CS 5154: Software Testing

Regression Testing

Instructor: Owolabi Legunsen

Fall 2021

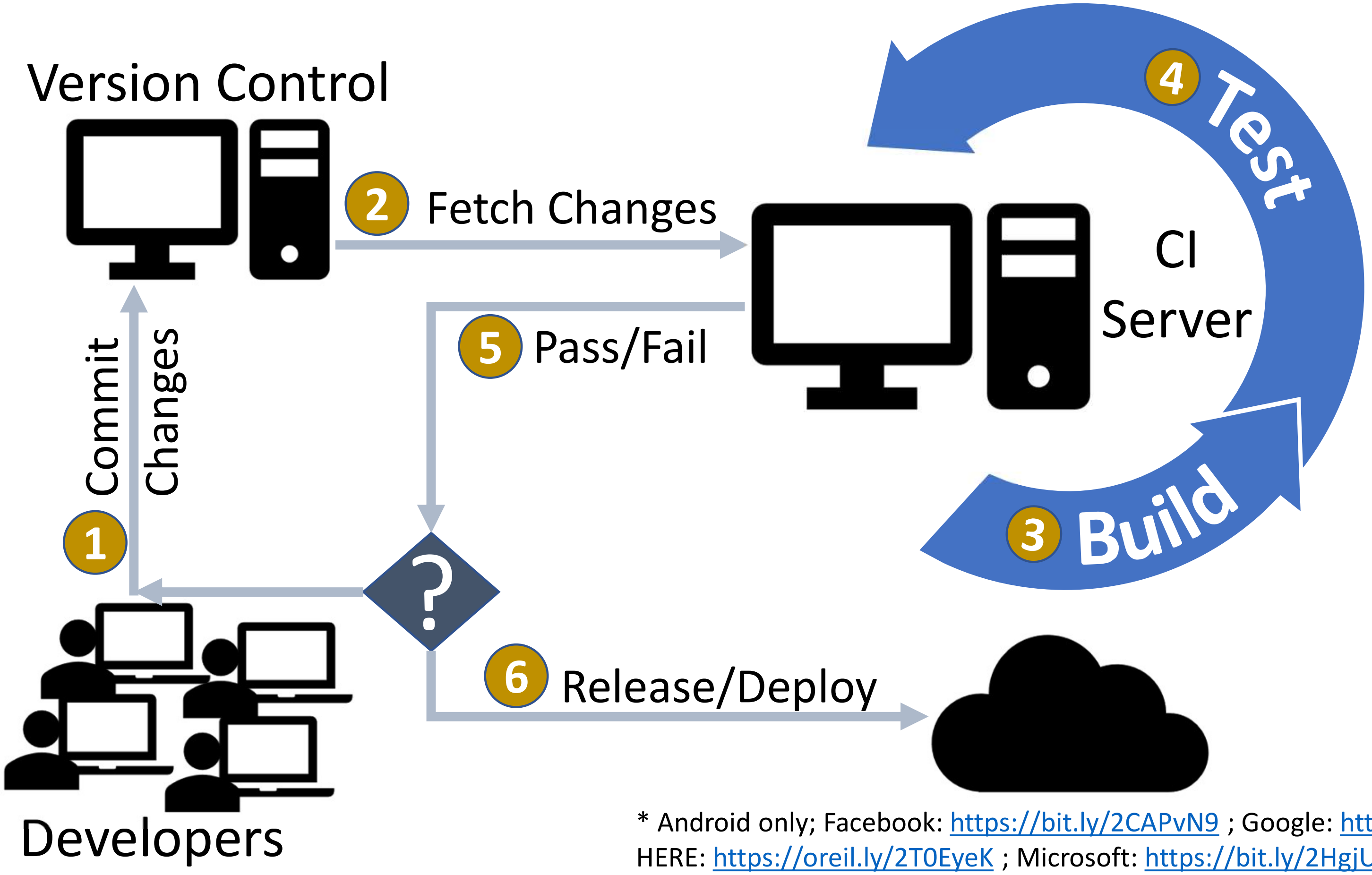
Review of the six CS5154 themes

1. How to automate the execution of tests? ✓
2. How to design and write high-quality tests? ✓
3. How to measure the quality of tests? ✓
4. How to automate the generation of tests? ✓
5. How to reduce the costs of running existing tests? ←
6. How to deal with bugs that tests reveal? **[??]**

What is regression testing?

Re-running tests to check that code changes do not break previously working functionality.

