ECE444: Software Engineering

QA 2: Performance Testing, Chaos Engineering, Static&Dynamic Analysis

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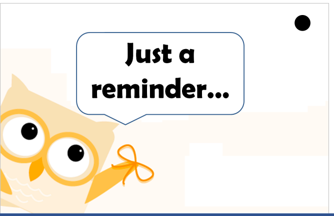
Learning Goals

- Understand opportunities and challenges for testing quality attributes; enumerate testing strategies to help evaluate the following quality attributes: usability, reliability, security, robustness (both general and architectural), performance, integration.
- Discuss the limitations of testing
- Give a one sentence definition of static&dynamic analysis.

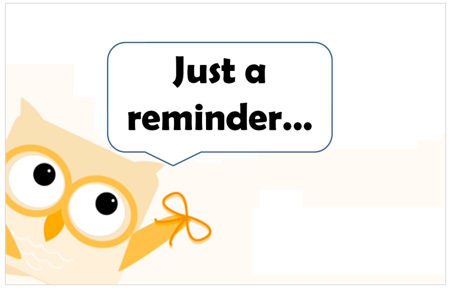
What is testing?

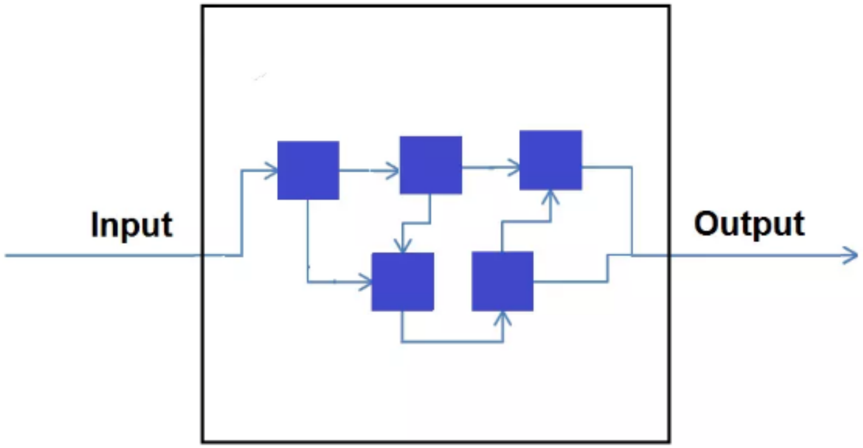
- *Direct execution of code on test data in a controlled environment*
- Principle goals:
  - Validation: program meets requirements, including quality attributes.
- Other goals:
  - Clarify specification: Testing can demonstrate inconsistency; either spec or program could be wrong
  - Learn about program: How does it behave under various conditions? Feedback to rest of team goes beyond bugs
  - Verify contract, including customer, legal, standards



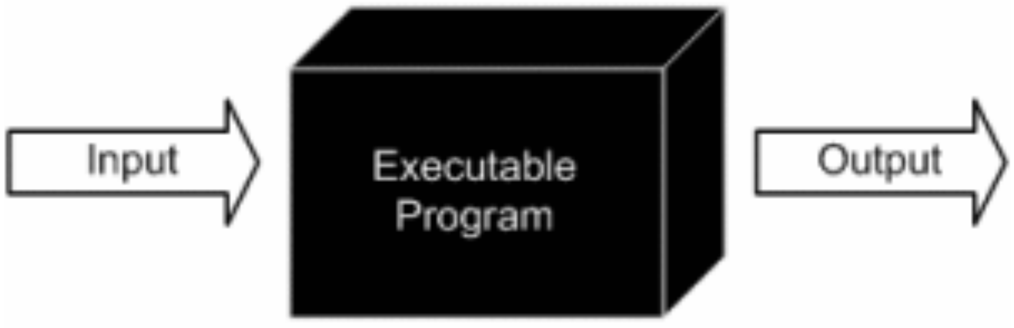
What are we covering?

- Program/system functionality:
  - Execution space (white box!).
  - Input or requirements space (black box!).
- The expected user experience (usability).
  - GUI testing, A/B testing
- The expected performance envelope (performance, reliability, robustness, integration).
  - Security, robustness, fuzz, and infrastructure testing.
  - Performance and reliability: soak and stress testing.
  - Integration and reliability: API/protocol testing

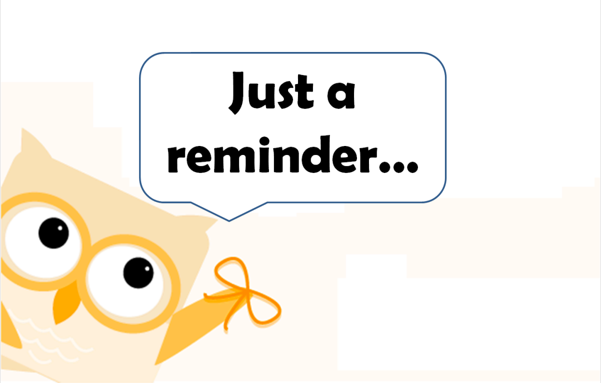




White box testing

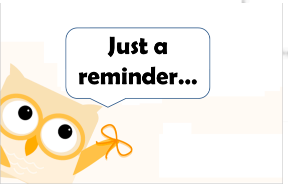


Black box testing

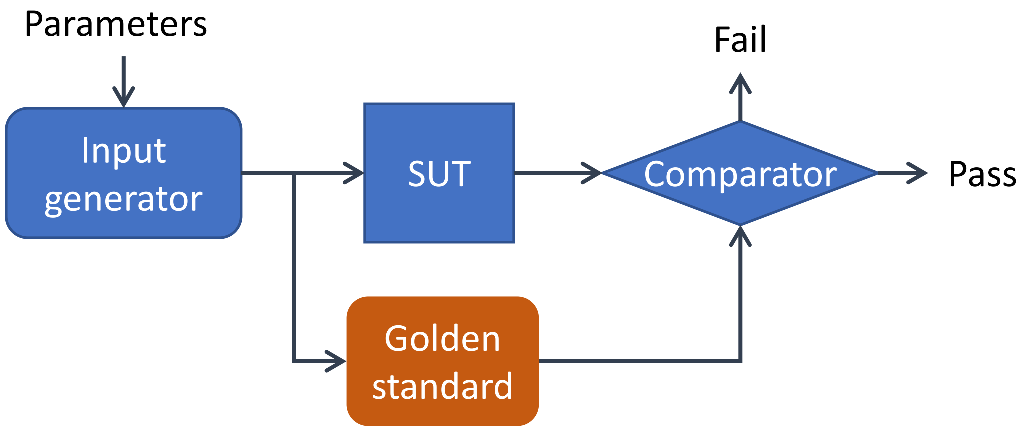


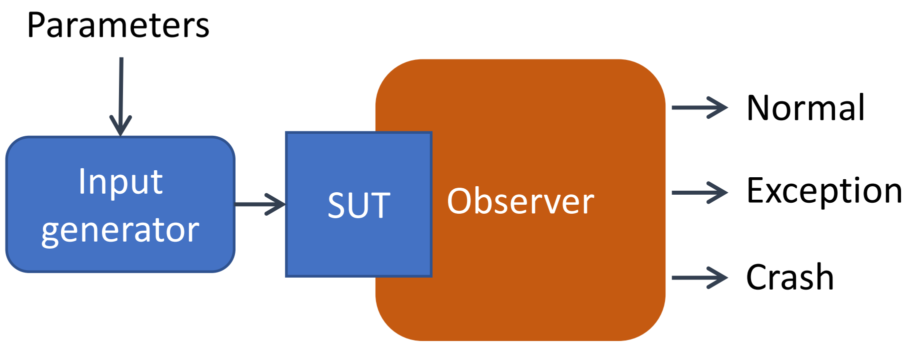
Regression testing

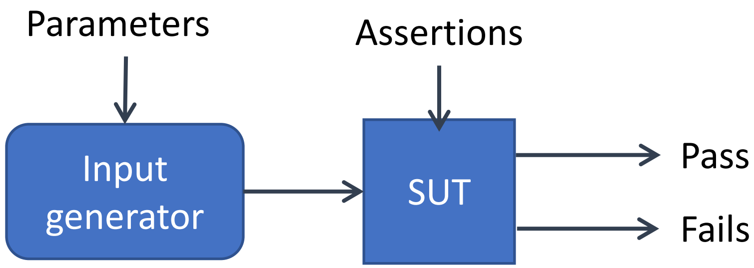
- Ensure that a small change in one part of the system does not break existing functionality elsewhere in the system.



The Oracle Problem







System under test (SUT)

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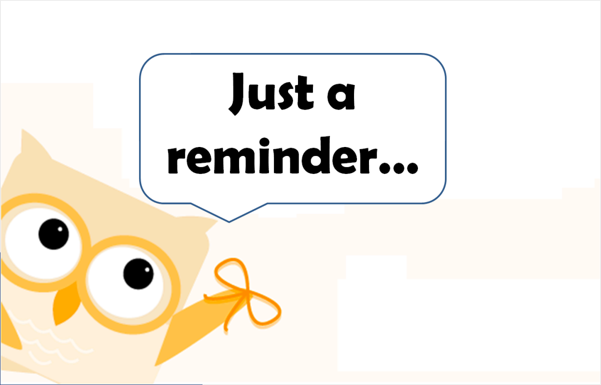
Quality Attributes

- **System Software Product Quality**
  - Functional suitability
    - Functional completeness
    - Functional correctness
    - Functional appropriateness
  - Performance efficiency
    - Time behavior
    - Resource utilization
    - Capacity
  - Compatibility
    - Coexistence
    - Interoperability
  - Usability
    - Appropriateness recognizability
    - Learnability
    - Operability
    - User error prediction
    - User interface aesthetics
    - Accessibility
  - Reliability
    - Maturity
    - Availability
    - Fault tolerance
    - Recoverability
  - Security
    - Confidentiality
    - Integrity
    - Nonrepudiation
    - Accountability
    - Authenticity
  - Maintainability
    - Modularity
    - Reusability
    - Analyzability
    - Modifiability
    - Testability
  - Portability
    - Adaptability
    - Installability
    - Replaceability



Performance Testing

- Specification? Oracle?
- Test harness? Environment?
- Nondeterminism?
- Unit testing?
- Automation?
- Coverage?

