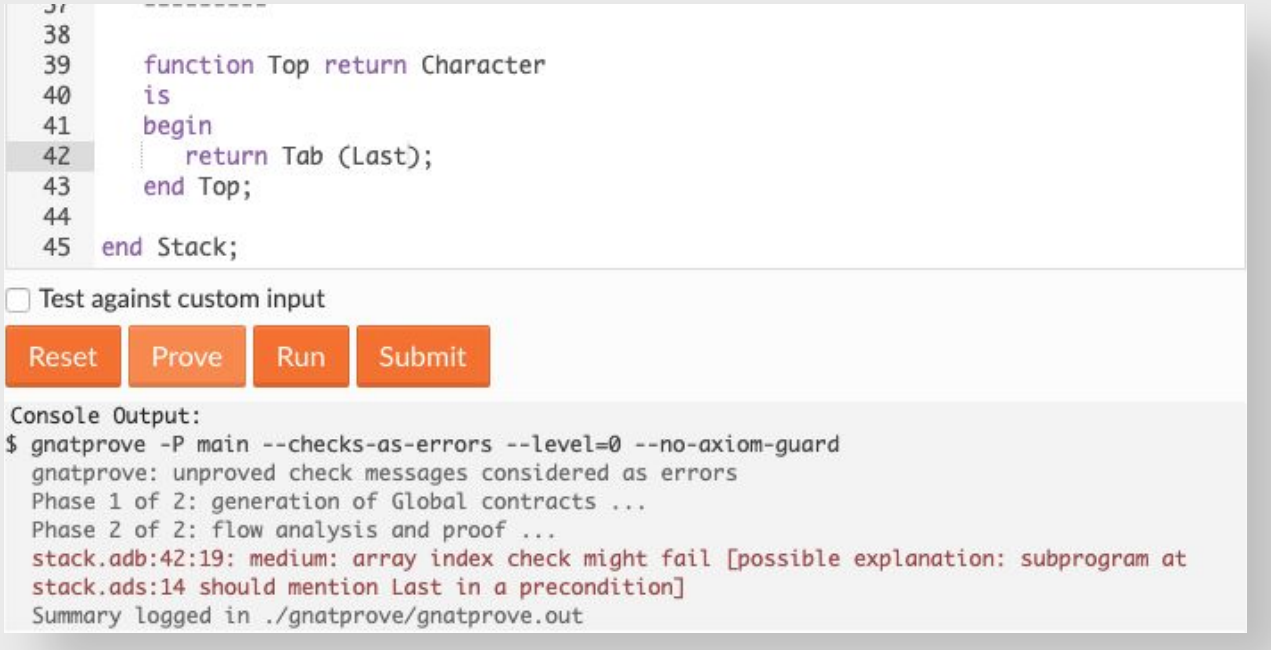
stack.adb:

```
35  -----------
36  -- Top --
37  -----------
38
39  function Top return Character
40  is
41  begin
>>  42    return Tab (Last);
43  end Top;
```

What happens when you run the prover now?
We should be all out of warnings, right?

Surprise! We've got one more warning to fix.

The SPARK Prover recognizes that if `Last = 0`, `Top` would throw an index out of bounds error.



Hint: *If `Post` specifies conditions after a function runs, how would you specify conditions before?*

Fixing the final warning.

We can use `Pre` conditions to specify that `Top` can't be called when the stack is empty.

stack.ads:

