

Builds

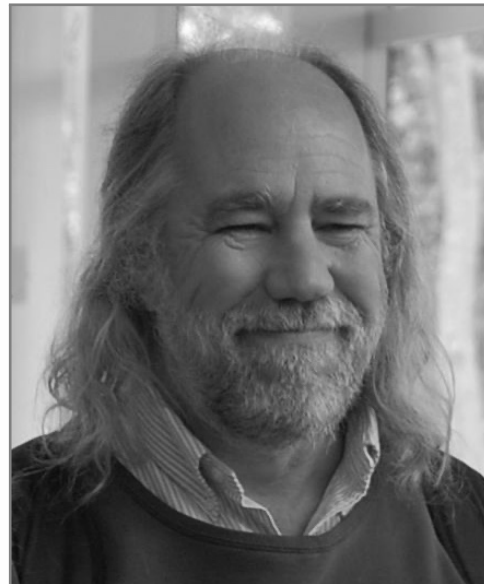
YEGOR BUGAYENKO

Lecture #21 out of 24

80 minutes

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GRADY BOOCH

“In general, there may be more internal releases to the development team, with only a few executable releases turned over to external parties. The internal releases represent a sort of continuous integration of the system and exist to force closure on some key system areas.”

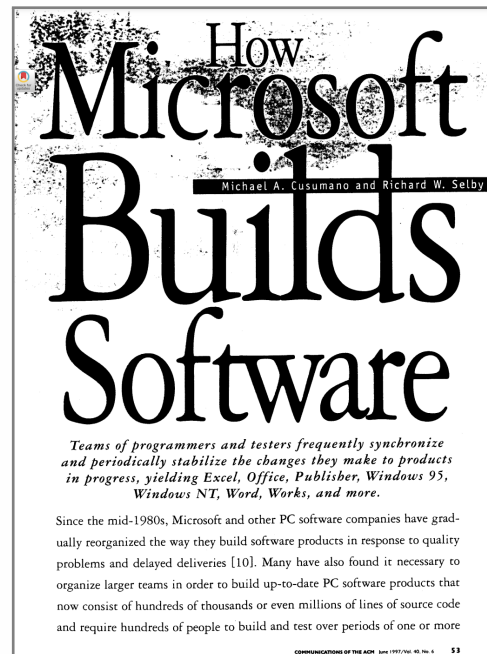
— Grady Booch, Robert A. Maksimchuk, Michael W. Engle, Bobbi J. Young, Jim Connallen, and Kelli A. Houston. *Object-Oriented Analysis and Design With Applications*. Addison-Wesley, 1994. doi:[10.5555/1407387](https://doi.org/10.5555/1407387)



MICHAEL CUSUMANO

“Regardless of how often individual developers check in their changes to the source code, a designated developer, called the project build master, generates a complete build of the product on a daily basis using the master version of the source code.”

— Michael A. Cusumano and Richard W. Selby. How Microsoft Builds Software. *Communications of the ACM*, 40(6):53–61, 1997. doi:[10.1145/255656.255698](https://doi.org/10.1145/255656.255698)



“[In Microsoft], the rule is that if developers check in code that ‘breaks’ the build by preventing it from completing the recompilation, they must fix the defect immediately.”

— Michael A. Cusumano and Richard W. Selby. How Microsoft Builds Software. *Communications of the ACM*, 40(6):53–61, 1997. doi:[10.1145/255656.255698](https://doi.org/10.1145/255656.255698)



KENT BECK

“Developers need freedom to make changes where they make the most sense. Therefore, integrate and test several times a day. Throw away unintegrated code after a couple of days and start over. Ignore code ownership. Program in pairs. Don’t integrate without unit tests.”

— Kent Beck. Extreme Programming: A Humanistic Discipline of Software Development. In *Proceedings of the International Conference on Fundamental Approaches to Software Engineering*, pages 1–6. Springer, 1998.
[doi:10.1007/bfb0053579](https://doi.org/10.1007/bfb0053579)



MARTIN FOWLER

“For most projects, the XP guideline of a ten minute build is perfectly within reason. Most of our modern projects achieve this. It’s worth putting in concentrated effort to make it happen, because every minute chiseled off the build time is a minute saved for each developer every time they commit.”