Specifications

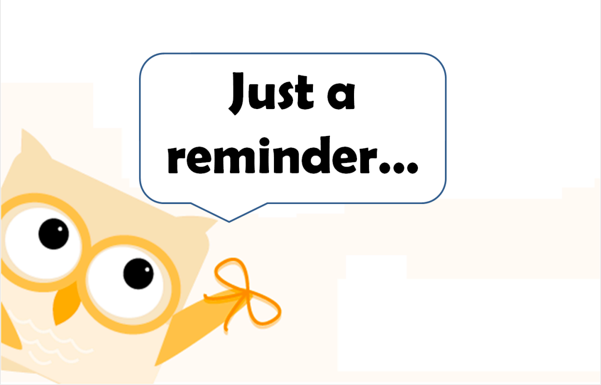
- Textual
- Assertions
- Formal specifications

```
/*@ requires amount >= 0;
    ensures balance == \old(balance)-amount &&
            \result == balance;
@*/
public int debit(int amount) {
    ...
}
```

- JML (Java modeling language specification)

```
/**
  * Calls the <code>read(byte[], int, int)</code> overloaded [..
  * @param buf The buffer to read bytes into
  * @return The value retured from <code>in.read(byte[], int, in
  * @exception IOException If an error occurs
  */
public int read(byte[] buf) throws IOException
{
    return read(buf, 0, buf.length);
}
```

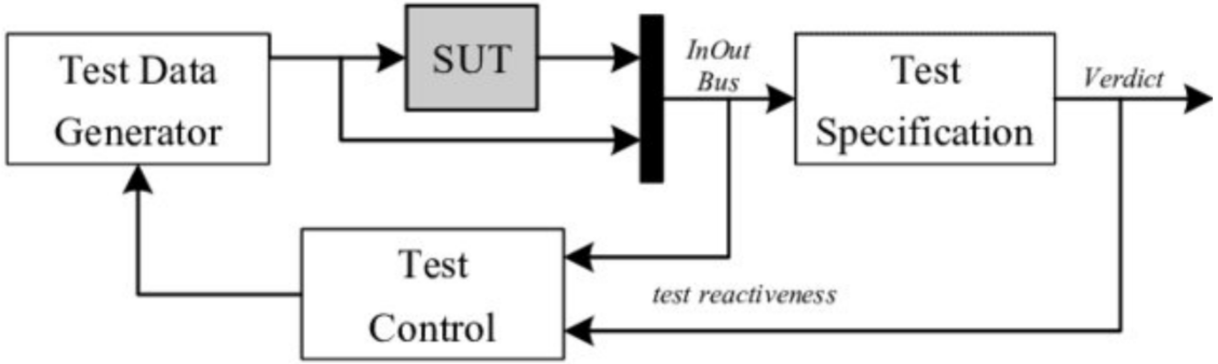
- Textual specification with JavaDoc



Test harness

Software system that contains test drivers, test scripts and other supporting tools that are required for the execution of any test case.

- Automation testing
- Integration Testing



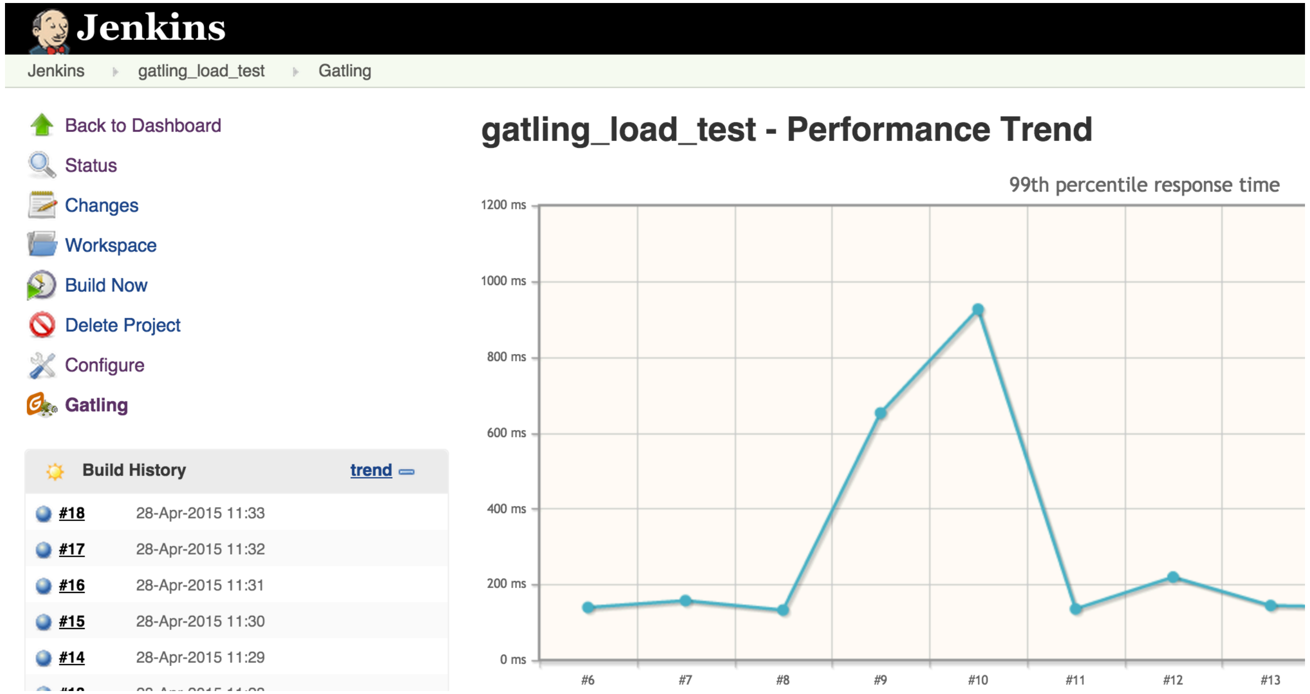
Zander, Justyna & Mosterman, Pieter & Schieferdecker, Ina. (2008). Quality of test specification by application of patterns.

Performance Testing

- Specification? Oracle?
- Test harness? Environment?
- Nondeterminism?
- Unit testing?
- Automation?
- Coverage?

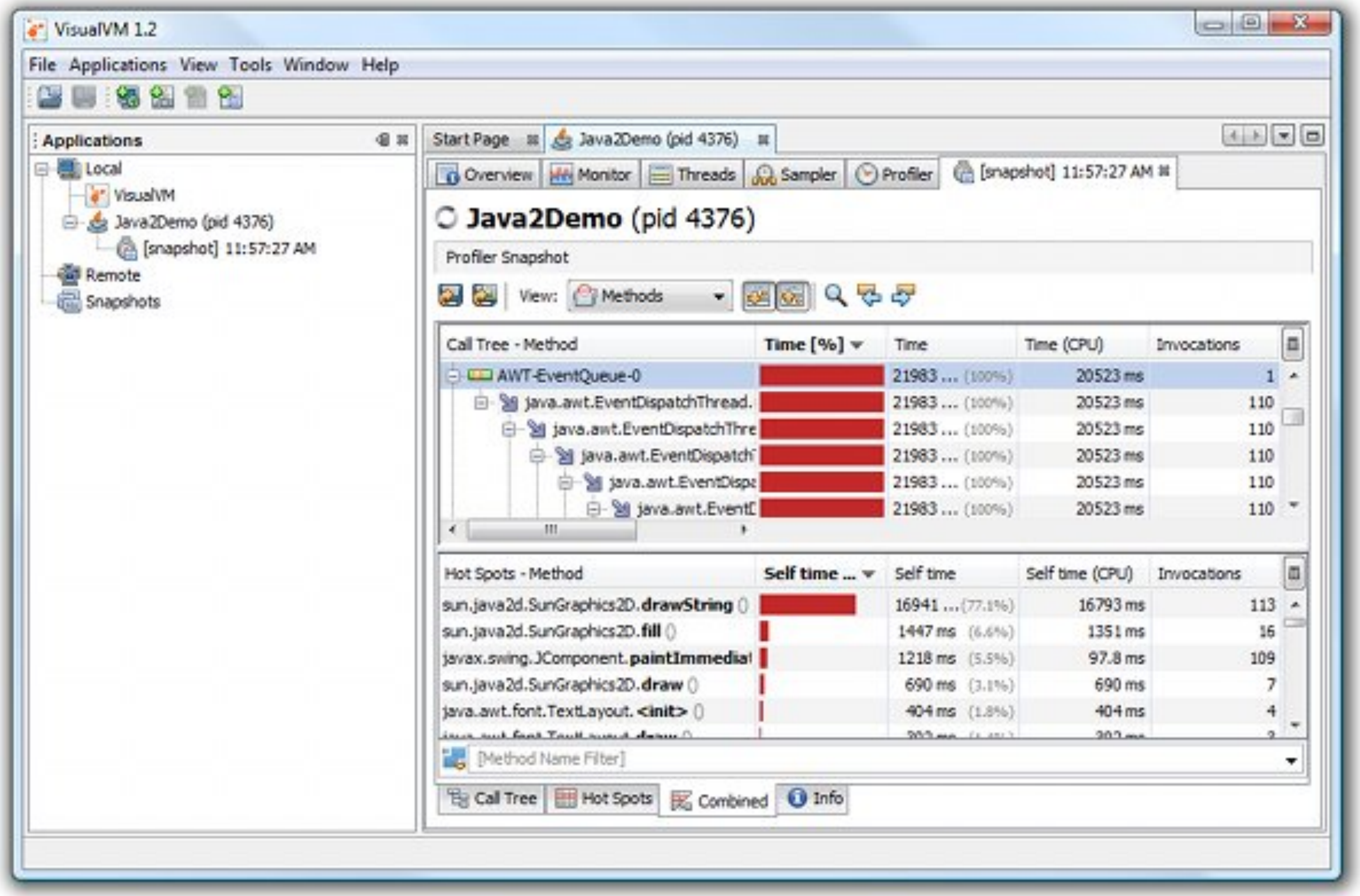
Unit and regression testing for performance

- Measure execution time of critical components
- Log execution times and compare over time



