

# Code Coverage

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Lecture #15 out of 24

80 minutes

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## Example, Part I

### Live Code:

```
1 int fibonacci(int n) {  
2     if (n <= 0) {  
3         return 0;  
4     }  
5     if (n <= 2) {  
6         return 1;  
7     }  
8     return fibonacci(n-1)  
9         + fibonacci(n-2);  
10 }
```

### Test Code:

```
1 assert fibonacci(1) == 1;  
2 assert fibonacci(2) == 1;
```

$$C = 7/10 = 70\%$$

## Example, Part II

### Live Code:

```
1 int fibonacci(int n) {  
2     if (n <= 0) {  
3         return 0;  
4     }  
5     if (n <= 2) {  
6         return 1;  
7     }  
8     return fibonacci(n-1)  
9         + fibonacci(n-2);  
10 }
```

### Test Code:

```
1 assert fibonacci(1) == 1;  
2 assert fibonacci(2) == 1;  
3  
4 assert fibonacci(9) == 34;  
5 assert fibonacci(10) == 55;
```

$$C = 9/10 = 90\%$$

## Some Kinds of Code Coverage

- Line Coverage
- Statement Coverage
- Branch Coverage
- Condition Coverage
- Function Coverage
- Linear Code Sequence and Jump (LCSAJ) Coverage
- Modified Condition / Decision Coverage (MC/DC)

## Four Kinds of Coverage

### Live Code:

```
1 int foo(int x) {  
2     if (x < 0) { return x; }  
3     if (x > 10 || x == 0) {  
4         return 42 / x;  
5     } else {  
6         return 1;  
7     }  
8 }
```

### Test Code:

```
1 assert foo(1) == 1;  
2 assert foo(50) == 42;
```

$$C_{\text{line}} = 6/6 = 100\%$$

$$C_{\text{statement}} = 5/6 = 83\%$$

$$C_{\text{branch}} = 3/4 = 75\%$$

$$C_{\text{condition}} = 3/5 = 60\%$$



WILLIAM ROBERT ELMENDORF

“A disciplined test control process is composed of five steps: 1) establish the intended extent of testing; 2) create a list of functional variations eligible for testing; 3) rank and subset the eligible variations so that test resources can be directed at those with the higher payoff; 4) calculate the test coverage of the test case library; and 5) verify attainment of the planned test coverage.”

— William Robert Elmendorf. Controlling the Functional Testing of an Operating System. *IEEE Transactions on Systems Science and Cybernetics*, 1969. doi:[10.1109/tssc.1969.300221](https://doi.org/10.1109/tssc.1969.300221)



DAVID GELPERIN

“However, only half regularly document their test designs, only half regularly save their tests for reuse after software changes, and an extremely small five percent provide regular measurements of code coverage.”

— D. Gelperin and B. Hetzel. The Growth of Software Testing. *Communications of the ACM*, 1988. doi:[10.1145/62959.62965](https://doi.org/10.1145/62959.62965)

| Test Practice   | %<br>Yes | %<br>Sometimes |
|---|----------|----------------|
| 1 Record of defects found during testing is maintained  | 73       | 16             |
| 2 Designated person is responsible for the test process | 65       | 13             |
| 3 Test plan describing objectives/ approach is required | 61       | 29             |
| 4 Testing is a systematic and organized activity        | 61       | 30             |
| 5 Full-time testers perform system testing              | 62       | 19             |
| 6 Testing is separated from development                 | 60       | 20             |
| 7 Tests are required to be rerun when software changes  | 51       | 35             |
| 8 Tests are saved and maintained for future use         | 51       | 28             |
| 9 Test specifications and designs are documented        | 48       | 36             |
| 10 Test procedure is documented in the standards manual | 45       | 15             |
| 11 A log of tests run is maintained                     | 42       | 35             |
| 12 A record of the time spent on testing is maintained  | 40       | 30             |
| 13 Test documents are formally peer-reviewed            | 31       | 29             |
| 14 Full-time testers perform integration testing        | 24       | 24             |
| 15 The cost of testing is measured and tracked          | 24       | 19             |
| 16 Test training is provided periodically               | 22       | 26             |
| 17 Test results are formally peer reviewed              | 20       | 31             |
| 18 Users are heavily involved in test activities        | 8        | 39             |
| 19 Tests are developed before coding                    | 8        | 29             |
| 20 A measurement of code coverage achieved is required  | 5        | 16             |

FIGURE 9. Analysis of Industry Test Practice Usage

“We note an inconsistency. A high percentage of the respondents felt that the testing in their organization was a systematic and organized activity (91% answered either “yes” or “sometimes” to this practice). However, [...] an extremely small 5% provide regular measurements of code coverage.”

