"Generating Tests for Your MATLAB Code" Workshop Guide

This workshop provides a step-by-step guide to generating automated tests using the MATLAB Unit Test Framework and MATLAB Test.

In this workshop, you will:

- fork and modify your own copy of the MathWorks Generating Tests for Your MATLAB Code Workshop repository on GitHub
- generate tests using your command history and MATLAB Copilot
- automatically find and run existing tests
- explore code coverage metrics for your tested code
- identify bugs based on testing and code coverage
- automate your testing using continuous integration (CI) practices with GitHub Actions and build tool

Note: Some of the file links may not work in the PDF version of this document, but they work work in the WorkshopGuide.m file in MATLAB.

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Workshop Requirements

The following steps cover all of the things you will need to successfully complete the workshop:

A) Use the free MATLAB Expo Workshop license for the workshop

- Go to: **https://www.mathworks.com/licensecenter/classroom/expo_2025_5**
- *Note:* If you do not have a MathWorks account, the above link will ask you to create an account for free

B) A GitHub account

- The workshop leverages free repository and CI capabilities offered by GitHub and GitHub Actions
- Go to: **https://github.com/signup**

Part 1: Getting the workshop files and configuring GitHub for automated testing and results publishing

In this section, we will:

1. Fork the workshop files to our personal GitHub account
2. Enable GitHub Actions for automated testing
3. Enable GitHub Pages for report publishing
4. Opening the workshop in MATLAB Online

Part 1.1: Fork the "Generating Tests for Your MATLAB Code Workshop" repository to your GitHub Account

First, we'll start by forking the "Generating Tests for Your MATLAB Code Workshop" repository to our own GitHub account.

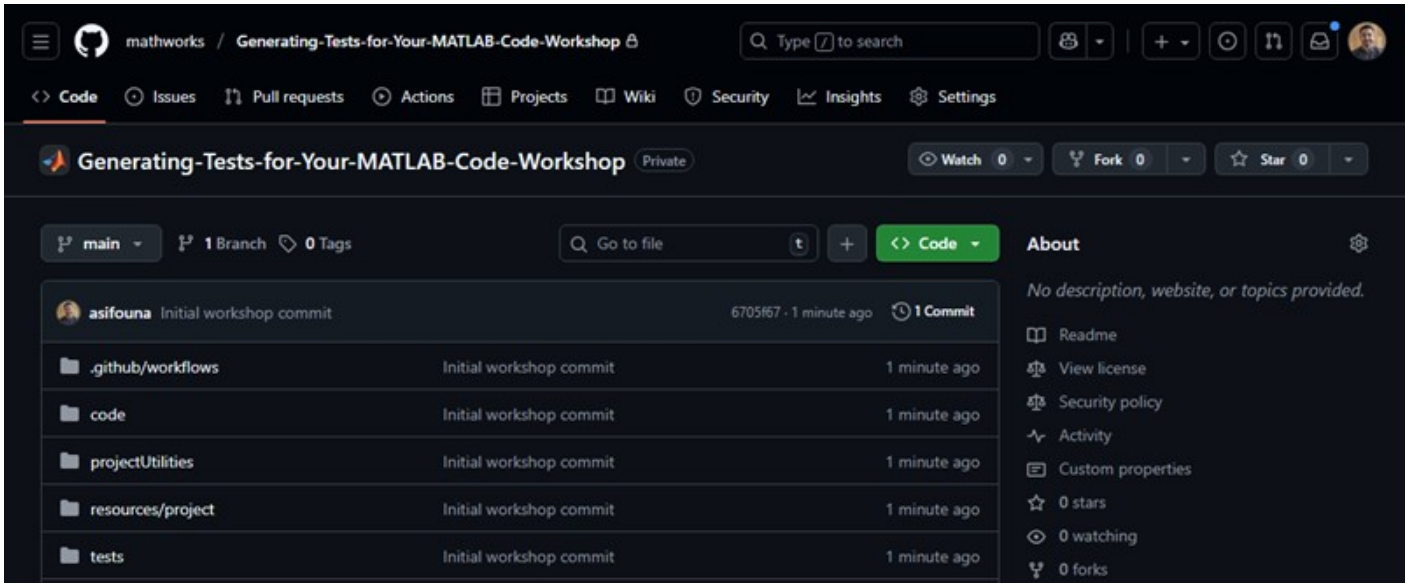
Wait... What does it mean to "fork a repository" and why should I do it?

Forking a repository allows you to freely experiment with changes to a project without affecting the original project.

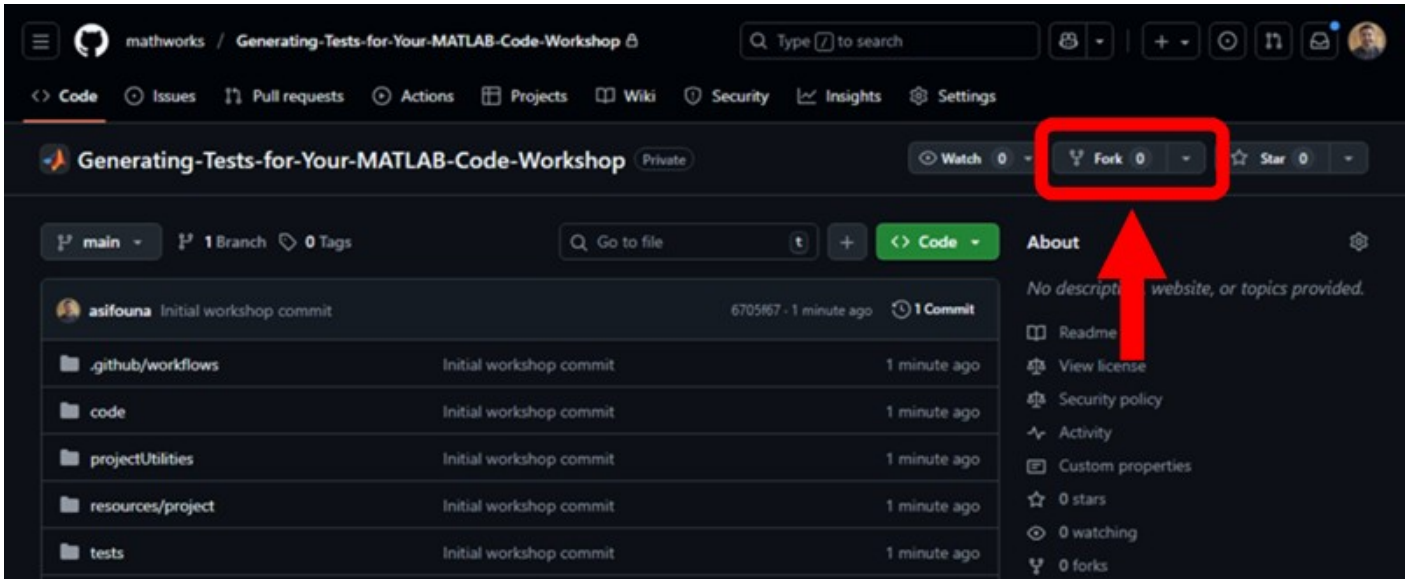
GitHub provides some great information about "why" and "how" to fork a repository: https://docs.github.com/en/enterprise-cloud@latest/pull-requests/collaborating-with-pull-requests/working-with-forks/fork-a-repo

Let's get started!

Go to: https://github.com/mathworks/Generating-Tests-for-Your-MATLAB-Code-Workshop

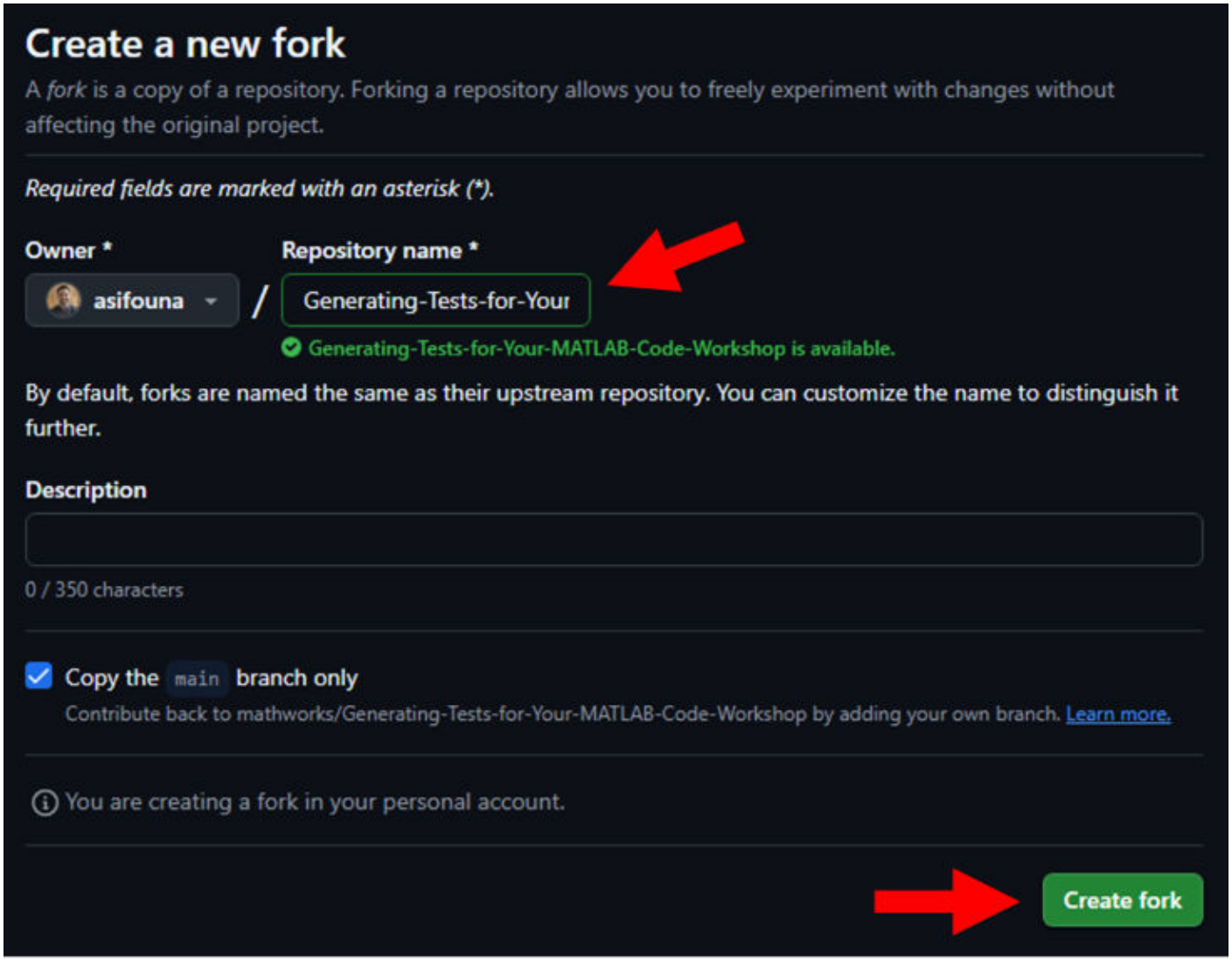


Press the "Fork" button (top right)



Create your fork

GitHub offers the ability to rename your copy of the repository, but this guide will assume the default name.



Notes:

- You may need to log into your GitHub account again during this step
- There's no problem with renaming your copy of the repository, but the rest of the workshop guide and screenshots assume the default repository name

Once you've forked the repository, you should see:

- your GitHub username in at the top of your repository
- "forked from mathworks/Generating-Tests-for-Your-MATLAB-Code-Workshop"

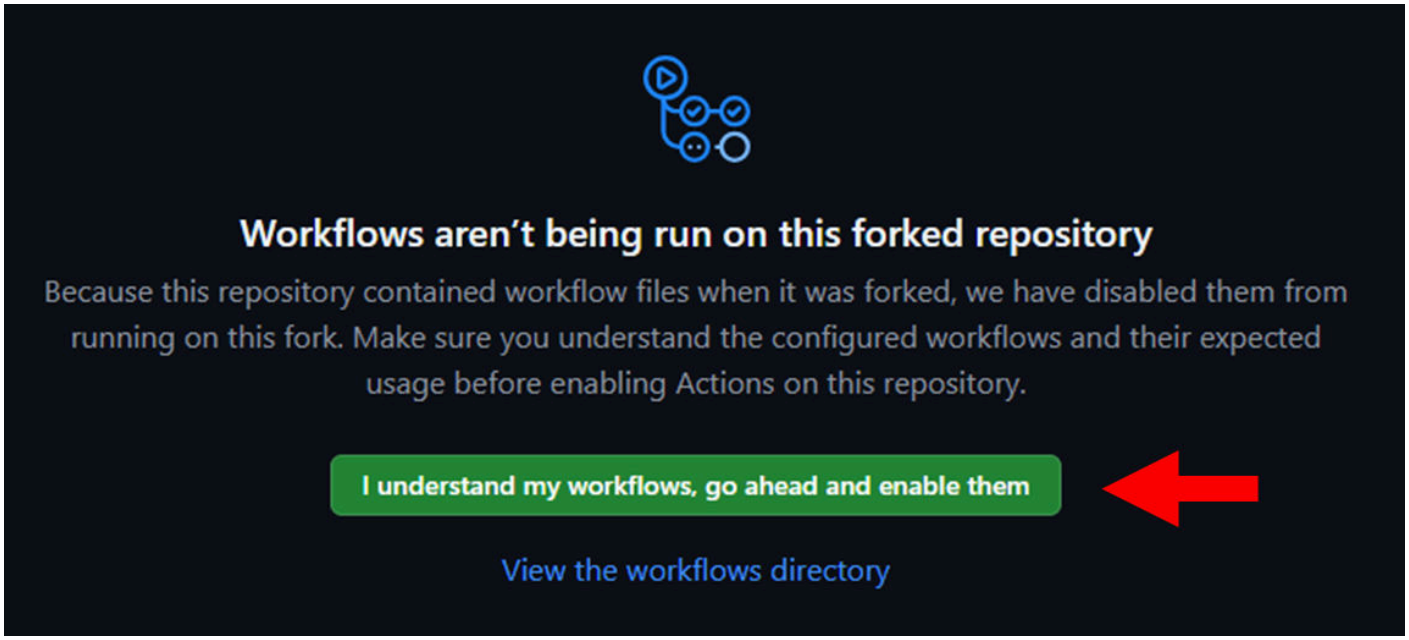
Before we go to MATLAB Online, let's enable some useful GitHub features that will be automatically triggered when we push our changes to GitHub later.

Part 1.2: Enable GitHub Actions

GitHub offers built-in continuous integration (CI) services via their "GitHub Actions" feature. By default, GitHub Actions is disabled for forked repositories, so we'll have to enable Actions before we can use them for the workshop. The workshop already provides a GitHub Actions YAML file to automatically test your code and publish test results so you can see them directly from your repository every time you push your code.

Select the "Actions" tab

Click the "I understand my workflows, go ahead and enable them" button

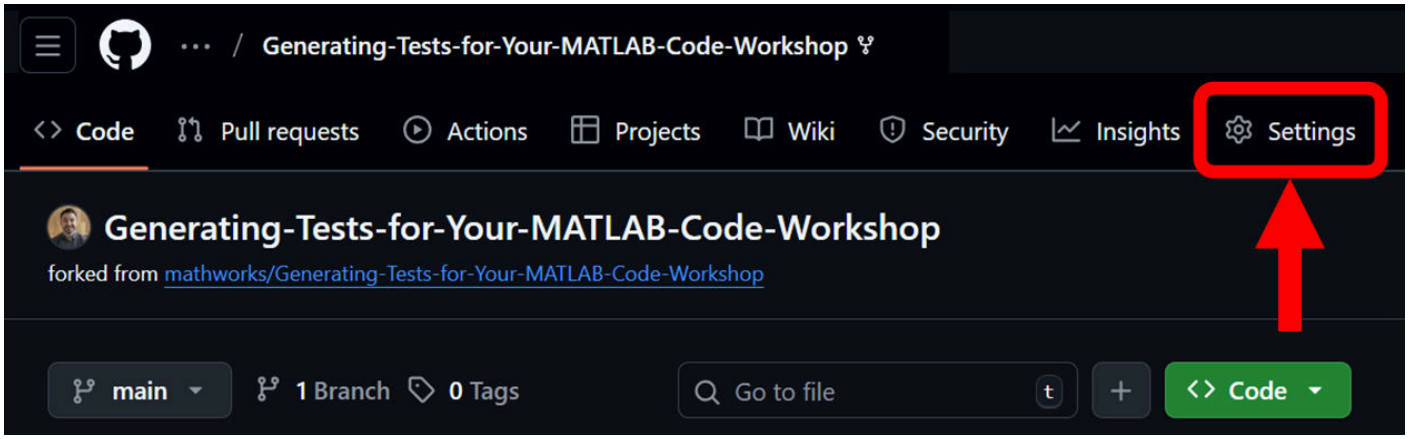


And that's it! GitHub Actions is now enabled for your repository.

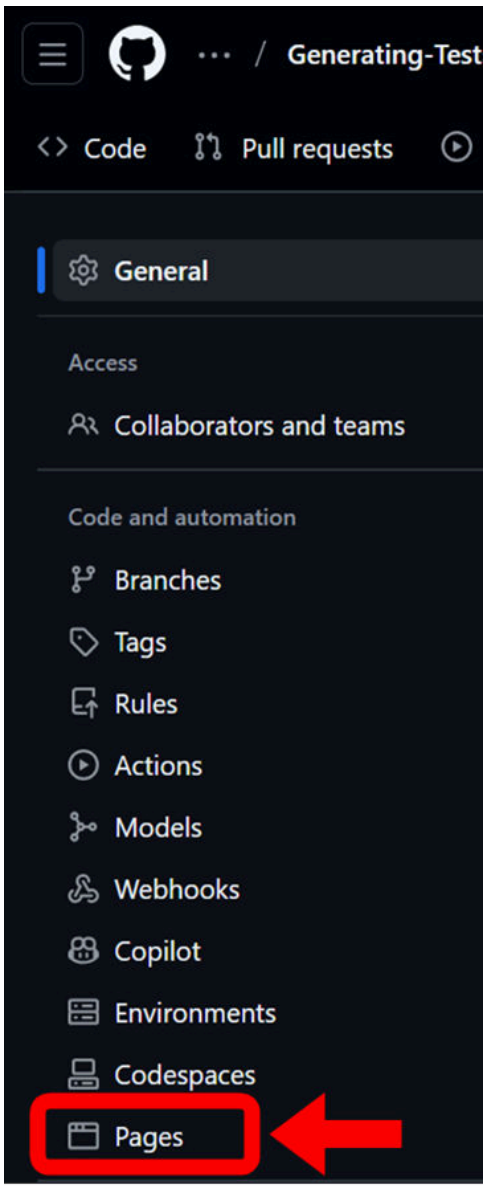
Part 1.3: Enable GitHub Pages to publish our test results

GitHub offers a built-in way to publish test reports and artifacts created from your CI jobs. By default, GitHub Pages is disabled for new repositories, so we'll have to enable Pages before we can publish our test reports.

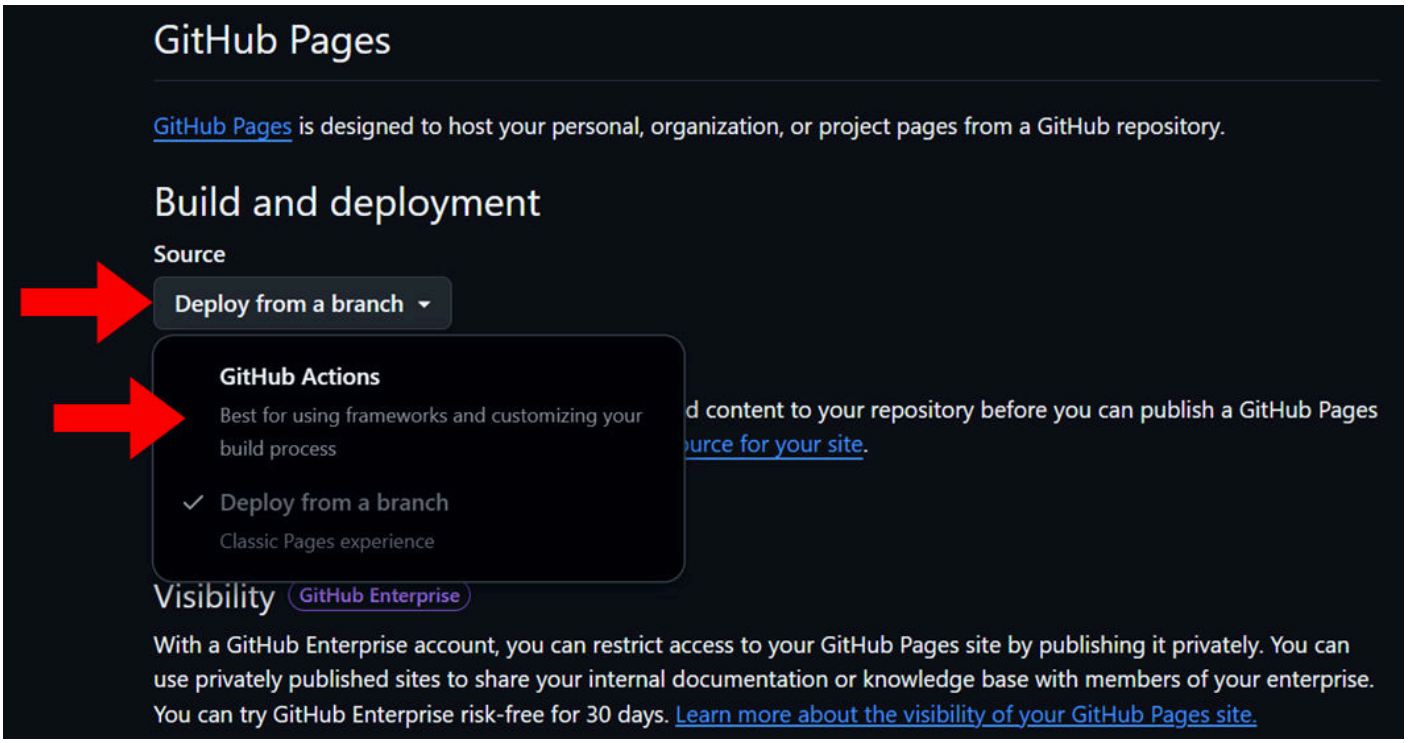
Select the "Settings" tab



Select the "Pages" entry on the left-side navigation panel



Change the "Build and deployment > Source" dropdown to "GitHub Actions"



GitHub Pages is now enabled and your GitHub Actions will be allowed to publish test results for everyone to see.

Part 1.4: Open the workshop in MATLAB Online

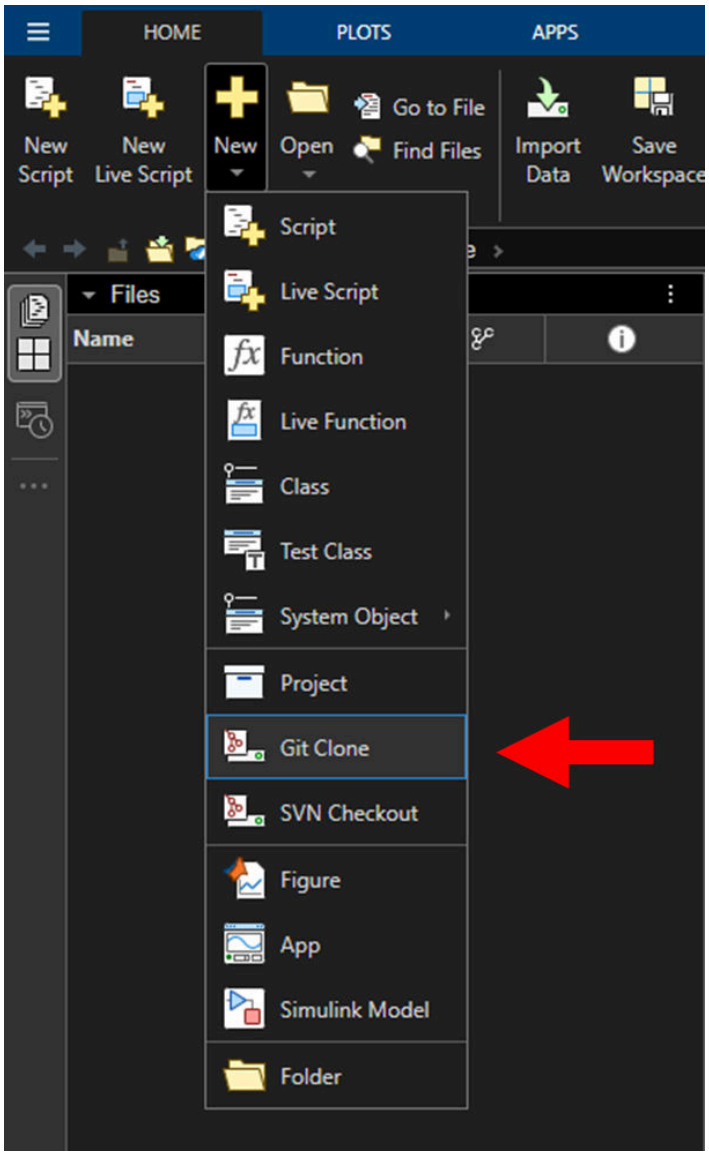
We are providing access to a special instance of MATLAB Online for MATLAB Expo, and we will be using this MATLAB Online to do the workshop.

Let's get started!

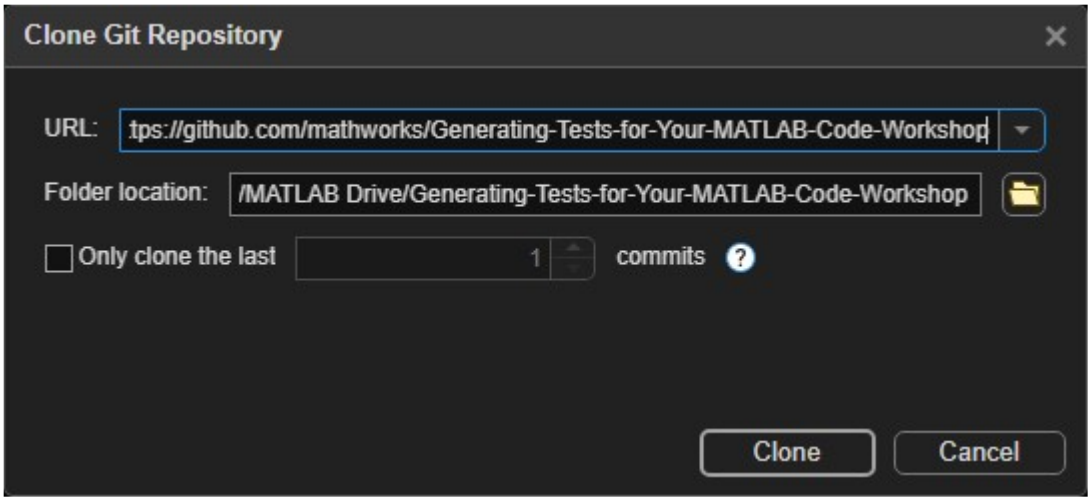
Go to: https://www.mathworks.com/licensecenter/classroom/expo_2025_5

- *Note:* If you do not have a MathWorks account, you will need to create one before continuing.

