Code Coverage

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Lecture #15 out of 24
80 minutes

Example, Part I

Live Code:

```
int fibonacci(int n) {
  if (n <= 0) {
    return 0;
  }
  if (n <= 2) {
    return 1;
  }
  return fibonacci(n-1)
    + fibonacci(n-2);
}
```

Test Code:

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

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

Example, Part II

Live Code:

```
int fibonacci(int n) {
  if (n <= 0) {
    return 0;
  }
  if (n <= 2) {
    return 1;
  }
  return fibonacci(n-1)
    + fibonacci(n-2);
}
```

Test Code:

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

assert fibonacci(9) == 34;
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:

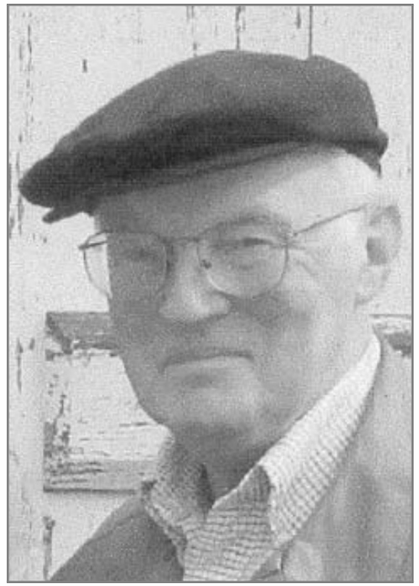
```
1 assert foo(1) == 1;
2 assert foo(50) == 42;
```

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

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

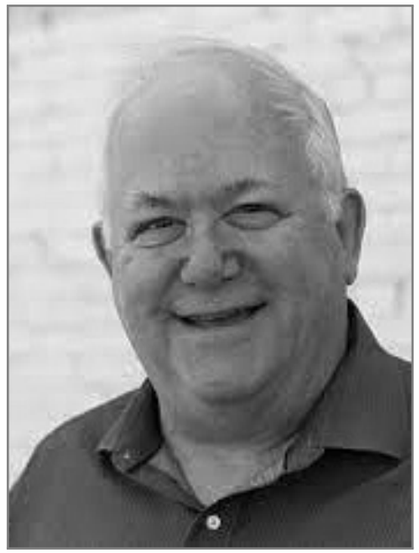
$$C_{\texttt{branch}} = 3/4 = 75\%$$

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



“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:

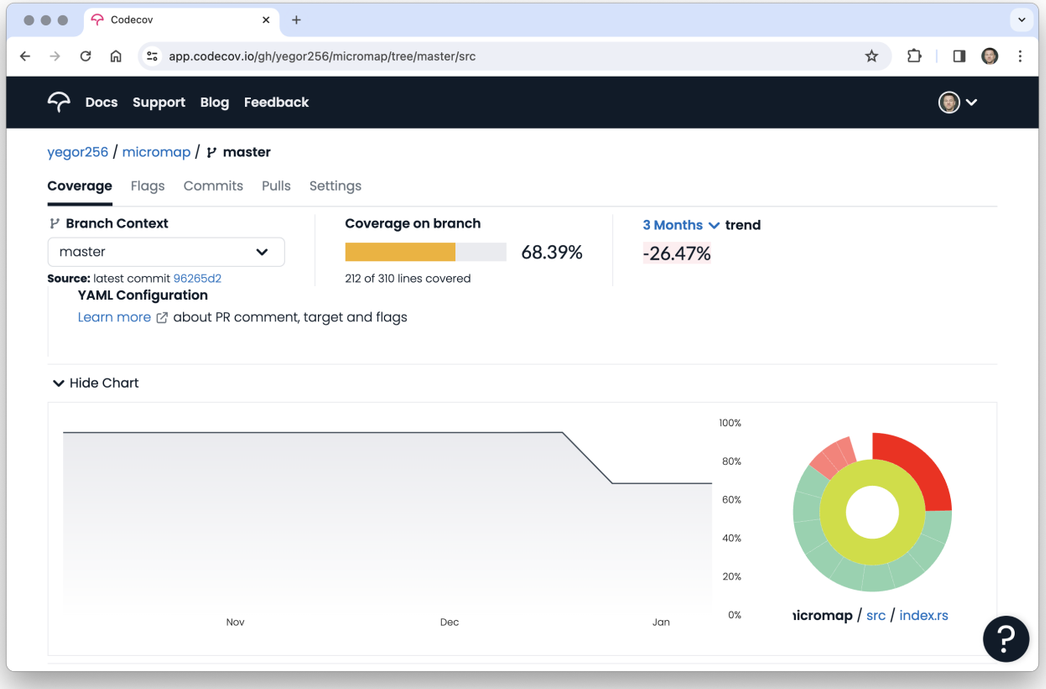
Methods		ASIL			
		A	B	C	D
1a	Statement coverage	++	++	+	+
1b	Branch coverage	+	++	++	++
1c	MC/DC (Modified Condition/Decision Coverage)	+	+	+	++