— *The Growth of Software Testing*, David Gelperin and Bill Hetzel, Communications of the ACM, 31(6), 1988





BORIS BEIZER

“Junky software takes more tests to achieve coverage, but it breaks under any systematic test.”

— Boris Beizer. *Black Box Testing*. ACM, 1995. doi:[10.5555/202699](https://doi.org/10.5555/202699)



BRIAN MARICK

“Coverage numbers (like many numbers) are dangerous because they’re objective but incomplete. They too often distort sensible action. Using them in isolation is as foolish as hiring based only on GPA.”

— Brian Marick. How to Misuse Code Coverage. In *Proceedings of the 16th International Conference on Testing Computer Software*, 1997



MARTIN FOWLER

“I would be suspicious of anything like 100% — it would smell of someone writing tests to make the coverage numbers happy, but not thinking about what they are doing.”

— Martin Fowler. Continuous Integration.  
<https://martinfowler.com/bliki/TestCoverage.html>, 1997. [Online; accessed 17-03-2024]



CEM KANER

“As you get near 100 percent line coverage, that doesn’t tell you the product is near release. It just tells you that the product is no longer obviously far from release according to this measure.”

— Cem Kaner, James Bach, and Bret Pettichord. *Lessons Learned in Software Testing: A Context-Driven Approach*. Wiley, 2002



PAVNEET SINGH KOCHHAR,  
DAVID LO, JULIA LAWALL,  
NACHIAPPAN NAGAPPAN

“Our results show that coverage has an insignificant correlation with the number of bugs that are found after the release of the software at the project level, and no such correlation at the file level.”

— Pavneet Singh Kochhar, David Lo, Julia Lawall, and Nachiappan Nagappan. Code Coverage and Postrelease Defects: A Large-Scale Study on Open Source Projects. *IEEE Transactions on Reliability*, 2017. doi:[10.1109/tr.2017.2727062](https://doi.org/10.1109/tr.2017.2727062)



GORAN PETROVIĆ

“Google does not enforce any code coverage thresholds across the entire codebase. Projects (or groups of projects) are free to define their own thresholds and goals. Many projects opt-into a centralized voluntary alerting system that defines five levels of code coverage thresholds.”

— Goran Petrović, Marko Ivanković, René Just, and Gordon Fraser. Code Coverage at Google. In *Proceedings of the 27th Joint Meeting on ESEC/FSE*, 2019. doi:[10.1145/3338906.3340459](https://doi.org/10.1145/3338906.3340459)

# Code Coverage Threshold Levels in Google

**Table 2: Coverage levels and corresponding thresholds. Many projects voluntarily set these thresholds as their goal.**

| LEVEL   | THRESHOLD   |
|---------|---|
| Level 1 | Coverage automation disabled                                    |
| Level 2 | Coverage automation enabled                                     |
| Level 3 | Project coverage at least 60%; Changelist coverage at least 70% |
| Level 4 | Project coverage at least 75%; Changelist coverage at least 80% |
| Level 5 | Project coverage at least 90%; Changelist coverage at least 90% |



ADAM BENDER

“Code coverage does not guarantee that the covered lines or branches have been tested correctly, it just guarantees that they have been executed by a test. But a low code coverage number does guarantee that large areas of the product are going completely untested by automation on every single deployment.”

— Carlos Arguelles, Marko Ivanković, and Adam Bender. Code Coverage Best Practices. <https://testing.googleblog.com/2020/08/code-coverage-best-practices.html>, 2020. [Online; accessed 15-03-2024]





“Many contracts are specifying that a certain percentage of the statements or instructions must be successfully executed before the acceptance of the software by the customer.”