Get the workshop files selecting Home > New > Git Clone



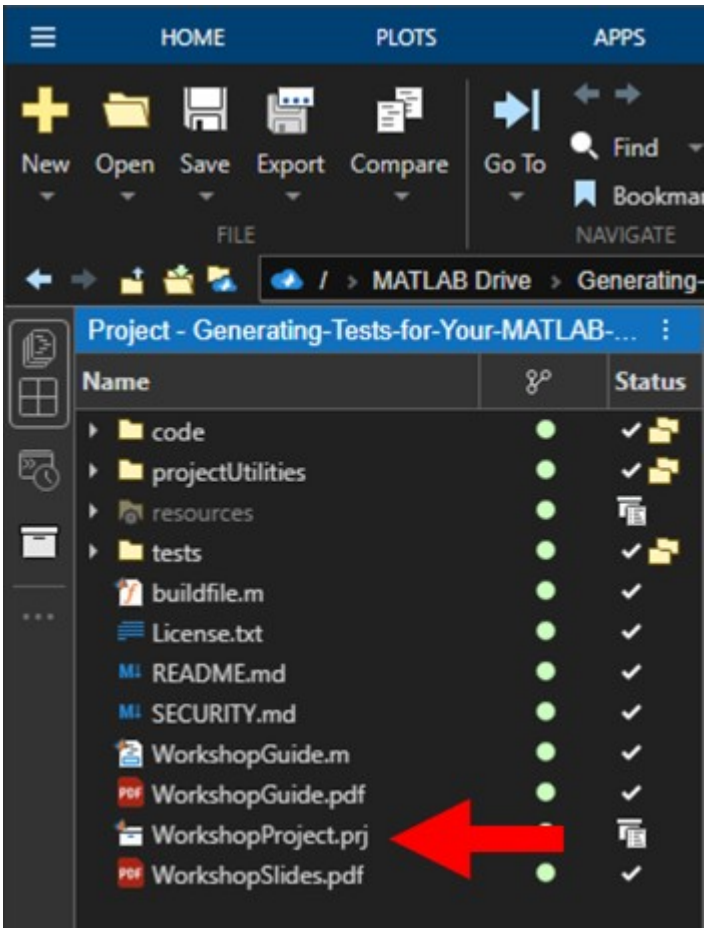
Enter the URL of your GitHub repository in the dialog and hit "Clone"



Open the workshop project by double-clicking on the `WorkshopProject.prj` file

A MATLAB project is a useful tool that makes it easy to:

- automatically set up your path consistently across multiple users and machines
- run startup and shutdown scripts when you open or close the project
- keep one project from affecting the environment of another project

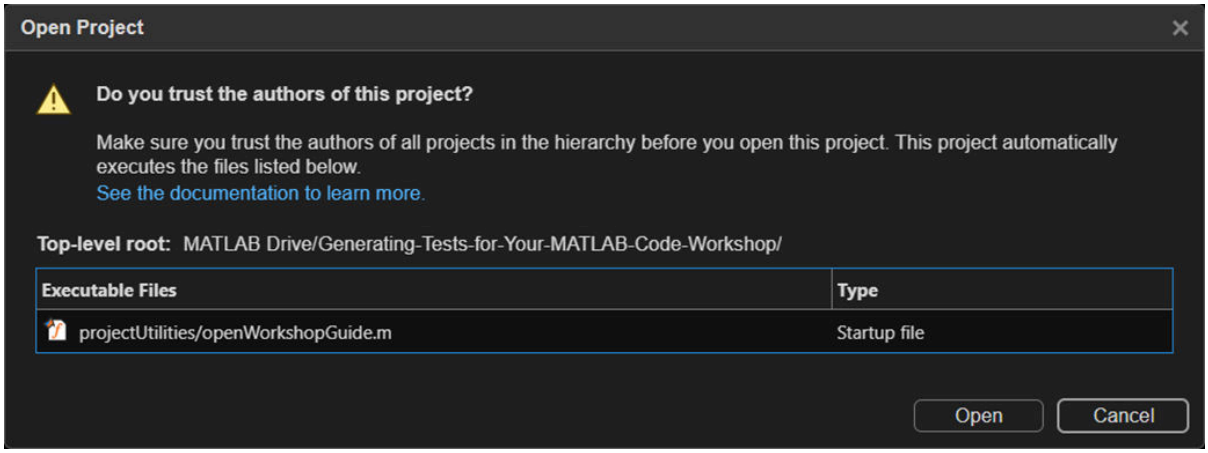


Give MATLAB permission to run project startup tasks

As part of our commitment to security, MATLAB will ask you for permission before executing any code during project startup the first time you open a project.

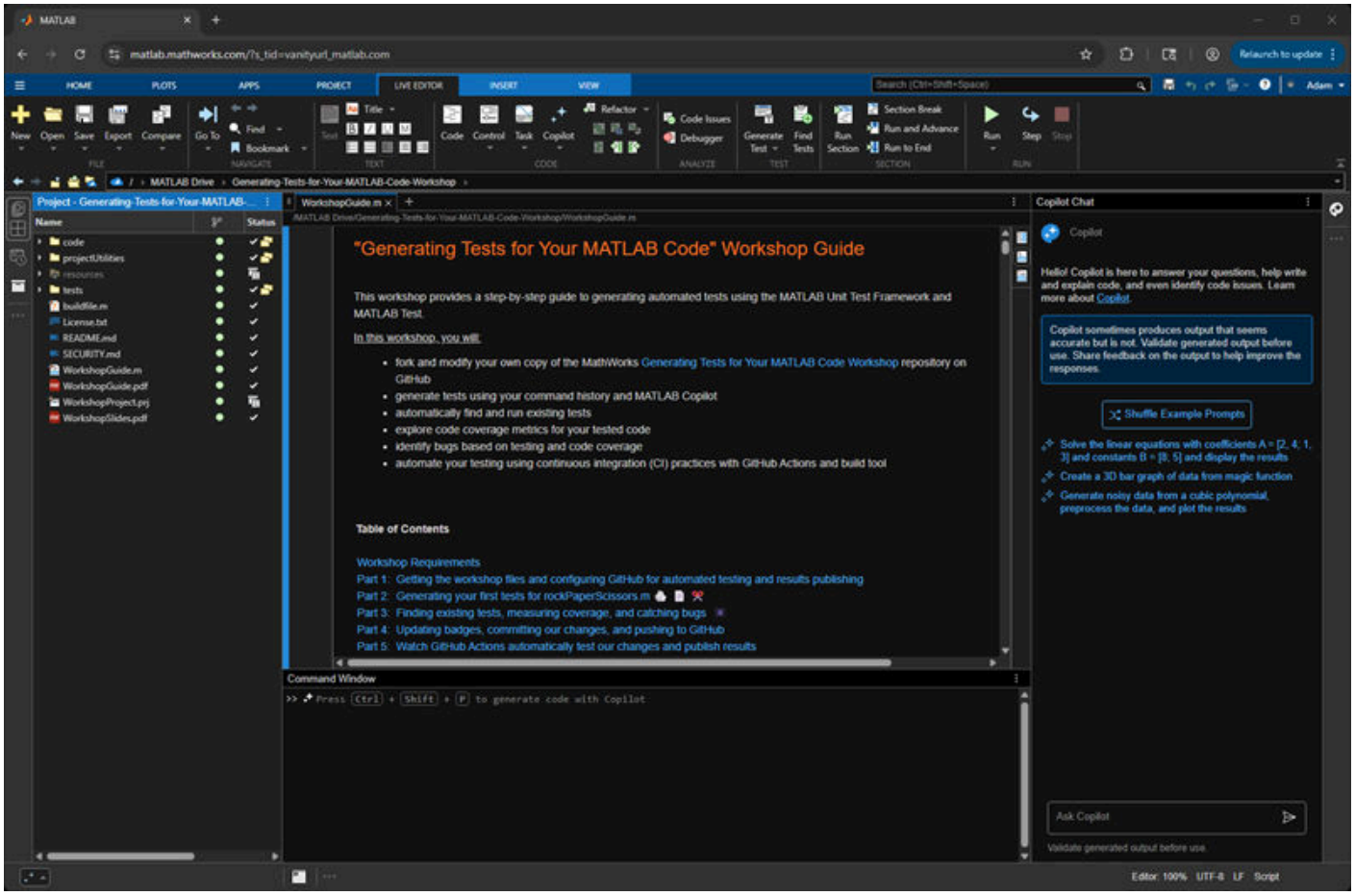
We have configured the workshop to automatically open the workshop guide (`WorkshopGuide.m`) for you when you open the project.

In the following dialog, please select "Open" to open the project and run this startup task.

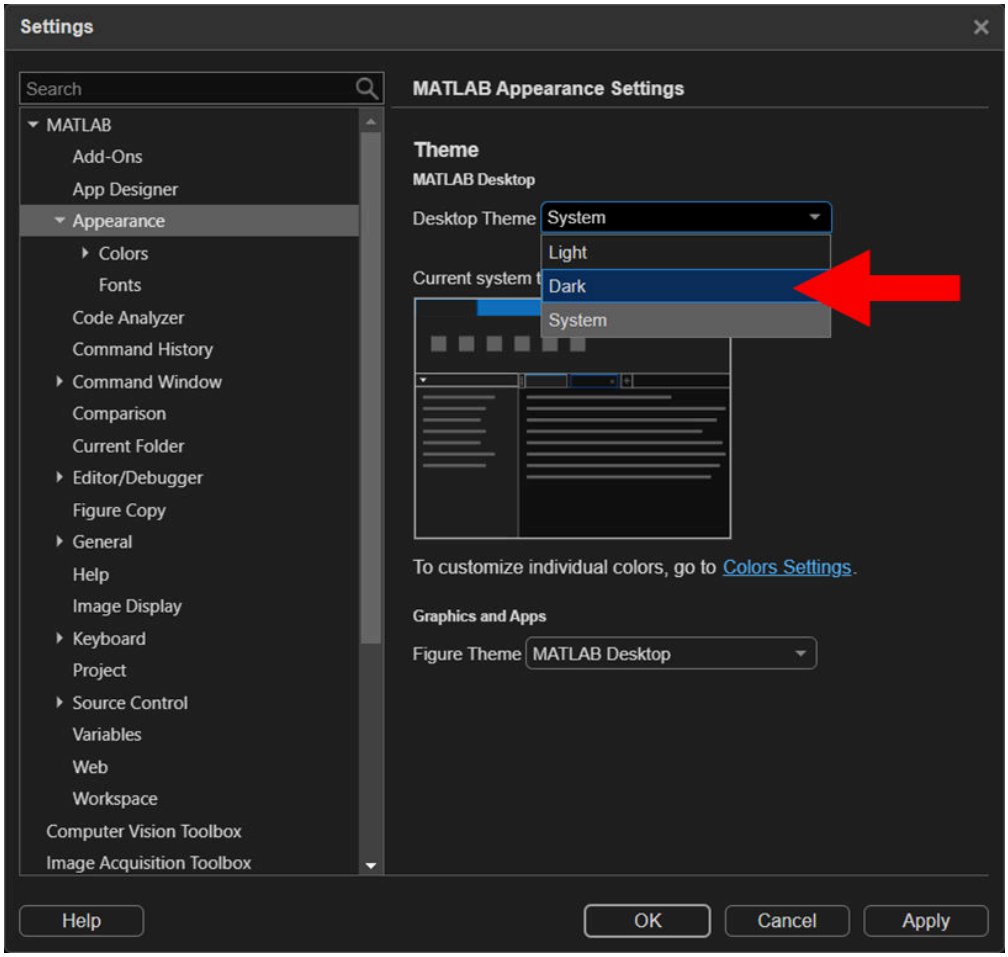


Note: If you select cancel, the project will still open, but it will not run any of the startup scripts.

Your MATLAB now should look something like this:



Note: You can enable Dark Mode by going to Home > Settings > MATLAB > Appearance and selecting "Dark" as the desktop theme.



Now you're ready to start generating tests!

Part 2: Generating your first tests for `rockPaperScissors.m`

In this section, we will:

1. Generate tests using your command history
2. Generate tests using MATLAB Copilot
3. Add generated tests to your project

Part 2.1: Generating your first test using Command History

For this workshop, we are going to use the `code/rockPaperScissors.m` function that emulates playing the game "rock, paper, scissors" as a starting point.

- *Note*: If you're unfamiliar with the "rock, paper, scissors" (also known as "rock, scissors, paper"), you can learn more about the game here: https://en.wikipedia.org/wiki/Rock_paper_scissors

Open the `rockPaperScissors` function

```
edit rockPaperScissors.m
```

Interactively test `rockPaperScissors.m` by playing rock, paper, scissors using the MATLAB Command Window

Here's an example code you can run at the Command Window:

```
>> player1Choice = "rock";
>> player2Choice = "scissors";
>> result = rockPaperScissors(player1Choice,player2Choice)

result =
    "Player 1 wins"
```

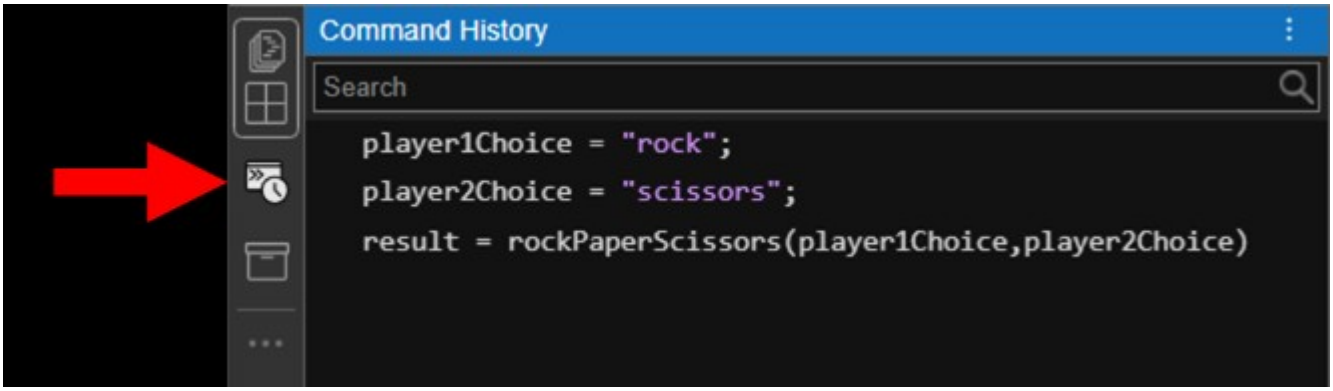
Feel free to try other inputs to see which player wins.

Generate our first test for the `rockPaperScissors` function using our command history

While we could start creating a test from scratch, wouldn't it be nice if we could reuse the interactive testing we did at the Command Window?

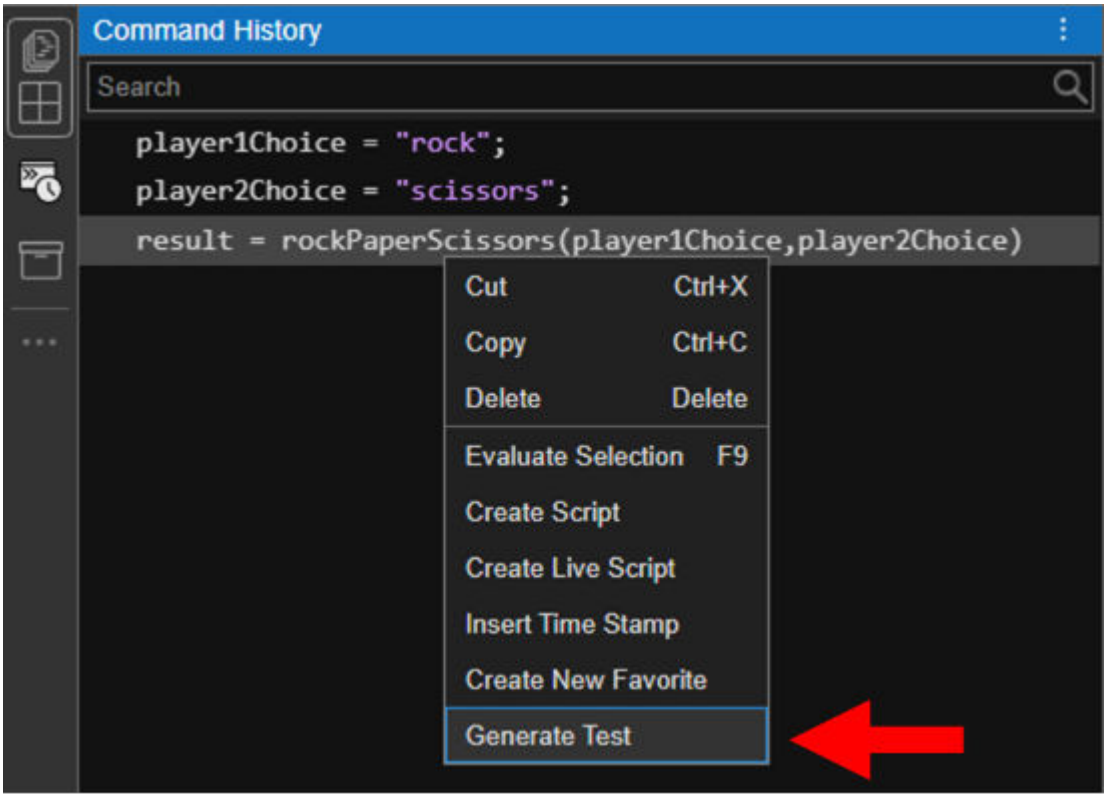
As of MATLAB R2025a, MATLAB Test™ introduced a feature to generate a test from your command history.

Go to the Command History panel



Note: You can also access your command history by pressing the "up" key while at the MATLAB Command Window

Right-Click one of your calls to `rockPaperScissors` and select "Generate Test"



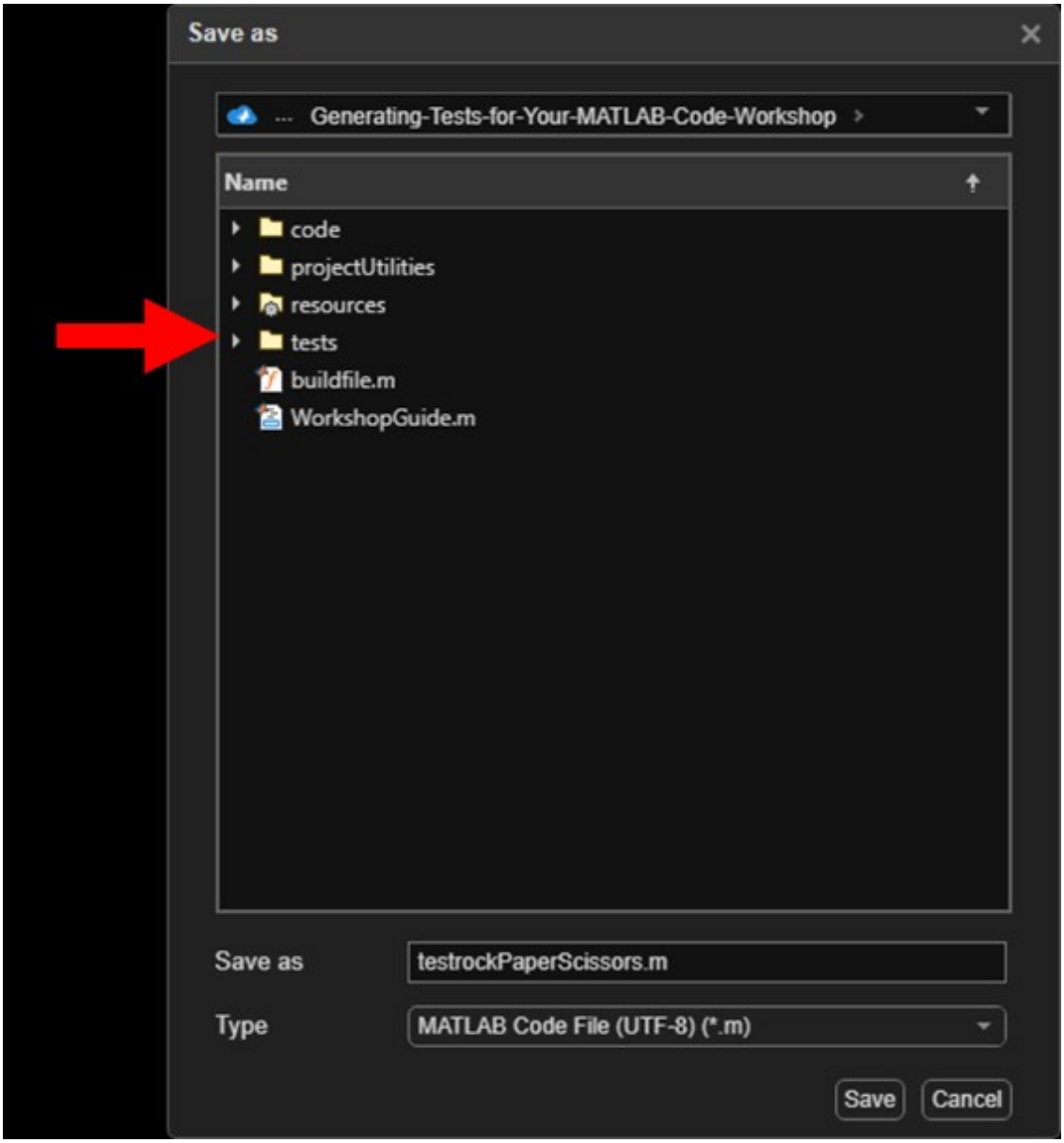
This will automatically gather all relevant code lines needed to execute that command successfully and generate a test for you. All you need to do is add in your expected output.

```
% This is an autogenerated sample test for file rockPaperScissors
classdef testrockPaperScissors < matlab.unittest.TestCase
    methods (Test)
        function test_rockPaperScissors(testCase)
            % Specify the input(s)
            player1Choice = "rock";
            player2Choice = "scissors";

            % Exercise the function
            actualOutput_result = rockPaperScissors(player1Choice,player2Choice);

            % Specify the expected output(s)
            expectedOutput_result =

            % Verify the results
            testCase.verifyEqual(actualOutput_result, expectedOutput_result);
        end
    end
end
```

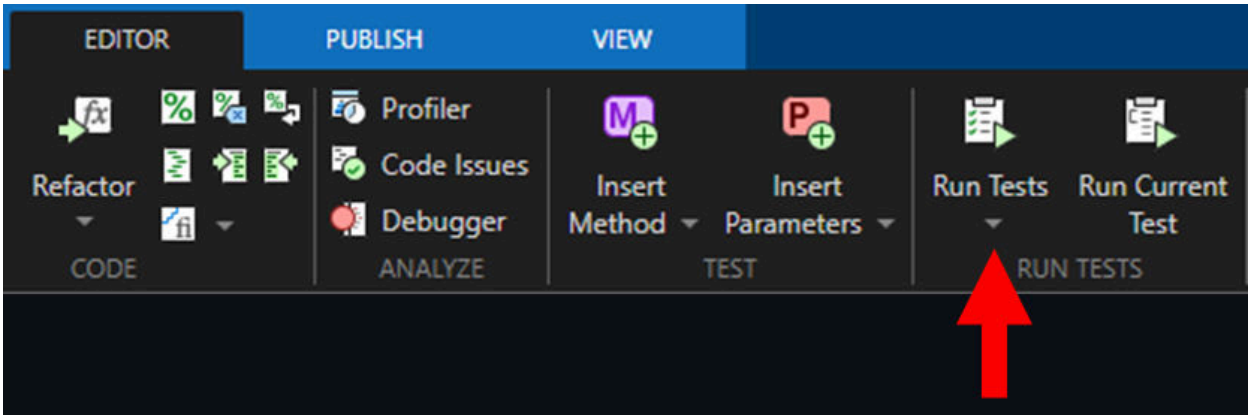
Add in your expected output

```
% This is an autogenerated sample test for file rockPaperScissors
classdef testrockPaperScissors < matlab.unittest.TestCase
    methods (Test)
        function test_rockPaperScissors(testCase)
            % Specify the input(s)
            player1Choice = "rock";
            player2Choice = "scissors";

            % Exercise the function
            actualOutput_result = rockPaperScissors(player1Choice,player2Choice);

            % Specify the expected output(s)
            expectedOutput_result = "Player 1 wins";

            % Verify the results
            testCase.verifyEqual(actualOutput_result, expectedOutput_result);
        end
    end
end
```

Save your test to the "`tests`" folder



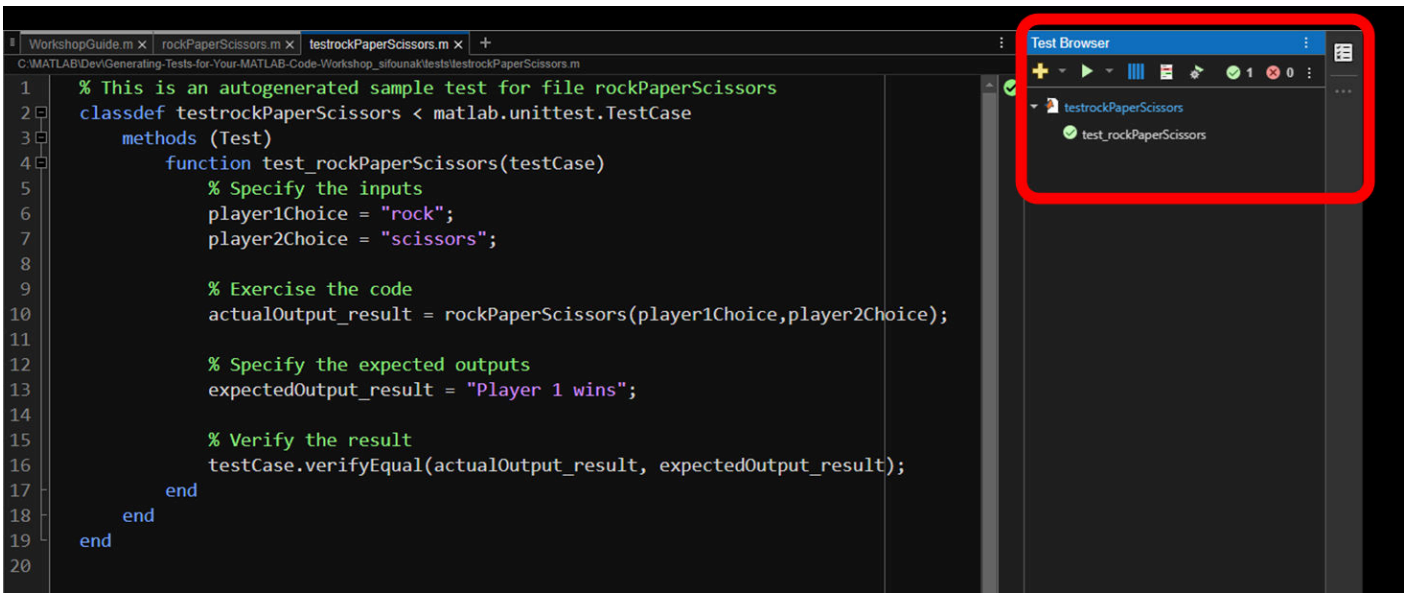
Run your test using the "Run Tests" button in the Editor toolstrip



As of R2023a, running tests from the Editor toolstrip will open the MATLAB Test Browser.

The MATLAB Test Browser makes it easy to:

- rerun tests without being in the test file
- explore test failure diagnostics
- filter results based on test status (pass, fail, incomplete)
- enable code coverage
- enable parallel test execution



After your tests are done running, you will be able to to quickly see that your tests have passed. Yay!

Part 2.2: Generate tests using MATLAB Copilot

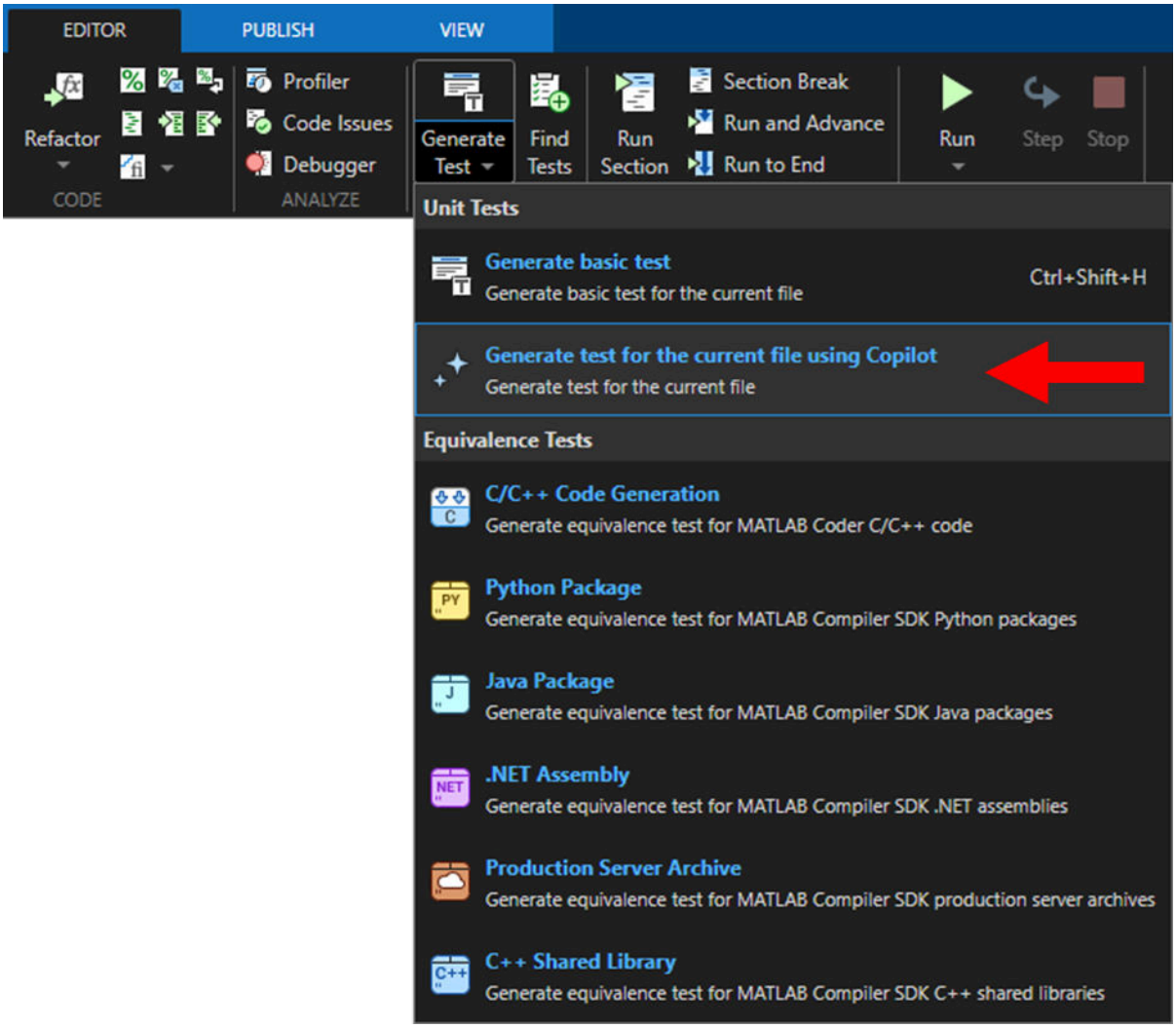
As of MATLAB R2025a, MATLAB now offers MATLAB Copilot (requires a separate license) that enables GenAI capabilities optimized for MATLAB code within the MATLAB Desktop. As with most platforms, we have a MATLAB Copilot chat panel to use AI in a conversational way.