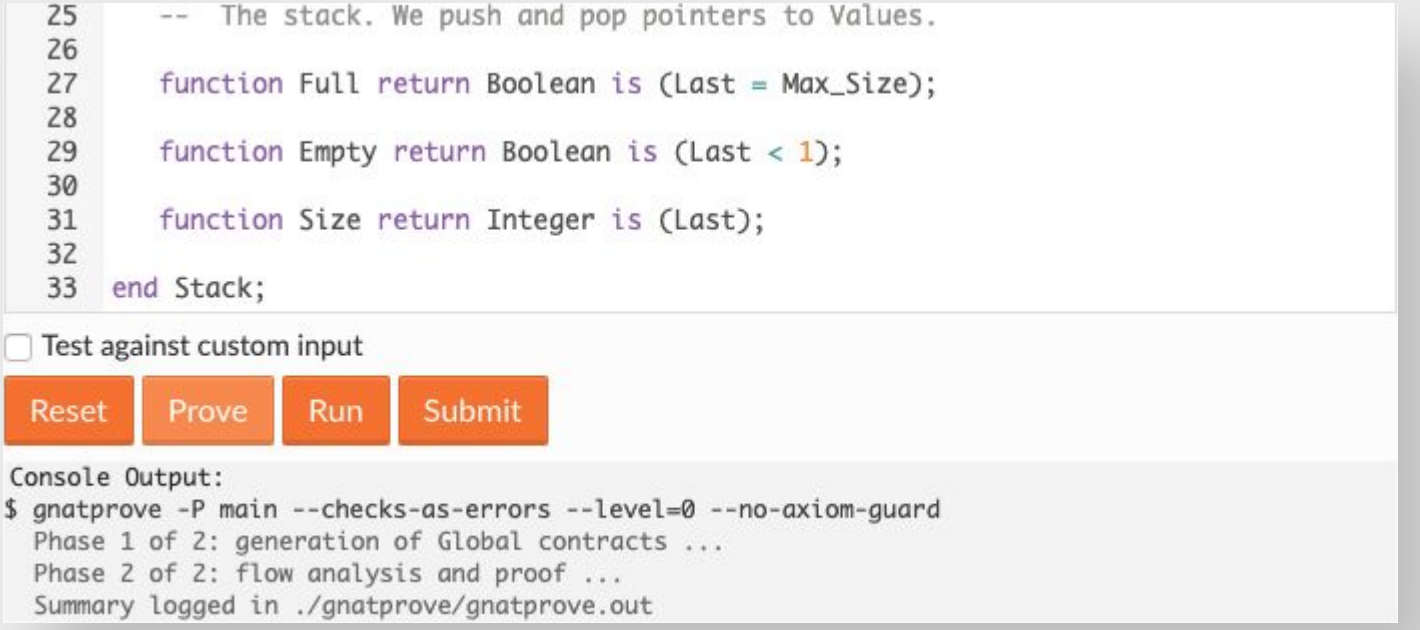
```
13
14  function Top return Character
15    with Post => Top'Result = Tab(Last),
>>16         Pre  => not Empty;
17
```

stack.ads:

```
28
29  function Empty return Boolean is (Last < 1);
30
```

Our code is bug-free!

Thanks to the SPARK Ada Prover, our code is proven to not raise exceptions, use uninitialized variables, and more!



Run the prover on your code to see for yourself.

Raise your hand if you need help or are still getting warnings!

Try submitting the program yourself!

Now that our program works,
Try submitting it by clicking “Submit”.

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Let's recap quickly...

1. SPARK Ada makes it easy for you to write bug-free programs!
2. Ada is a modern language that you can use on a variety of systems for a variety of purposes.
3. Employers are looking for developers that can engineer robust software & Ada enables that!

What did you learn today?

We created a fun quiz to test your knowledge and see what you learned from this workshop.

http://mlhlocal.host/quiz

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AdaCore

Where to go from here...

1. **Explore the differences between Ada, C++, & Java.**
   http://mlhlocal.host/adacore-ada-vs-java

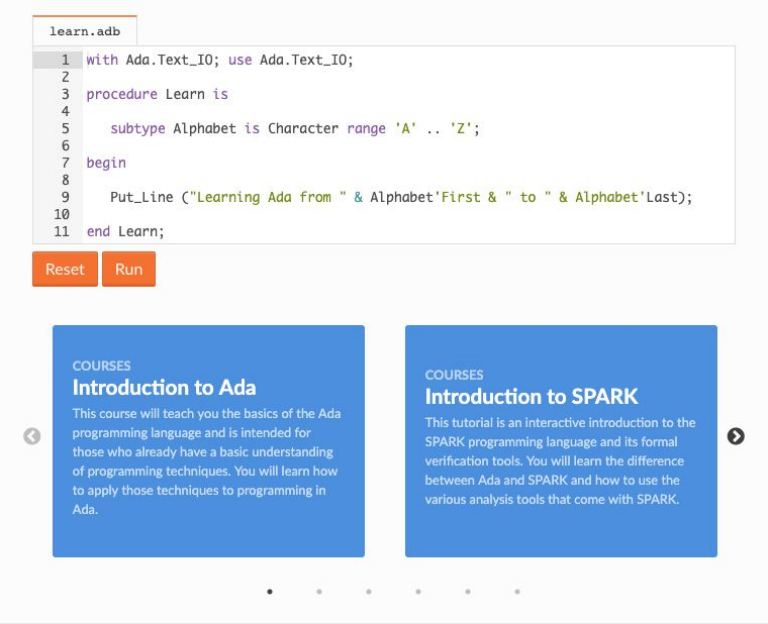
2. **Keep learning Ada & SPARK.**
   http://mlhlocal.host/learn-ada

3. **Complete the additional practice problems.**
   These problems & way more are in your email!

Keep Learning Ada and SPARK

Introduction to Ada and Introduction to SPARK

Learn more about Ada and SPARK with the Introduction to Ada and Introduction to SPARK courses on learn.adacore.com. You can also try your new Ada and SPARK skills by visiting the labs section.



Learning shouldn’t stop when the workshop ends...

Check your email for access to:

- These workshop slides
- Practice problems to keep learning
- Deeper dives into key topics
- Instructions to join the community
- More opportunities from MLH!


MLH localhost
Workshop
Bug-free Coding with SPARK Ada
v.0.0.2