— Martin Fowler. Continuous Integration.
<http://martinfowler.com/articles/continuousIntegration.html>,
2006. [Online; accessed 07-02-2024]



JEZ HUMBLE

“Automation is the key. It allows all of the common tasks involved in the creation and deployment of software to be performed by developers, testers, and operations personnel, at the push of a button.”

— Jez Humble and David Farley. *Continuous Delivery: Reliable Software Releases Through Build, Test, and Deployment Automation*. Pearson Education, 2010.
[doi:10.5555/1869904](https://doi.org/10.5555/1869904)



BOGDAN VASILESCU

“Our main finding is that continuous integration improves the productivity of project teams, who can integrate more outside contributions, without an observable diminishment in code quality.”

— Bogdan Vasilescu, Yue Yu, Huaimin Wang, Premkumar Devanbu, and Vladimir Filkov. Quality and Productivity Outcomes Relating to Continuous Integration in GitHub. In *Proceedings of the 10th Joint Meeting on Foundations of Software Engineering*, pages 805–816, 2015. doi:[10.1145/2786805.2786850](https://doi.org/10.1145/2786805.2786850)



KAI HUANG

“Our results show there are good reasons for the rise of CI. Compared to projects that do not use CI, projects that use CI: release twice as often, accept pull requests faster (1.6x), and have developers who are less worried about breaking the build.”

— Michael Hilton, Timothy Tunnell, Kai Huang, Darko Marinov, and Danny Dig. Usage, Costs, and Benefits of Continuous Integration in Open-Source Projects. In *Proceedings of the 31st International Conference on Automated Software Engineering*, pages 426–437, 2016. doi:[10.1145/2970276.2970358](https://doi.org/10.1145/2970276.2970358)



Figure 1: CI usage of projects in GitHub. Projects are sorted by popularity (number of stars).

“In the most popular (starred) group, 70% of projects use CI. As the projects become less popular, the percentage of projects using CI declines to 23%. Observation: Popular projects are more likely to use CI.”

Source: Michael Hilton, Timothy Tunnell, Kai Huang, Darko Marinov, and Danny Dig. Usage, Costs, and Benefits of Continuous Integration in Open-Source Projects. In *Proceedings of the 31st International Conference on Automated Software Engineering*, pages 426–437, 2016. doi:[10.1145/2970276.2970358](https://doi.org/10.1145/2970276.2970358)

Table 3: CI usage by programming language. For each language, the columns tabulate: the number of projects from our corpus that predominantly use that language, how many of these projects use CI, the percentage of projects that use CI.

| Language | Total Projects | # Using CI | Percent CI |
|--------------|----------------|------------|------------|
| Scala | 329 | 221 | 67.17 |
| Ruby | 2721 | 1758 | 64.61 |
| Go | 1159 | 702 | 60.57 |
| PHP | 1806 | 982 | 54.37 |
| CoffeeScript | 343 | 176 | 51.31 |
| Clojure | 323 | 152 | 47.06 |
| Python | 3113 | 1438 | 46.19 |
| Emacs Lisp | 150 | 67 | 44.67 |
| JavaScript | 8495 | 3692 | 43.46 |
| Other | 1710 | 714 | 41.75 |
| C++ | 1233 | 483 | 39.17 |
| Swift | 723 | 273 | 37.76 |
| Java | 3371 | 1188 | 35.24 |
| C | 1321 | 440 | 33.31 |
| C# | 652 | 188 | 28.83 |
| Perl | 140 | 38 | 27.14 |
| Shell | 709 | 185 | 26.09 |
| HTML | 948 | 241 | 25.42 |
| CSS | 937 | 194 | 20.70 |
| Objective-C | 2745 | 561 | 20.44 |
| VimL | 314 | 59 | 18.79 |

“Languages that have the highest CI usage are also dynamically-typed (e.g., Python and JavaScript). One possible explanation may be that in the absence of a static type system which can catch errors early on, these languages use CI to provide extra safety.”

Source: Michael Hilton, Timothy Tunnell, Kai Huang, Darko Marinov, and Danny Dig. Usage, Costs, and Benefits of Continuous Integration in Open-Source Projects. In *Proceedings of the 31st International Conference on Automated Software Engineering*, pages 426–437, 2016. doi:[10.1145/2970276.2970358](https://doi.org/10.1145/2970276.2970358)



Figure 5: Build time distribution by result, in seconds

“The average build time is just under 500 seconds. Errored builds are those that occur before the build begins (e.g., when a dependency cannot be downloaded), and failed builds are those that the build is not completed successfully.”