Profiling

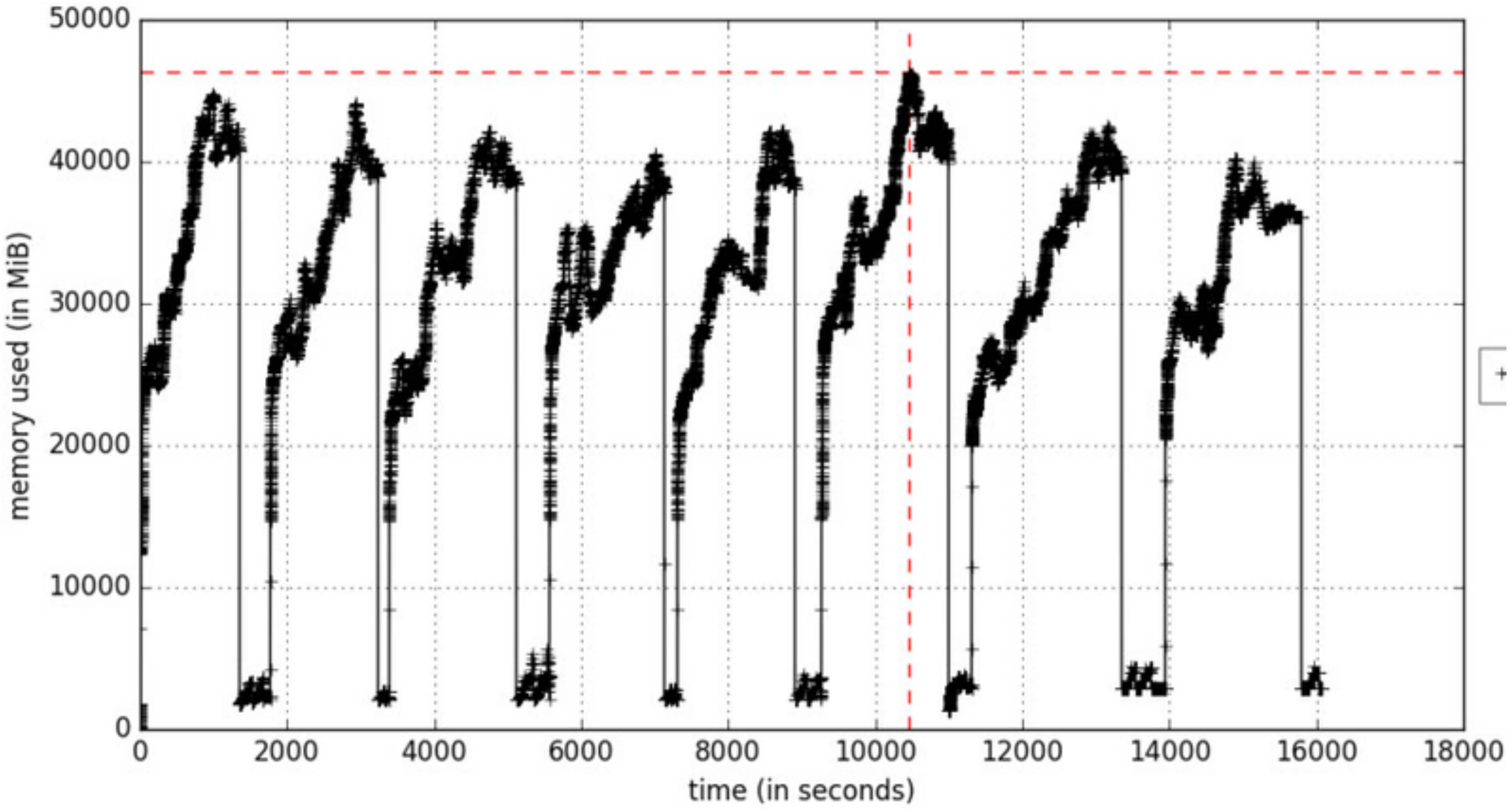
- Finding bottlenecks in execution time and memory



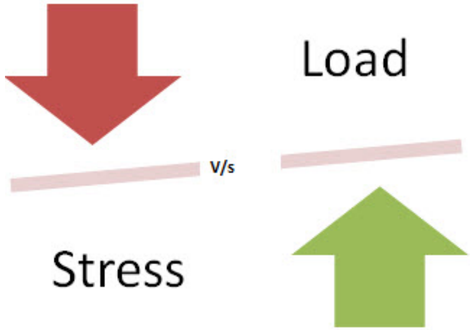
Profiling

- Memory profile as a function of time

memory-profile package



Robustness: Stress Testing



- Robustness testing technique: test beyond the limits of normal operation.
- Can apply at any level of system granularity.
- Stress tests commonly put a greater emphasis on robustness, availability, and error handling under a heavy load, than on what would be considered "correct" behavior under normal circumstances.

Soak testing

- **Problem:** A system may behave exactly as expected under artificially limited execution conditions.
  - E.g., Memory leaks may take longer to lead to failure
- **Soak testing:** testing a system with a significant load over a significant period of time
- Used to check reaction of a subject under test under a possible simulated environment for a given duration and for a given threshold.

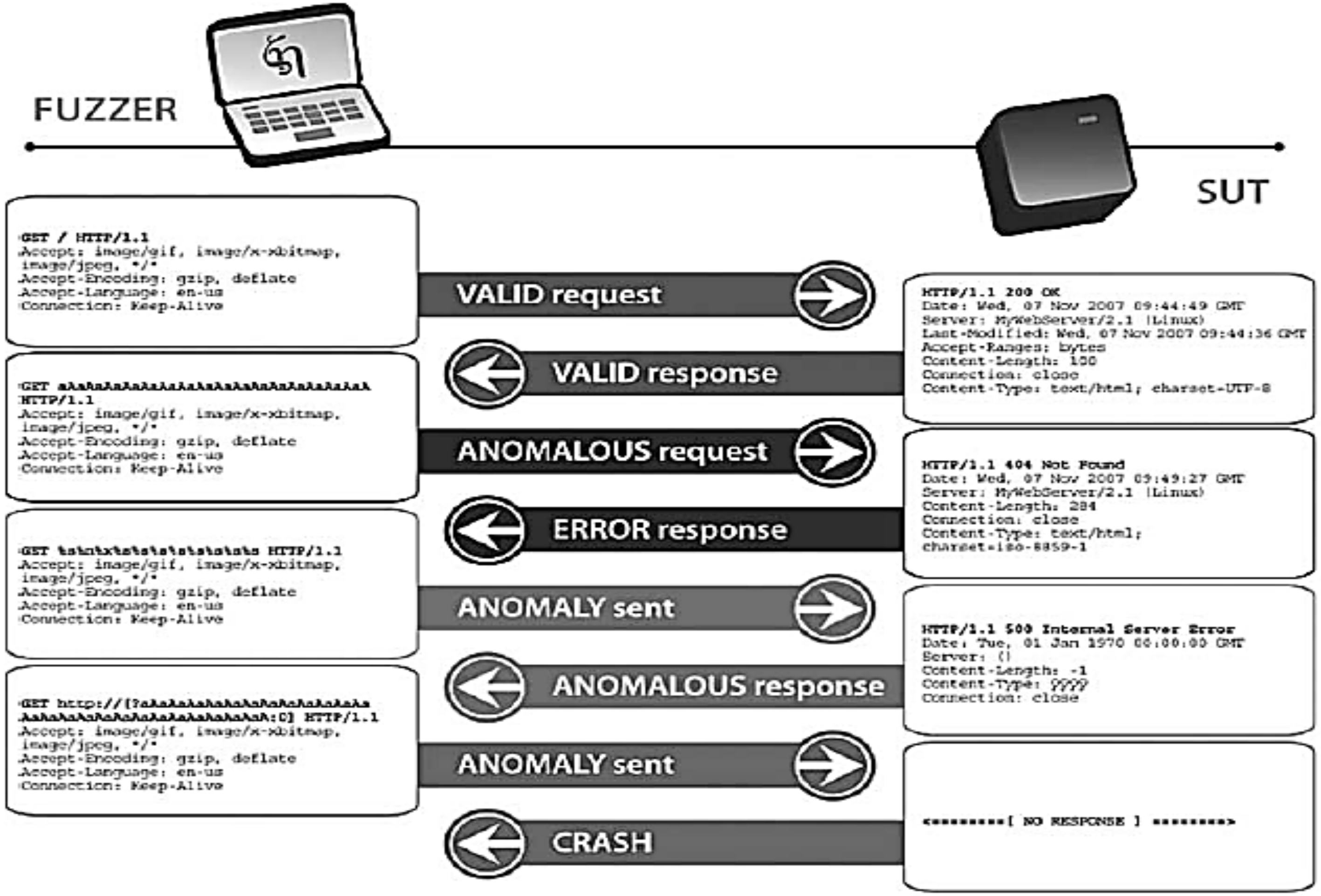
Reliability: Fuzz testing

- The purpose of fuzzing is to send anomalous data to a system in order to crash it, therefore revealing reliability problems.
- Programs and frameworks that are used to create fuzz tests or perform fuzz testing are commonly called **fuzzers**.
- Also known as **fuzzing** or **monkey testing**

Reliability: Fuzz testing

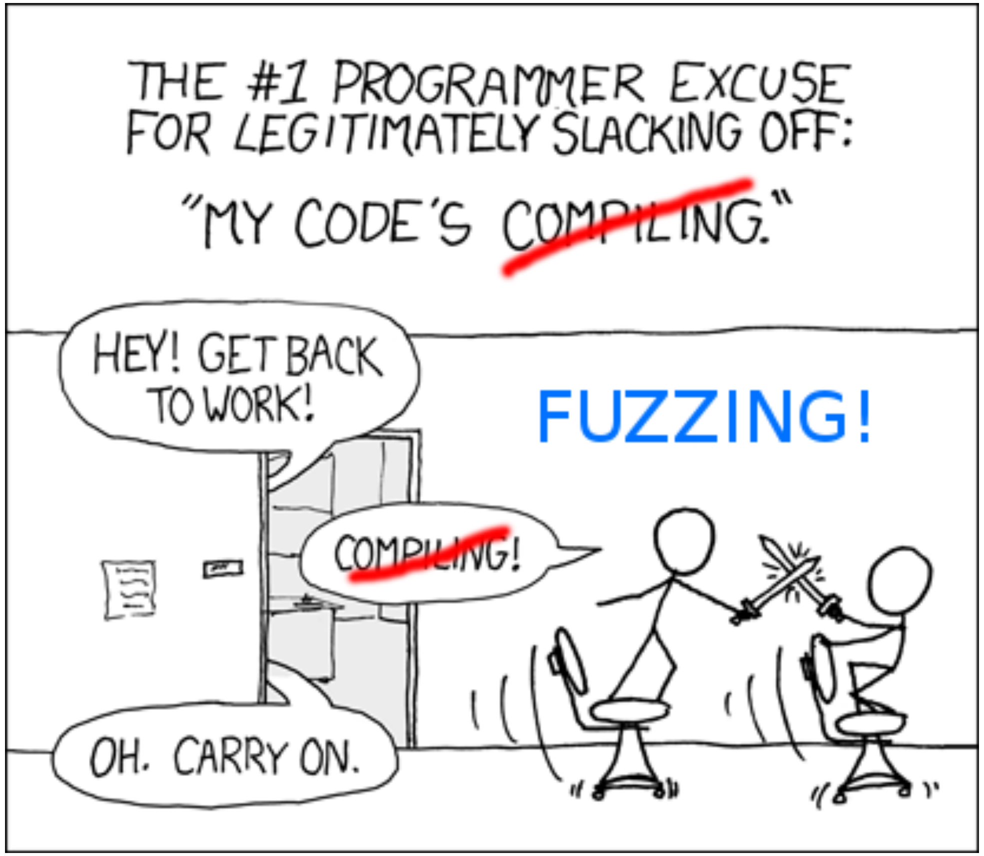
- Negative software testing method that feeds malformed and unexpected input data to a program, device, or system with the purpose of finding security-related defects, or any critical flaws leading to denial of service, degradation of service, or other undesired behavior
- black-box testing