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


Codecov
app.codecov.io/gh/yegor256/micromap/tree/master/src
Docs Support Blog Feedback
yegor256 / micromap / master
Coverage Flags Commits Pulls Settings
Branch Context
master
Source: latest commit 96265d2
Coverage on branch
68.39%
212 of 310 lines covered
3 Months trend
-26.47%
YAML Configuration
Learn more about PR comment, target and flags
Hide Chart
100%
80%
60%
40%
20%
0%
Nov
Dec
Jan
micromap / src / index.rs

Line Coverage

yegor256 / micromap / master

Coverage Flags Commits Pulls Settings

micromap / src / iterators.rs — Uncovered | Partial | Covered

```
110     #[inline]
111     #[must_use]
112     fn into_iter(self) -> Self::IntoIter {
113         IntoIter {
114             pos: 0,
115             map: ManuallyDrop::new(self),
116         }
117     }
118 }
119
120 impl<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
128 impl<'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

```yaml
---
name: tarpaulin
on:
  push:
    branches:
      - master
jobs:
  tarpaulin:
    runs-on: ubuntu-22.04
    steps:
      - uses: actions/checkout@v4
      - uses: actions-rs/toolchain@v1
        with:
          toolchain: stable
          override: true
      - uses: actions-rs/tarpaulin@v0.1
        with:
          version: '0.22.0'
          args: '--all-features --exclude-files src/lib.rs -- --test-threads 1'
      - uses: codecov/codecov-action@v3
        with:
          token: ${{ secrets.CODECOV_TOKEN }}
          fail_ci_if_error: true
```

Code Coverage Threshold, JaCoCo Example

```
<project>
  [...]
  <build>
    <plugins>
      <plugin>
        <groupId>org.jacoco</groupId>
        <artifactId>jacoco-maven-plugin</artifactId>
        <version>0.8.11</version>
        <executions>
          <execution>
            <id>jacoco-initialize</id>
            <goals>
              <goal>prepare-agent</goal>
            </goals>
          </execution>
          <execution>
            <id>jacoco-check</id>
            <goals>
              <goal>check</goal>
            </goals>
            <configuration>
              <rules>
                [...]  ← Next slide
              </rules>
            </configuration>
          </execution>
          <execution>
            <id>report</id>
            <goals>
              <goal>report</goal>
            </goals>
          </execution>
        </executions>
      </plugin>
    </plugins>
  </build>
</project>
```

Code Coverage Threshold, JaCoCo Rules

```
<rules>
  <rule>
    <element>BUNDLE</element>
    <limits>
      <limit>
        <counter>INSTRUCTION</counter>
        <value>COVEREDRATIO</value>
        <minimum>0.67</minimum>
      </limit>
      <limit>
        <counter>LINE</counter>
        <value>COVEREDRATIO</value>
        <minimum>0.84</minimum>
      </limit>
      <limit>
        <counter>BRANCH</counter>
        <value>COVEREDRATIO</value>
        <minimum>0.47</minimum>
      </limit>
      <limit>
        <counter>COMPLEXITY</counter>
        <value>COVEREDRATIO</value>
        <minimum>0.57</minimum>
      </limit>
      <limit>
        <counter>METHOD</counter>
        <value>COVEREDRATIO</value>
        <minimum>0.76</minimum>
      </limit>
      <limit>
        <counter>CLASS</counter>
        <value>MISSEDCOUNT</value>
        <maximum>2</maximum>
      </limit>
    </limits>
  </rule>
</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