Source: Michael Hilton, Timothy Tunnell, Kai Huang, Darko Marinov, and Danny Dig. Usage, Costs, and Benefits of Continuous Integration in Open-Source Projects. In *Proceedings of the 31st International Conference on Automated Software Engineering*, pages 426–437, 2016. doi:[10.1145/2970276.2970358](https://doi.org/10.1145/2970276.2970358)



MICHAEL HILTON

“Developers use CI to guarantee quality, consistency, and viability across different environments. However, adding and maintaining automated tests causes these benefits to come at the expense of increased time and effort.”

— Michael Hilton, Nicholas Nelson, Timothy Tunnell, Darko Marinov, and Danny Dig. Trade-Offs in Continuous Integration: Assurance, Security, and Flexibility. In *Proceedings of the 11th Joint Meeting on Foundations of Software Engineering*, pages 197–207, 2017. doi:[10.1145/3106237.3106270](https://doi.org/10.1145/3106237.3106270)

Table 2: Barriers developers encounter when using CI

| Barrier | Broad | Focused |
|---|-------|---------|
| B1 Troubleshooting a CI build failure | 50% | 64% |
| B2 Overly long build times | 38% | 50% |
| B3 Automating the build process | 34% | 26% |
| B4 Lack of support for the desired workflow | 31% | 42% |
| B5 Setting up a CI server or service | 27% | 29% |
| B6 Maintaining a CI server or service | 27% | 40% |
| B7 Lack of tool integration | 26% | 12% |
| B8 Security and access controls | 21% | 14% |

“When a CI build fails, some participants begin the process of identifying why the build failed. Sometimes, this can be fairly straightforward...”

Source: Michael Hilton, Nicholas Nelson, Timothy Tunnell, Darko Marinov, and Danny Dig. Trade-Offs in Continuous Integration: Assurance, Security, and Flexibility. In *Proceedings of the 11th Joint Meeting on Foundations of Software Engineering*, pages 197–207, 2017. doi:[10.1145/3106237.3106270](https://doi.org/10.1145/3106237.3106270)



Figure 1: Maximum acceptable build time (minutes)

“[Fowler, 2006] suggests most projects should try to follow the XP guideline of a 10-minute build. When we asked our 523 participants what is the maximum acceptable time for a CI build to take, the most common answer was also 10 minutes.”

Source: Michael Hilton, Nicholas Nelson, Timothy Tunnell, Darko Marinov, and Danny Dig. Trade-Offs in Continuous Integration: Assurance, Security, and Flexibility. In *Proceedings of the 11th Joint Meeting on Foundations of Software Engineering*, pages 197–207, 2017. doi:[10.1145/3106237.3106270](https://doi.org/10.1145/3106237.3106270)



Figure 6: Flaky vs True test failures reported by Pivotal developers (N=42)

“Pivotal developers experienced similar numbers of flaky and true CI failures per week. However, for the largest category, >10 fails a week, there were twice as many flaky failures as true failures.”

Source: Michael Hilton, Nicholas Nelson, Timothy Tunnell, Darko Marinov, and Danny Dig. Trade-Offs in Continuous Integration: Assurance, Security, and Flexibility. In *Proceedings of the 11th Joint Meeting on Foundations of Software Engineering*, pages 197–207, 2017. doi:[10.1145/3106237.3106270](https://doi.org/10.1145/3106237.3106270)



JOHN MICCO

“Unfortunately, across our entire corpus of tests, we [in Google] see a continual rate of about 1.5% of all test runs reporting a ‘flaky’ result.”

— John Micco. Flaky Tests at Google and How We Mitigate Them.
<https://testing.googleblog.com/2016/05/flaky-tests-at-google-and-how-we.html>, may 2016. [Online; accessed 25-02-2024]

Google Thoughts About Flaky Tests

- Almost 16% of our 4.2M tests have some level of flakiness
- 84% of transitions from Pass -> Fail are from 'flaky' tests
- We spend up to 16% of our compute resources re-running flaky tests
- Certain people/automation more likely to cause breakages (oops!)
- Certain languages more likely to cause breakages (sorry)

Source: John Micco. The State of Continuous Integration Testing at Google. *ICST*, 2017



CARMINE VASSALLO

“In total, the 349 projects underwent 116,741 builds, of which 30,792 (26%) failed. It is interesting to notice how the percentage of build failures is approximately the same in OSS and ING.”