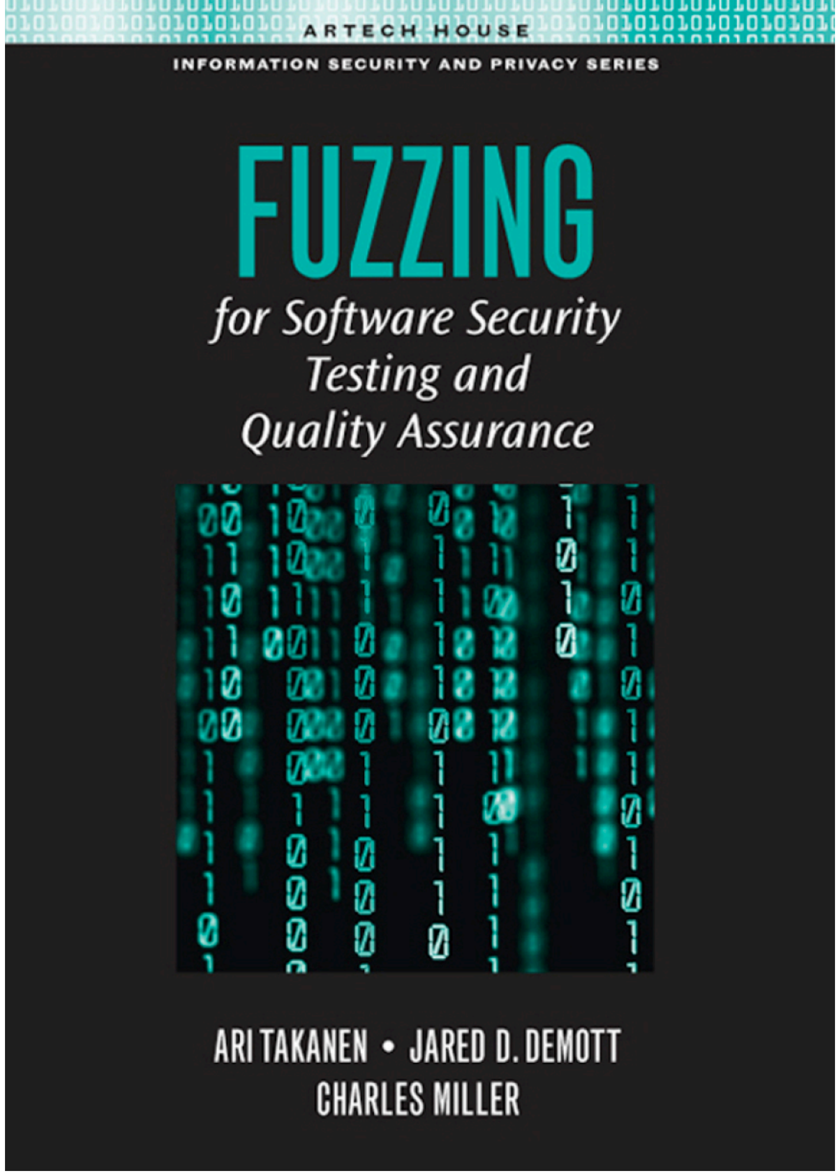
Fuzzing Process



System under test (SUT)

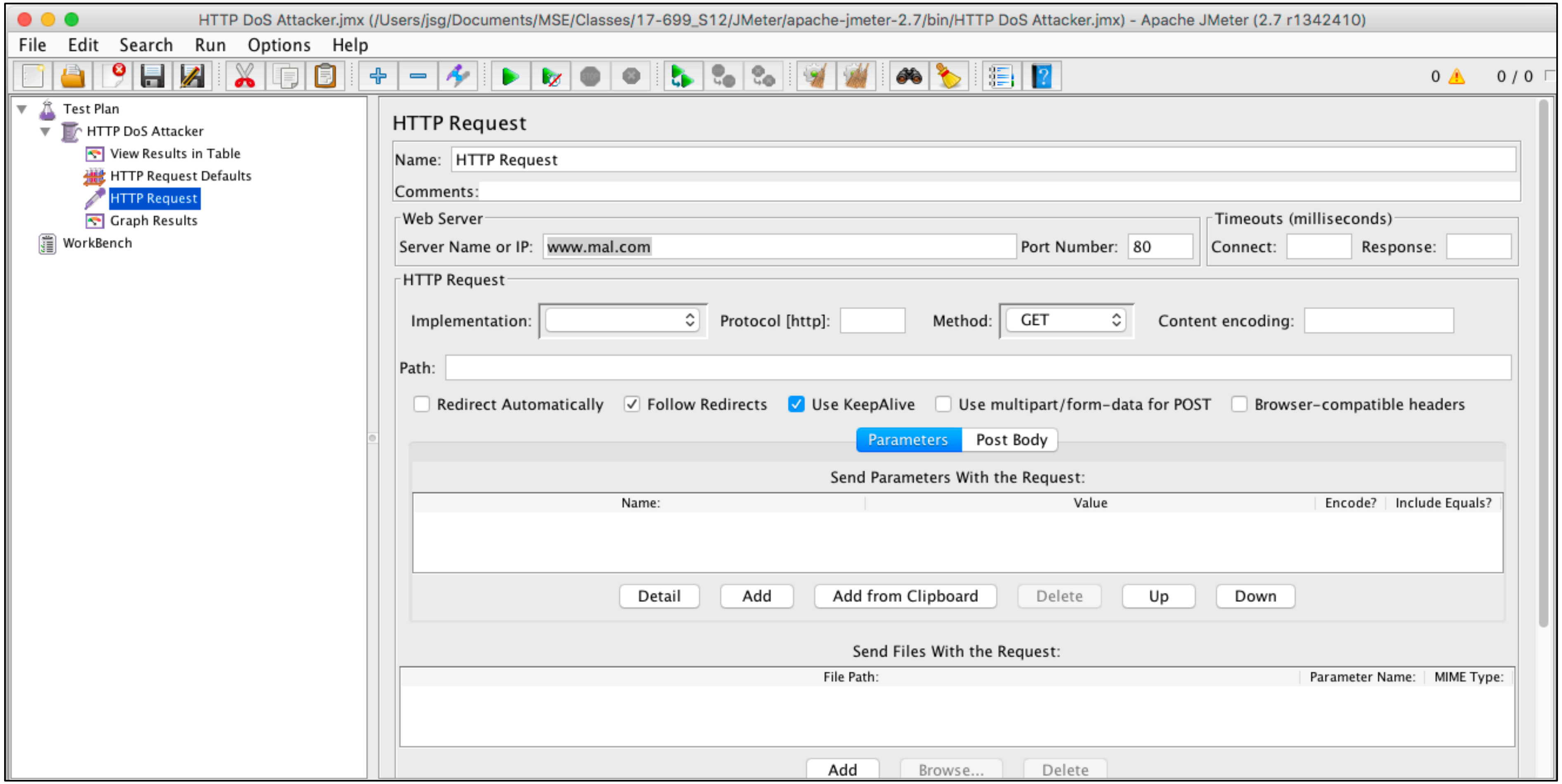
Reliability: Fuzz testing





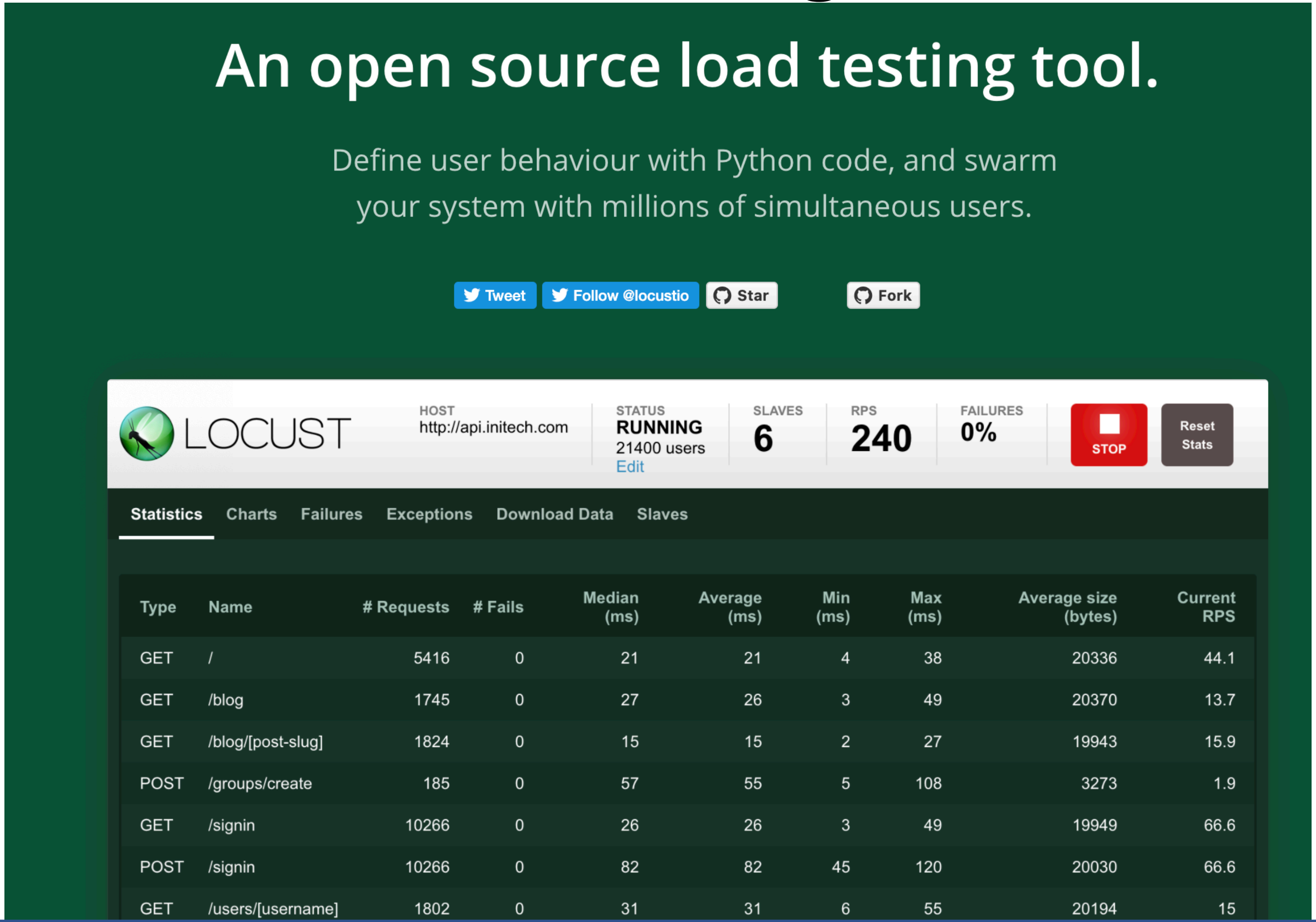
(A. Takanen et al, Fuzzing for Software Security Testing and Quality Assurance, 2008)

Performance testing tools: JMeter



http://jmeter.apache.org

Performance testing tools: Locust



https://github.com/locustio/locust

Chaos Engineering

Principle of Chaos Engineering

Proactively inject failures in order to be prepared when disaster strikes.