To make testing even easier, MATLAB Test enables 1-click buttons to automatically generate tests for the code you are looking at.

Go back to `rockPaperScissors.m`

```
edit rockPaperScissors.m
```

In the Editor toolstrip, use the "Generate Test" drop down menu and select "Generate test for the current file using MATLAB Copilot"



MATLAB Copilot will generate multiple ready-to-run tests.

rockPaperScissors.m | RockPaperScissorsTest.m

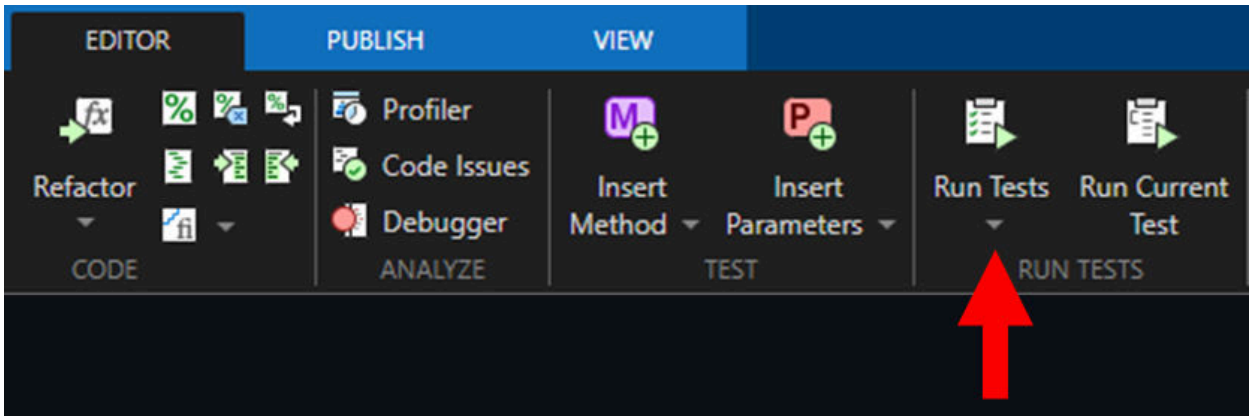
C:\MATLAB\Dev\Generating-Tests-for-Your-MATLAB-Code-Workshop_sifounak\tests\RockPaperScissorsTest.m

```
% This test file was generated by Copilot. Validate generated output before use.
classdef RockPaperScissorsTest < matlab.unittest.TestCase
    methods(Test)
        function testTie(testCase)
            p1 = "rock";
            p2 = "rock";
            expectedResult = "Tie";

            actualResult = rockPaperScissors(p1, p2);

            testCase.verifyEqual(actualResult, expectedResult);
        end

        function testPlayer1Wins(testCase)
            p1 = "rock";
            p2 = "scissors";
            expectedResult = "Player 1 wins";

```

Note: As with all Copilot technologies, remember to validate the output before using it in production systems.

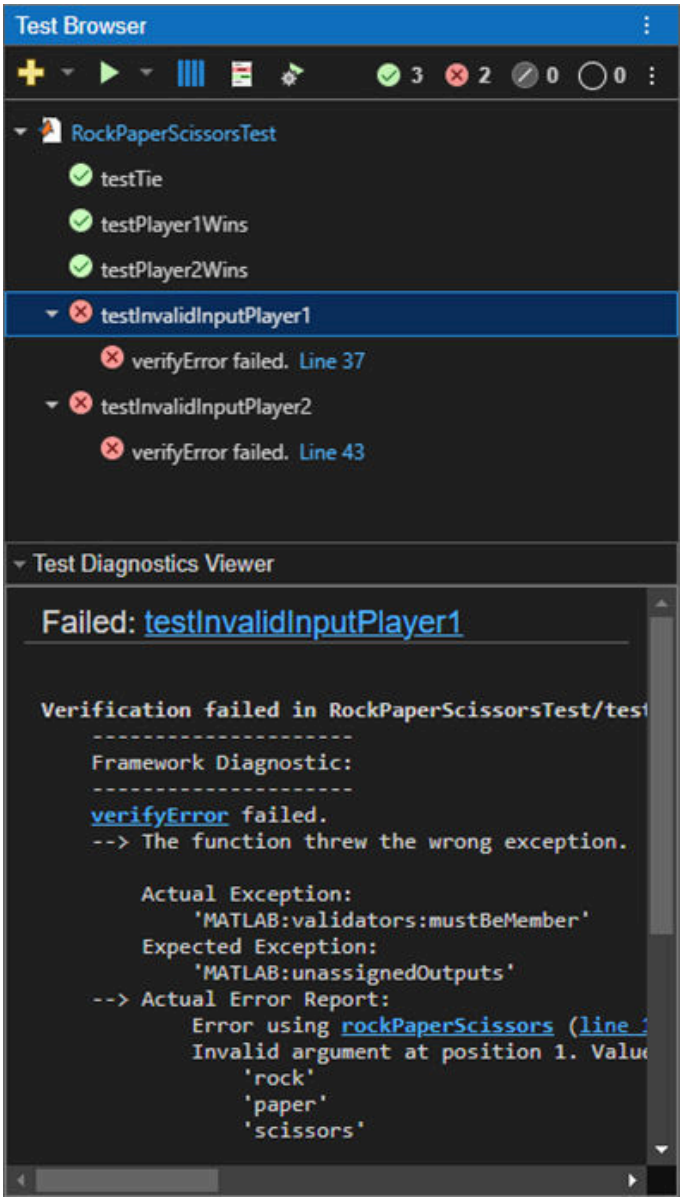
Save and run your generated tests

Just like before, save your new tests to the "`tests`" folder and run your tests.



Look at your test results in the MATLAB Test Browser

- *Note:* Depending on the tests MATLAB Copilot generates, you may end up with some failing tests.



For the sake of time in this workshop, let's simply comment out or remove any failing tests from the test file and rerun the tests to ensure all remaining tests pass.

Note on generated test failures:

- In the screenshot above, MATLAB Copilot generated two failing tests where it intentionally provided invalid inputs to the `rockPaperScissors` function to ensure the function would error in the expected way. This practice is called "negative testing." However, in this case, the tests failed because MATLAB Copilot was expecting the incorrect error message compared to the error the function gave. To fix this, we can simply put in the right error message for the test to check or remove these two tests completely if we don't find them

very useful at this time. In either case, this reinforces the fact that we should always validate the output of LLMs.

Part 2.3: Add generated tests to your project

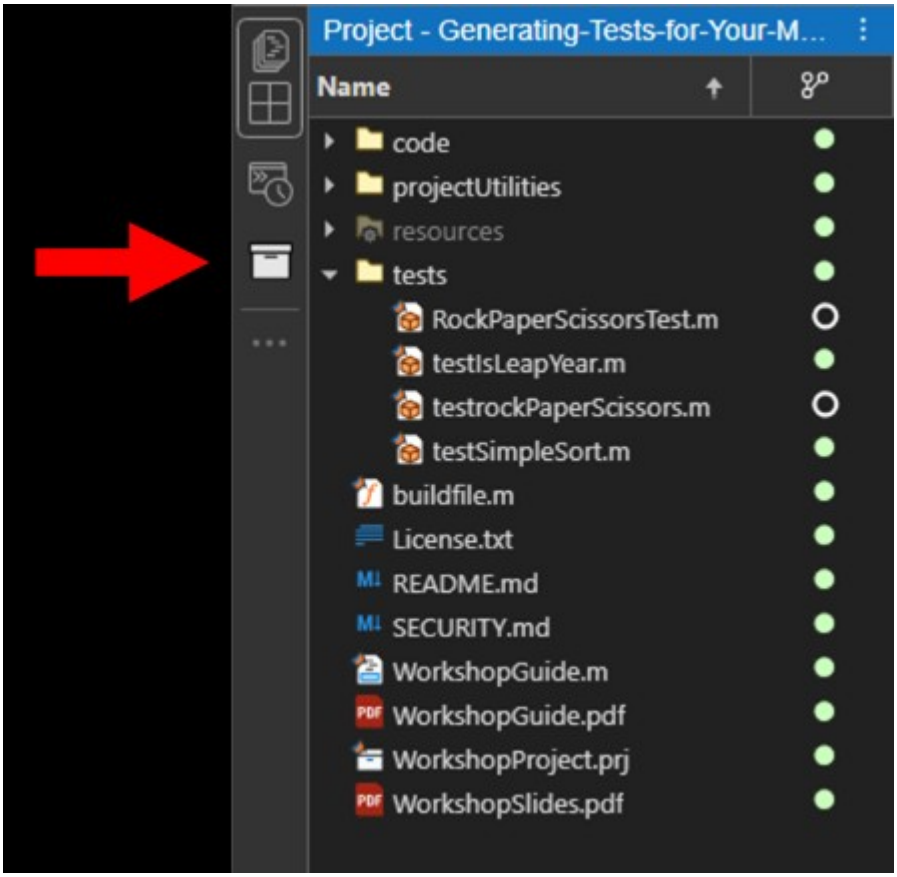
When you create a new file directly from the Project side panel, the file is automatically added to the project and to source control.

However, when you create a new file in another way (e.g., "New > Function," the "+" button on the Editor's tab toolbar, or the test generation options), MATLAB leaves it up to you to decide whether or not to include the file in your project.

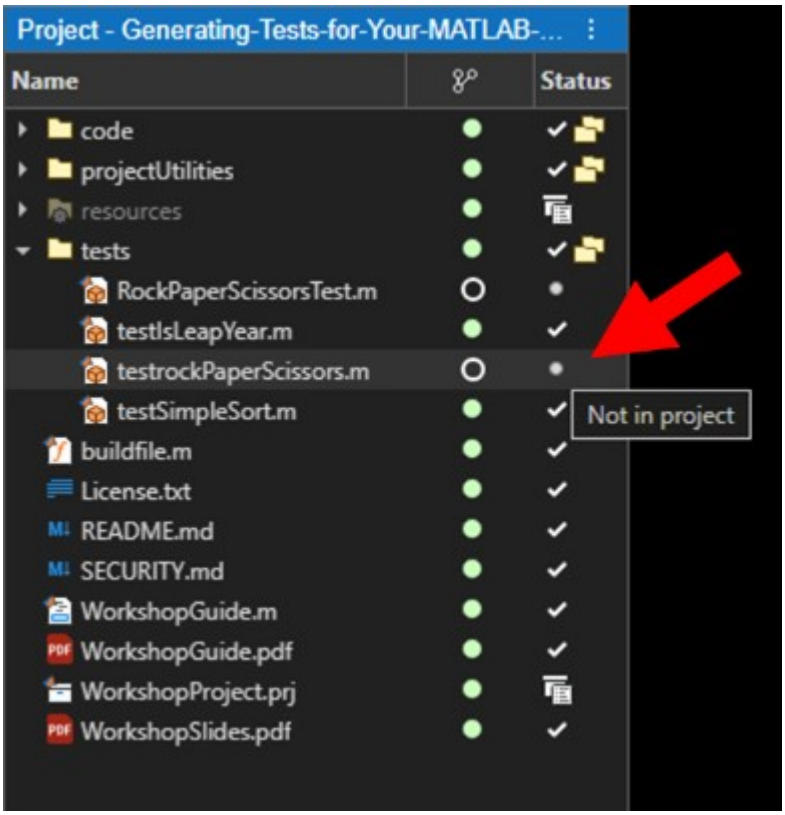
Let's add our 2 new test files to the project

Find your new test files in the "tests" folder using the Project side panel

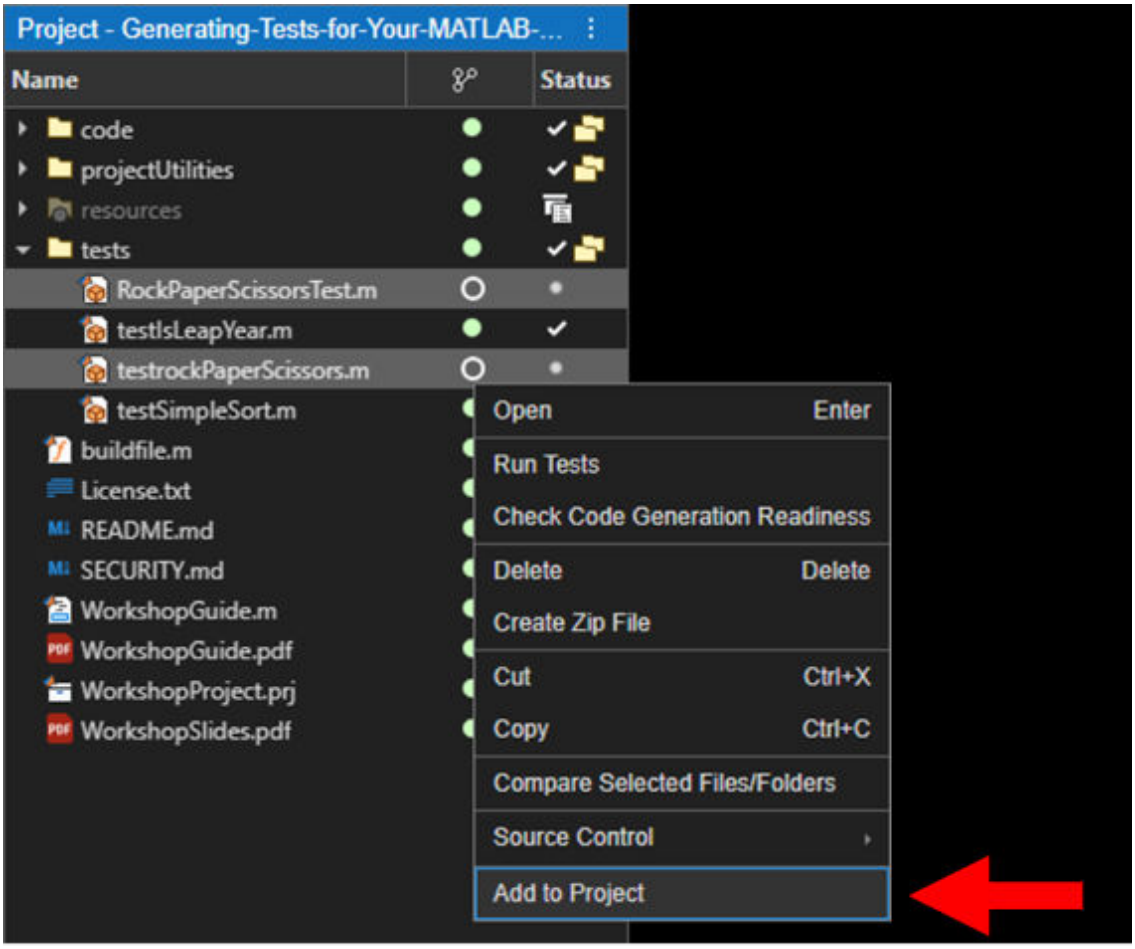
Go back to the Project side panel.



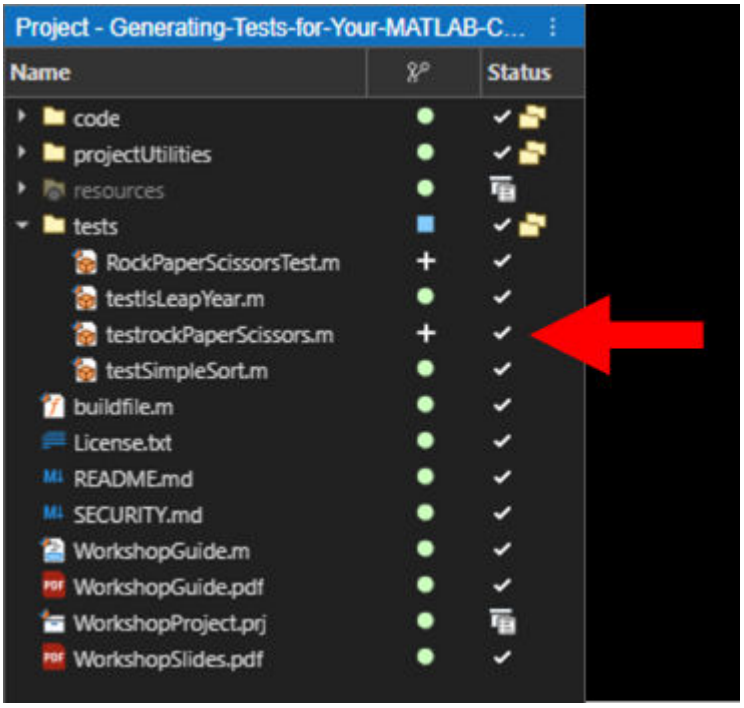
You can identify files not in your project when the Status column is not a check mark or the Git column is an empty circle.



Right-click the test files and select "Add to Project"



Confirm your test files have been added to the project by seeing the check mark in the Status column and the "+" icon in the Git column



Congratulations! You just created multiple tests for MATLAB code!

It was easier than you thought, right?

Part 3: Finding existing tests, measuring coverage, and catching bugs

In this section, we will:

1. Find existing tests for `isLeapYear.m`
2. Enable and explore code coverage
3. Identify missing coverage and a bug
4. Fix the bug
5. Add a test point to an existing test suite

Part 3.1: Finding existing tests for a code file

When working with a new codebase or making changes to an existing file, you should run any existing tests that exercise that function to make sure you haven't broken anything.

But this raises several questions:

- Are there are any existing tests?
- Where are the tests?
- Should we just run all the tests?
- How do we know which tests (or if any tests) actually exercise the code we are working on?

In MATLB R2025a, MATLAB Test introduced a "Find Tests" feature that automatically finds any tests related to the file you are looking at and ignores any tests that are not related to this file.

Let's see how this works using the `isLeapYear` function.

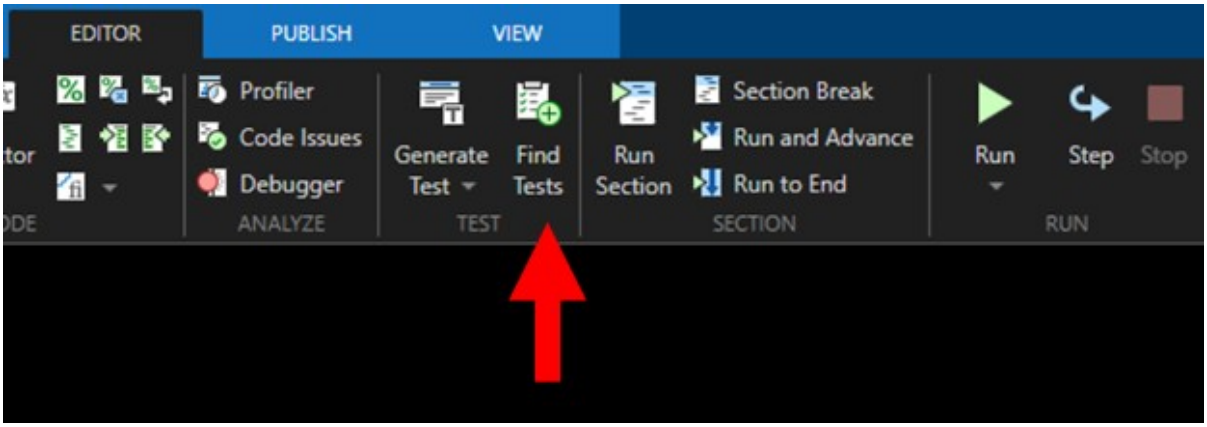
A leap year is defined as a year that is either:

- divisible by 400
- divisible by 4 and not divisible by 100

Open `code/isLeapYear.m`

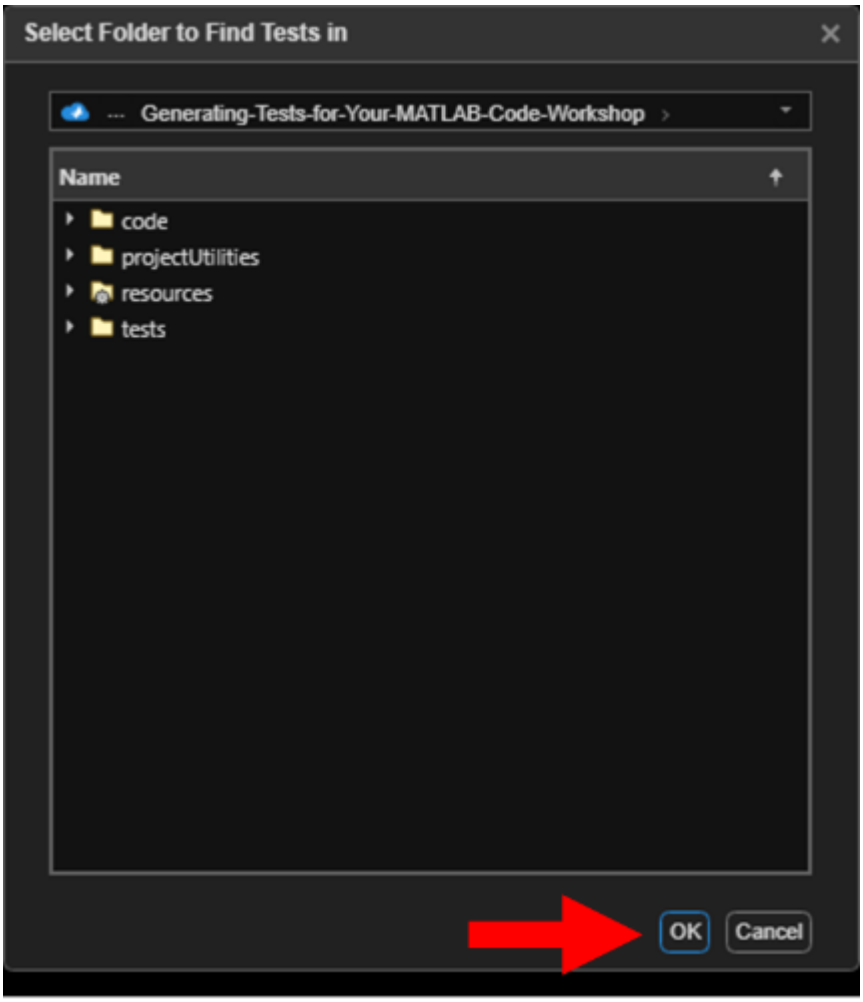
```
edit isLeapYear.m
```

Press the "Find Tests" button in the Editor toolstrip

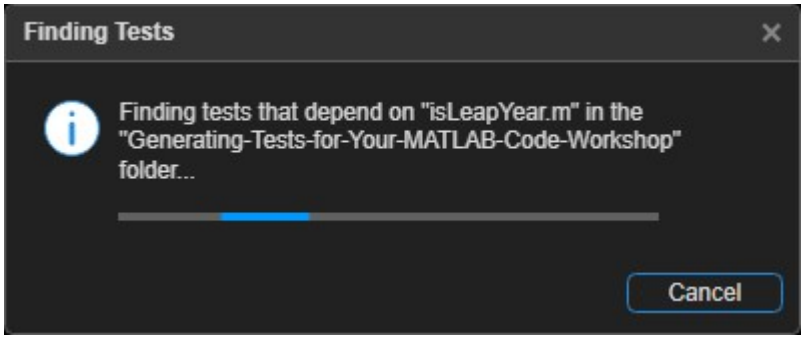


Select the root of your project to identify all tests in your project that use `isLeapYear`

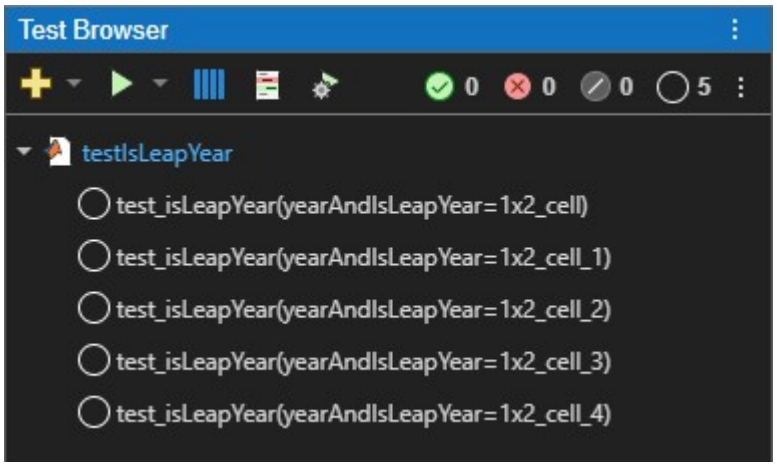
- *Note:* This root of your project is the default location, so you can just choose "Select Folder"



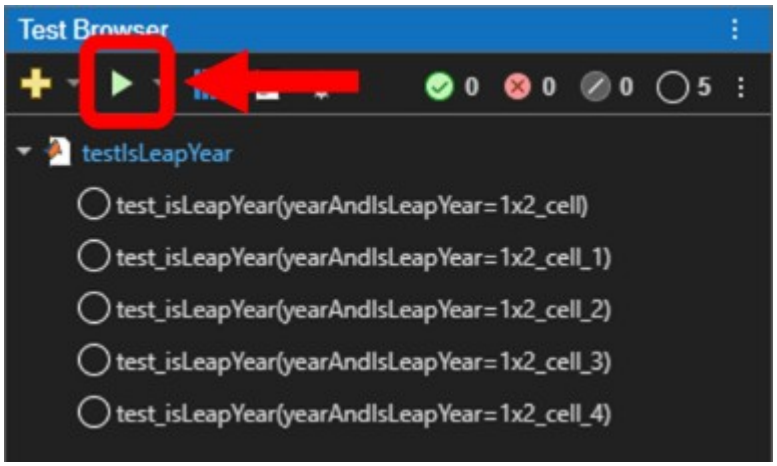
MATLAB automatically will perform a dependency analysis on `isLeapYear`.



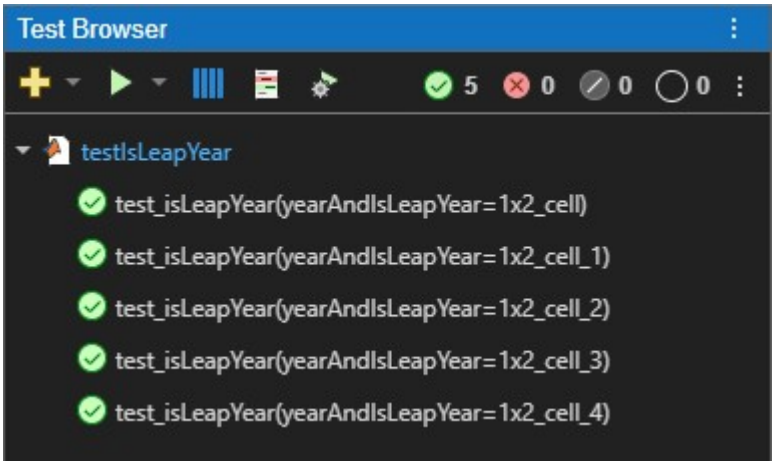
After the dependency analysis, you will see 5 tests that are related to `isLeapYear` open in the MATLAB Test Browser.



Run the tests in the MATLAB Test Browser using the "Run" button



It looks like all the tests passed!



Part 3.2: Using code coverage to understand how much of your code is being exercised by your tests

It was great that we already had tests for `isLeapYear`, but how much of `isLeapYear` being exercised by those tests?

"Code coverage" is a way to measure how much and which parts of your code have been exercised by your tests.