— John B. Bowen. A Survey of Standards and Proposed Metrics for Software Quality Testing. *Computer*, 12(8):37–42, 1979. doi:10.1109/mc.1979.1658854

## Industry Standards that Require Code Coverage

- ISO-26262: “Road Vehicles” functional safety (Switzerland)
- IEC 61508: “Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems” (UK)
- DO-178C: “Software Considerations in Airborne Systems and Equipment Certification” (USA)
- IEC 62304: “Medical Device Software” (UK)

ISO-26262:

| Methods |  | ASIL |    |    |    |
|---------|--|------|----|----|----|
|         |  | A    | B  | C  | D  |
| 1a      | Statement coverage                           | ++   | ++ | +  | +  |
| 1b      | Branch coverage                              | +    | ++ | ++ | ++ |
| 1c      | MC/DC (Modified Condition/Decision Coverage) | +    | +  | +  | ++ |

Table 12 (Software Unit Level), ISO 26262-6

| Methods |                   | ASIL |   |    |    |
|---------|-------------------|------|---|----|----|
|         |                   | A    | B | C  | D  |
| 1a      | Function coverage | +    | + | ++ | ++ |
| 1b      | Call coverage     | +    | + | ++ | ++ |

Table15 (Software Architectural Level), ISO 26262-6

IEC 61508:

SIL: Safety Integrity Level

| Method |                    | SIL 1 | SIL 2 | SIL 3 | SIL 4 |
|--------|--------------------|-------|-------|-------|-------|
| ...    | ...                | ...   | ...   | ...   | ...   |
| 7a     | Function Coverage  | ++    | ++    | ++    | ++    |
| 7b     | Statement Coverage | +     | ++    | ++    | ++    |
| 7c     | Branch Coverage    | +     | +     | ++    | ++    |
| 7d     | MC/DC              | +     | +     | +     | ++    |

Table B.2 from DIN EN 61508-3

DO-178C:

| Level | Impact           | Coverage Level | % of Systems | % of Software |
|-------|------------------|----------------|--------------|---------------|
| A     | Catastrophic     | MC/DC, C1, C0  | 20-30%       | 40%           |
| B     | Hazardous/Severe | C1, C0         | 20%          | 30%           |
| C     | Major            | C0             | 25%          | 20%           |
| D     | Minor            | -              | 20%          | 10%           |
| E     | No Effect        | -              | 10%          | 5%            |

IEC 62304:

| Methods |  | ASIL |    |    |    |
|---------|--|------|----|----|----|
|         |  | A    | B  | C  | D  |
| 1a      | Statement coverage                           | ++   | ++ | +  | +  |
| 1b      | Branch coverage                              | +    | ++ | ++ | ++ |
| 1c      | MC/DC (Modified Condition/Decision Coverage) | +    | +  | +  | ++ |

Table 12 (Software Unit Level), ISO 26262-6

| Methods |                   | ASIL |   |    |    |
|---------|-------------------|------|---|----|----|
|         |                   | A    | B | C  | D  |
| 1a      | Function coverage | +    | + | ++ | ++ |
| 1b      | Call coverage     | +    | + | ++ | ++ |

Table15 (Software Architectural Level), ISO 26262-6

# Codecov.io



# Line Coverage

yegor256 / micromap / master

CoverageFlagsCommitsPullsSettings

micromap / src / iterators.rs

UncoveredPartialCovered

110#[inline]

111#[must\_use]

112fn into\_iter(self) -> Self::IntoIter {

113 IntoIter {

114 pos: 0,

115 map: ManuallyDrop::new(self),

116 }

117}

118}

119

120impl<K: PartialEq, V, const N: usize> Drop for IntoIter<K, V, N> {

121 fn drop(&mut self) {

122 for i in self.pos..self.map.len {

123 self.map.item\_drop(i);

124 }

125 }

126}

127

128impl<'a, K, V> DoubleEndedIterator for Iter<'a, K, V> {

129 fn next\_back(&mut self) -> Option<Self::Item> {

130 self.iter.next\_back().map(|p| {

131 let p = unsafe { p.assume\_init\_ref() };

132 (&p.0, &p.1)

133 })