— Carmine Vassallo, Gerald Schermann, Fiorella Zampetti, Daniele Romano, Philipp Leitner, Andy Zaidman, Massimiliano Di Penta, and Sebastiano Panichella. A Tale of CI Build Failures: An Open Source and a Financial Organization Perspective. In *Proceedings of the International Conference on Software Maintenance and Evolution (ICSME)*, pages 183–193. IEEE, 2017. doi:[10.1109/ICSME.2017.67](https://doi.org/10.1109/ICSME.2017.67)



THOMAS RAUSCH

“Process metrics have a significant impact on the build outcome in 8 of the 14 projects on average, but the strongest influencing factor across all projects is overall stability in the recent build history. For 10 projects, more than 50% (up to 80%) of all failed builds follow a previous build failure.”

— Thomas Rausch, Waldemar Hummer, Philipp Leitner, and Stefan Schulte. An Empirical Analysis of Build Failures in the Continuous Integration Workflows of Java-Based Open-Source Software. In *Proceedings of the 14th International Conference on Mining Software Repositories*, pages 345–355. IEEE, 2017.
[doi:10.1109/msr.2017.54](https://doi.org/10.1109/msr.2017.54)

TABLE I
NAME, DESCRIPTION AND METADATA OF PROJECTS USED AS RESEARCH SUBJECTS

| Name | Description | Age VCS* | Commits | Committers | Age CI* | Builds | Build freq.* | Fail ratio |
|-------------------|---|----------|---------|------------|---------|--------|--------------|------------|
| Apache Storm | Distributed computation framework | 1961 | 11656 | 253 | 647 | 5472 | 8.5 | 0.69 |
| Crate.IO | Scalable SQL database | 1390 | 13722 | 69 | 1024 | 21864 | 21.4 | 0.63 |
| JabRef | Application for managing BibTeX databases | 1407 | 16851 | 112 | 1046 | 9615 | 9.2 | 0.29 |
| Butterknife | Android dependency injection library | 1426 | 894 | 114 | 1426 | 1220 | 0.9 | 0.34 |
| jcabi-github | Object-oriented wrapper of Github API | 1179 | 2543 | 60 | 1024 | 1316 | 1.3 | 0.45 |
| Hystrix | Fault tolerance library for distributed systems | 1532 | 2321 | 103 | 880 | 1228 | 1.4 | 0.48 |
| Openmicroscopy | Microscopy data environment | 4364 | 55571 | 59 | 1501 | 16383 | 10.9 | 0.19 |
| Presto | Distributed SQL query engine for big data | 1635 | 23500 | 308 | 1180 | 19112 | 16.2 | 0.49 |
| RxAndroid | RxJava bindings for Android | 1264 | 495 | 74 | 880 | 728 | 0.8 | 0.16 |
| SpongeAPI | Minecraft plugin API | 874 | 3692 | 213 | 874 | 8835 | 10.1 | 0.24 |
| Spring Boot | Java application framework | 1561 | 11300 | 566 | 1276 | 10051 | 7.9 | 0.28 |
| Square OkHttp | HTTP+HTTP/2 client for Android and Java | 1651 | 3832 | 263 | 1576 | 7439 | 4.7 | 0.49 |
| Square Retrofit | HTTP client for Android and Java | 2336 | 1640 | 231 | 1576 | 3040 | 1.9 | 0.20 |
| WordPress-Android | WordPress for Android | 2697 | 21548 | 66 | 1191 | 15025 | 12.6 | 0.14 |

* in days

Source: Thomas Rausch, Waldemar Hummer, Philipp Leitner, and Stefan Schulte. An Empirical Analysis of Build Failures in the Continuous Integration Workflows of Java-Based Open-Source Software. In *Proceedings of the 14th International Conference on Mining Software Repositories*, pages 345–355. IEEE, 2017.
[doi:10.1109/msr.2017.54](https://doi.org/10.1109/msr.2017.54)