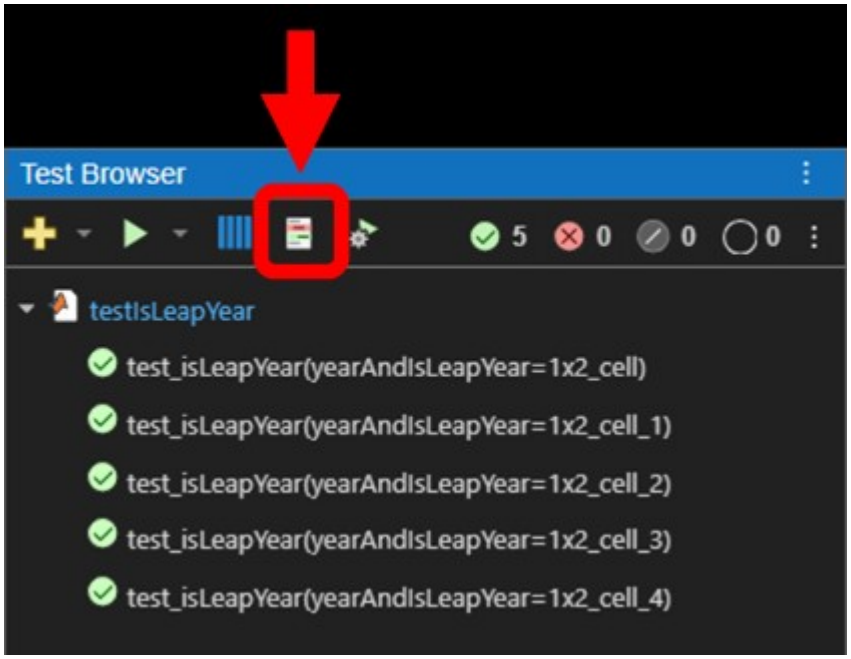
There are several types of code coverage metrics:

- Statement coverage: Measure which statements have been executed
- Decision coverage: Measures whether both `true` and `false` conditions have been exercised for logical branches (e.g., `if`, `switch/case`)
- Condition coverage: When logical branches are composed of multiple logical conditions (e.g., `x > 5 && x < 10`), this measures whether the `true` and `false` have been exercised for each logical condition
- Modified Condition/Decision Coverage (MC/DC): A modified set of decision + condition coverage metrics that is primarily used in code certification processes

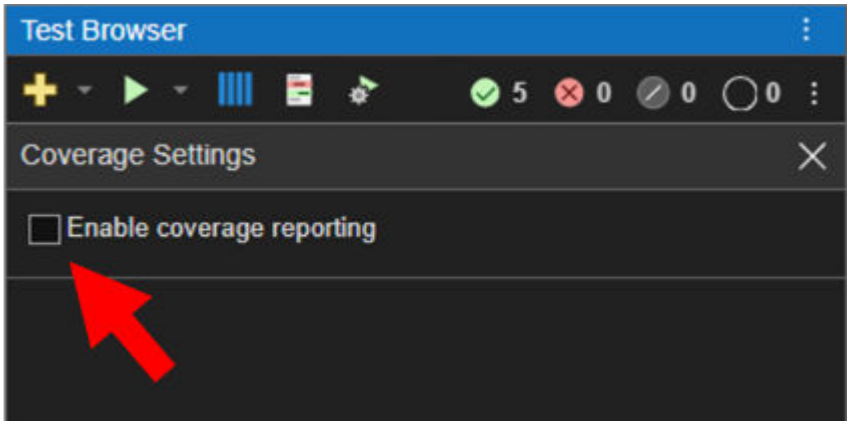
Note: Decision, Condition, and MC/DC metrics require MATLAB Test

the MATLAB Unit Test Framework can automatically measure code coverage, but it is off by default, so let's enable code coverage!

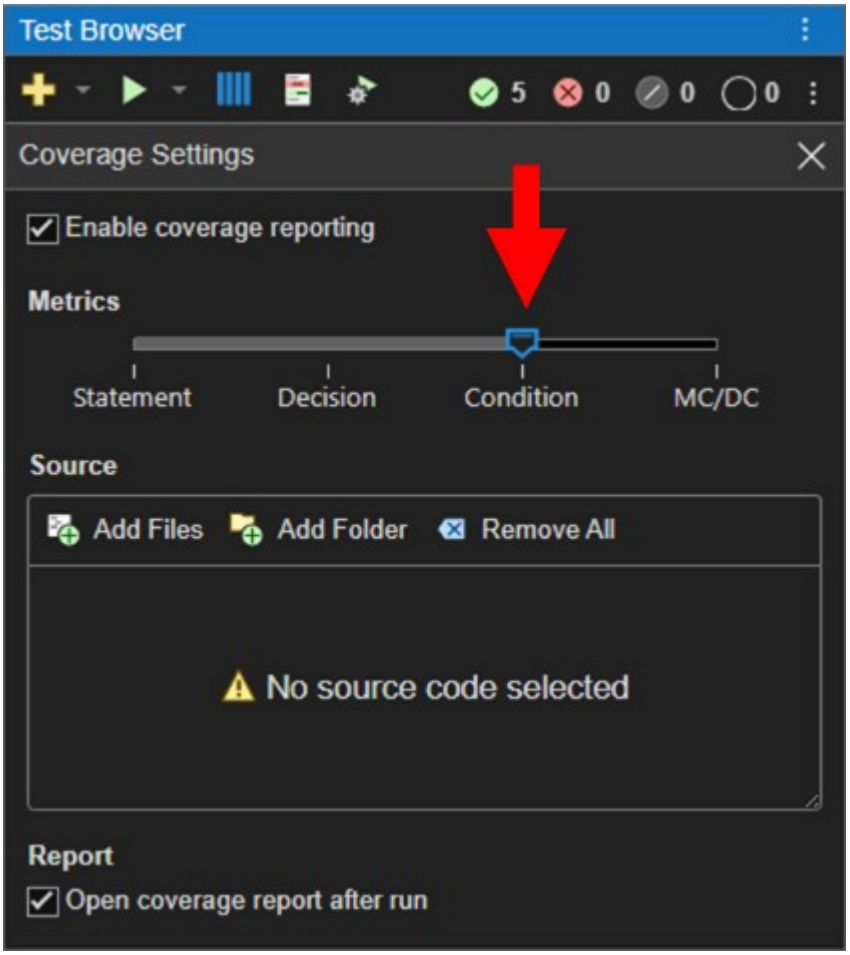
Open code coverage settings



Enable coverage reporting



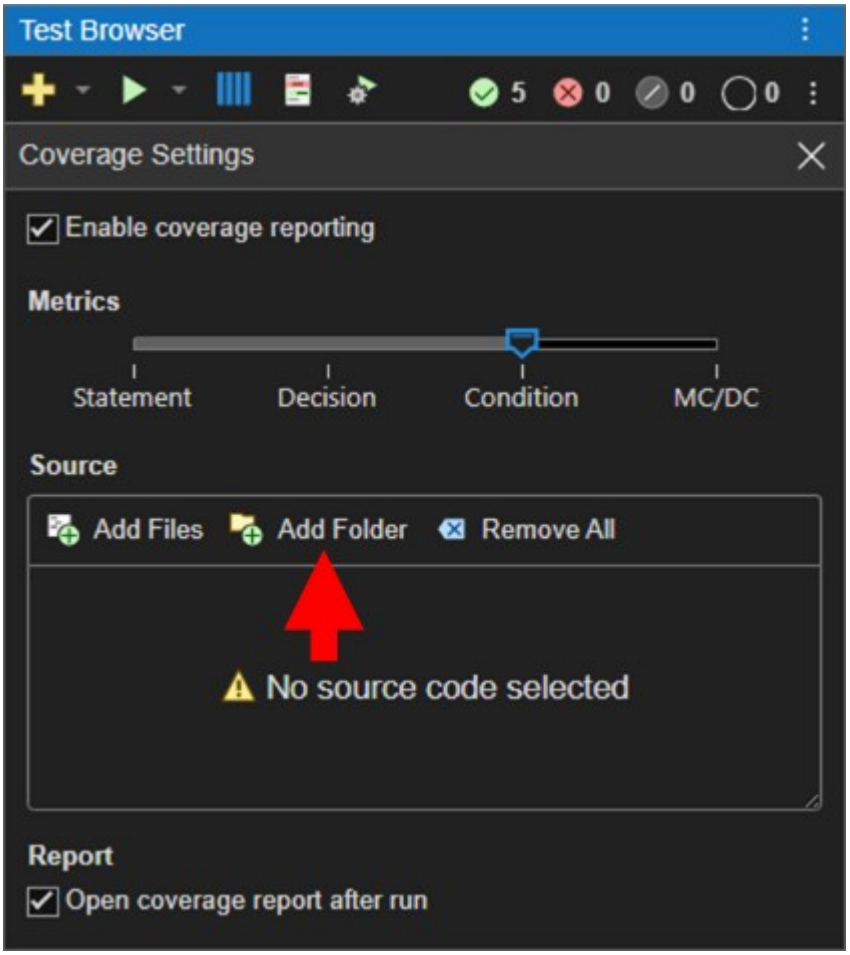
Select the "Condition" coverage metric



For this workshop, we will skip MC/DC since it is a significantly more advanced topic and primarily used in certification workflows.

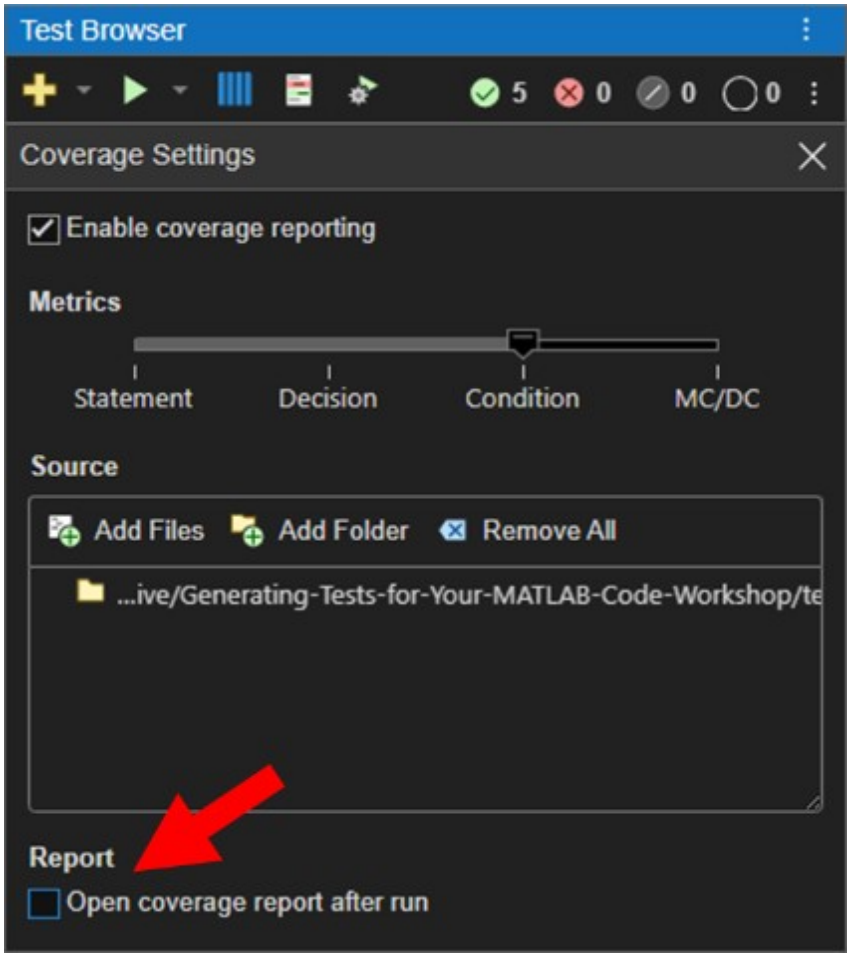
Add the "`code`" folder to the "Source" list

By selecting specific files or folders, we can focus our code coverage measurements on only the files and folders you select and avoid complicating our code coverage reports with code that is less critical for our application.

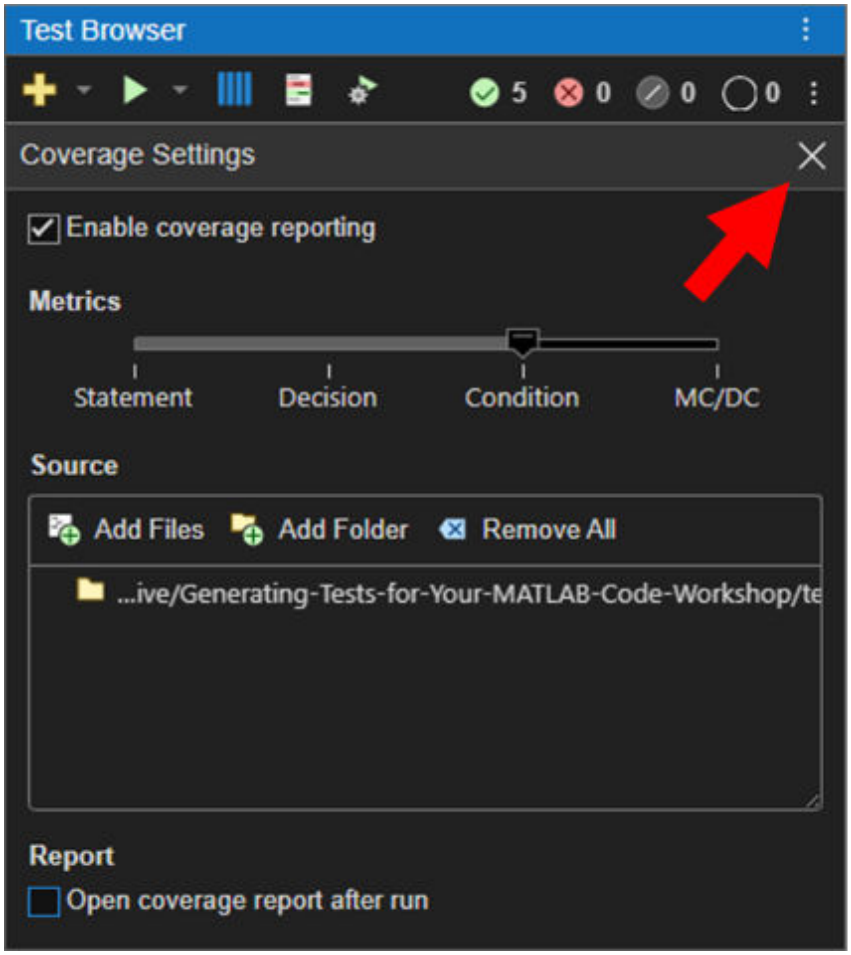


Deselect "Open coverage report after run"

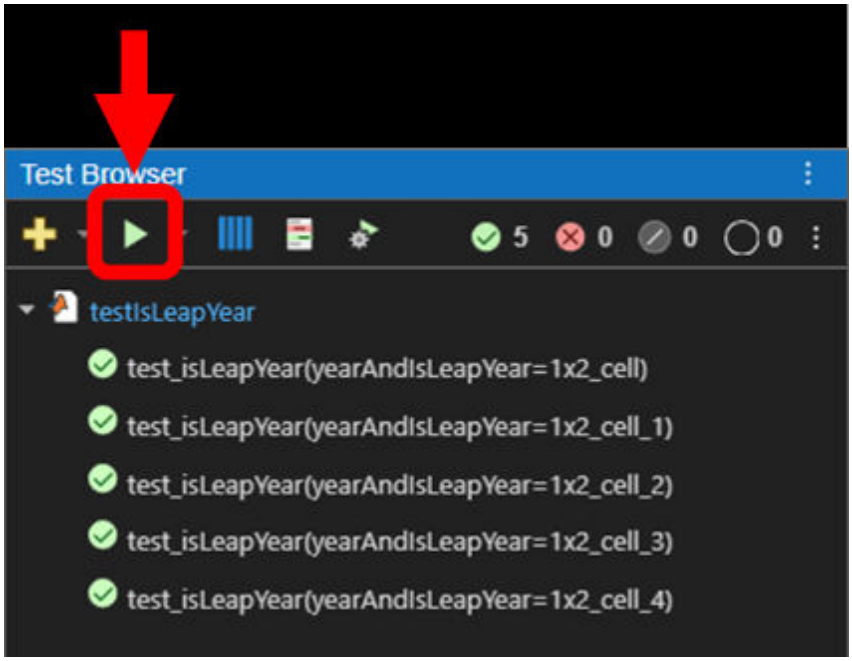
While this option offers the convenience of automatically open the coverage report after your tests are done running, it can sometimes be distracting when you are rerunning tests frequently.



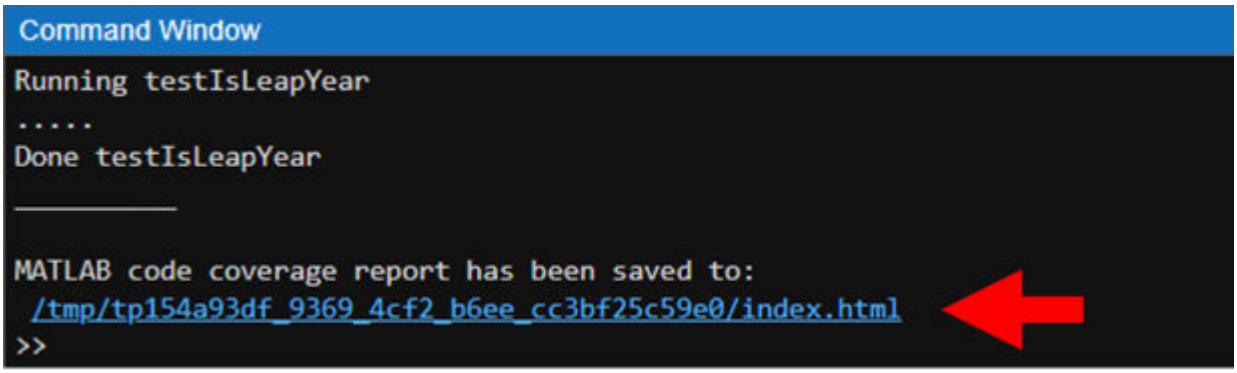
Close the Coverage Settings



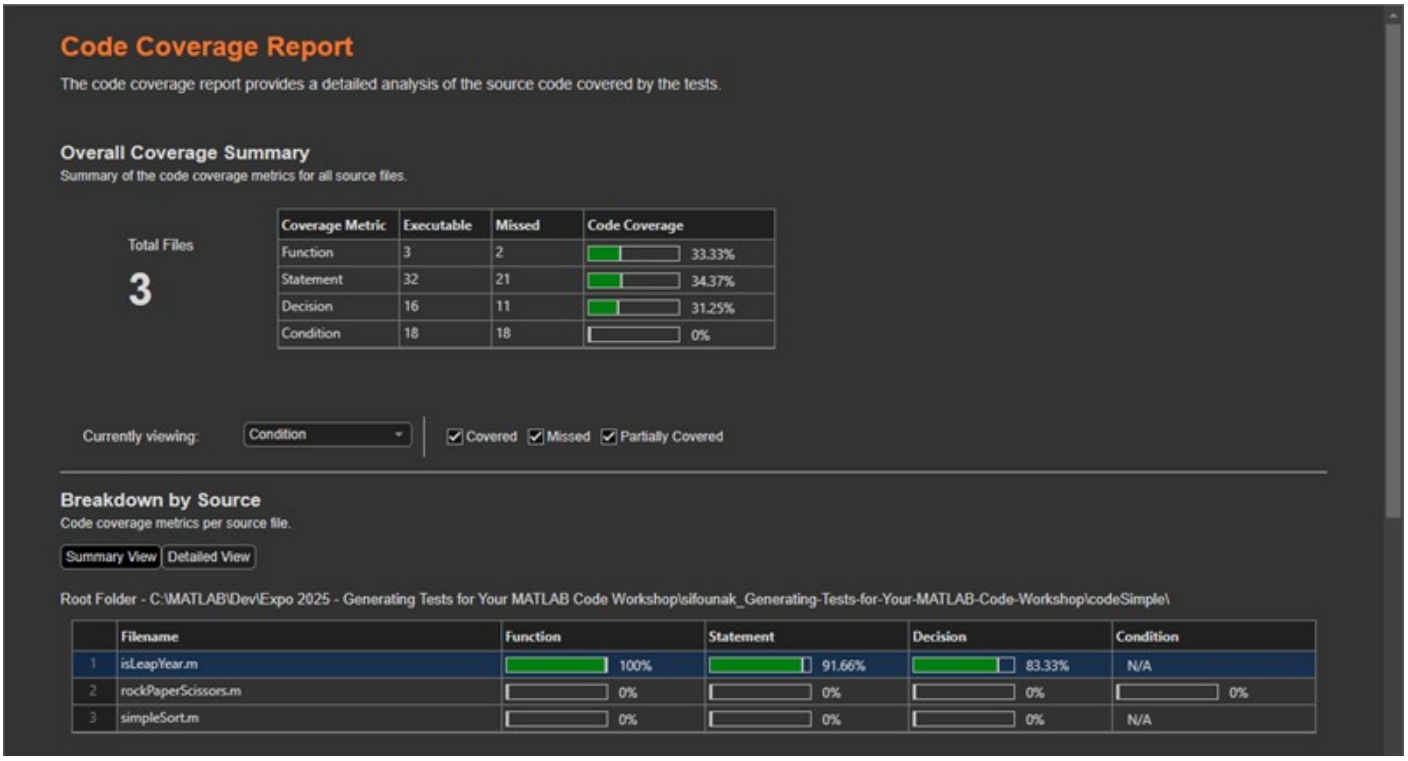
Rerun your tests



Click the link in the Command Window to open the code coverage report



You should see a Code Coverage Report very similar to the one below.



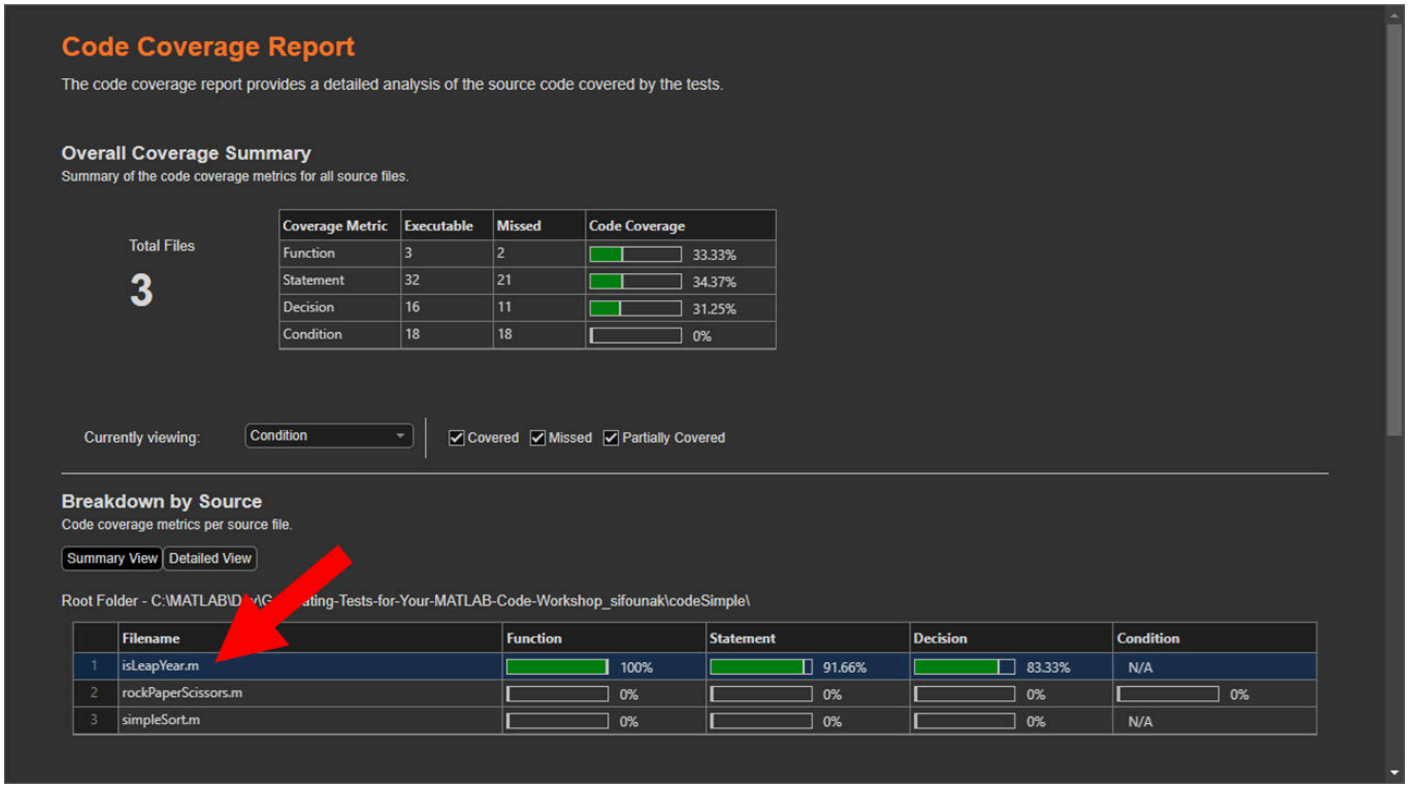
The top of the report gives you an overall summary of the coverage metrics for all of the code in the folders you have chosen, while the "Breakdown by Source" table gives you a breakdown of coverage metrics by file.

For this workshop, we will focus on the "Breakdown by Source" and the detailed coverage inside each of the code files.

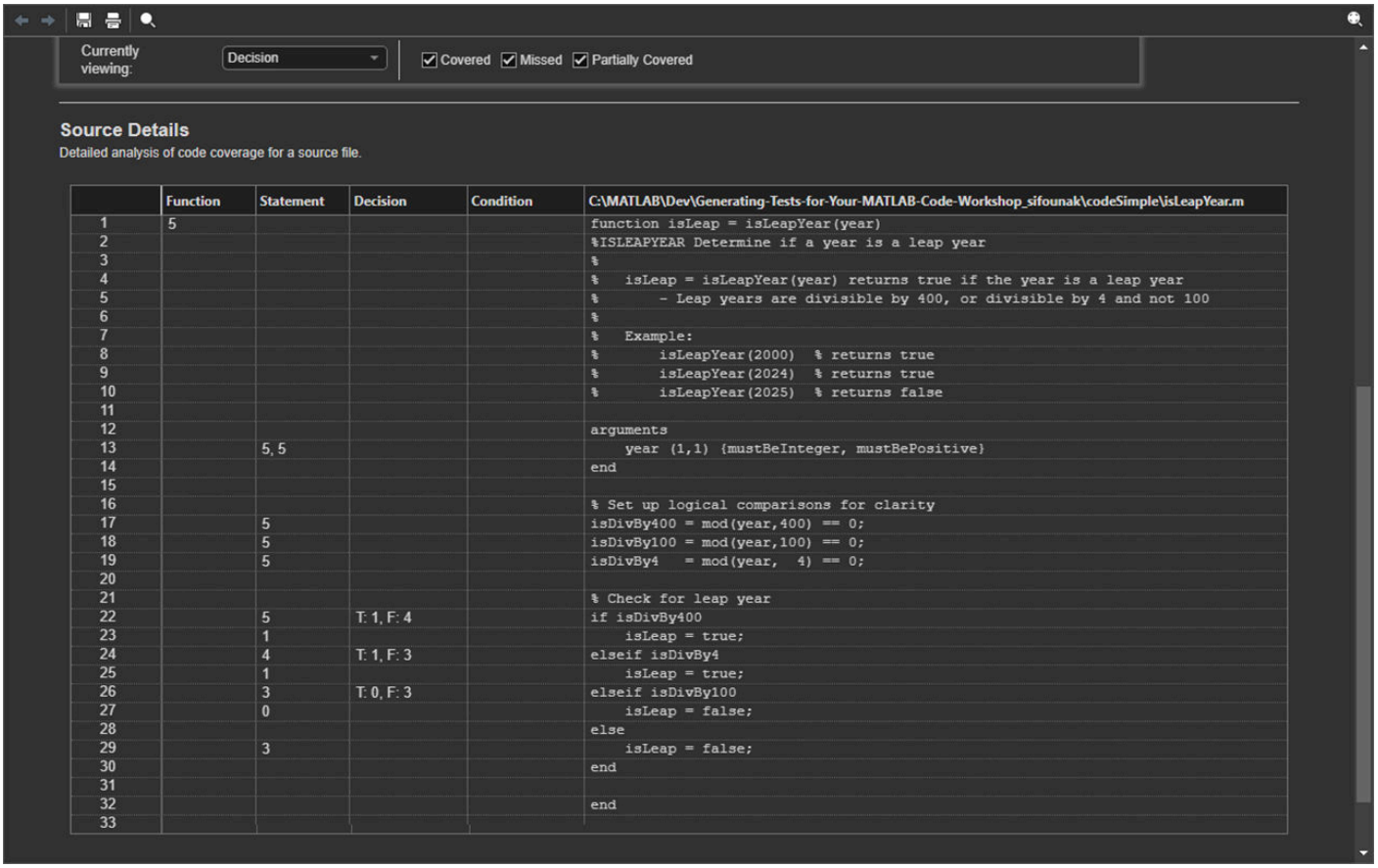
Part 3.3: Identifying testing gaps (and potential bugs) for `isLeapYear` using code coverage

Let's look at the detailed coverage metrics for the `isLeapYear.m` file and and see which parts of the code have been exercised.