A common setting for regression testing: CI



Builds per day:

- Facebook: 60K*
- Google: 17K
- HERE: 100K
- Microsoft: 30K
- Single open-source projects: up to 80

Releases per day

- Etsy: 50

* Android only; Facebook: https://bit.ly/2CAPvN9 ; Google: https://bit.ly/2SYY4rR ; HERE: https://oreil.ly/2T0EyeK ; Microsoft: https://bit.ly/2HgjUpw ; Etsy: https://bit.ly/2IiSOJP ;

What we’ll talk about today

Problem: Regression testing can be very slow

Solution: Techniques to speed up regression testing

Developers

* Android only; Facebook: https://bit.ly/2CAPvN9 ; Google: https://bit.ly/2SYY4rR ;
HERE: https://oreil.ly/2T0EyeK ; Microsoft: https://bit.ly/2HgjUpw ; Etsy: https://bit.ly/2IiSOJP ;

Regression testing can be very slow

	test execution time	**number of tests**
<APACHE ANT>	~5min	1667
guava-libraries Guava: Google Core Libraries for Java 1.6+	~10min	641534
jetty://	~45min	1296
continuum™	~45min	361
	~45min	631
Apache Camel	~4h	4975
hadoop	~17h	8663

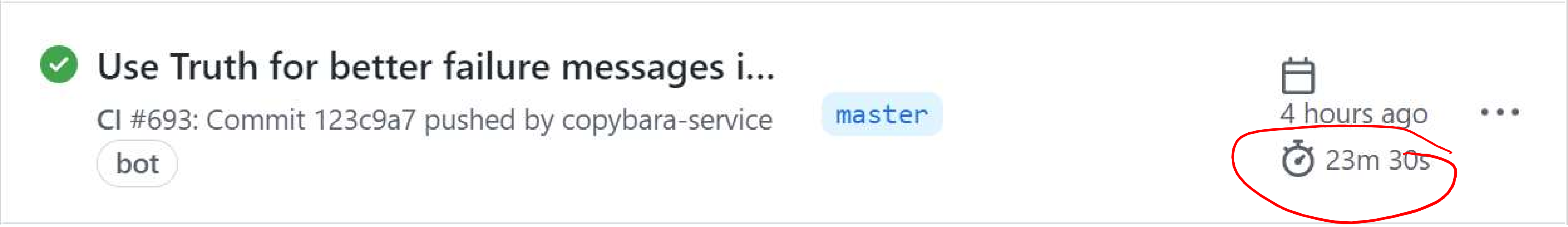
Re-run many times each day

The cost of regression testing is growing!

guava-libraries

Guava: Google Core Libraries for Java 1.6+

- 2015: ~10min 641,534 tests
- Today: **~24min** **1,713,729 tests**



Use Truth for better failure messages i...