TABLE II
DESCRIPTION AND FREQUENCY OF ERROR CATEGORIES

| Label | Projects | Description |
|---------------|----------|---|
| testfailure | 12 | An automated test did not pass |
| compile | 12 | Compilation error |
| git | 12 | VCS interaction error, e.g., worker fails to fetch code |
| buildconfig | 11 | Faulty build config, e.g., syntax error in pom.xml |
| crash | 11 | Build environment crashed or exceeded time limit |
| dependency | 11 | Dependency error, e.g., invalid version number |
| quality | 10 | Coding-rule violation during code inspection |
| unknown | 9 | Errors without a clearly identifiable cause |
| itestfailure | 4 | An automated integration test failed |
| doc | 3 | Documentation issue, e.g., undocumented methods |
| license | 3 | License criteria not met, e.g., missing license headers |
| compatibility | 2 | API incompatibility, e.g., due to version conflict |
| androidsdk | 1 | Android SDK-related error, e.g., download failed |
| buildout | 1 | Specific build error of Python submodule in Crate.IO |

Source: Thomas Rausch, Waldemar Hummer, Philipp Leitner, and Stefan Schulte. An Empirical Analysis of Build Failures in the Continuous Integration Workflows of Java-Based Open-Source Software. In *Proceedings of the 14th International Conference on Mining Software Repositories*, pages 345–355. IEEE, 2017. doi:[10.1109/msr.2017.54](https://doi.org/10.1109/msr.2017.54)

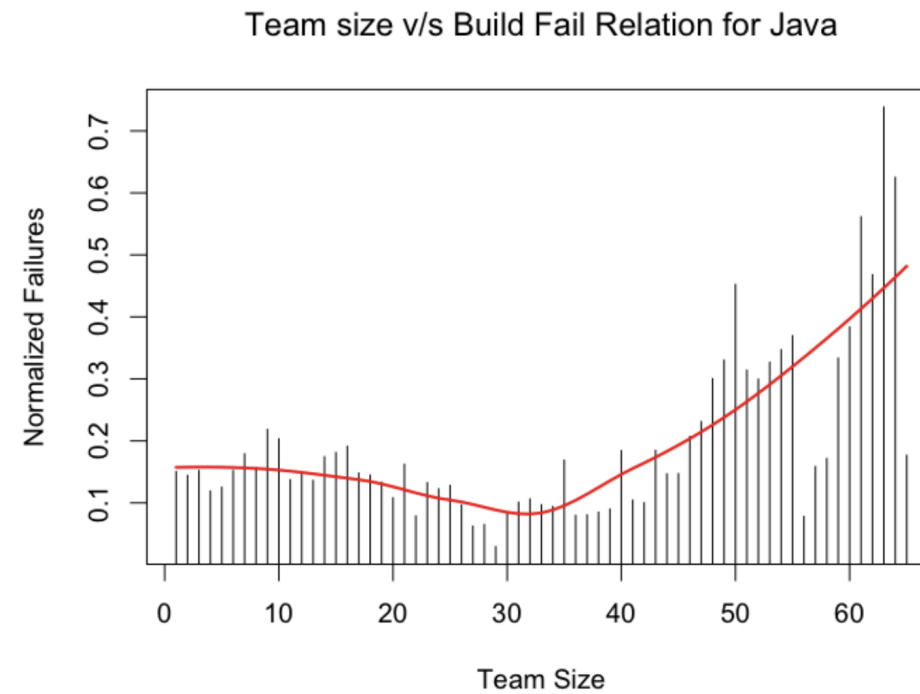
“On average, 41% of builds fail because of test failures... On average, 30% of errors occur in the first half of the build runtime. The later half is dominated by 70% testfailures. Together with a build-retry approach, testfailures can cause long delays in the feedback loop.”



ROMIT JAIN

“We observed that team size generally increases the number of build failures. The interesting observation here is the minima after which there is a positive curve.”

— Romit Jain, Saket Kumar Singh, and Bharavi Mishra. A Brief Study on Build Failures in Continuous Integration: Causation and Effect. In *Proceedings of the Progress in Advanced Computing and Intelligent Engineering*, pages 17–27. Springer, 2018. doi:[10.1007/978-981-13-0224-4_2](https://doi.org/10.1007/978-981-13-0224-4_2)



Source: Romit Jain, Saket Kumar Singh, and Bharavi Mishra. A Brief Study on Build Failures in Continuous Integration: Causation and Effect. In *Proceedings of the Progress in Advanced Computing and Intelligent Engineering*, pages 17–27. Springer, 2018. doi:[10.1007/978-981-13-0224-4_2](https://doi.org/10.1007/978-981-13-0224-4_2)



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On October 16, 2018,
GitHub launched “Actions”



MEHDI GOLZADEH

“Together with Travis, GHA covers more than 80% of all usages. Moreover, in only 18 months GHA has overtaken all other CIs in popularity.”