"Chaos Engineering is the discipline of experimenting on a distributed system in order to build confidence in the system's capability to withstand turbulent conditions in production."

Goal: To intentionally break things, compare measured with expected impact, and correct any problems uncovered this way.


amazon
webservices
CHAOS
MONKEY


SIMIAN
ARMY

NETFLIX

Chaos monkey/Simian army

- A Netflix infrastructure testing system.
- “Malicious” programs randomly trample on components, network, datacenters, AWS instances…
  - Chaos monkey was the first – disables production instances at random.
  - Other monkeys include Latency Monkey, Doctor Monkey, Conformity Monkey, etc… Fuzz testing at the infrastructure level.
  - Force failure of components to make sure that the system architecture is resilient to unplanned/random outages.
- Netflix has open-sourced their chaos monkey code.

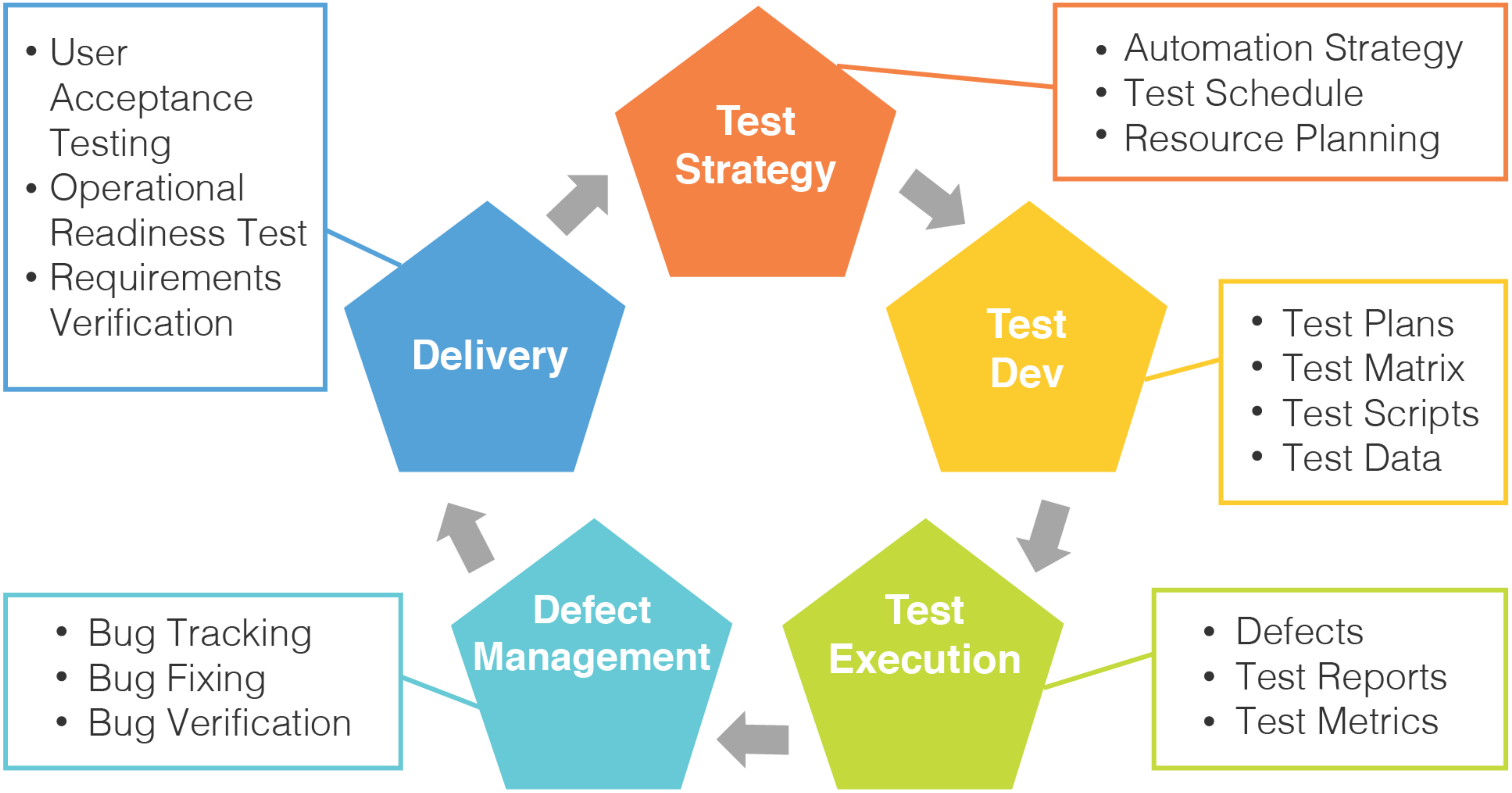
Awesome Chaos Engineering awesome

A curated list of awesome Chaos Engineering resources.

https://github.com/dastergon/awesome-chaos-engineering

GREMLIN

https://www.youtube.com/watch?v=VUwi5Jtw3ow&feature=youtu.be

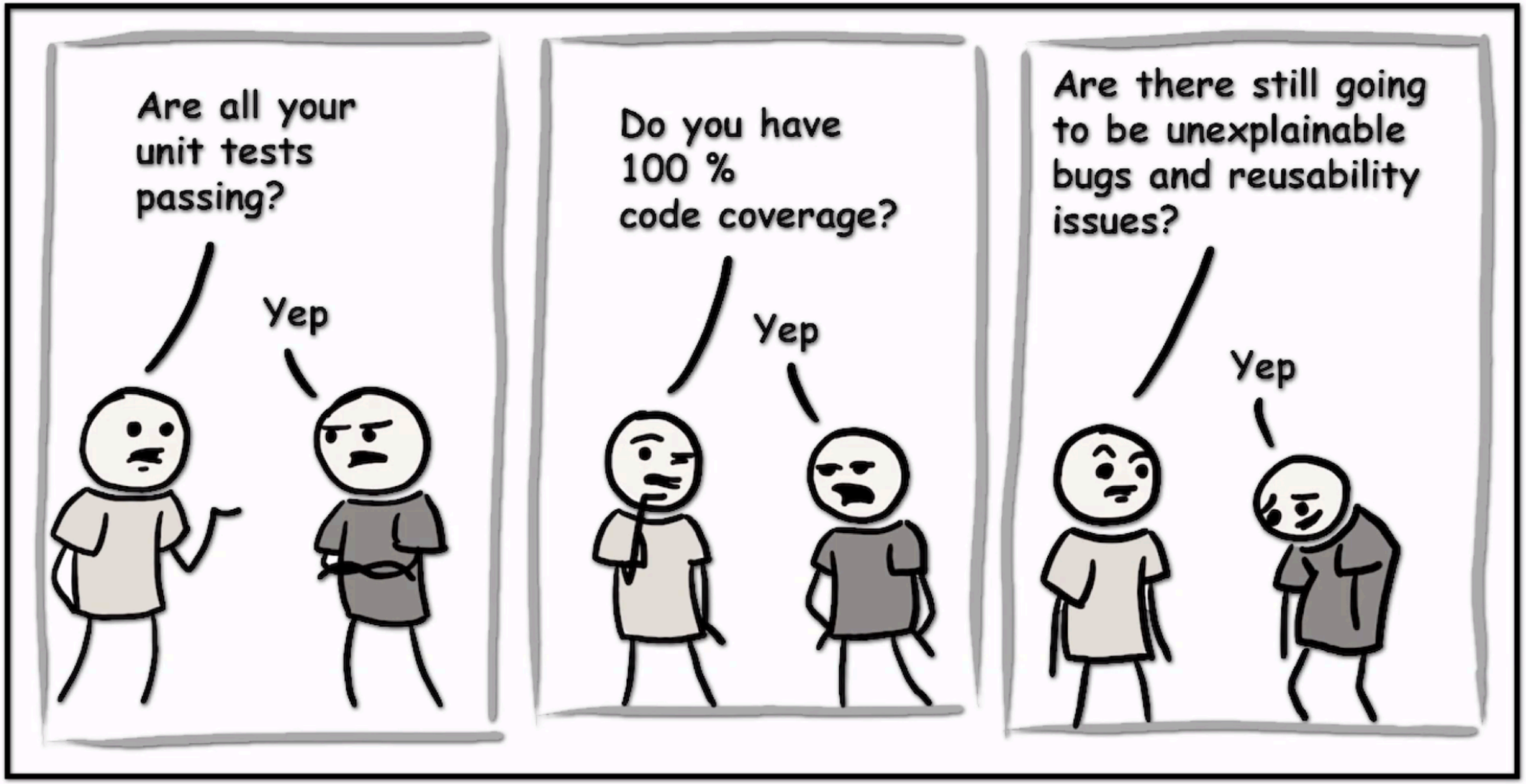

Test Strategy
Automation Strategy
Test Schedule
Resource Planning
Test Dev
Test Plans
Test Matrix
Test Scripts
Test Data
Test Execution
Defects
Test Reports
Test Metrics
Defect Management
Bug Tracking
Bug Fixing
Bug Verification
Delivery
User Acceptance Testing
Operational Readiness Test
Requirements Verification

Limits of Testing

- Cannot find bugs in code not executed, cannot assure absence of bugs
- Oracle problem
- Nondeterminism, flaky tests
  - Certain kinds of bugs occur only under very unlikely conditions
- Hard to observe/assert specifications
  - Memory leaks, information flow, …
- Potentially expensive, long run times
- Potentially high manual effort
- Verification, not validation
- …

Recording

But coverage has limitations.



Low coverage means insufficient testing.

Summary

- Quality assurance is important, often underestimated
- Many forms of QA, testing popular
- Testing beyond functional correctness

Definition: software analysis

The systematic examination of a software artifact to determine its properties.