134 }

135}

# Tarpaulin for Rust

```
Code Blame 23 lines (23 loc) · 551 Bytes Raw Copy Download Edit View Source
```

```
1  ---
2  name: tarpaulin
3  on:
4    push:
5      branches:
6        - master
7  jobs:
8    tarpaulin:
9      runs-on: ubuntu-22.04
10     steps:
11       - uses: actions/checkout@v4
12       - uses: actions-rs/toolchain@v1
13         with:
14           toolchain: stable
15           override: true
16       - uses: actions-rs/tarpaulin@v0.1
17         with:
18           version: '0.22.0'
19           args: '--all-features --exclude-files src/lib.rs -- --test-threads 1'
20       - uses: codecov/codecov-action@v3
21         with:
22           token: ${ secrets.CODECOV_TOKEN }
23           fail_ci_if_error: true
```

## Code Coverage Threshold, JaCoCo Example

```
1 <project>
2   [...]
3   <build>
4     <plugins>
5       <plugin>
6         <groupId>org.jacoco</groupId>
7         <artifactId>jacoco-maven-plugin</artifactId>
8         <version>0.8.11</version>
9         <executions>
10          <execution>
11            <id>jacoco-initialize</id>
12            <goals>
13              <goal>prepare-agent</goal>
14            </goals>
15          </execution>
16          <execution>
17            <id>jacoco-check</id>
18            <goals>
19              <goal>check</goal>
20            </goals>
21          </configuration>
22            <rules>
23              [...] ← Next slide
24            </rules>
25          </configuration>
26        </execution>
27      <execution>
28        <id>report</id>
29        <goals>
30          <goal>report</goal>
31        </goals>
32      </execution>
33    </executions>
34  </plugin>
35 </plugins>
36 </build>
37 </project>
```

## Code Coverage Threshold, JaCoCo Rules

```

1 <rules>
2   <rule>
3     <element>BUNDLE</element>
4     <limits>
5       <limit>
6         <counter>INSTRUCTION</counter>
7         <value>COVEREDRATIO</value>
8         <minimum>0.67</minimum>
9       </limit>
10      <limit>
11        <counter>LINE</counter>
12        <value>COVEREDRATIO</value>
13        <minimum>0.84</minimum>
14      </limit>
15      <limit>
16        <counter>BRANCH</counter>
17        <value>COVEREDRATIO</value>
18        <minimum>0.47</minimum>
19      </limit>
20    </limits>
21    <limit>
22      <counter>COMPLEXITY</counter>
23      <value>COVEREDRATIO</value>
24      <minimum>0.57</minimum>
25    </limit>
26    <limit>
27      <counter>METHOD</counter>
28      <value>COVEREDRATIO</value>
29      <minimum>0.76</minimum>
30    </limit>
31    <limit>
32      <counter>CLASS</counter>
33      <value>MISSEDCOUNT</value>
34      <maximum>2</maximum>
35    </limit>
36  </rules>
37
```

Source: <https://github.com/volodya-lombrozo/jtcop>



Code Coverage can be calculated by a few tools:

- JaCoCo for Java
- Istanbul for Javascript
- Gcov for C/C++
- Coverage.py for Python
- Simplecov for Ruby
- Tarpaulin for Rust

# References

Carlos Arguelles, Marko Ivanković, and Adam Bender. Code Coverage Best Practices. <https://testing.googleblog.com/2020/08/code-coverage-best-practices.html>, 2020. [Online; accessed 15-03-2024].

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William Robert Elmendorf. Controlling the Functional Testing of an Operating System. *IEEE Transactions on Systems Science and Cybernetics*, 1969. doi:[10.1109/tssc.1969.300221](https://doi.org/10.1109/tssc.1969.300221).

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Pavneet Singh Kochhar, David Lo, Julia Lawall, and Nachiappan Nagappan. Code Coverage and Postrelease Defects: A Large-Scale Study on Open Source Projects. *IEEE Transactions on Reliability*, 2017. doi:[10.1109/tr.2017.2727062](https://doi.org/10.1109/tr.2017.2727062).

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Goran Petrović, Marko Ivanković, René Just, and Gordon Fraser. Code Coverage at Google. In *Proceedings of the 27th Joint Meeting on ESEC/FSE*, 2019. doi:[10.1145/3338906.3340459](https://doi.org/10.1145/3338906.3340459).