— Mehdi Golzadeh, Alexandre Decan, and Tom Mens. On the Rise and Fall of CI Services in GitHub. In *Proceedings of the International Conference on Software Analysis, Evolution and Reengineering (SANER)*, pages 662–672. IEEE, 2022.
[doi:10.1109/SANER53432.2022.00084](https://doi.org/10.1109/SANER53432.2022.00084)



Fig. 2: Number of repositories using a specific CI.

Source: Mehdi Golzadeh, Alexandre Decan, and Tom Mens. On the Rise and Fall of CI Services in GitHub. In *Proceedings of the International Conference on Software Analysis, Evolution and Reengineering (SANER)*, pages 662–672. IEEE, 2022. doi:[10.1109/SANER53432.2022.00084](https://doi.org/10.1109/SANER53432.2022.00084)



WING LAM

“We find that 53% of flaky tests detected in CI runs are not detected in isolation.”

— Wing Lam, Stefan Winter, Angello Astorga, Victoria Stodden, and Darko Marinov. Understanding Reproducibility and Characteristics of Flaky Tests Through Test Reruns in Java Projects. In *Proceedings of the 31st International Symposium on Software Reliability Engineering (ISSRE)*, pages 403–413. IEEE, 2020. doi:[10.1109/issre5003.2020.00045](https://doi.org/10.1109/issre5003.2020.00045)



OWAIN PARRY

“The causes and associated factors of flaky tests:
1. Asynchronicity and Concurrency, 2. Platform Dependencies, 3. Floating-Point numbers, 4. Order-dependent tests, 5. Unordered Collections, 6. Shared access to static fields, 7. Timeouts, 8. I/O and Network, 9. Algorithmic Non-determinism.”

— Owain Parry, Gregory M. Kapfhammer, Michael Hilton, and Phil McMinn. A Survey of Flaky Tests. *ACM Transactions on Software Engineering and Methodology*, 31(1):1–74, 2021. doi:[10.1145/3476105](https://doi.org/10.1145/3476105)



PEI LIU

“We start by collecting a set of 84,475 open-source Android apps from the most popular three online code hosting sites, namely Github, GitLab, and Bitbucket. We then look into those apps and find that only around 10% of apps have leveraged CI/CD services, i.e., the majority of open-source Android apps are developed without accessing CI/CD services.”

— Pei Liu, Xiaoyu Sun, Yanjie Zhao, Yonghui Liu, John Grundy, and Li Li. A First Look at CI/CD Adoptions in Open-Source Android Apps. In *Proceedings of the 37th International Conference on Automated Software Engineering*, pages 1–6, 2022. doi:[10.1145/3551349.3561341](https://doi.org/10.1145/3551349.3561341)



SHANTO RAHMAN

“FlakeSync works by identifying a critical point, representing some key part of code that must be executed early w.r.t. other concurrently executing code, and a barrier point, representing the part of code that should wait until the critical point has been executed. FlakeSync can modify code to check when the critical point is executed and have the barrier point keep waiting until the critical point has been executed, essentially synchronizing these two parts of code for the specific test execution.”

— Shanto Rahman and August Shi. FlakeSync: Automatically Repairing Async Flaky Tests. In *Proceedings of the 46th International Conference on Software Engineering (ICSE)*, page 920. IEEE, 2024

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<https://testing.googleblog.com/2016/05/flaky-tests-at-google-and-how-we.html>, may 2016. [Online; accessed 25-02-2024].

John Micco. The State of Continuous Integration Testing at Google. *ICST*, 2017.

Owain Parry, Gregory M. Kapfhammer, Michael Hilton, and Phil McMinn. A Survey of Flaky Tests. *ACM Transactions on Software Engineering and Methodology*, 31(1):1–74, 2021. doi:[10.1145/3476105](https://doi.org/10.1145/3476105).

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