

# 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;
```

$$C = 3/10 = 30\%$$

## 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;
```

$$C = 5/10 = 50\%$$

## 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;
```

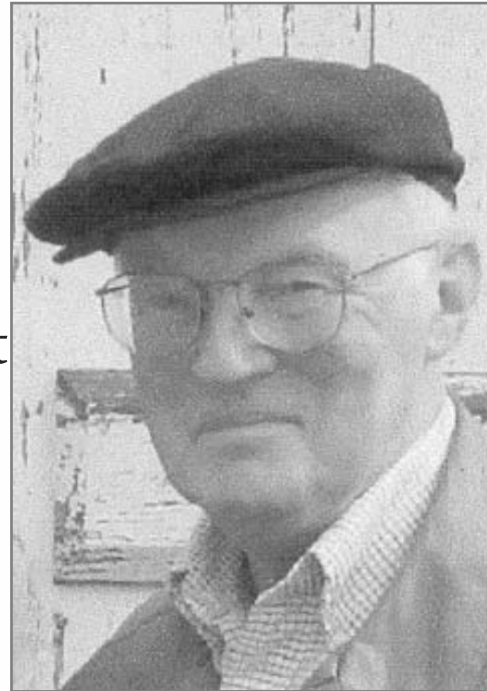
$$C_{\text{line}} = 6/6 = 100\%$$

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

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

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

+2pt



“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

+2pt



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

— *Black Box Testing*, Boris Beizer, 1995

+2pt



“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



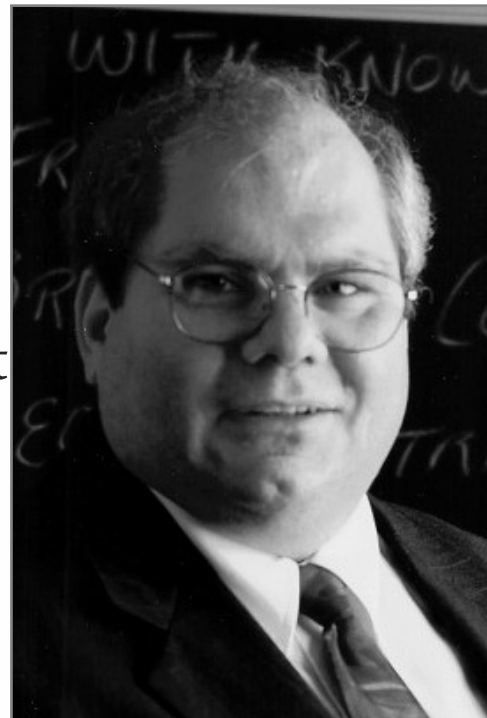
+2pt



“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

+2pt



“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

+2pt



“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

+2pt



“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%

+2pt



“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)	+	+	+	++

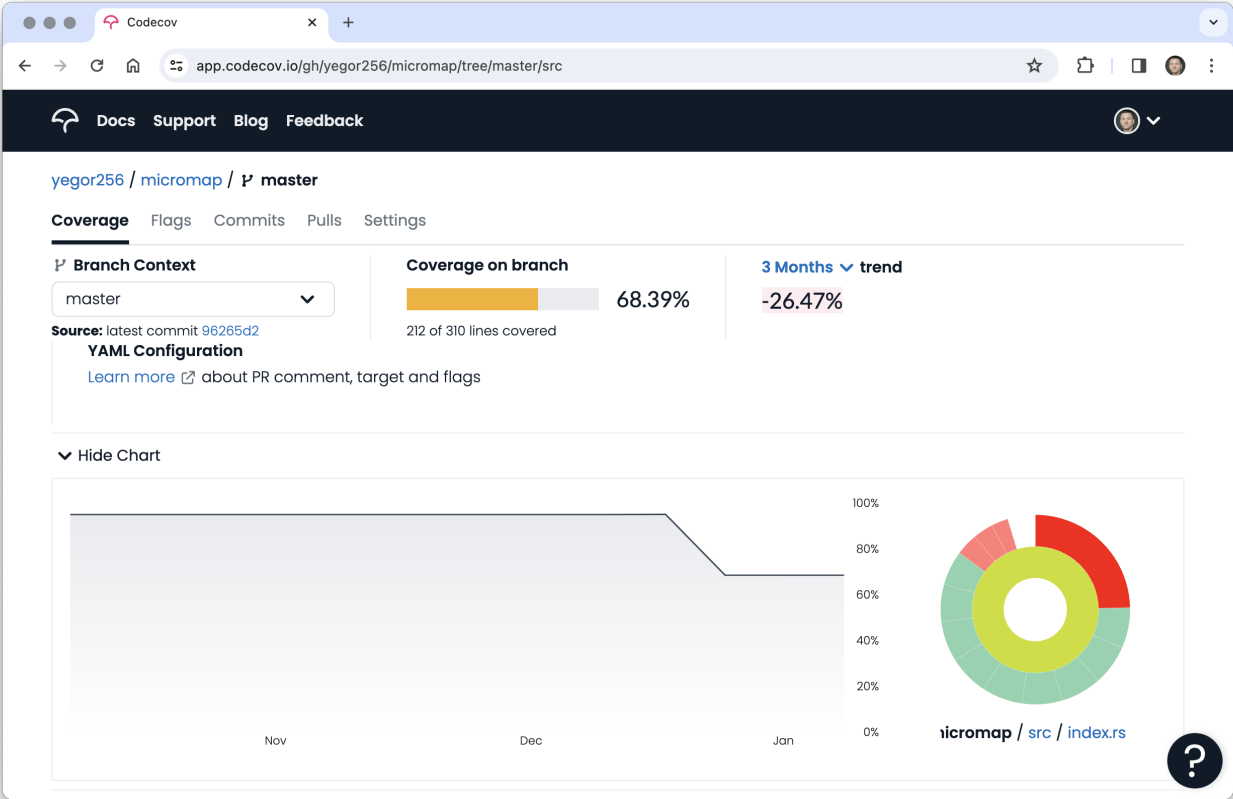
Table 12 (Software Unit Level), ISO 26262-6

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      <limit>
21        <counter>COMPLEXITY</counter>
22        <value>COVEREDRATIO</value>
23        <minimum>0.57</minimum>
24      </limit>
25      <limit>
26        <counter>METHOD</counter>
27        <value>COVEREDRATIO</value>
28        <minimum>0.76</minimum>
29      </limit>
30      <limit>
31        <counter>CLASS</counter>
32        <value>MISSEDCOUNT</value>
33        <maximum>2</maximum>
34      </limit>
35    </limits>
36  </rule>
37</rules>

```

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