Select the `isLeapYear.m` row in the "Breakdown by Source" table



Scroll down to see the detailed source code and coverage metrics



	Function	Statement	Decision	Condition	C:\MATLAB\Dev\Generating-Tests-for-Your-MATLAB-Code-Workshop_sifounak\codeSimple\isLeapYear.m
1	5				function isLeap = isLeapYear(year)
2					%ISLEAPYEAR Determine if a year is a leap year
3					%
4					% isLeap = isLeapYear(year) returns true if the year is a leap year
5					% - Leap years are divisible by 400, or divisible by 4 and not 100
6					%
7					% Example:
8					% isLeapYear(2000) % returns true
9					% isLeapYear(2024) % returns true
10					% isLeapYear(2025) % returns false
11					
12					arguments
13		5, 5			year (1,1) {mustBeInteger, mustBePositive}
14					end
15					
16					% Set up logical comparisons for clarity
17		5			isDivBy400 = mod(year,400) == 0;
18		5			isDivBy100 = mod(year,100) == 0;
19		5			isDivBy4 = mod(year, 4) == 0;
20					
21					% Check for leap year
22		5	T: 1, F: 4		if isDivBy400
23		1			isLeap = true;
24		4	T: 1, F: 3		elseif isDivBy4
25		1			isLeap = true;
26		3	T: 0, F: 3		elseif isDivBy100
27		0			isLeap = false;
28					else
29		3			isLeap = false;
30					end
31					
32					end
33					

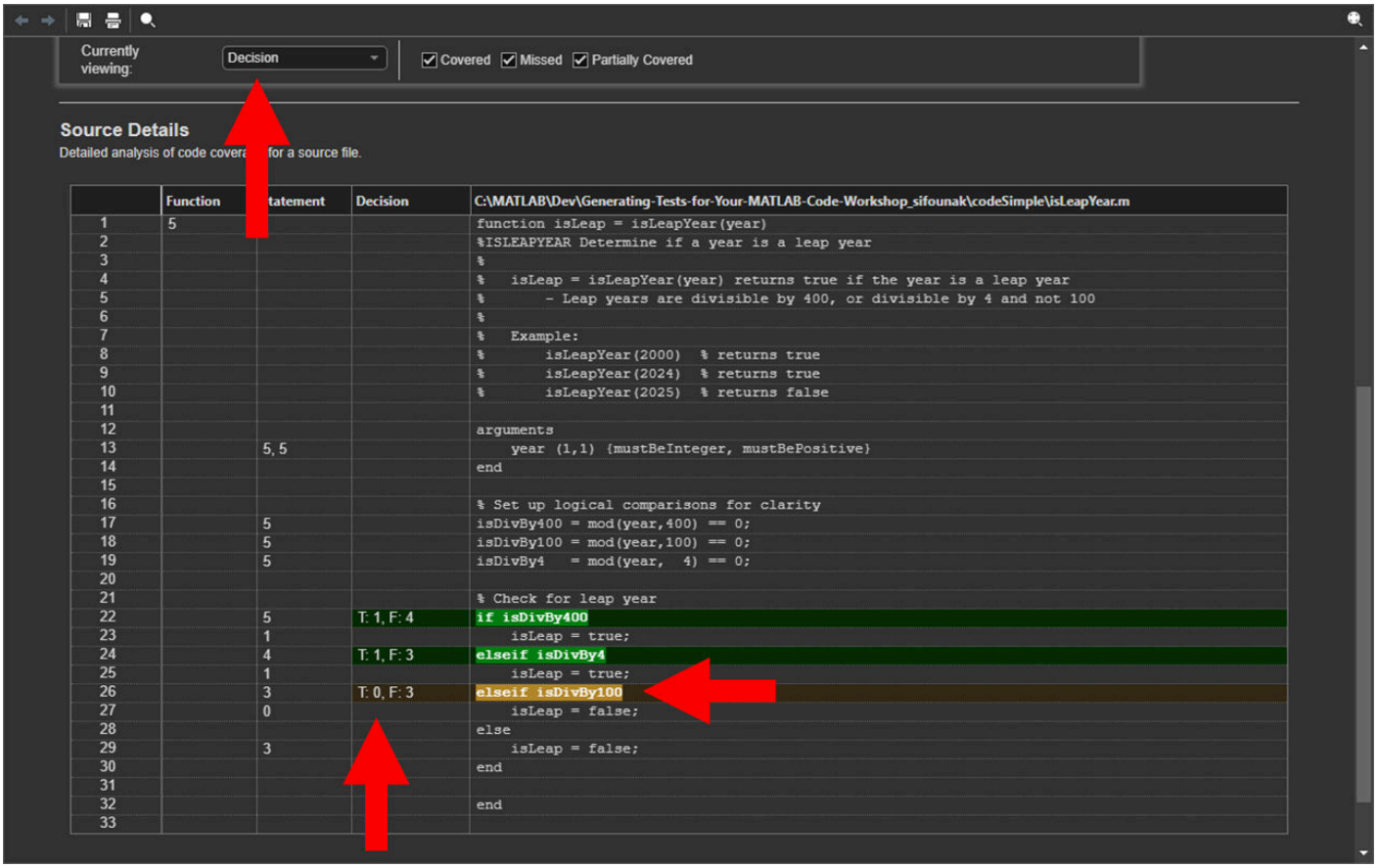
Well, that seems like a rather boring detailed report, right?

The reason we don't really see a whole lot of interesting data in Source Details is because we are looking at the "Condition" coverage metric, but the `isLeapYear` is a very simple code with no conditions in its logical branches. We can also see that the "Condition" column is empty, which further supports this conclusion.

However, we can see that the Statement and Decision columns have data in them, so let's take a look at those coverage metrics.

Select "Decision" coverage in the "Currently viewing" overlay at the top of the page

Now the coverage report looks much more interesting!



We can see several kinds of highlights you may see in the source code:

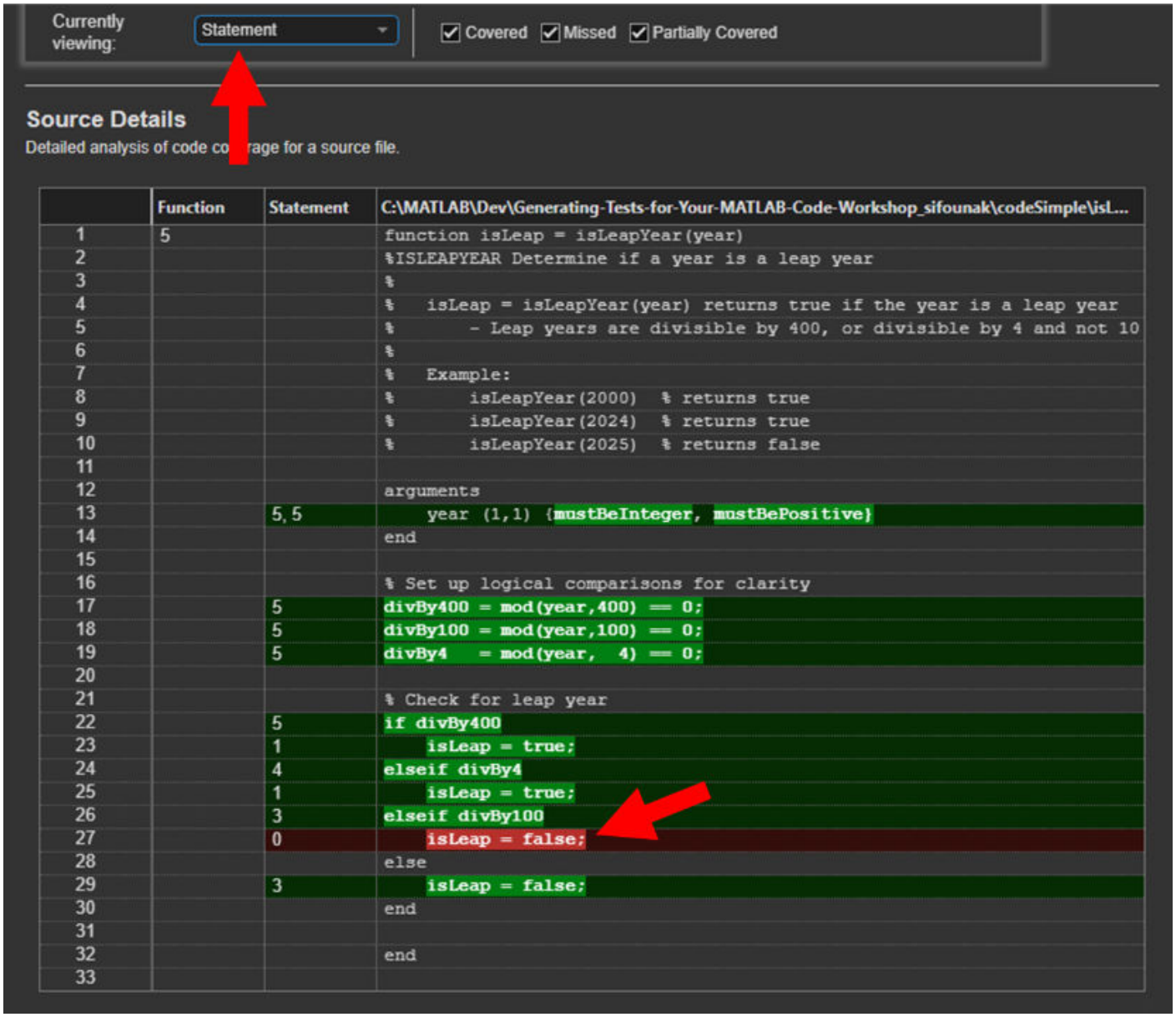
- Green: Both true and false decisions have been exercised
- Yellow: Only one of the true or false decisions have been exercised
- Red: None of the true or false decisions have been exercised

Note: The coverage report does not have any red because all of the decision branches have been at least partially exercised by at least one test

In addition to the source code highlights, the "Decision" column shows how many times each decision outcome (true and false) has been exercised by your tests. You can use these numbers to identify which condition outcome you did not exercise or help you decide whether you want to exercise a specific code branch more times.

We can also take a look at the "Statement" coverage metrics to see which statements in our code have and have not been exercised by our tests.

Select "Statement" coverage in the "Currently viewing" overlay at the top of the page



	Function	Statement	C:\MATLAB\Dev\Generating-Tests-for-Your-MATLAB-Code-Workshop_sifounak\codeSimple\isL...
1	5		function isLeap = isLeapYear(year)
2			%ISLEAPYEAR Determine if a year is a leap year
3			%
4			% isLeap = isLeapYear(year) returns true if the year is a leap year
5			% - Leap years are divisible by 400, or divisible by 4 and not 10
6			%
7			% Example:
8			% isLeapYear(2000) % returns true
9			% isLeapYear(2024) % returns true
10			% isLeapYear(2025) % returns false
11			
12			arguments
13		5, 5	year (1,1) {mustBeInteger, mustBePositive}
14			end
15			
16			% Set up logical comparisons for clarity
17		5	divBy400 = mod(year,400) == 0;
18		5	divBy100 = mod(year,100) == 0;
19		5	divBy4 = mod(year, 4) == 0;
20			
21			% Check for leap year
22		5	if divBy400
23		1	isLeap = true;
24		4	elseif divBy4
25		1	isLeap = true;
26		3	elseif divBy100
27		0	isLeap = false;
28			else
29		3	isLeap = false;
30			end
31			
32			end
33			

From the highlights, we can see that line 27 of our code has never been exercised by our tests.

Now we can ask the questions:

- Do we just need an extra test to exercise this piece of the code?
- Is this code unreachable (i.e., is it "dead code") and can be removed?
- Or is this a symptom of a bug in our code?

Let's try to find the answers to our questions.

Part 3.4: Debugging `isLeapYear.m`

Before we dive in, let's take a moment to explain how a leap year is determined.

A leap year is a year satisfies either of these criteria

- The year is divisible by 400
- The year is divisible by 4, but it is not divisible by 100

From the Decision coverage above, it looks like we're missing a test case that satisfies the "divisible by 100" part of the logic, so let's try testing the code with a year that is divisible by 100, but not divisible by 400.

Let's use the year 1900, since it is divisible by 100 and not divisible by 400. The result of this test should be `false` because it does not satisfy either of the criteria above.

```
>> isLeapYear(1900)

ans =
  logical
   1
```

Oh no! We got the wrong answer! It looks like we found a bug in our code!

Where is the bug?

When we look at the code flow, we see that the logical branches are being executed in this order:

1. Is the number divisible by 400?
2. Is the number divisible by 4?
3. Is the number divisible by 100?

Ah! There's our problem! We are checking whether the year is divisible by 4 before we check whether the year is divisible by 100. We'll never hit the "divisible by 100" code branch because all years that are divisible by 100 are also divisible by 4.

Fix the bug and test our changes

One easy way to fix the code is to switch the order of logical branch #2 (lines 24-25) and logical branch #3 (lines 26-27).

But...!

With logic branches, it's often useful to consider whether the logic can be written in a simpler, more readable way. One way to do this is to write the logic the same way we would describe it verbally. Earlier in this section, we defined a leap year as "a year that is divisible by 400, or it is a year divisible by 4 and not divisible by 100."

Using the variables we've already defined in the code, we can rewrite the following code:

```
% Check for leap year
if isDivBy400
    isLeap = true;
elseif isDivBy4
    isLeap = true;
elseif isDivBy100
    isLeap = false;
else
    isLeap = false;
end
```

as:

```
% Check for leap year
if isDivBy400 || (isDivBy4 && ~isDivBy100)
    isLeap = true;
else
    isLeap = false;
end
```

This code is much more readable than the multiple `if/elseif` blocks we had before because:

- the code is simpler to look at
- it makes it clear that there are only 2 possible outcomes: `true` and `false`
- the `true` case is ultimately broken down into 2 conditions: `condition1 || condition2`
- if neither of the conditions is satisfied, the answer is `false`

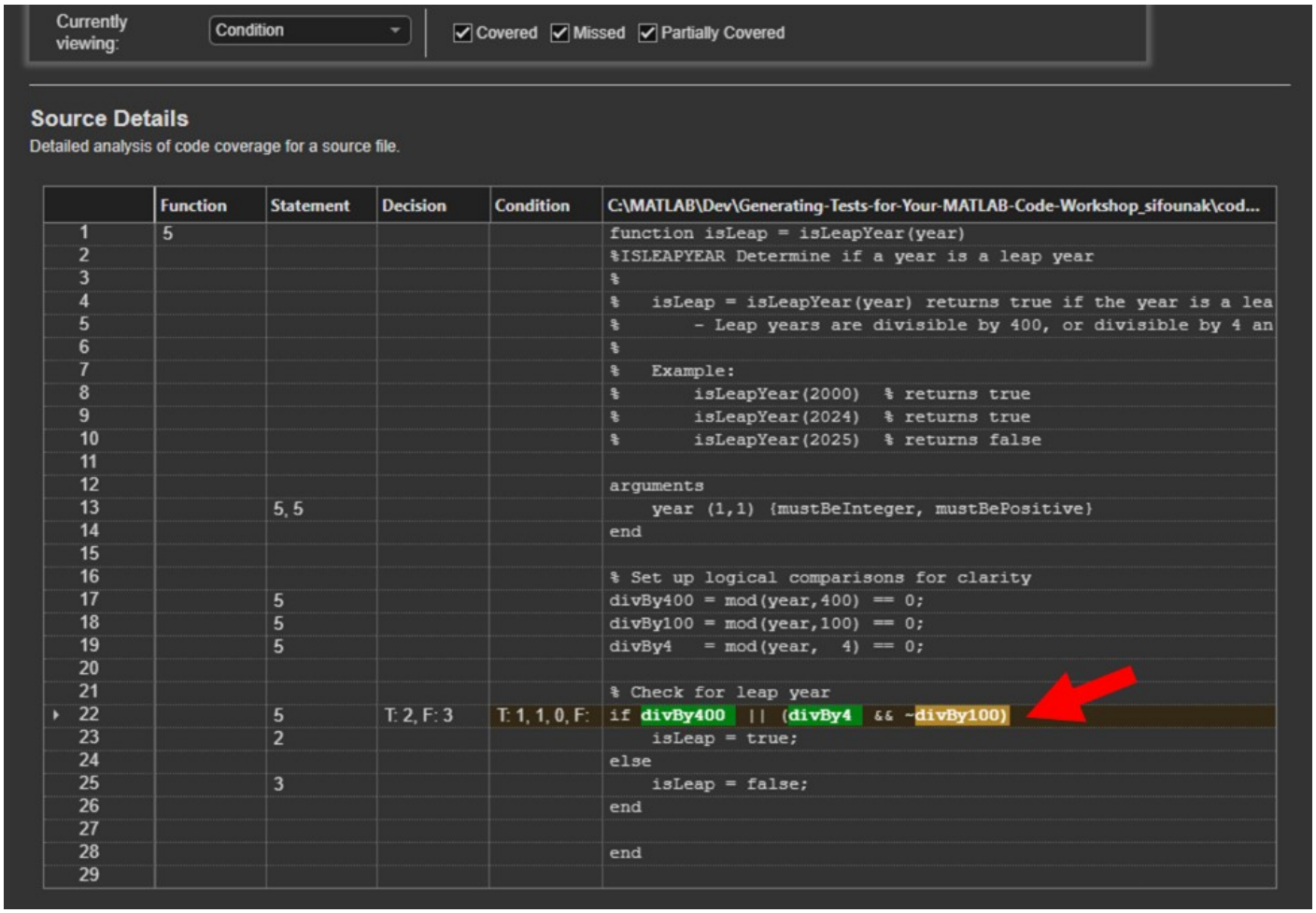
Let's update the code and run it again.

```
>> isLeapYear(1900)

ans =
  logical
   0
```

Yay! We've fixed the bug!

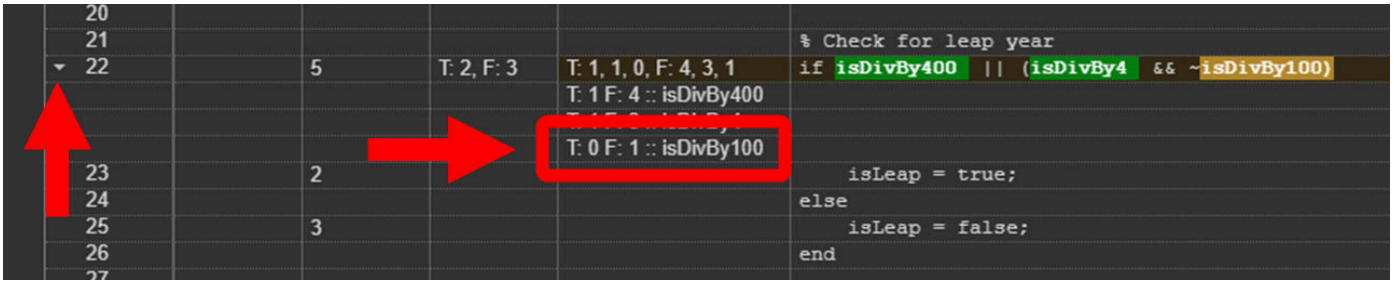
Rerun our tests to see how our code coverage is affected by these changes

Rerunning our tests and opening the coverage report, we see that we now have interesting data in our "Condition" coverage.



Unfortunately, we still see yellow highlights in the "not divisible by 100" logic. This means that we are missing some part of this coverage.

We can dig a bit deeper into the details of each condition by expanding the results on line 22 using the collapsible triangle to the left of the line numbers.



Looking at the coverage data, we see that we are still missing the coverage for the case where a year is divisible by 100 and not 400.

But didn't we test this with the year 1900?

Oh wait! We did test this, but we only tested the code interactively at the Command Window, but we never added the test point to our automated test suite.

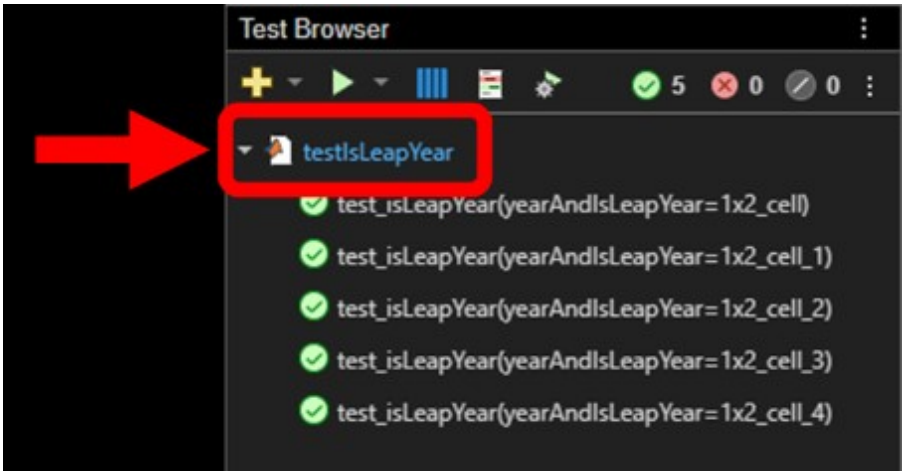
Let's add a new test point so that we never run into this bug again.

Part 3.5: Add an additional automated test point for `isLeapYear.m`

Open the test file for `isLeapYear` and add another test point

Wait... Where is the test file for `isLeapYear`? We never actually saw the test file because we found the tests using "Find Tests."

Luckily, the MATLAB Test Browser makes it easy to open the test files related to each test by simply clicking on the test file name. In our case, all of the test points are located in the `testIsLeapYear.m` file.



This is what the test file looks like:

```
classdef testIsLeapYear < matlab.unittest.TestCase

    properties (TestParameter)
        yearAndIsLeapYear = { ...
            {2000, true}; ...
            {2024, true}; ...
            {2025, false}; ...
            {1985, false}; ...
            {1999, false} };
    end

    methods (Test, ParameterCombination = "sequential")

        function test_isLeapYear(testCase, yearAndIsLeapYear)

            % Extract input and expected output from parameter for clarity
            year = yearAndIsLeapYear{1};
            expected_isLeap = yearAndIsLeapYear{2};

            % Exercise the code
            actual_isLeap = isLeapYear(year);

            % Verify results
            testCase.verifyEqual(actual_isLeap, expected_isLeap);
        end
    end
end
```

Hm... This seems a bit strange. The MATLAB Test Browser showed 5 tests, but this test file looks like it only has 1 test.

What's going on here?

The answer: The test in `testIsLeapYear.m` is a parameterized test.

Understanding parameterized tests

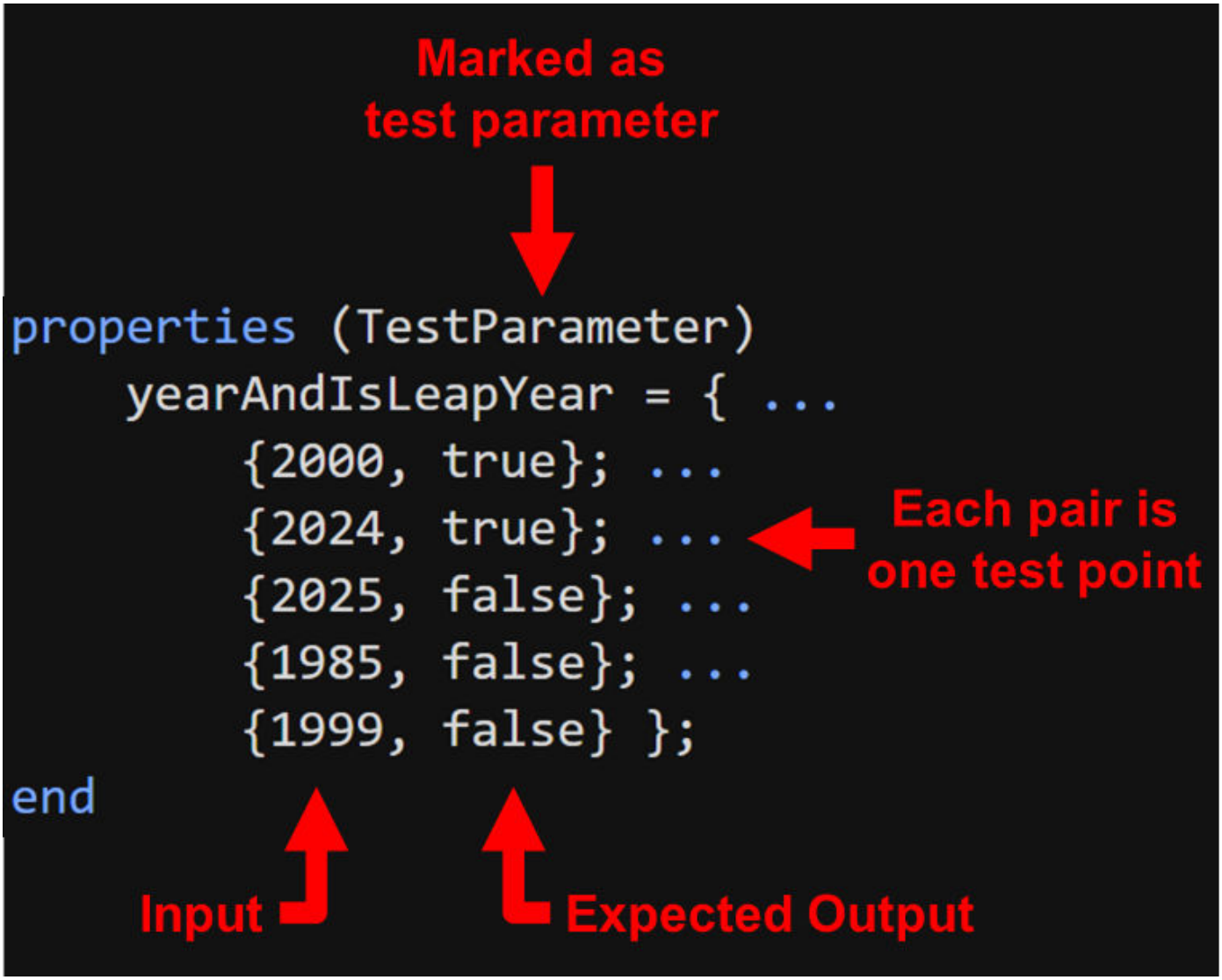
A parametrized test is a kind of test that enables you to reuse a single test function across multiple test points (i.e., multiple inputs).

Parameterized tests are extremely useful when:

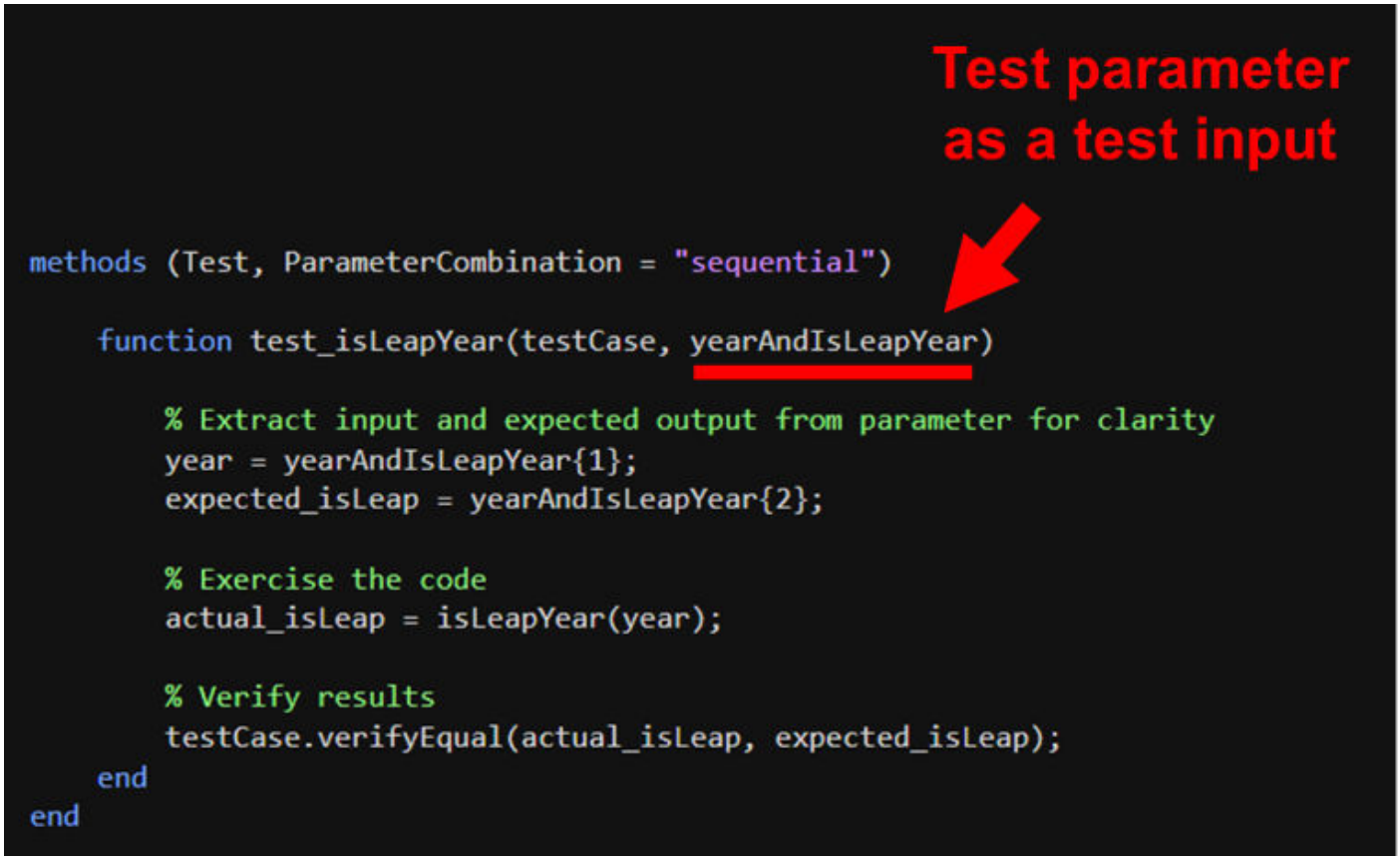
- you need to test a code multiple times with multiple inputs
- the calling syntax is the same across the tests
- the verifications are the same across the tests

The way a parameterized test works is by defining a test parameter (or multiple test parameters) that contain the inputs you want to pass into your code, and passing that test parameter to your test function.