Principle techniques

- **Dynamic:**
  - **Testing:** Direct execution of code on test data in a controlled environment.
  - **Analysis:** Tools extracting data from test runs.
- **Static:**
  - **Inspection:** Human evaluation of code, design documents (specs and models), modifications.
  - **Analysis:** Tools reasoning about the program without executing it.

```
129     }
130 }
```

Problems @ Javadoc Declaration Console

```
<terminated> ClassLoaderLeakExample [Java Application] /Library/Java/JavaVirtualMachines/jdk1.8.0_40.jdk/Contents/Home/bin/java (Oct 20, 2014, 4:15:32 PM)
java.lang.OutOfMemoryError: Java heap space
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```

What’s a memory leak?

How can we tackle this problem?

- Testing:

- Inspection:

- Static analysis:

Wouldn't it be nice if we could learn about the program's memory usage as it was running?

Common dynamic analyses

- Coverage
- Performance
- Memory usage
- Security properties
- Concurrency errors
- Invariant checking
- Fault localization
- Anomaly detection

Collecting execution info

- Instrument at compile time
  - e.g., Aspects, logging, bytecode rewriting
- Run on a specialized VM
  - e.g., valgrind
- Instrument or monitor at runtime
  - also requires a special VM
  - e.g., hooking into the JVM using debugging symbols to profile/monitor (VisualVM)

Collecting execution info

- Instrum... t com... no
- Run on a spe...
  - e.g., valg... nd
- Instrument or m... nitor at ru... ne
  - a... ires ...
  - ... ols to profile/monitor
  - (v...