CI #693: Commit 123c9a7 pushed by copybara-service

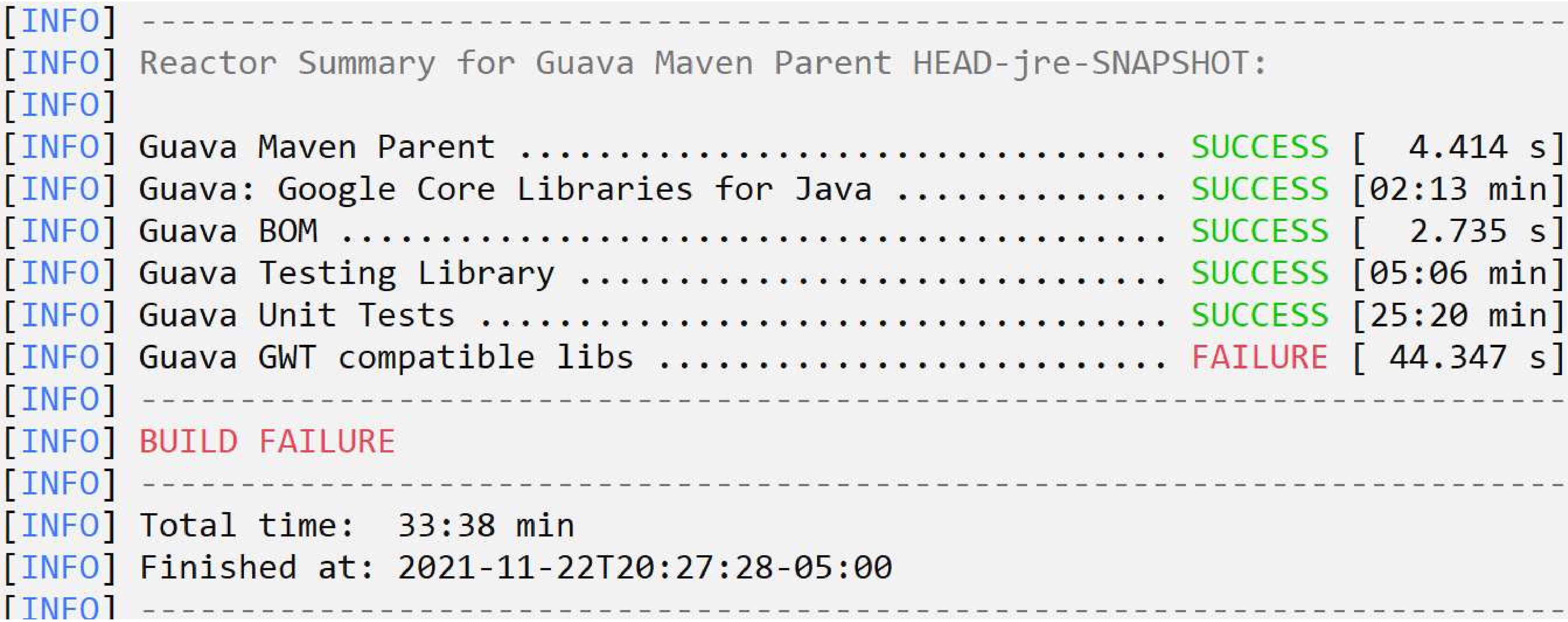
bot

master

4 hours ago

23m 30s

Testing Google Guava locally: ~1/2 of lecture time



```
[INFO] ------------------------------------------------------------------------
[INFO] Reactor Summary for Guava Maven Parent HEAD-jre-SNAPSHOT:
[INFO]
[INFO] Guava Maven Parent ................................. SUCCESS [  4.414 s]
[INFO] Guava: Google Core Libraries for Java .............. SUCCESS [02:13 min]
[INFO] Guava BOM .......................................... SUCCESS [  2.735 s]
[INFO] Guava Testing Library .............................. SUCCESS [05:06 min]
[INFO] Guava Unit Tests ................................... SUCCESS [25:20 min]
[INFO] Guava GWT compatible libs .......................... FAILURE [ 44.347 s]
[INFO] ------------------------------------------------------------------------
[INFO] BUILD FAILURE
[INFO] ------------------------------------------------------------------------
[INFO] Total time:  33:38 min
[INFO] Finished at: 2021-11-22T20:27:28-05:00
[INFO] ------------------------------------------------------------------------
```

Why is the cost of regression testing growing?

- Number of changes per day is growing linearly
- Number of tests that are being run is growing linearly
- So, test execution time is growing quadratically

Google

In 2011,

- 75+ million tests run per day
- 20+ revisions per minute

*https://testing.googleblog.com/2011/06/testing-at-speed-and-scale-of-google.html

What are your ideas for speeding up testing?

- don't test all versions
- localize testing to modules that changed
- refactor code to allow localization
- prioritize what modules to test
- parallelization
- aggregate tests across module
- cache and reuse old test results

Last semester's ideas for speeding up testing

- parallelize
- run test affected by changes ✓ RTS
- write fewer tests that satisfy stronger criteria
- pick and choose test based how long they take and budget prioritization
- run test outside work hours
- designate core tests and random fraction of others ✓