In our case, we are using one test parameter that contains both the inputs and expected outputs of our function. The following diagram explains each part of the test parameter definition.



Looking at the test function, you can see it takes this test parameter as an additional input. This test parameter will have a different value every time the function is called.



You can learn more about parameterized testing here: https://www.mathworks.com/help/matlab/matlab_prog/use-parameters-in-class-based-tests.html

Add another test point

To add another test point, we need to add another input and expected output pair to the `yearAndIsLeapYear` test parameter array.

To do this, you can replace the following code:

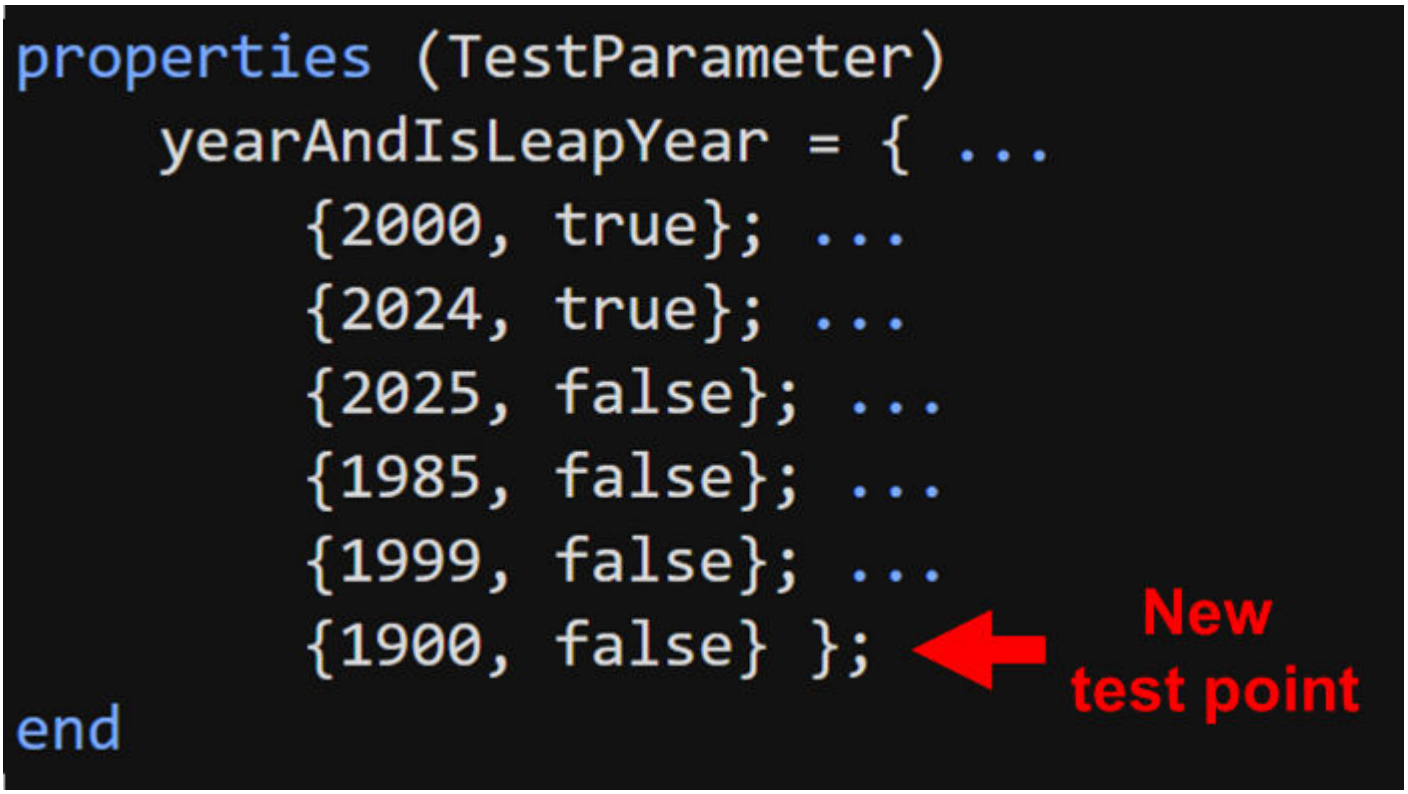
```
yearAndIsLeapYear = { ...
    {2000, true}; ...
    {2024, true}; ...
    {2025, false}; ...
    {1985, false}; ...
    {1999, false} };
```

with:

```
yearAndIsLeapYear = { ...
    {2000, true}; ...
    {2024, true}; ...
```

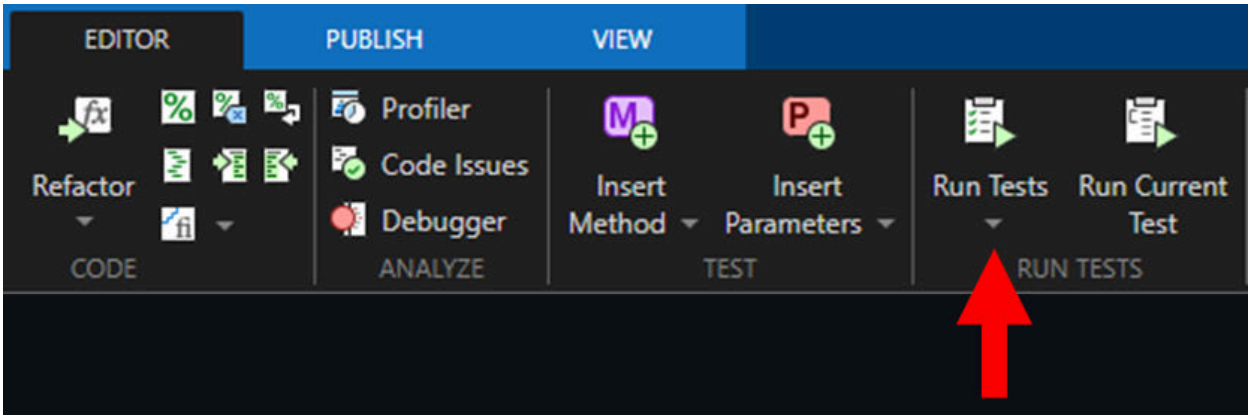
```
        {2025, false}; ...
        {1985, false}; ...
        {1999, false}; ...
        {1900, false} };
```

You should end up with a test parameter that looks like:

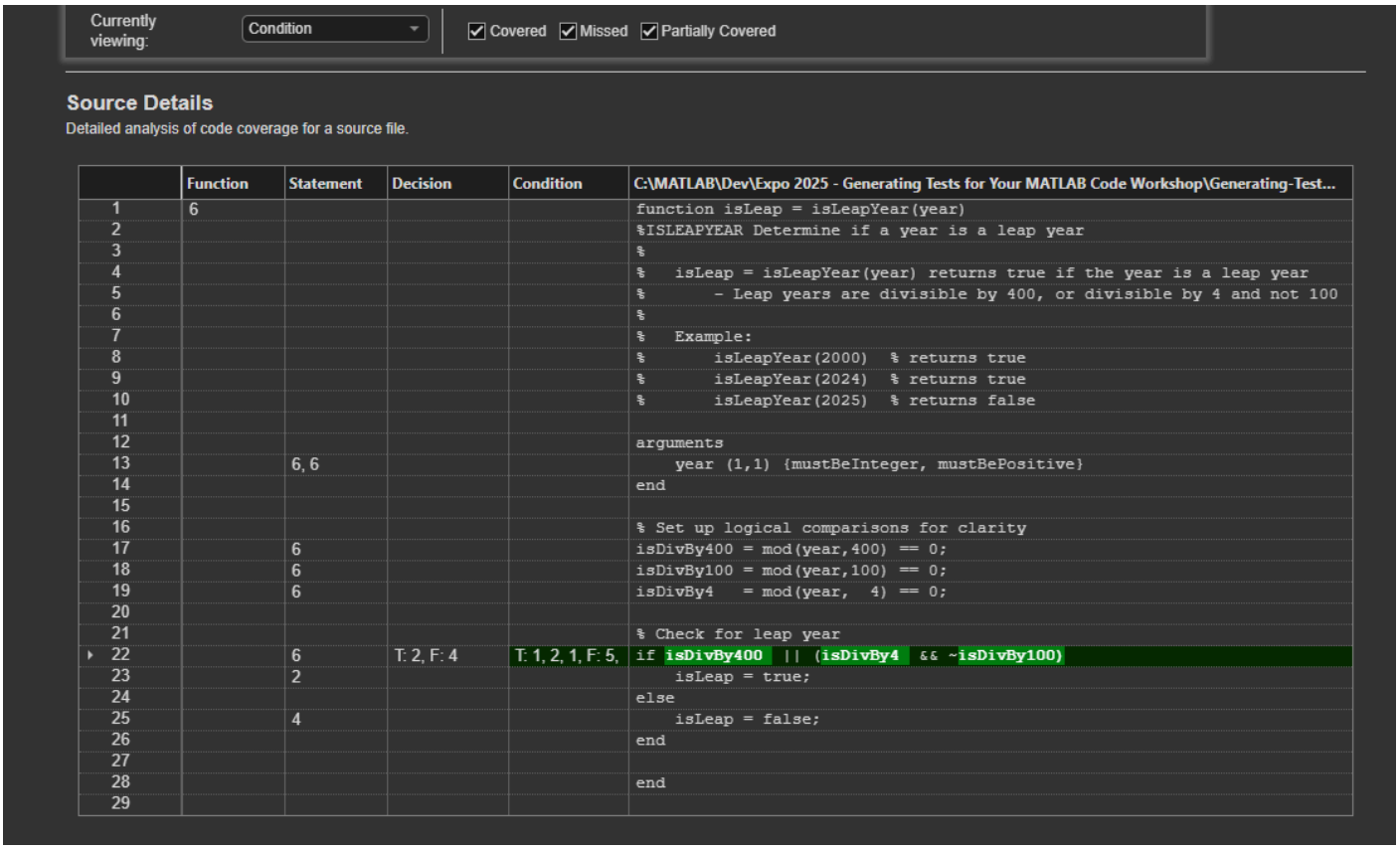


Rerun your tests and look at the coverage report

Note: You must use the "Run Tests" button in order to pick up the new test point we added. The "Run" button in the MATLAB Test Browser will run all of the tests it lists, but it will not automatically pick up new tests in the files.



It looks like we've achieved full condition coverage for `isLeapYear`. Yay! 🎉

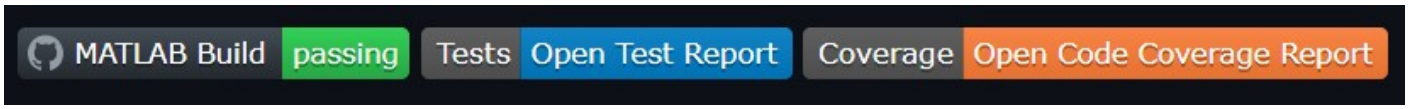


Part 4: Updating badges, committing our changes, and pushing to GitHub

In this section, we will:

1. Update the repository badges in `README.md`
2. Commit our changes to source control
3. Generate a GitHub Personal Access Token
4. Push our changes to GitHub

Part 4.1: Update repository badges

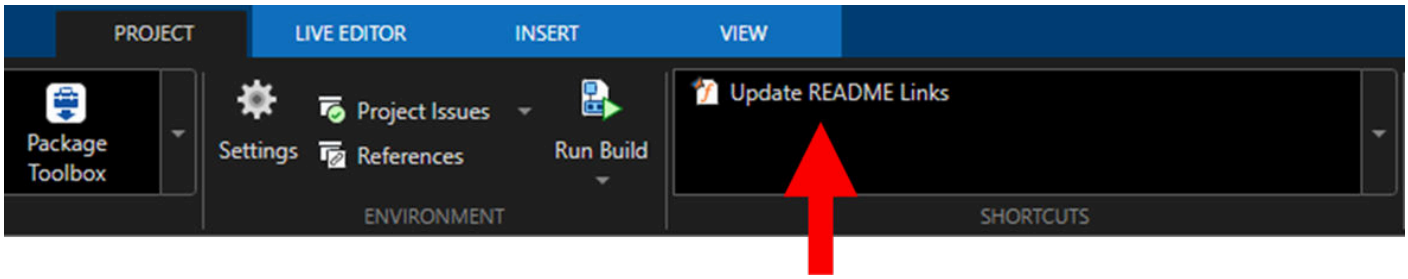


Repository badges are great ways to showcase the quality of your code and provide easy ways for people to explore various aspects of your repository, such as your build status and published results.

Badges are defined in a repository's `README.md`. One unfortunate aspect of badges is that they are always hardcoded to a specific repository's URL. Since we forked these badges from another repository, we will need to update the badge so they point to our repository instead.

To make this easy, the workshop provides a useful project shortcut that will automatically update the links in your `README.md` file.

Update the badges by single-clicking the "Update README Link" item in the "Shortcuts" section of the Project toolstrip



Note: If you want to manually update the links, you will need to make the following changes to all of the links in the `README.md` file:

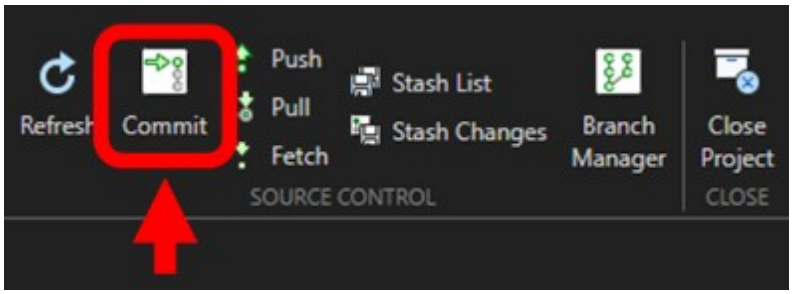
- replace "mathworks" GitHub username with your GitHub username
- replace "Generating-Tests-for-Your-MATLAB-Code-Workshop" repository name with your GitHub repository name

Your badges should now but up-to-date and point to your personal repository.

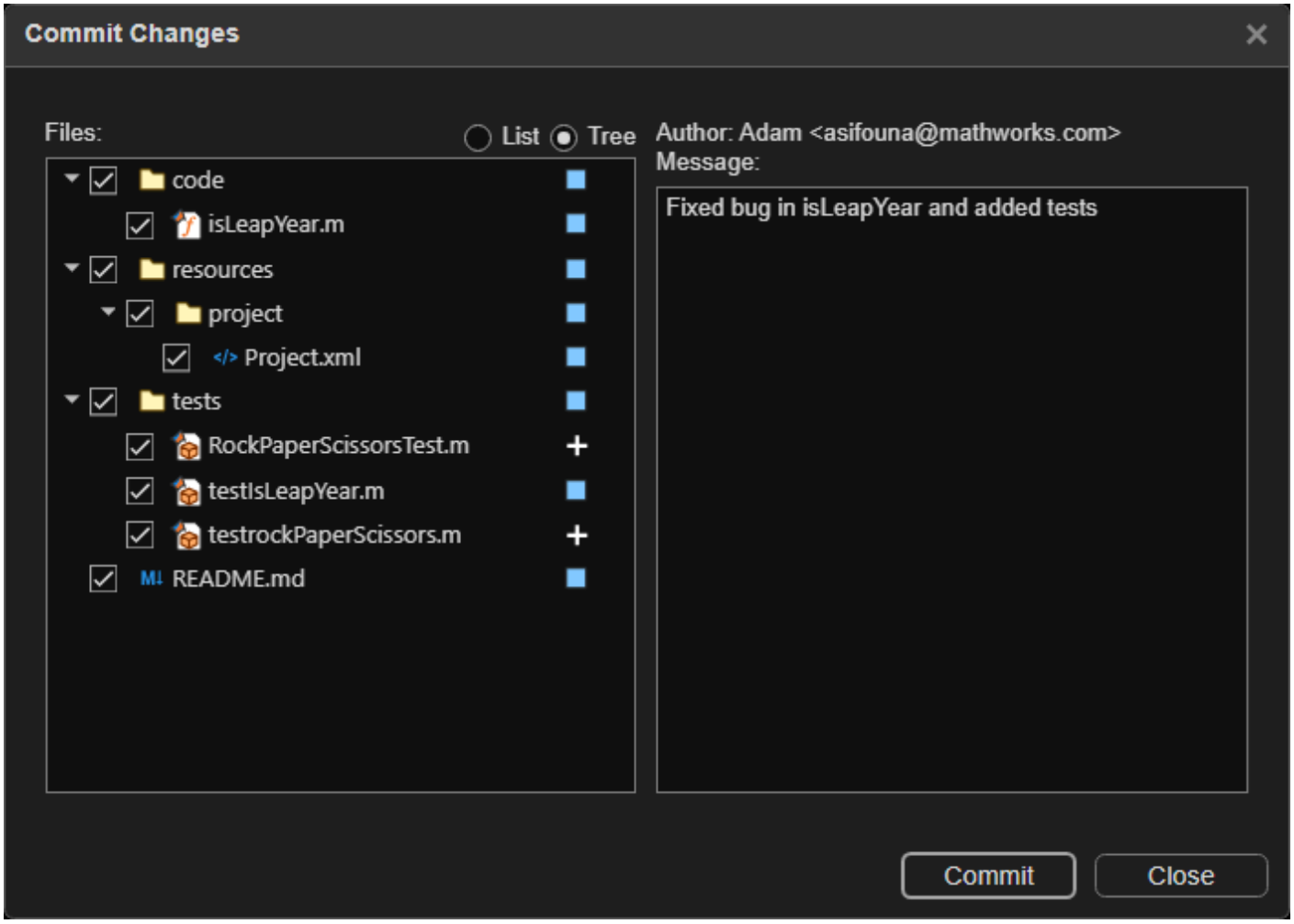
Part 4.2: Commit our changes to source control

Now that we've fixed a bug, added tests and test points, and updated our badges, it's time to commit our changes!

In the "Project" toolstrip tab, press "Commit"



Type in a commit message and press "Commit"



We've now committed our changes and can always get back to this version of our codebase if we ever need to.

Usually, the next step is to push our changes back to GitHub. This is really easy and straightforward when using Git from a desktop application (e.g., the desktop version of MATLAB). However, since we are pushing our changes from an online application (MATLAB Online), GitHub requires a Personal Access Token to allow MATLAB Online to push our changes back to GitHub.

Part 4.3: Generating a GitHub Personal Access token to enable MATLAB Online to push our changes to our GitHub repository

Over the last few years, GitHub has increased its focus on security. One of the major user-facing ways GitHub is enforcing some of these better security practices is by moving away from the use of passwords, and recommending that people use personal access tokens instead.

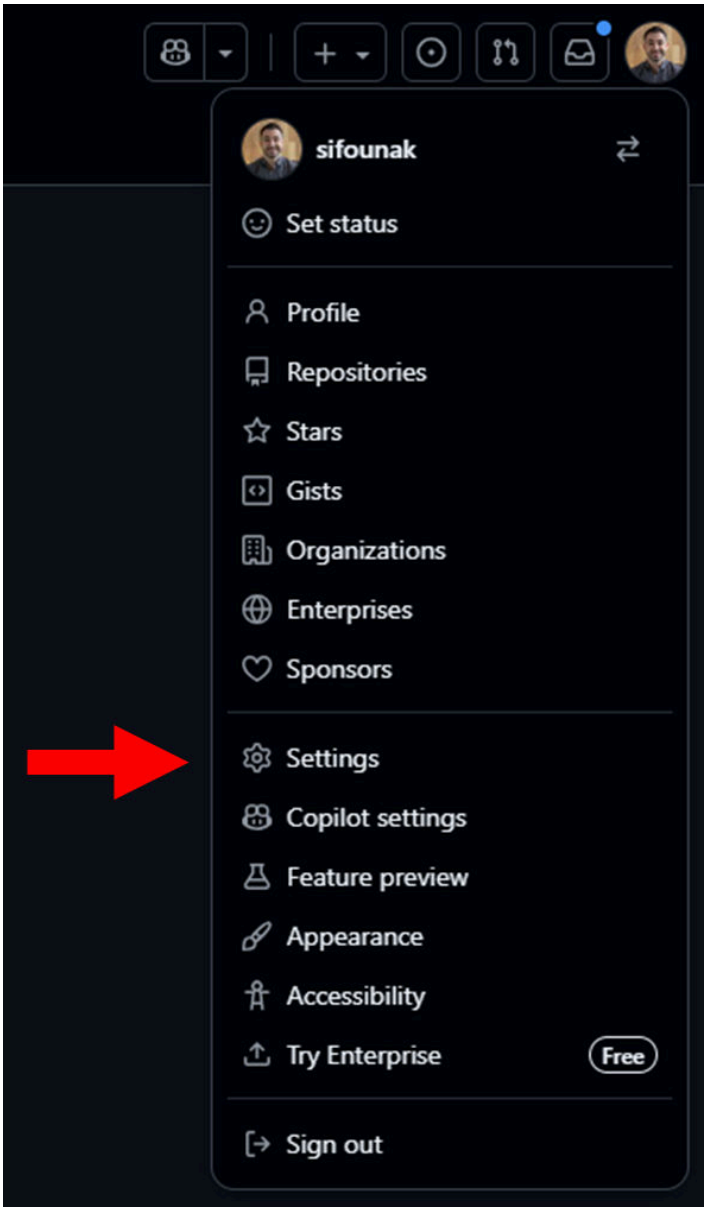
Personal access tokens are meant to be treated like passwords:

- They are supposed to be difficult or impossible to memorize or guess
- They are not meant to be written down
- They are not meant to be shared with others

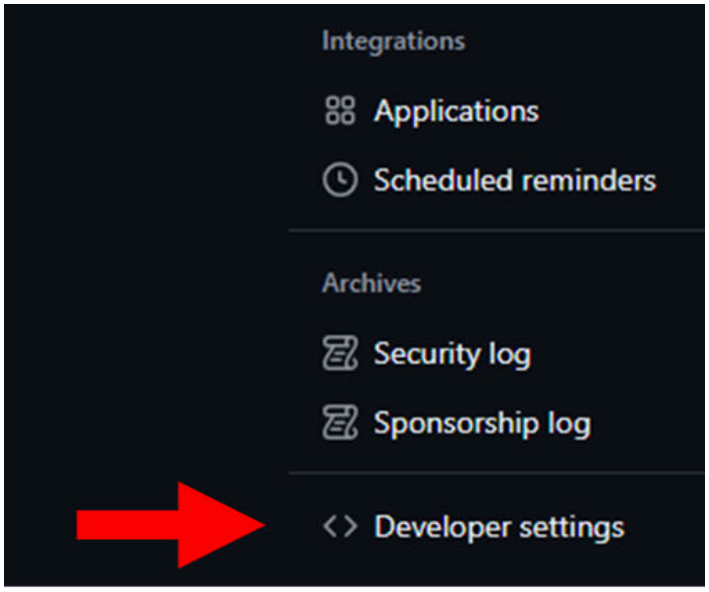
When you install Git on your desktop, it comes with the GitHub Credential Manager. The GitHub Credential Manager will accept a username/password combination, will securely get and store a Personal Access Token for you, and make it very easy to push and pull changes without manually generating a Personal Access Token.

For this MATLAB Online session, we will need to manually create a Personal Access Token to give MATLAB Online permission to push changes to GitHub. GitHub provides directions for how to create a personal access token, but this part of the workshop will give you a step-by-step guide to creating your Person Access Token.