Note: some of these methods require a *static* pre processing step!

Avoid mixing up static things done to collect info and the dynamic analyses that use the info.

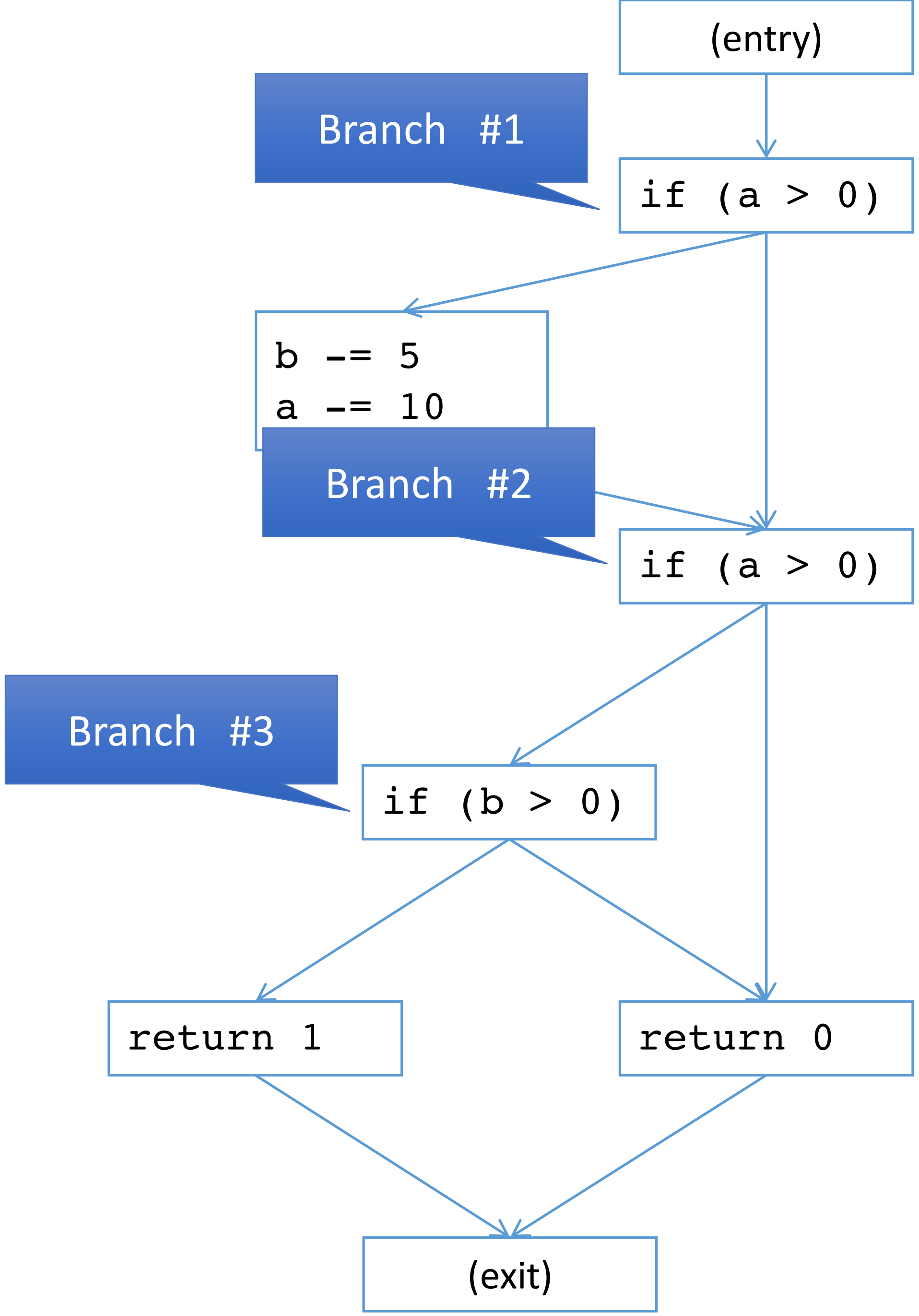
Example: Test Coverage

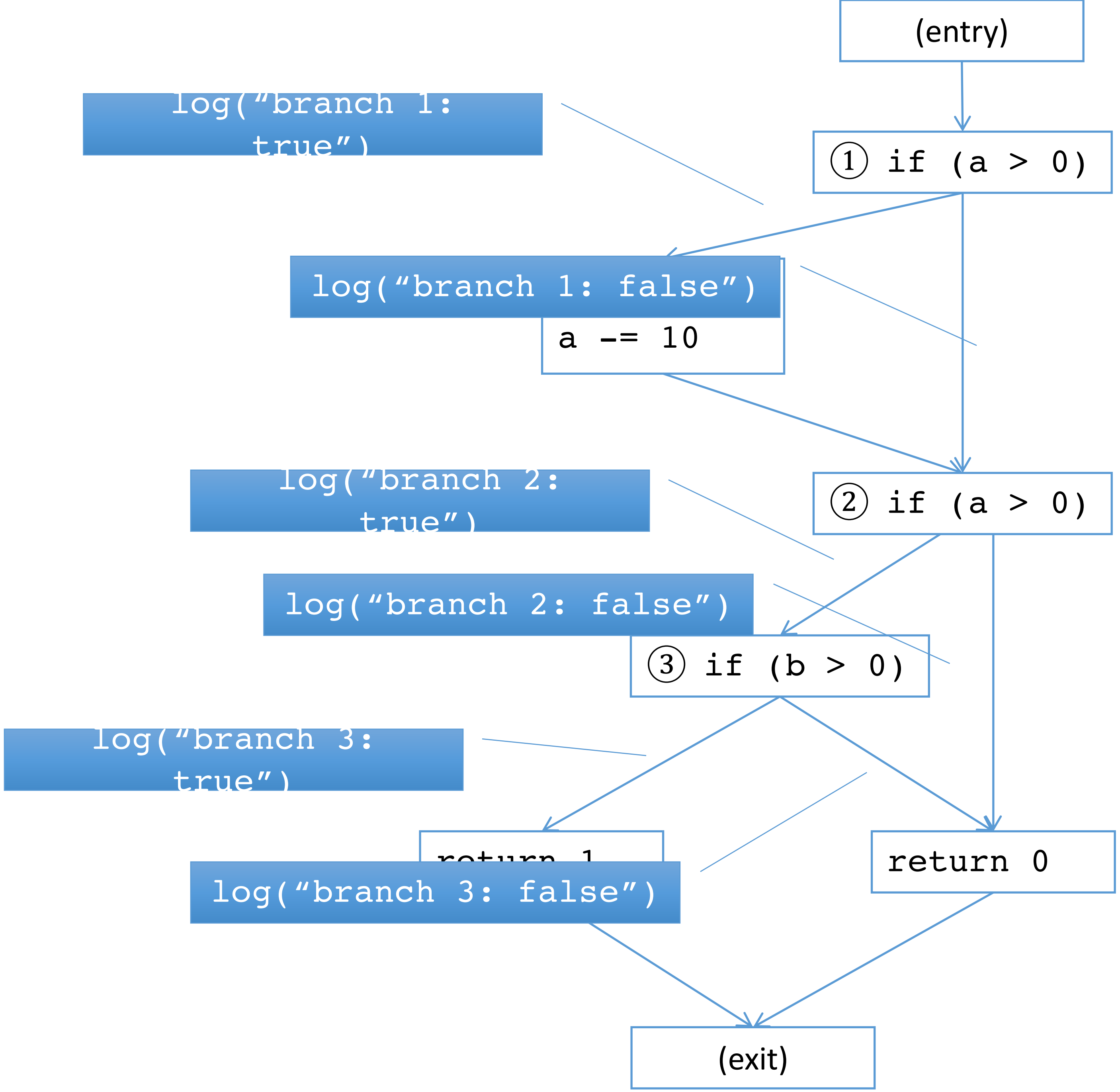
- Statement: Has each statement in the program been executed?
- Branch: Has each of each control structure been executed?
- Function: Has each function in the program been called?
- Path: requires that all paths through the Control Flow Graph are covered.
- ...

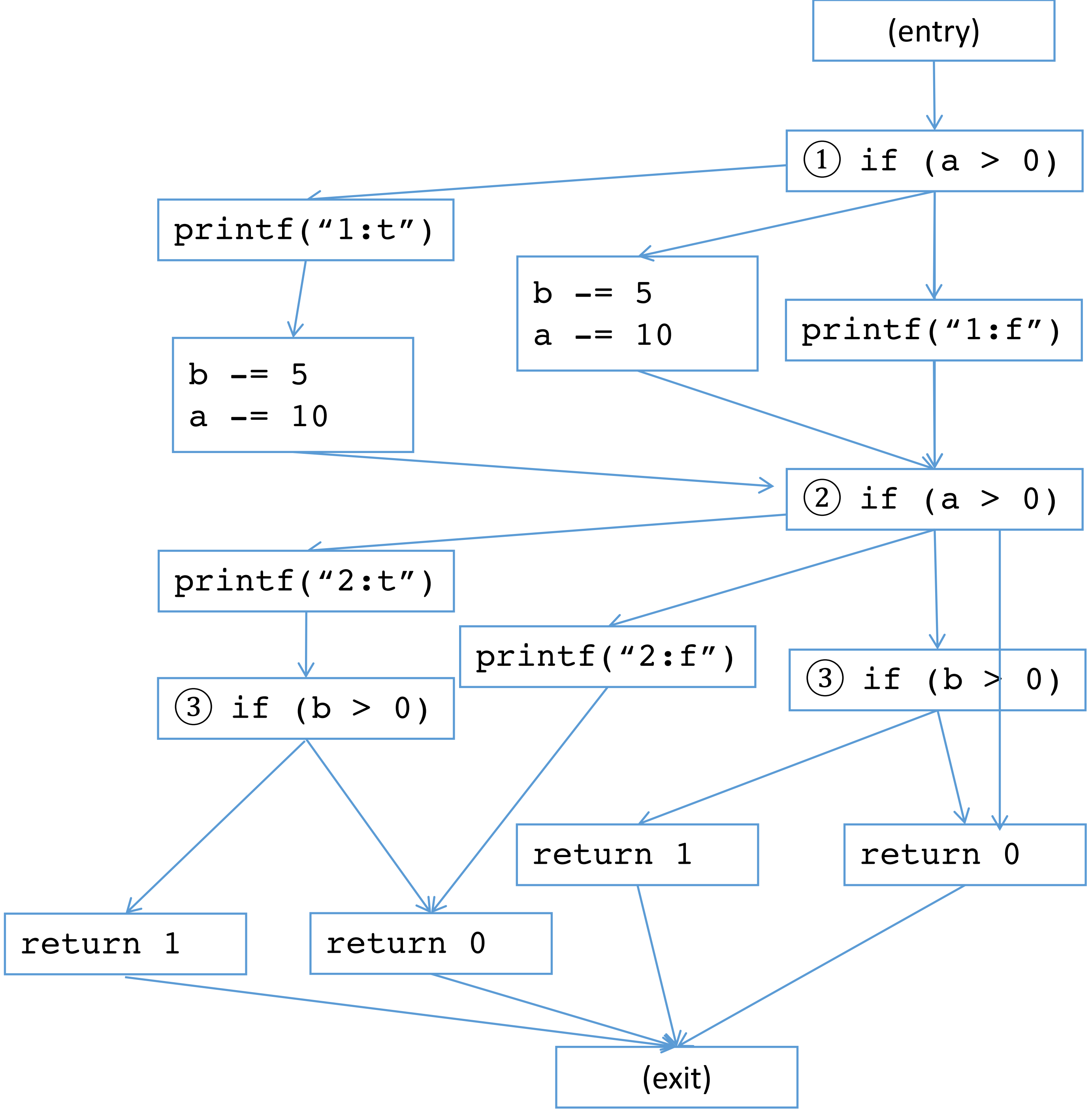
Instrumentation: a simple example

- How might tools that compute test suite coverage work?
- One option: *instrument* the code to track a certain type of data as the program executes.
  - **Instrument:** add of special code to track a certain type of information as a program executes.
  - Rephrase: insert logging statements (e.g., at compile time).
- What do we want to log/track for branch coverage computation?

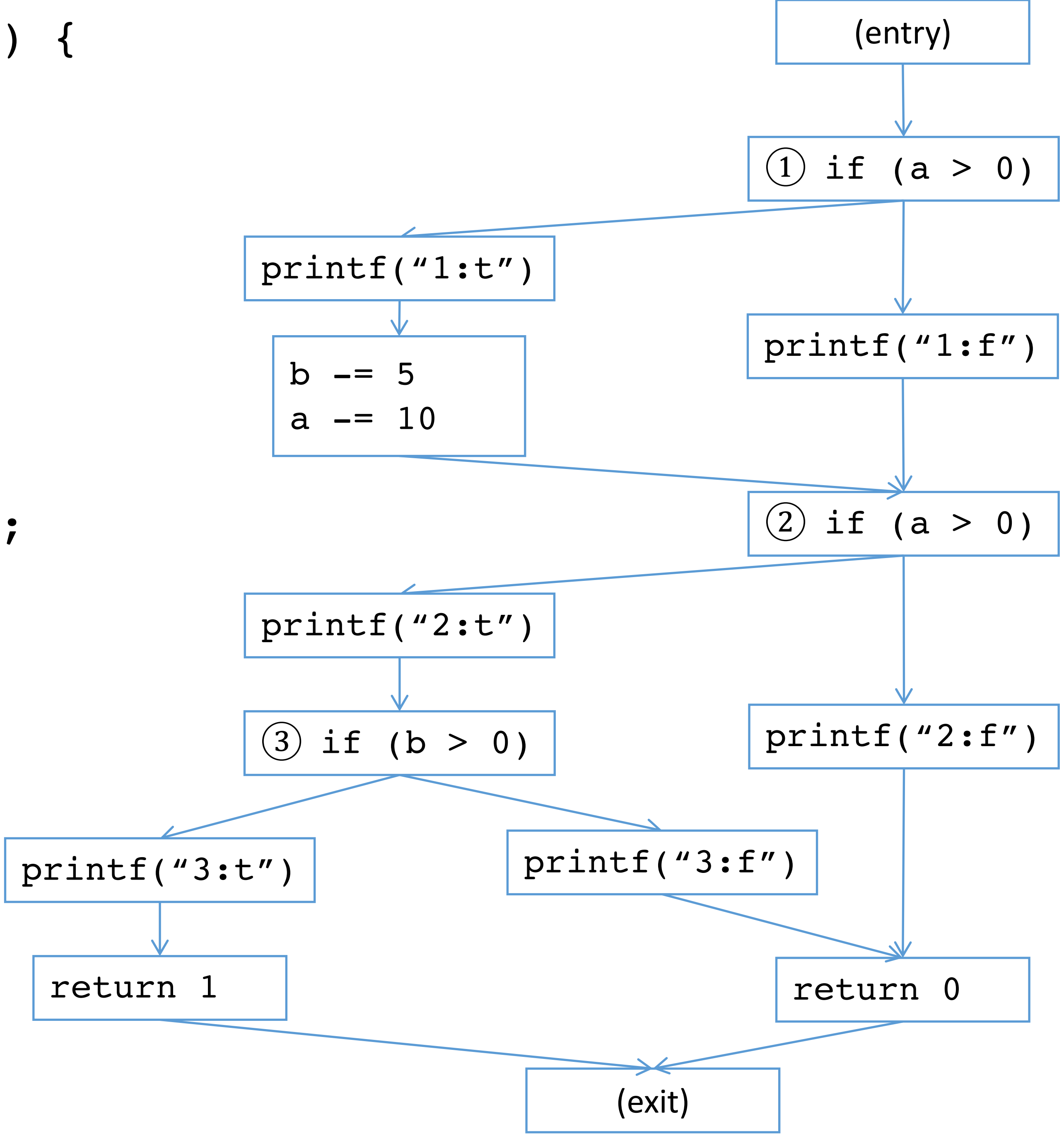
```
int foobar(a,b) {
  if (a > 0) {
    b -= 5;
    a -= 10;
  }
  if(a > 0) {
    if (b > 0)
      return 1;
  }
  return 0;
}
```



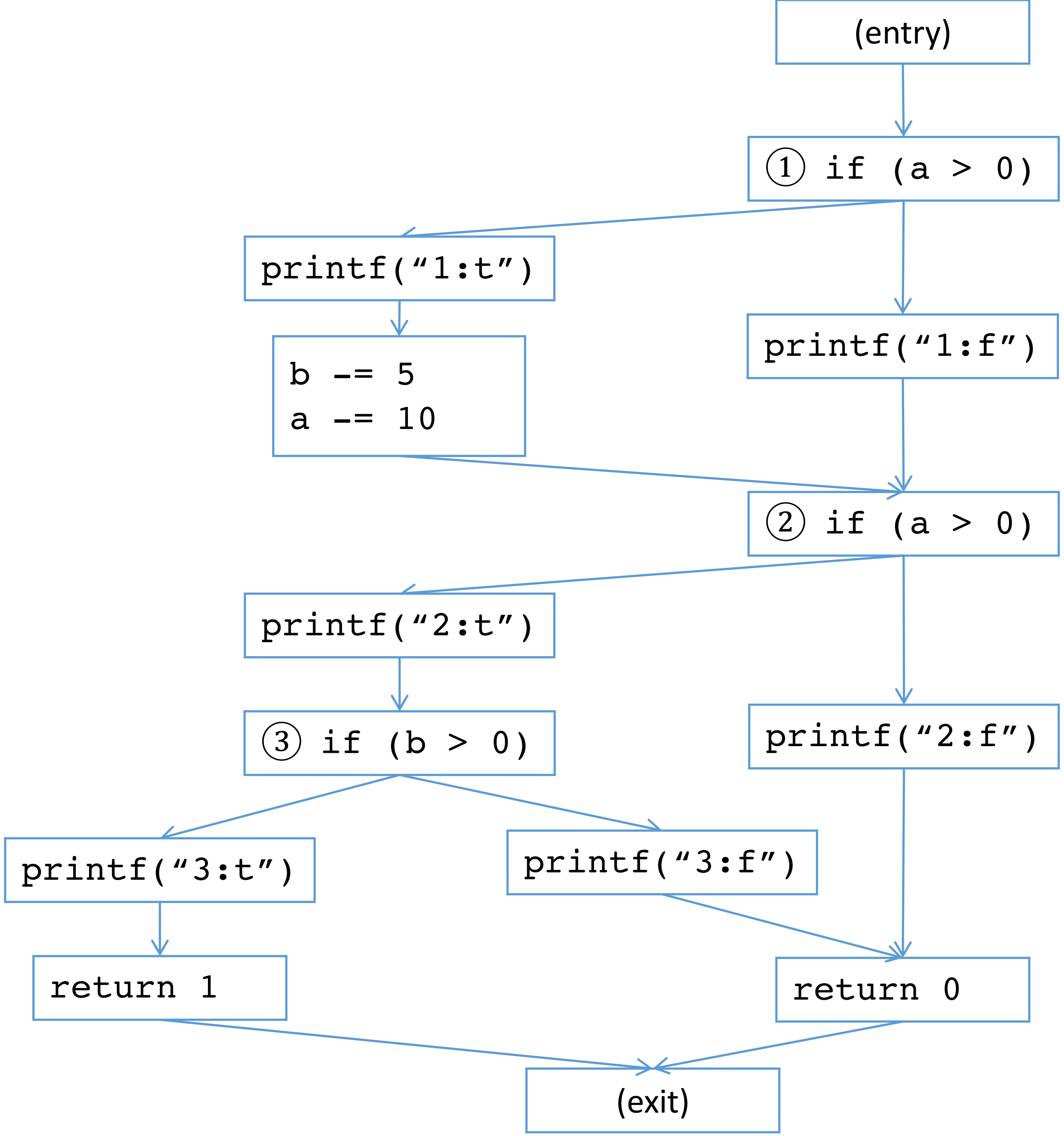

(entry)
① if (a > 0)
log("branch 1: true")
log("branch 1: false")
a -= 10
② if (a > 0)
log("branch 2: true")
log("branch 2: false")
③ if (b > 0)
log("branch 3: true")
log("branch 3: false")
return 0
(exit)


(entry)
① if (a > 0)
printf("1:t")
b -= 5
a -= 10
printf("1:f")
b -= 5
a -= 10
② if (a > 0)
printf("2:t")
printf("2:f")
③ if (b > 0)
③ if (b > 0)
return 1
return 0
return 1
return 0
(exit)

