

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:

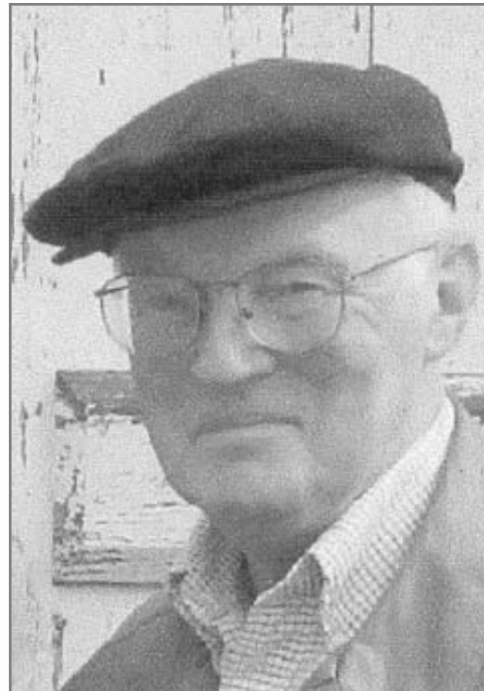
```
1 assert foo(1) == 1;  
2 assert foo(50) == 42;
```

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

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

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

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



“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, 5(4), 1969



“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.”

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

| Test Practice | % Yes | % 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



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

— *Black Box Testing*, Boris Beizer, 1995



“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*, 1997



“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, *Test Coverage*, 1997



“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, Bret Pettichord, *Lessons Learned in Software Testing: A Context-Driven Approach*, 2002



“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.”

— *Code Coverage and Postrelease Defects: A Large-Scale Study on Open Source Projects*, Pavneet Singh Kochhar, David Lo, Julia Lawall, Nachiappan Nagappan, IEEE Transactions on Reliability, 66(4), 2017



“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.”

— *Code Coverage at Google*, Goran Petrović, Marko Ivanković, René Just, Gordon Fraser, Proceedings of the 27th Joint Meeting on ESEC/FSE, 2019

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% |



“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.”

— *Code Coverage Best Practices*, Carlos Arguelles, Marko Ivanković, Adam Bender, Google Blog, 2020

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:

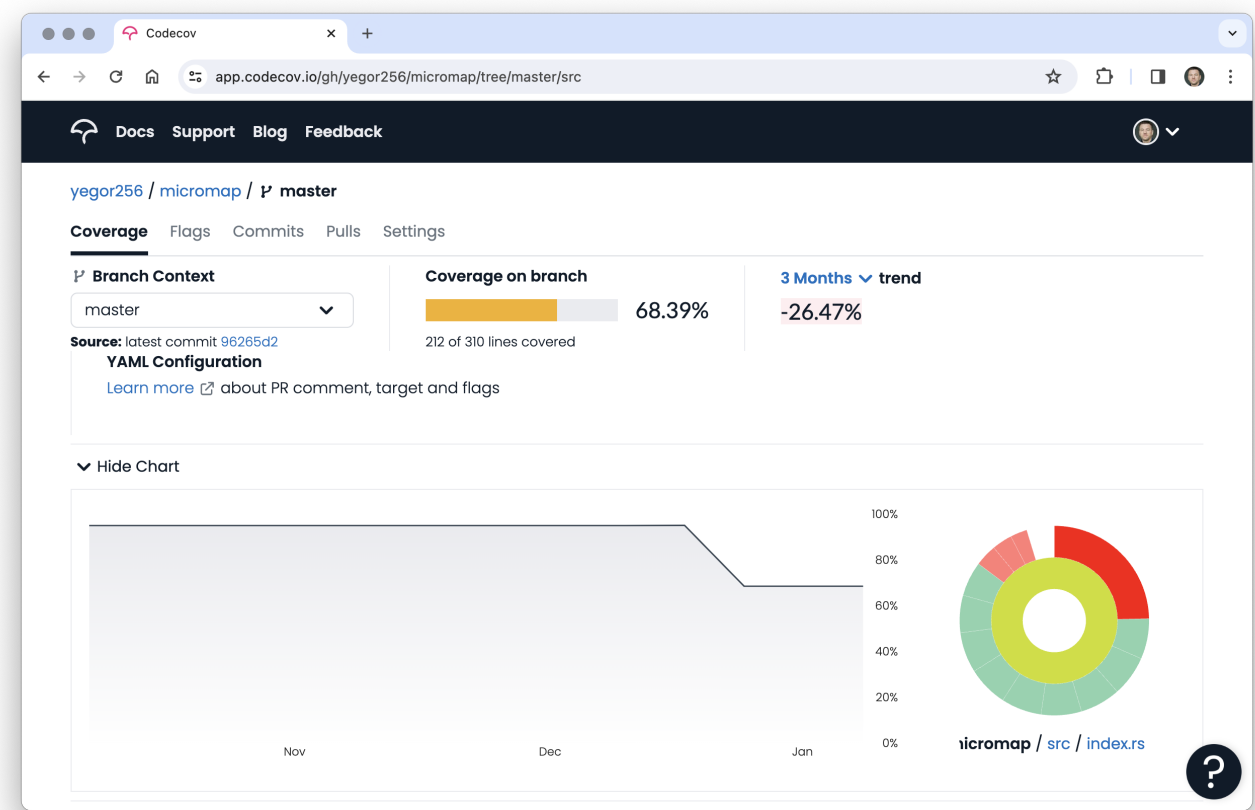
| Methods | | ASIL | | | |
|---------|--|------|----|----|----|
| | | A | B | C | D |
| 1a | Statement coverage | ++ | ++ | + | + |
| 1b | Branch coverage | + | ++ | ++ | ++ |
| 1c | MC/DC (Modified Condition/Decision Coverage) | + | + | + | ++ |

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>

```

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

Read this:

Code Coverage Best Practices, Carlos Arguelles, Marko Ivanković, Adam Bender,
Google Blog, 2020

Black Box Testing, Boris Beizer, John Wiley & Sons, 1995