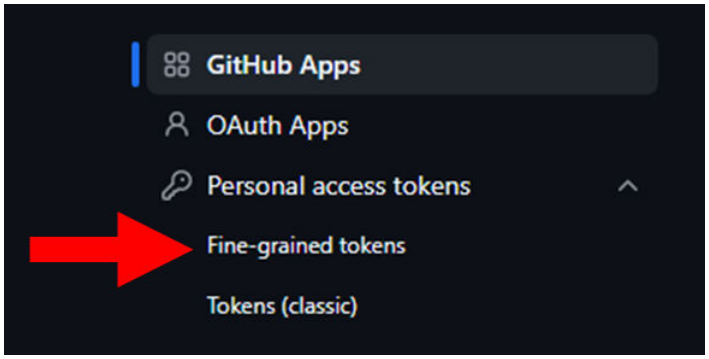
On GitHub, press your profile picture (top right of the page) and select "Settings"



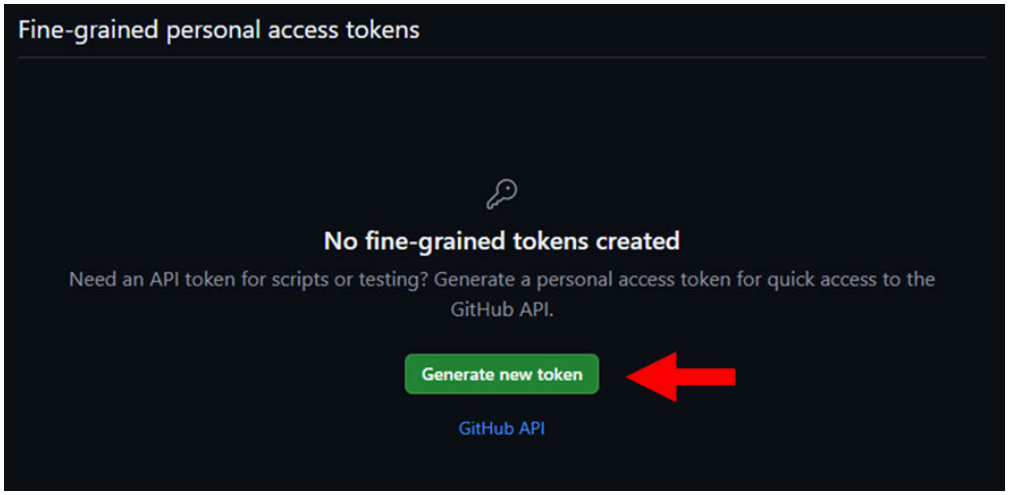
Select "Developer settings" at the bottom of the left-hand navigation menu



Select "Personal access tokens > Fine-grained tokens"

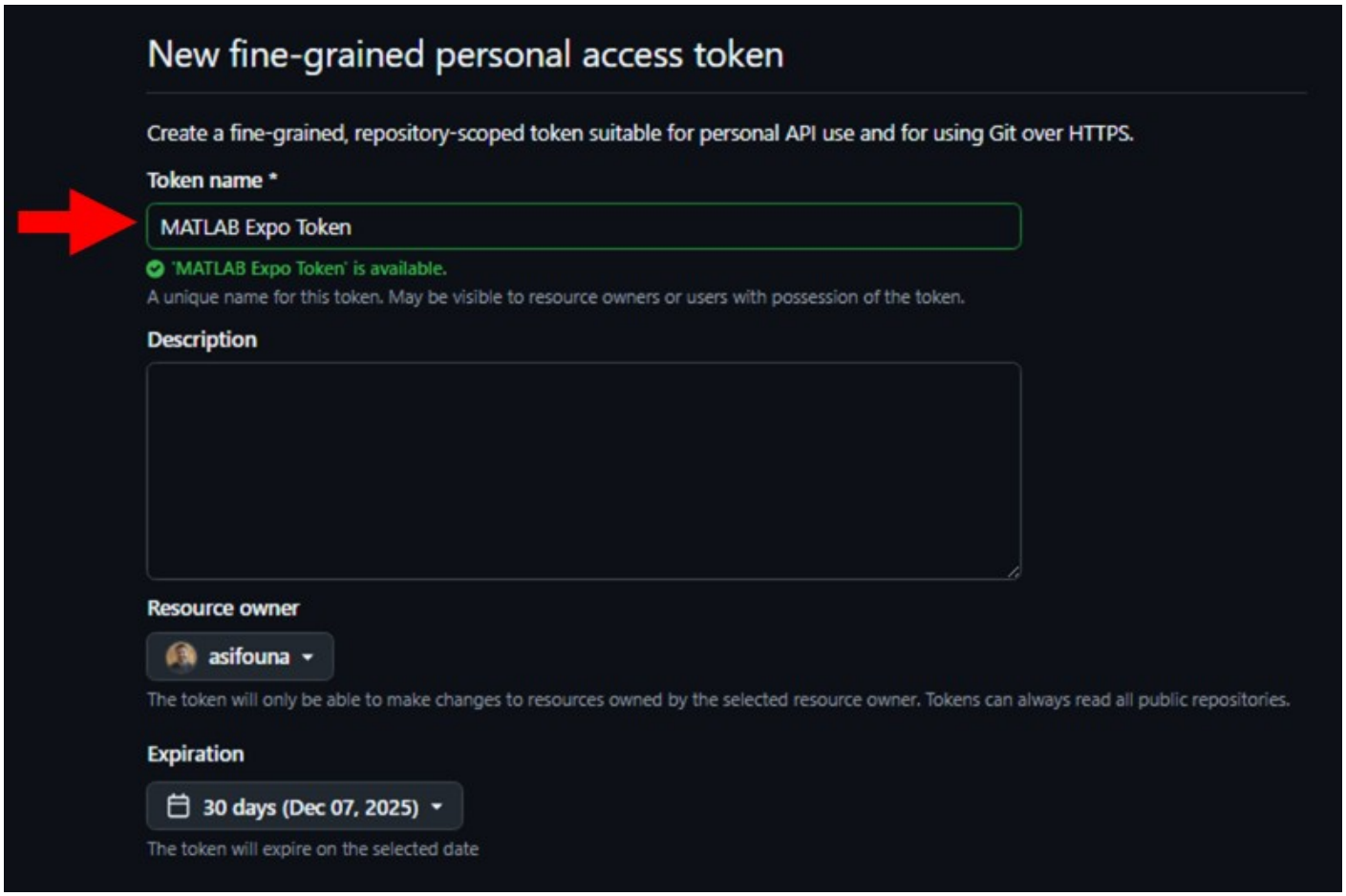


Press "Generate new token"

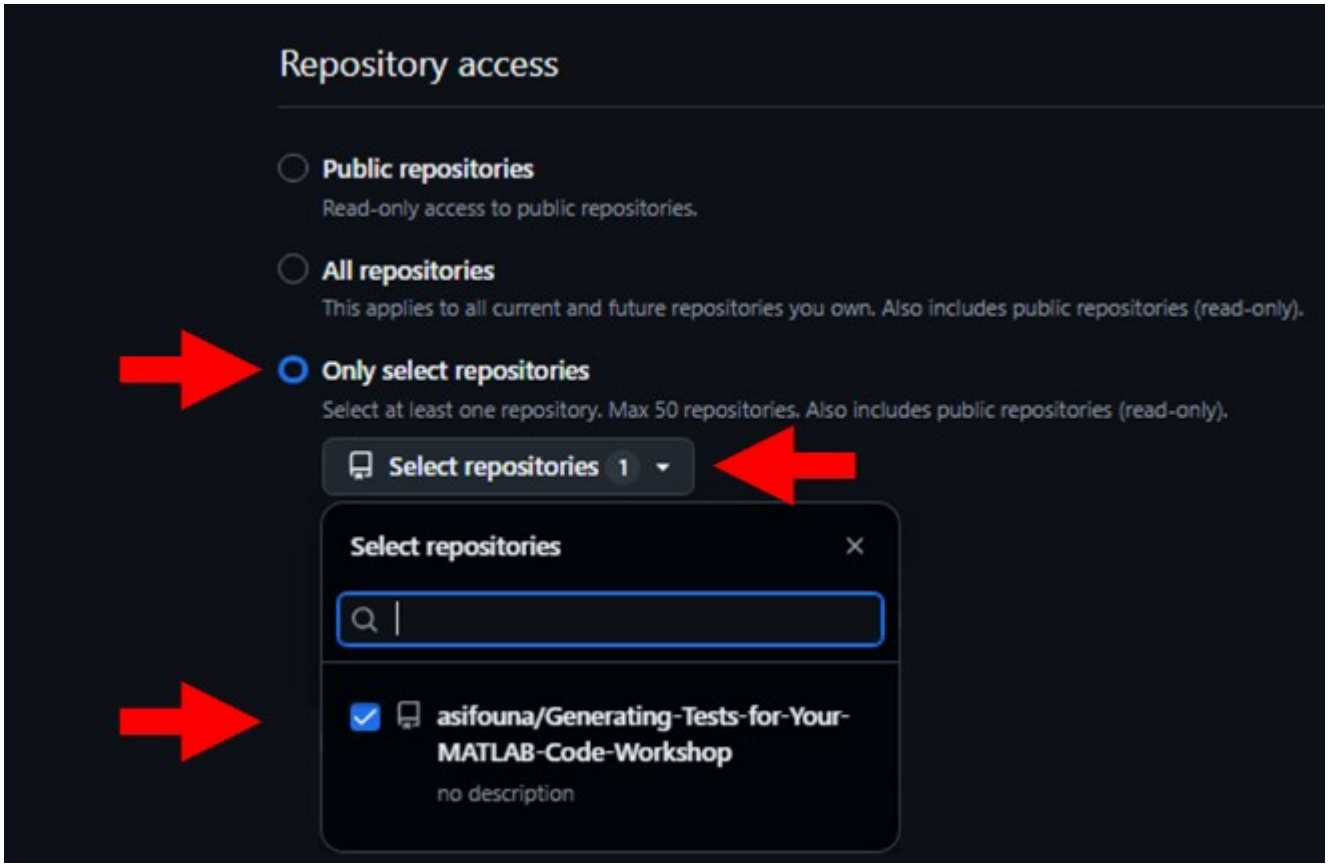


Note: You may need to log into GitHub again to complete this action.

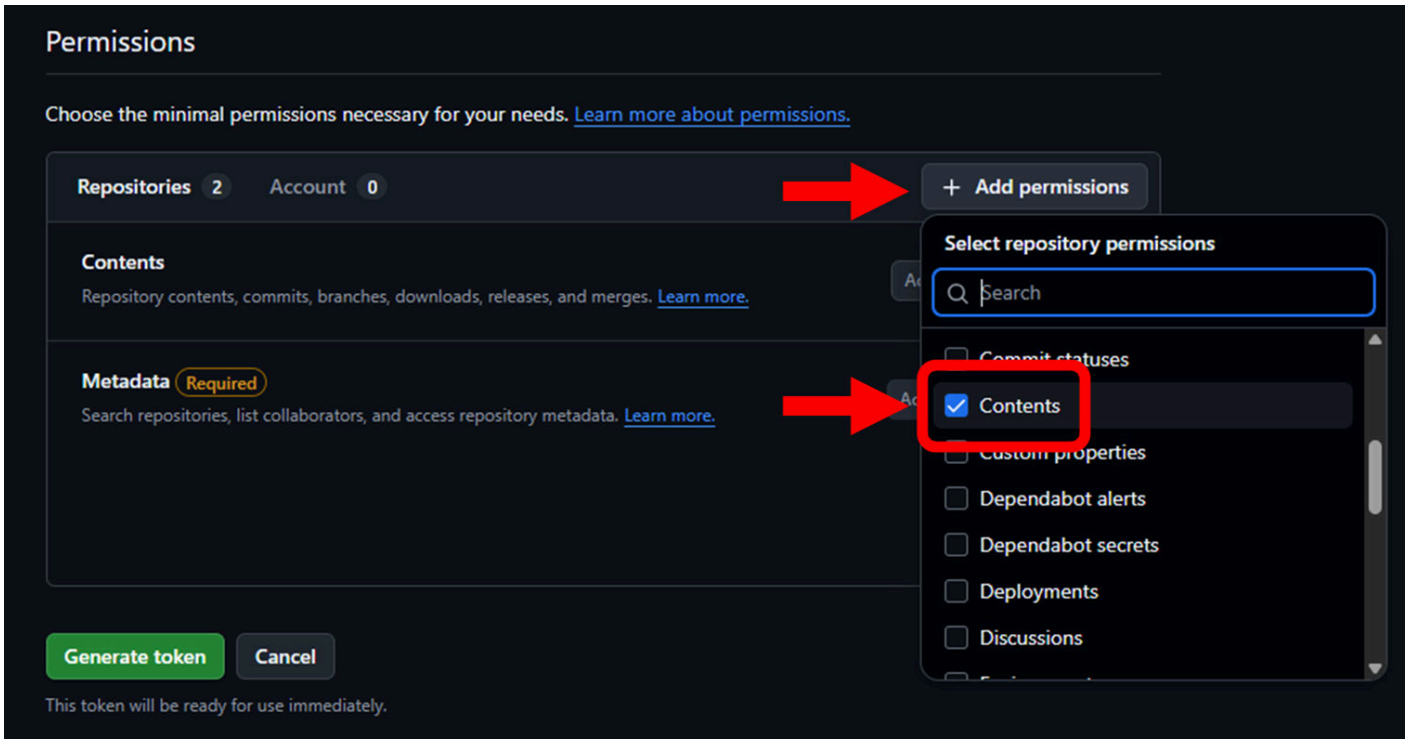
Name your token



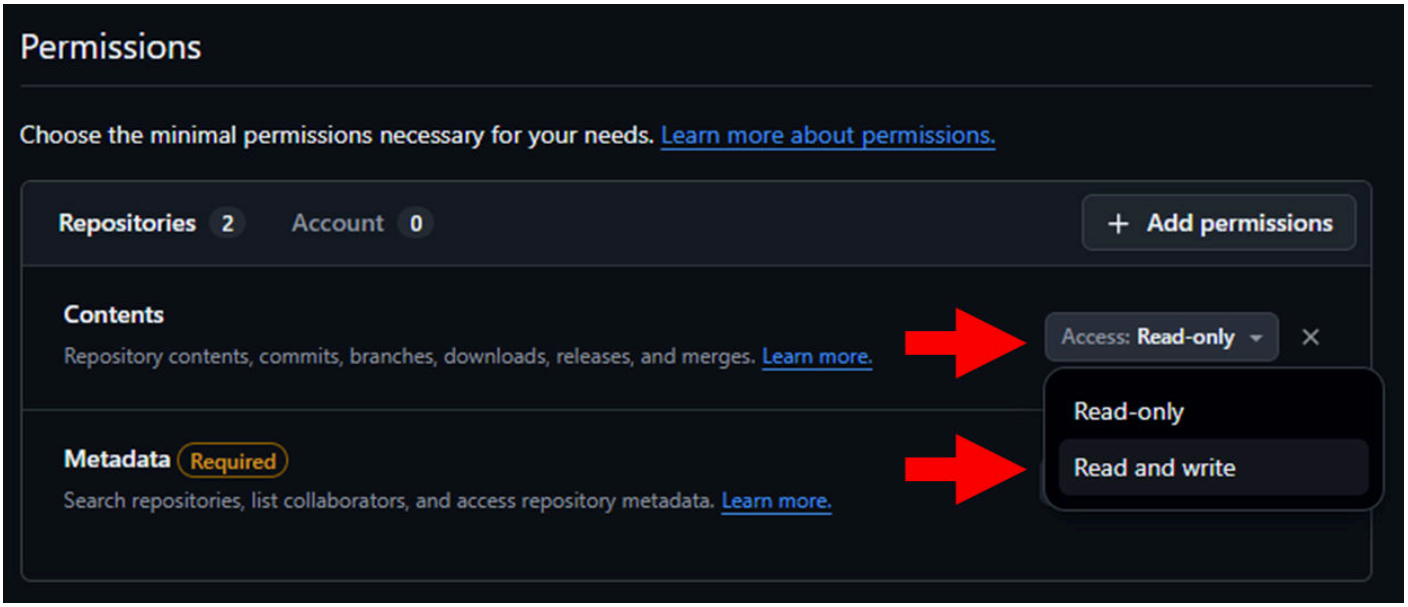
Limit token access to only the workshop repo



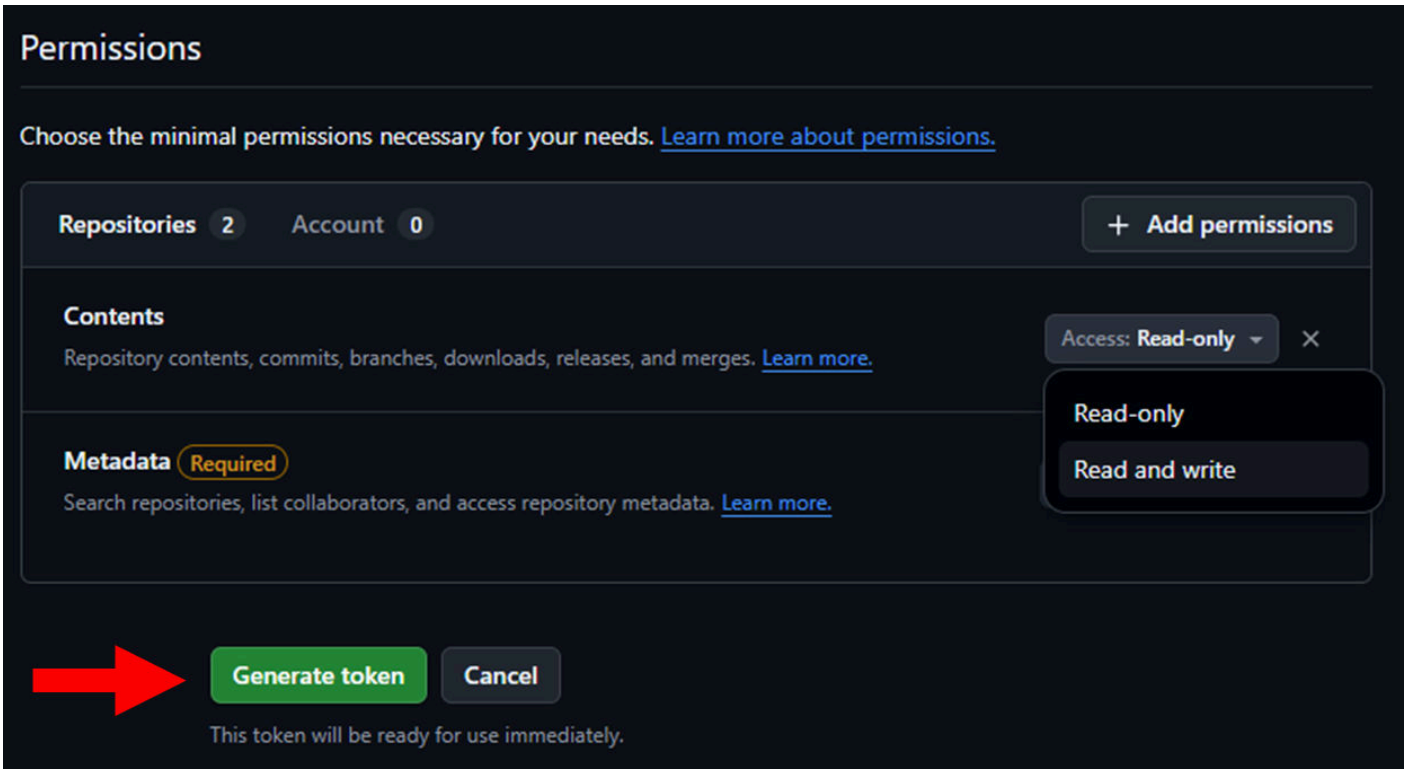
Select "Add Permissions > Contents" to enable pushing changes to your repository



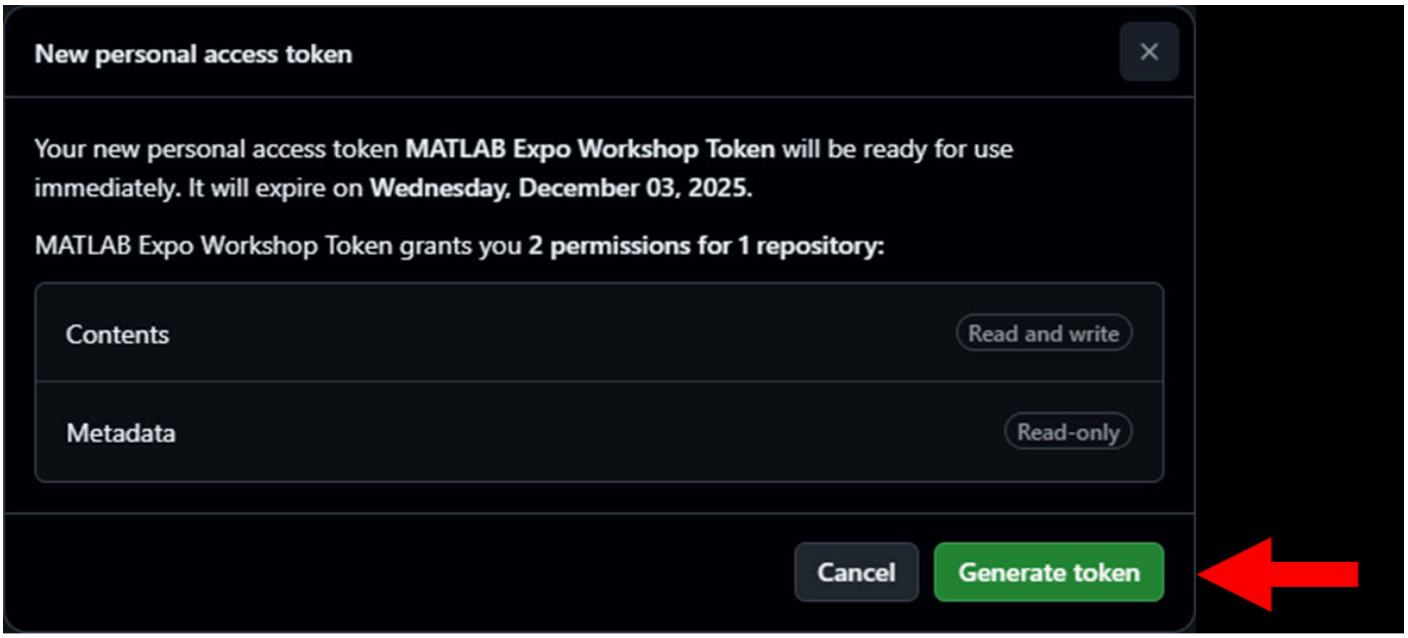
Change "Contents" access permissions to "Read and write"



Press "Generate token"



Confirm the creation of the token

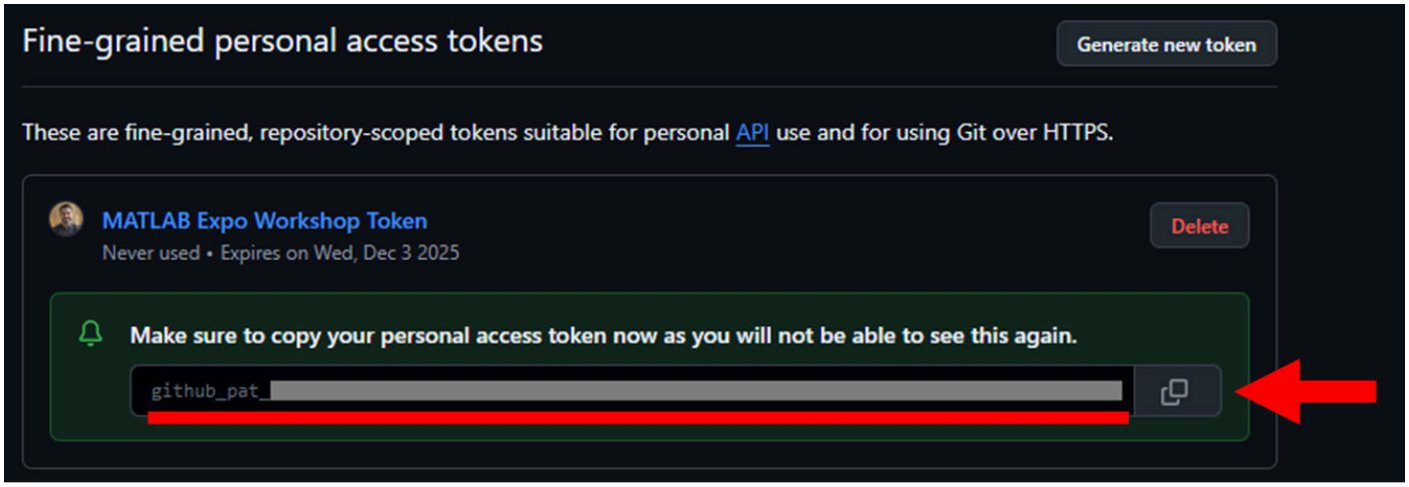


Copy your personal access token to your clipboard

WARNING:

- You only have 1 chance to copy the personal access token, so do not navigate away from the page until you have used the token wherever you need it.
- If you forget to copy your token string or you need to give another service access to your repository at a later time, you will need to create a new token.

Any service that generates access token strings will only allow you to see or copy the token string the moment the token is created. As soon as you refresh the page or navigate away, the token string will be hidden forever. This protects you from having your token stolen or copied if someone breaks into your account.

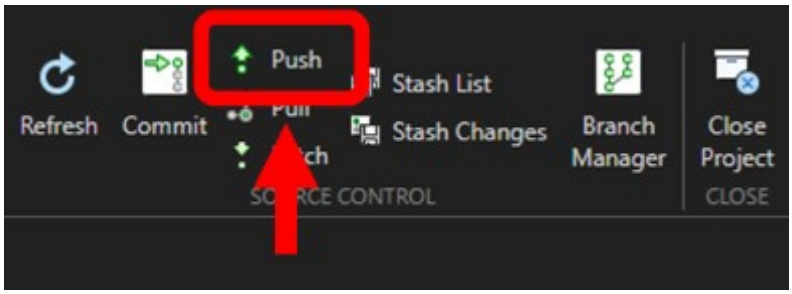


Your personal access token should start with "`github_pat_`" followed by many alphanumeric characters.

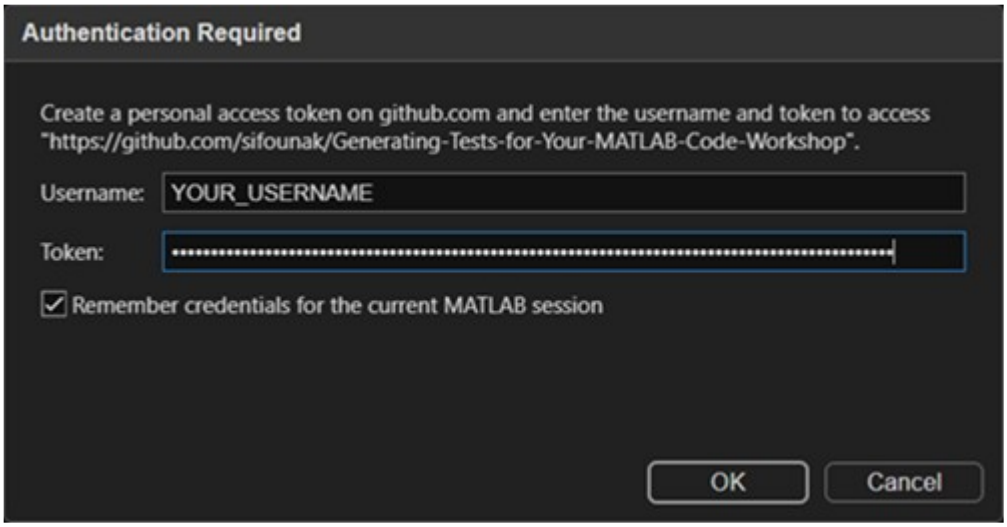
Part 4.4: Pushing our changes to GitHub

Now let's push our changes to GitHub!

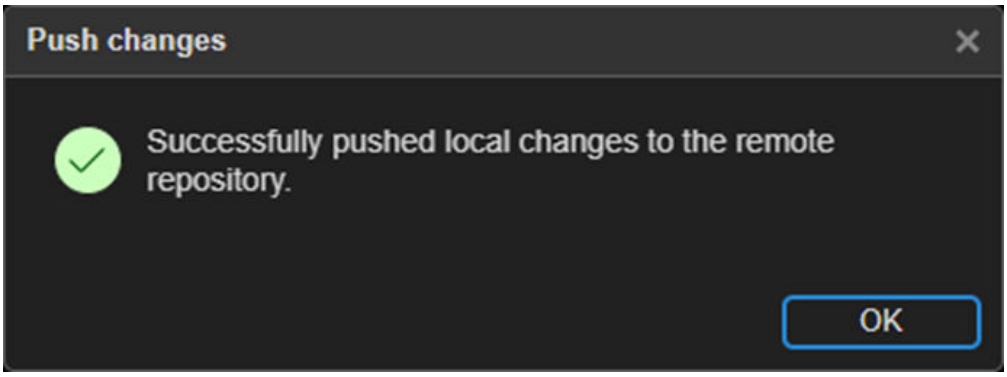
In the Projects tab, press the "Push" button



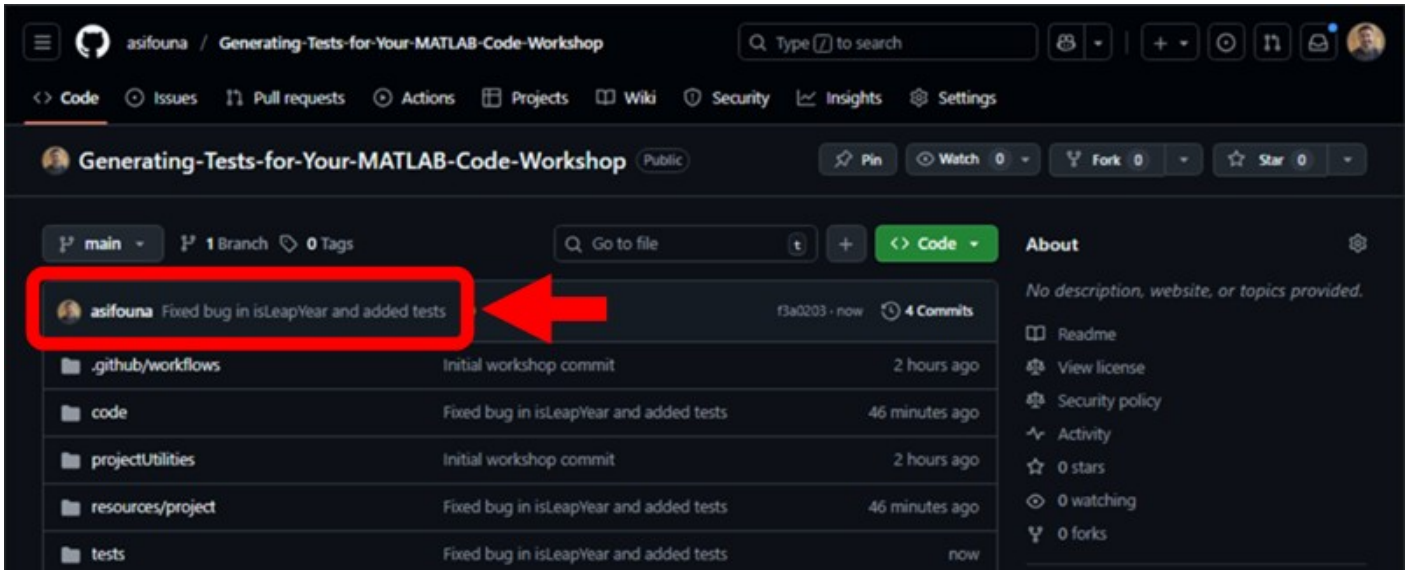
Enter your username and paste your personal access token into the MATLAB Online Git dialog and press "Ok"



At this point, all of your changes will be pushed to GitHub.



We should now be able to see our latest changes directly on our GitHub repository.



Part 5: Watch GitHub Actions automatically test our changes and publish results

In this section, we will:

1. Explore GitHub Actions as it automatically tests our changes and publishes test results
2. View our published test and code coverage results

Part 5.1: Watch GitHub Actions automatically test our code and publish our results

Once we push our changes back to Git, GitHub Actions will automatically test our code and publish our test results.

To make this possible, the workshop provides you a pre-written GitHub Actions YAML file that tells GitHub Actions how to get MATLAB and what to do with your code as soon as changes are pushed.