```c
int foobar(a,b) {
  if (a > 0) {
    b -= 5;
    a -= 10;
  }
  if(a > 0) {
    if (b > 0)
      return 1;
  }
  return 0;
}
```



```c
int foobar(a,b) {
  if (a > 0) {
    printf(“1:t”);
    b -= 5;
    a -= 10;
  } else {
    printf(“1:f”);
  }
  if(a > 0) {
   printf(“2:t”);
   if (b > 0) {
     printf(“3:t”);
     return 1;
   } else {
     printf(“3:f”);
   }
  } else {
   printf(“2:f”);
  }
  return 0;
}
```



```
int foobar(a,b) {
  if (a > 0) {
    printf("1:t ");
    b -= 5;
    a -= 10;
  } else {
    printf("1:f ");
  }
  if(a > 0) {
    printf("2:t ");
    if (b > 0) {
      printf("3:t ");
      return 1;
    } else {
      printf("3:f ");
    }
  } else {
    printf("2:f ");
  }
  return 0;
}
```

- Test cases: (0,0), (1,0), (11,0), (11,6)
  - foobar(0,0): "1:f 2:f "
  - foobar(1,0): "1:t 2:f "
  - foobar(11,0): "1:t 2:t 3:f "
  - foobar(11,6): "1:t 2:t 3:t "

Assuming we saved how many branches were in this method when we instrumented it, we could now process these logs to compute branch coverage.

Common dynamic analyses

- Coverage
- Performance
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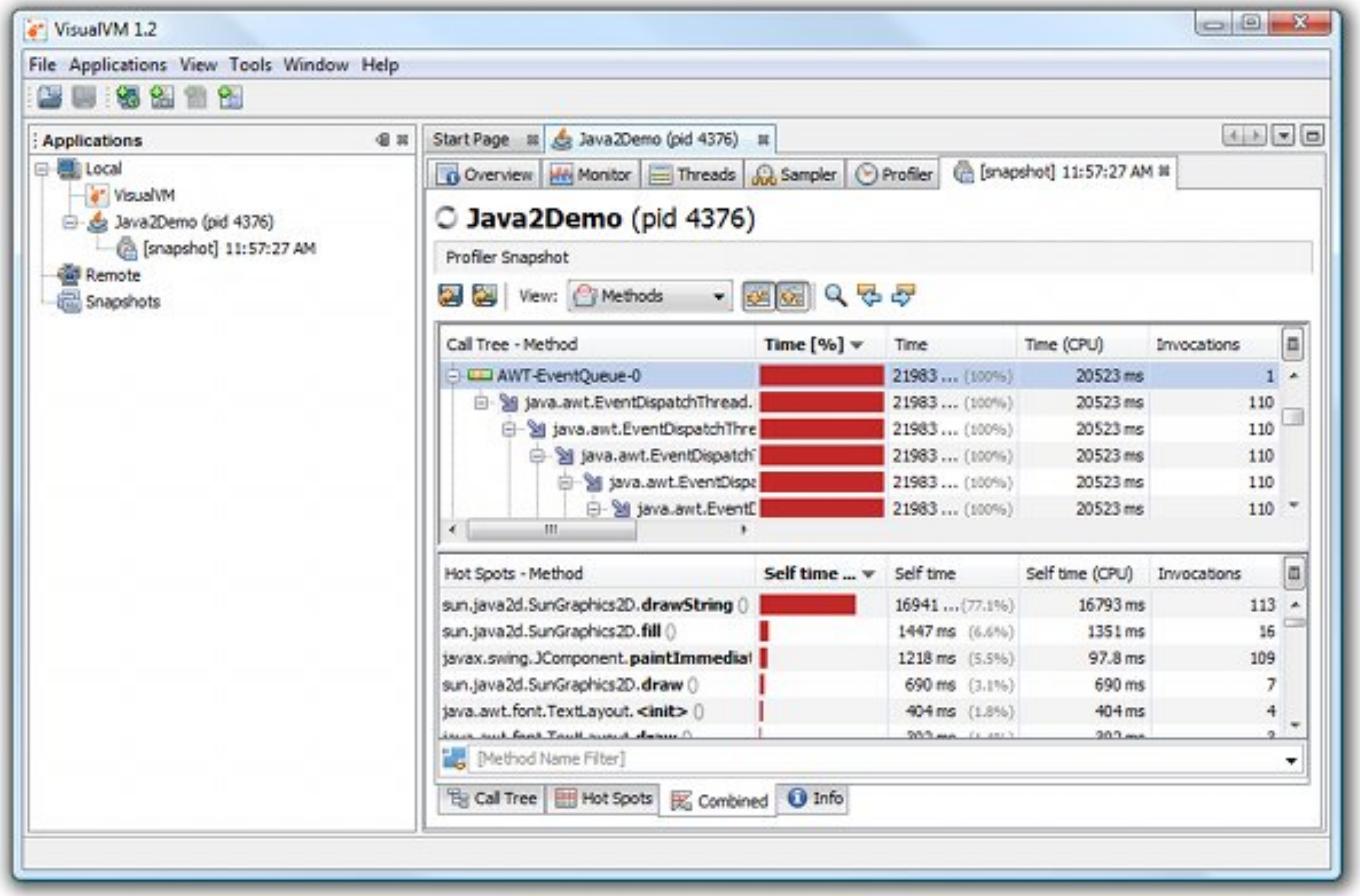
Profiling

- Finding bottlenecks in execution time and memory



Limitation: Dynamic analysis

- Cost

  Performance overhead for recording

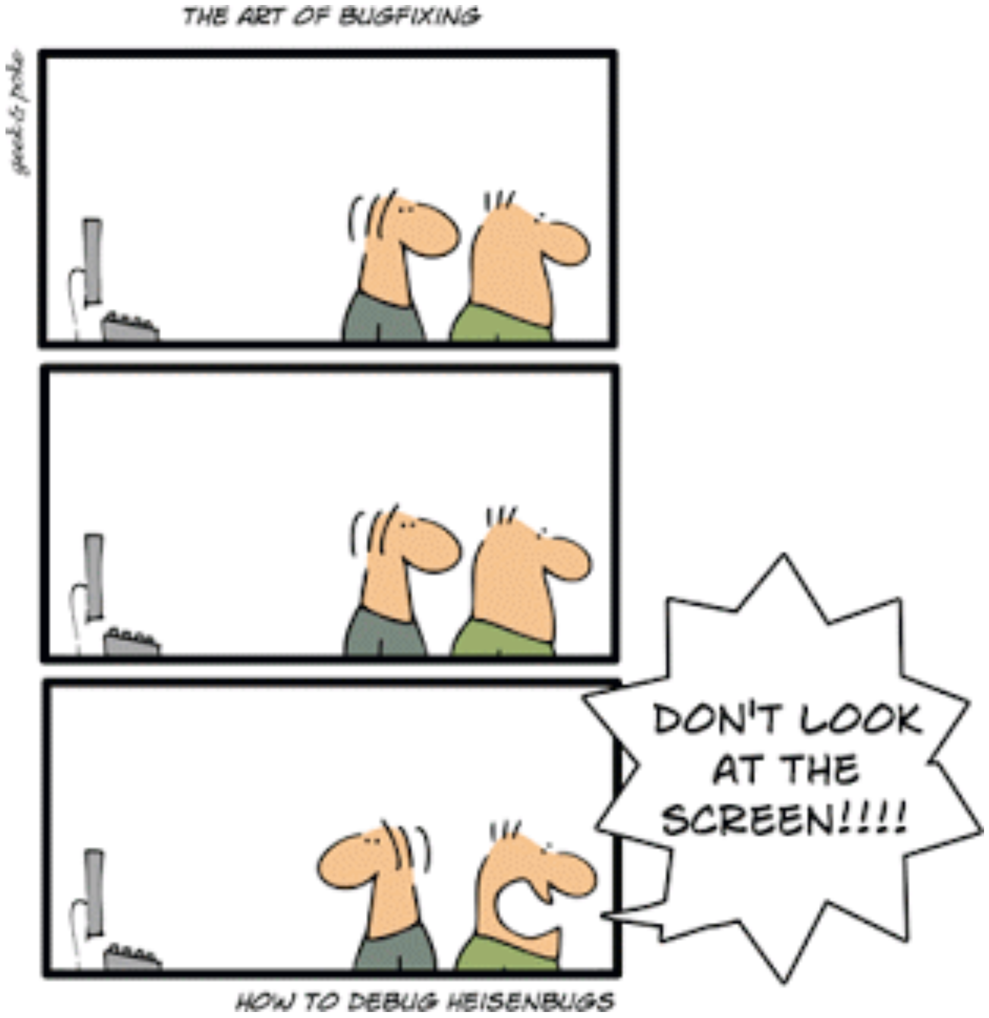
  - Acceptable for use in testing?
  - Acceptable for use in production?

Very input dependent

- Good if you have lots of tests!
- Can also use logs from live software runs that include actual user interactions (sometimes, see next slides).
- Or: specific inputs that replicate specific defect scenarios (like memory leaks).

Heisenbugs

- Heisenbugs occur because common attempts to debug a program, such as inserting output statements or running it with a debugger, usually have the side-effect of altering the behavior of the program in subtle ways, such as changing the memory addresses of variables and the timing of its execution.



https://www.testing-whiz.com/blog/heisenbug-elusive-bug

Heisenbuggy behavior

- Instrumentation and monitoring can change the behavior of a program.
  - e.g., slowdown, memory overhead.
- **Important question 1:** can/should you deploy it live?
  - Or possibly just deploy for debugging something specific?
- **Important question 2:** *Will the monitoring meaningfully change the program behavior with respect to the property you care about?*

Too much data

- Logging events in large and/or long-running programs (even for just one property!) can result in HUGE amounts of data.
- How do you process it?
  - Common strategy: sampling

Lifecycle

- During QA
  - Instrument code for tests
  - Let it run on all regression tests
  - Store output as part of the regression
- During Production
  - Only works for web apps
  - Instrument a few of the servers
    - Use them to gather data
    - Statistical analysis, similar to seeding defects in code reviews
  - Instrument all of the servers
    - Use them to protect data

Summary

- Dynamic analysis: selectively record data at runtime
- Data collection through instrumentation
- Integrated tools exist (e.g., profilers)
- Analyzes only concrete executions, runtime overhead