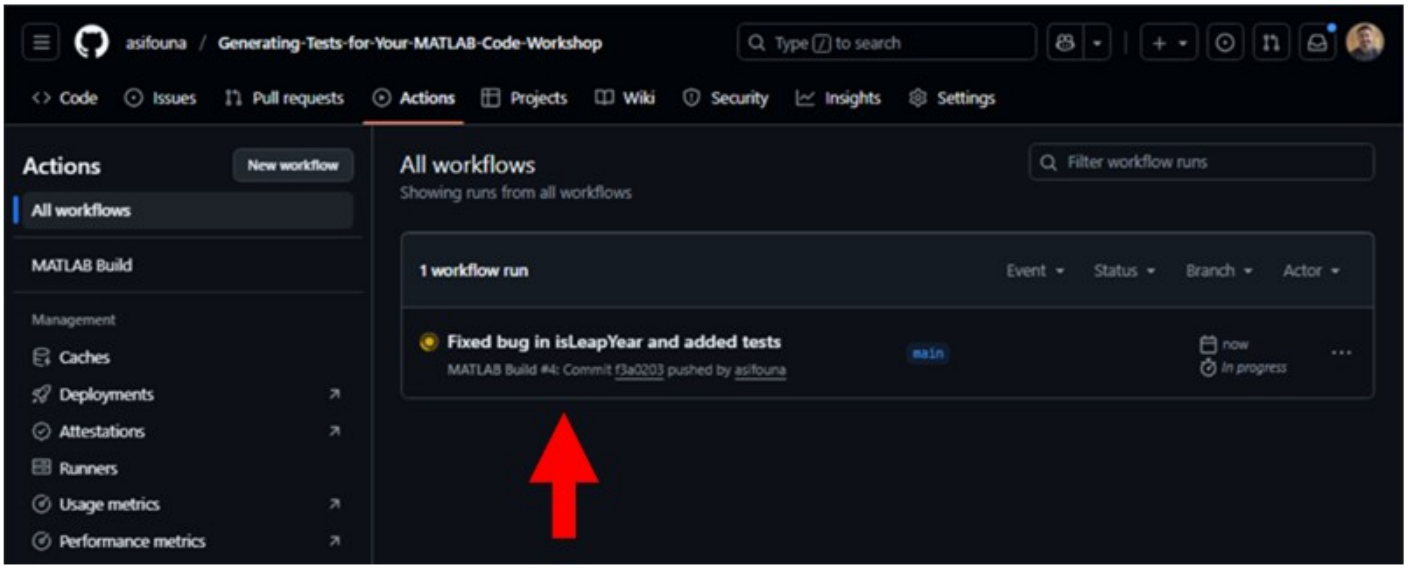
- You can learn more about GitHub Actions YAML files here: https://docs.github.com/en/actions/reference/workflows-and-actions/workflow-syntax

Note: We are using the MATLAB build tool to automate some of the build actions, but all of these actions can be accomplished with simple MATLAB code, as well.

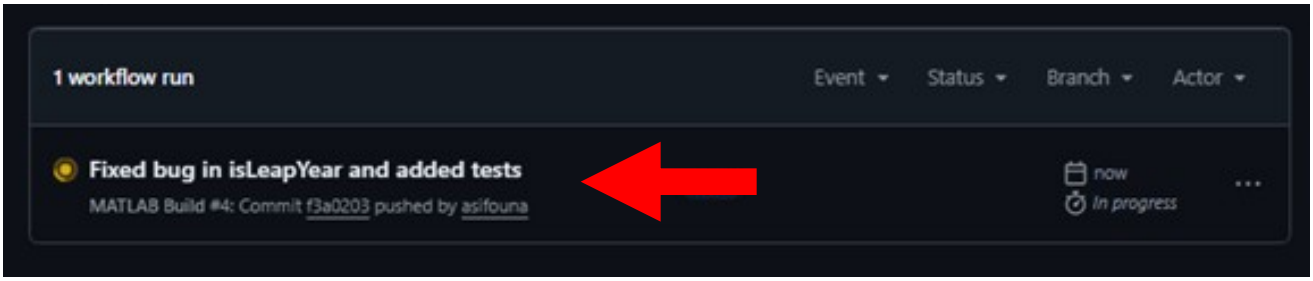
- You can learn more about the MATLAB build tool here: https://www.mathworks.com/help/matlab/matlab_prog/overview-of-matlab-build-tool.html

Select the "Actions" tab to see your build in action

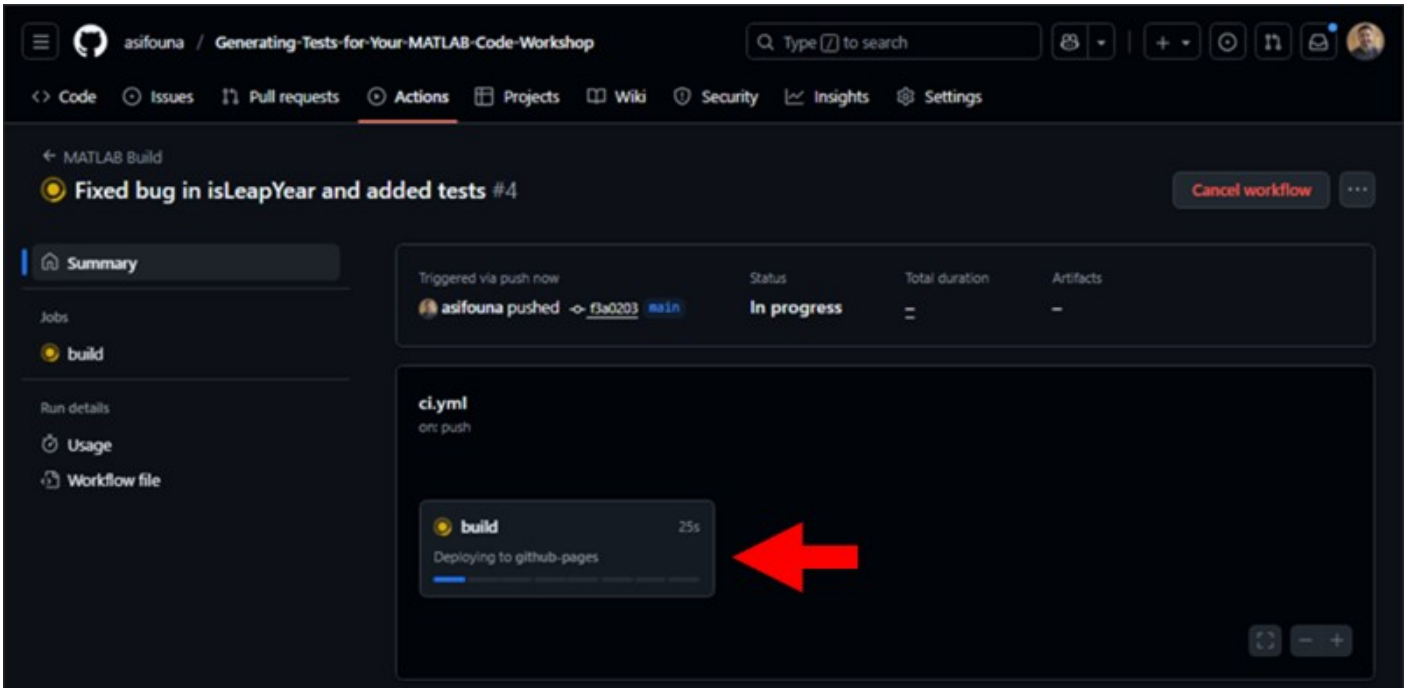
Here you'll see all the builds that are running or have been run in the past.



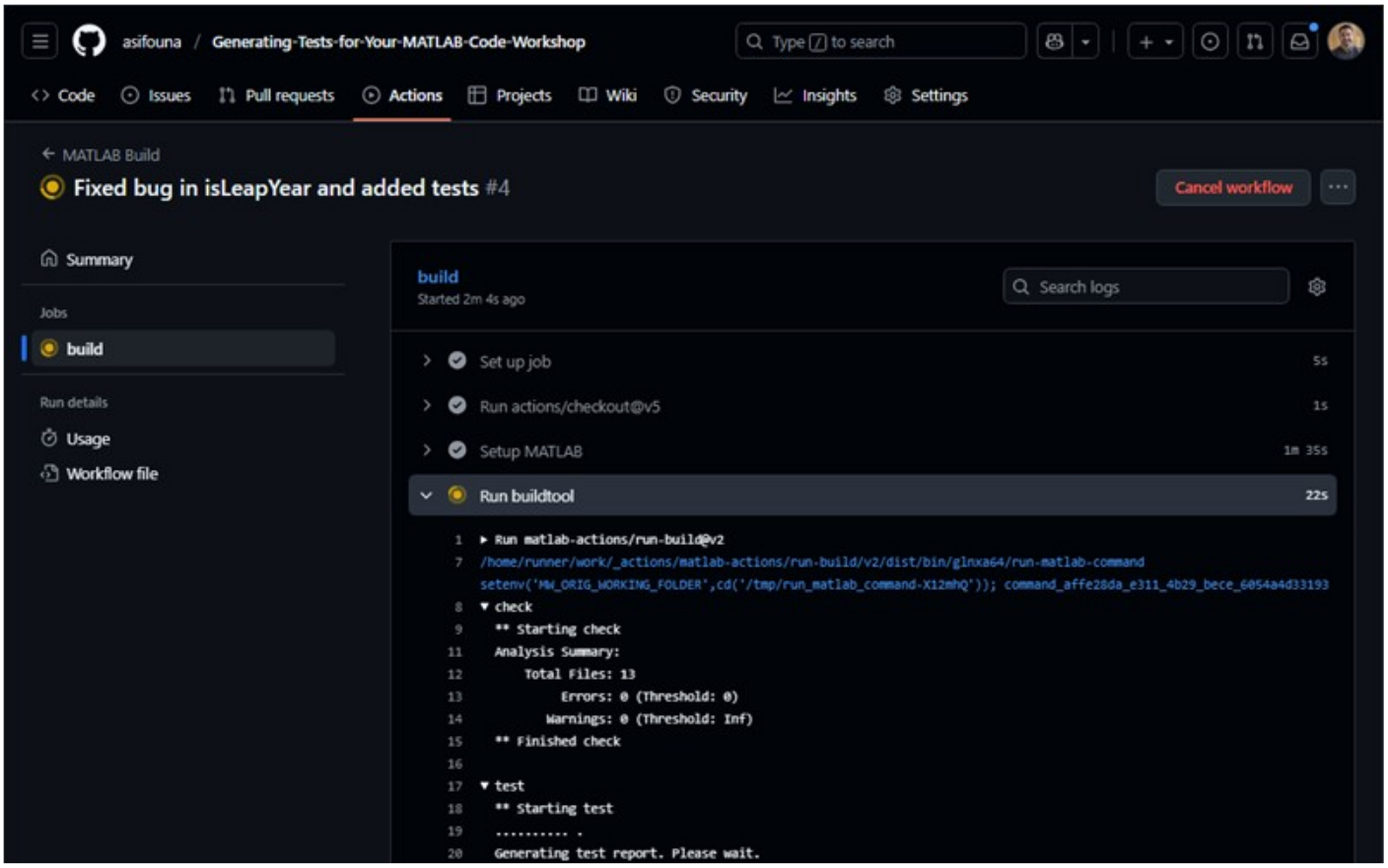
Dive deeper by selecting the listed workflow item



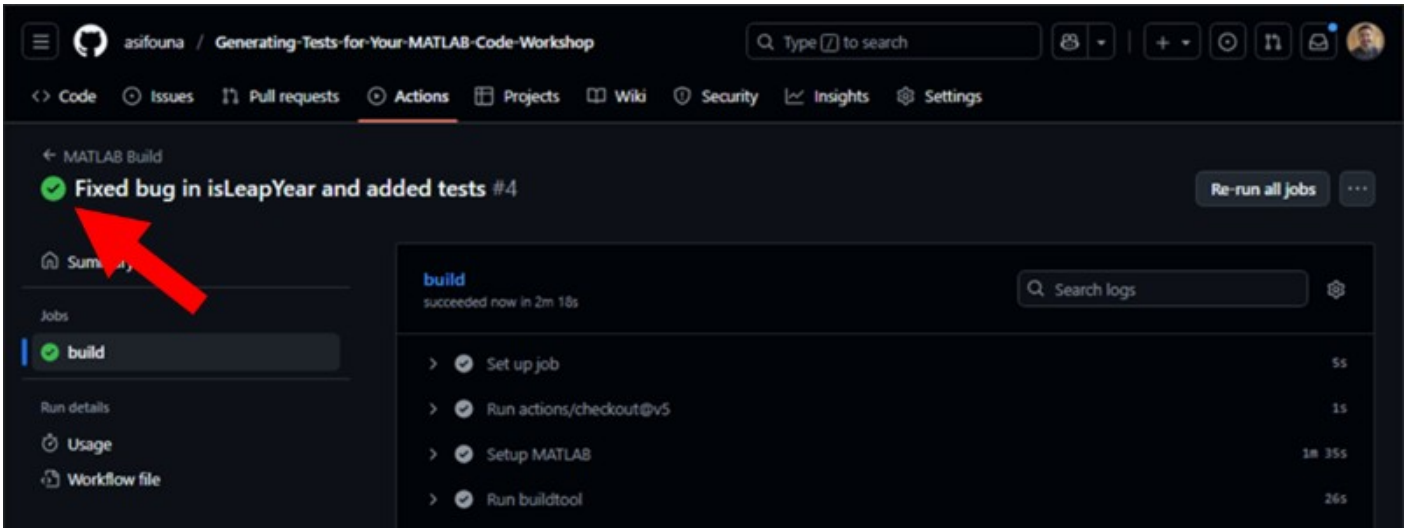
Select the "build" box



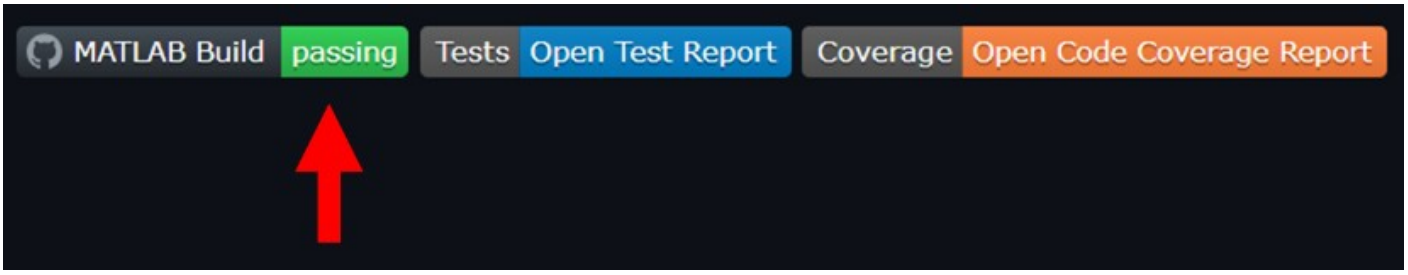
Observe the GitHub Actions log as your build is running



The icon next to the build reflects the result of the build. A green check mark means the build ran successfully.



Another place you can see an indication of your passing build is on your repository home page.



Note: You may need to refresh your browser a few times for the status to update.

We now have a repository that will automatically test our code every time we push any changes!

Part 5.2: Viewing your test and coverage results directly in GitHub

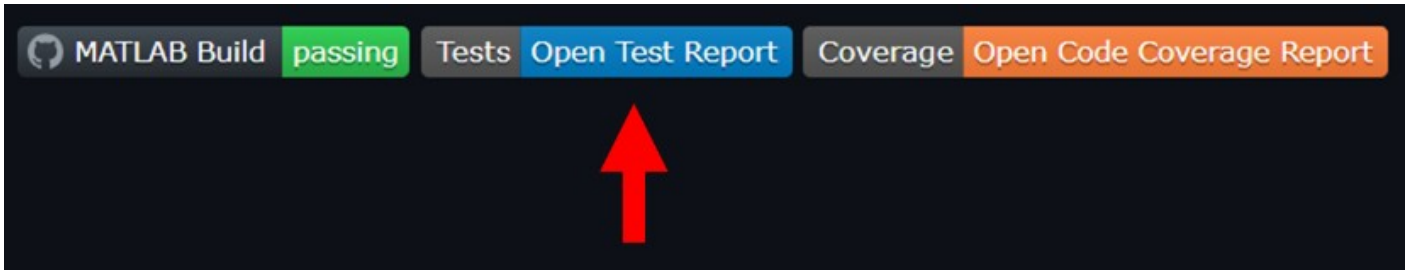
Once our build completes, anyone that can see your repository will be able to explore your published test and code coverage results.

The badges on your repository's home page offer an easy way to:

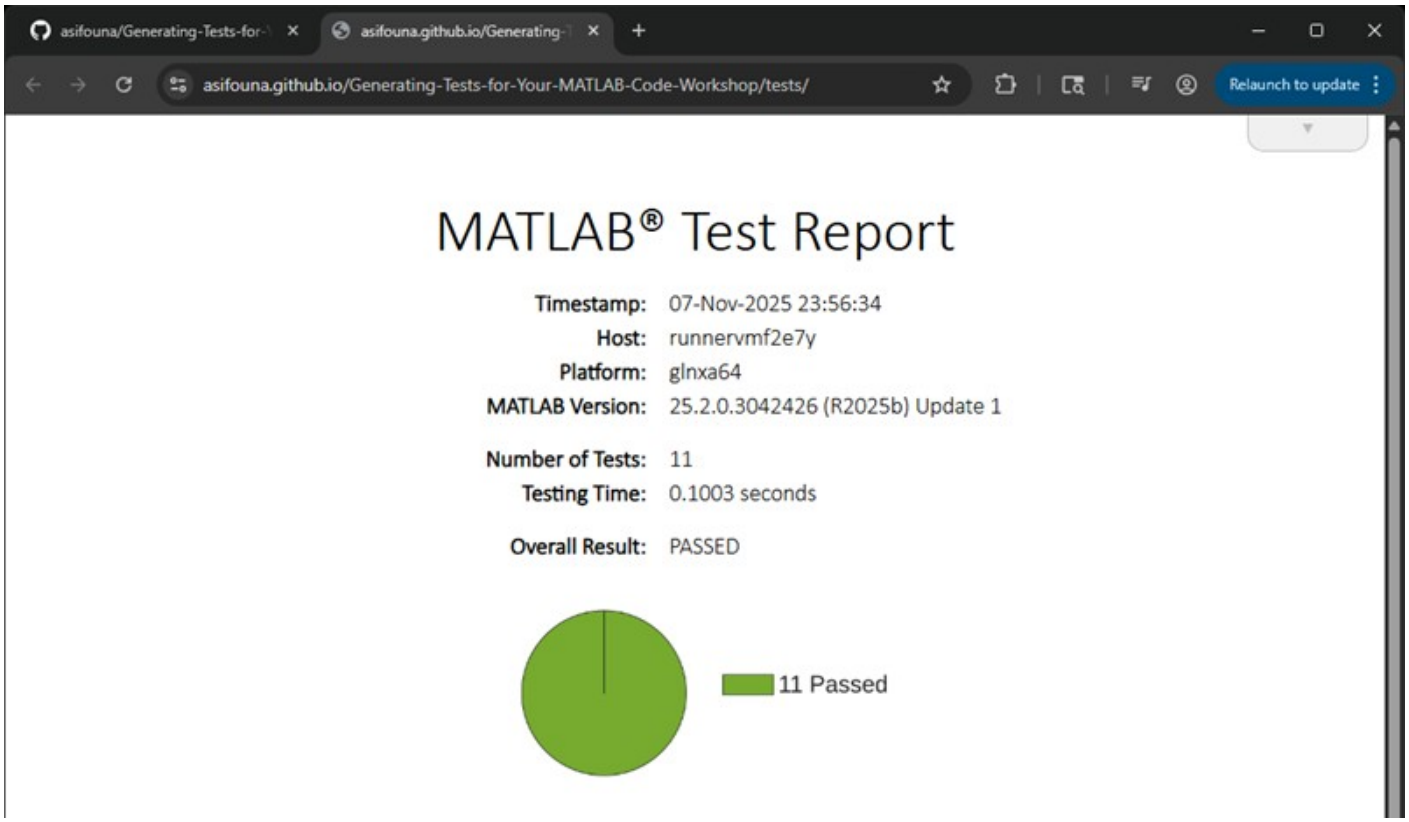
- See whether your last build passed or failed
- Open the published test report
- Open the published code coverage report

Note: Badge links will navigate your current browser tab to the link destination, so you will need to navigate back to the main repository page to select a different badge or report

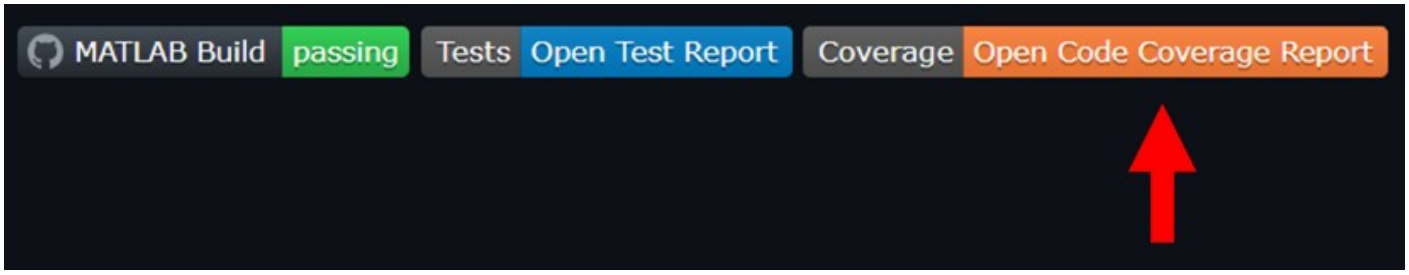
View your test report by selecting the "Open Test Report" badge



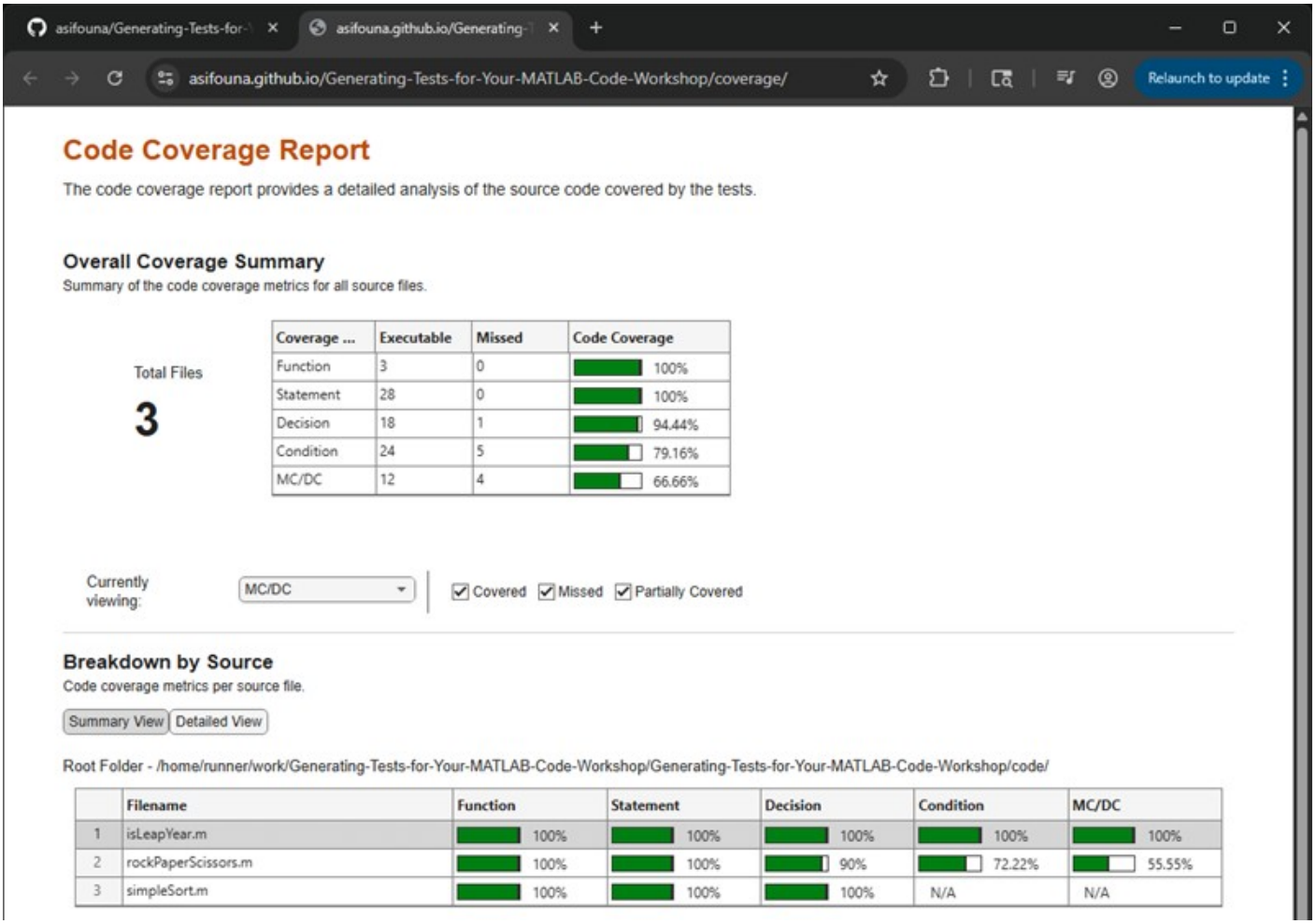
The test report looks like this:



View your code coverage report by selecting the "Open Code COverage Report" badge



The code coverage report looks like this:



Now anyone that visits your repository can immediately see the quality of your code, they can explore your test and code coverage results, and they will have more confidence in the code you are writing!

Homework: Hands-on experience with property-based testing

Everything we've done until now is considered "example-based testing." This is the practice of passing a specific input to a function and comparing its results to a specific expected output. For every specific input, we will need a specific output to compare it against.

Another way to test a code is by identifying "properties" (i.e., characteristics) of the results it produces that stay the same no matter what the input is. Once these properties are identified, you can write tests that check these properties against many different test inputs. Being able to run tests against many different inputs (even randomly generated inputs) can sometimes help you discover bugs and edge cases that you might have missed with a smaller sample of test inputs.

Let's explore this concept with an example.

The workshop contains a function named `simpleSort` that sorts an input using a simple bubble sorting algorithm. This function:

- sorts an input in an ascending order
- does not remove duplicates

The properties the result can be determined by this logic:

- Since the function sorts numbers in an ascending order, the change from one element to the next must be greater than or equal to zero
- Since the function does not remove duplicate numbers, the result must have the same number of elements as the input

To get you started, we have provided a test named `testSimpleSort` with both:

- a single example-based test
- a commented out property-based test that will be tested against many inputs without any expected outputs

There are two local functions that are missing the code to check whether the result satisfies each of the properties. Since the code is missing, each of the property-based tests will fail until you provide code to check the properties.

Your homework: Uncomment the property-based test in `testSimpleSort` and add code to the `checkIsSortedAscending` and `checkHasSameNumberOfElements` local functions at the bottom of the file to make the property-based test pass.

Workshop wrap-up and additional information

Congratulations on completing the "Generating Tests for Your MATLAB Code" Workshop!

During this workshop, you have successfully:

- generated tests using your command history and MATLAB Copilot
- automatically found and ran existing tests
- explored code coverage metrics for your tested code
- identified bugs based on your testing and code coverage
- automated your testing using GitHub Actions
- published your test and code coverage results to GitHub Pages

We hope this workshop has shown you the value of software testing, how approachable software testing is with MATLAB and MATLAB Test, and how to automate testing using continuous integration (CI) practices.

Check out these links for more information about features we discussed or additional features that may help you as you test your code:

- Generating tests with MATLAB Test: https://www.mathworks.com/help/matlab-test/ug/generate-tests-for-matlab-source-code.html
- Generating equivalence tests for automated C/C++ code generation: https://www.mathworks.com/help/matlab-test/ug/generate-c-code-and-test-for-equivalence.html
- Parameterized testing: https://www.mathworks.com/help/matlab/matlab_prog/use-parameters-in-class-based-tests.html
- Property-based testing: https://en.wikipedia.org/wiki/Software_testing#Property_testing
- Finding existing tests using "Find Tests": https://www.mathworks.com/help/matlab-test/ug/find-tests-that-depend-on-files.html
- MATLAB Test Browser: https://www.mathworks.com/help/matlab/ref/testbrowser-app.html
- Code coverage: https://www.mathworks.com/help/matlab-test/ug/collect-code-coverage-metrics-for-matlab-source-code.html
- CI Configuration Examples repository: https://github.com/mathworks/ci-configuration-examples
- MATLAB build tool overview: https://www.mathworks.com/help/matlab/matlab_prog/overview-of-matlab-build-tool.html
- MATLAB build tool introduction blog post: https://blogs.mathworks.com/developer/2022/10/17/building-blocks-with-buildtool
- Faster testing with MATLAB build tool blog post: https://blogs.mathworks.com/developer/2025/07/02/test-impact-analysis-intro