Goals for a regression testing technique

1. Detect regression faults as soon as possible

2. Reduce costs of testing

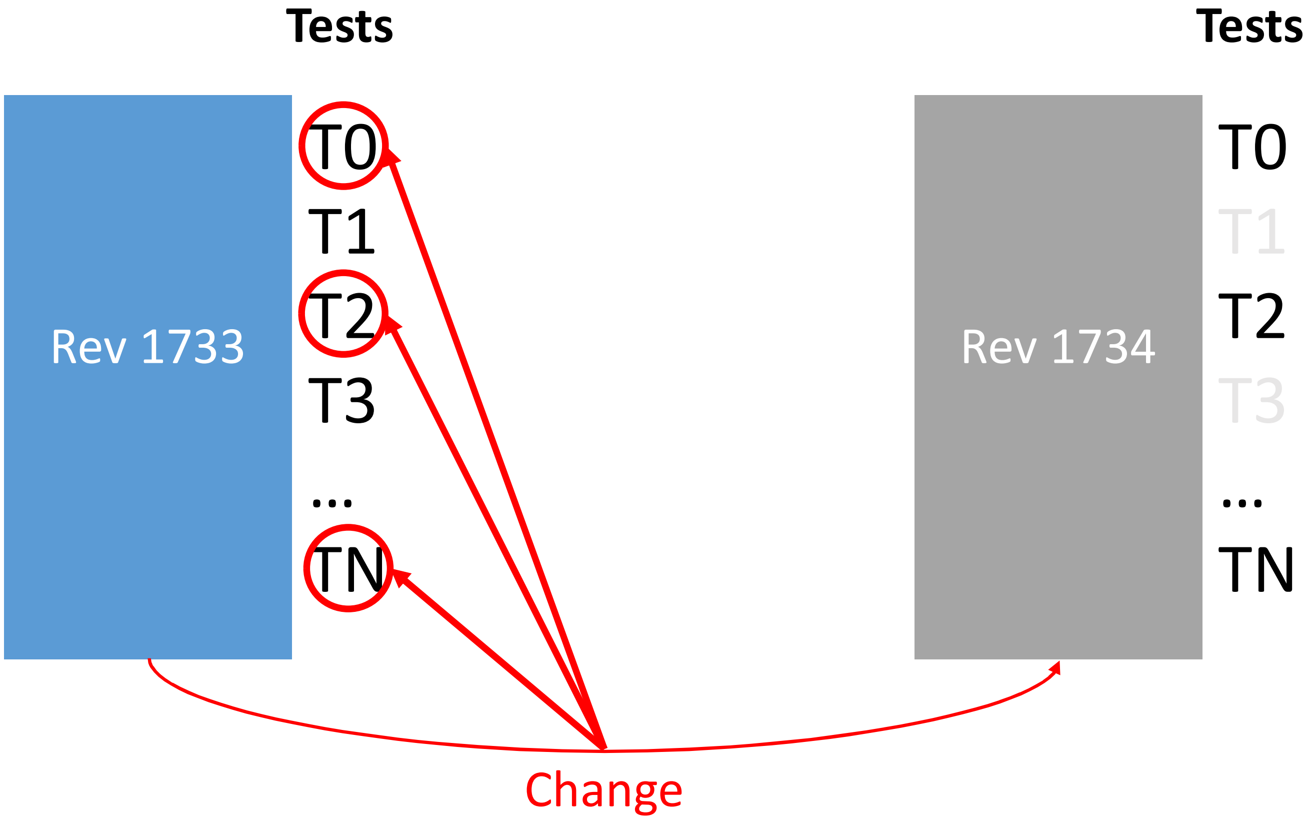
    a. Costs in machine time to run tests

    b. Costs in in developer time to wait for test results

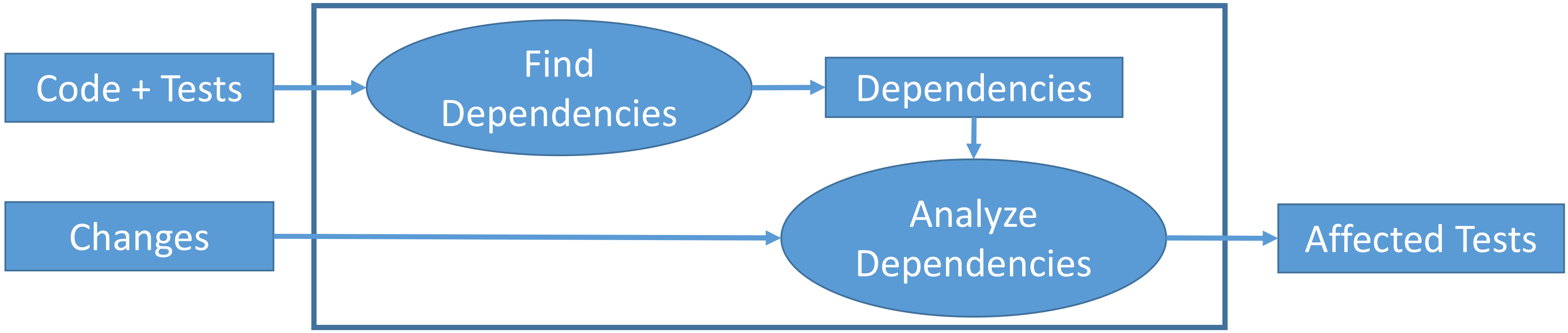
Some regression testing techniques

- **RetestAll :** Re-run all tests after a change
- **Regression Test Selection (RTS) :** Re-run subset of tests that are “affected” by code changes
- **Test-Suite Reduction (Minimization) :** Remove redundant tests
- **Test-Case Prioritization :** Order tests so that those that are “more important” are run first

Regression Test Selection (RTS)



How RTS works



after ??

- An **affected test** can behave differently due to code changes

- A test is affected if any of its dependencies changed

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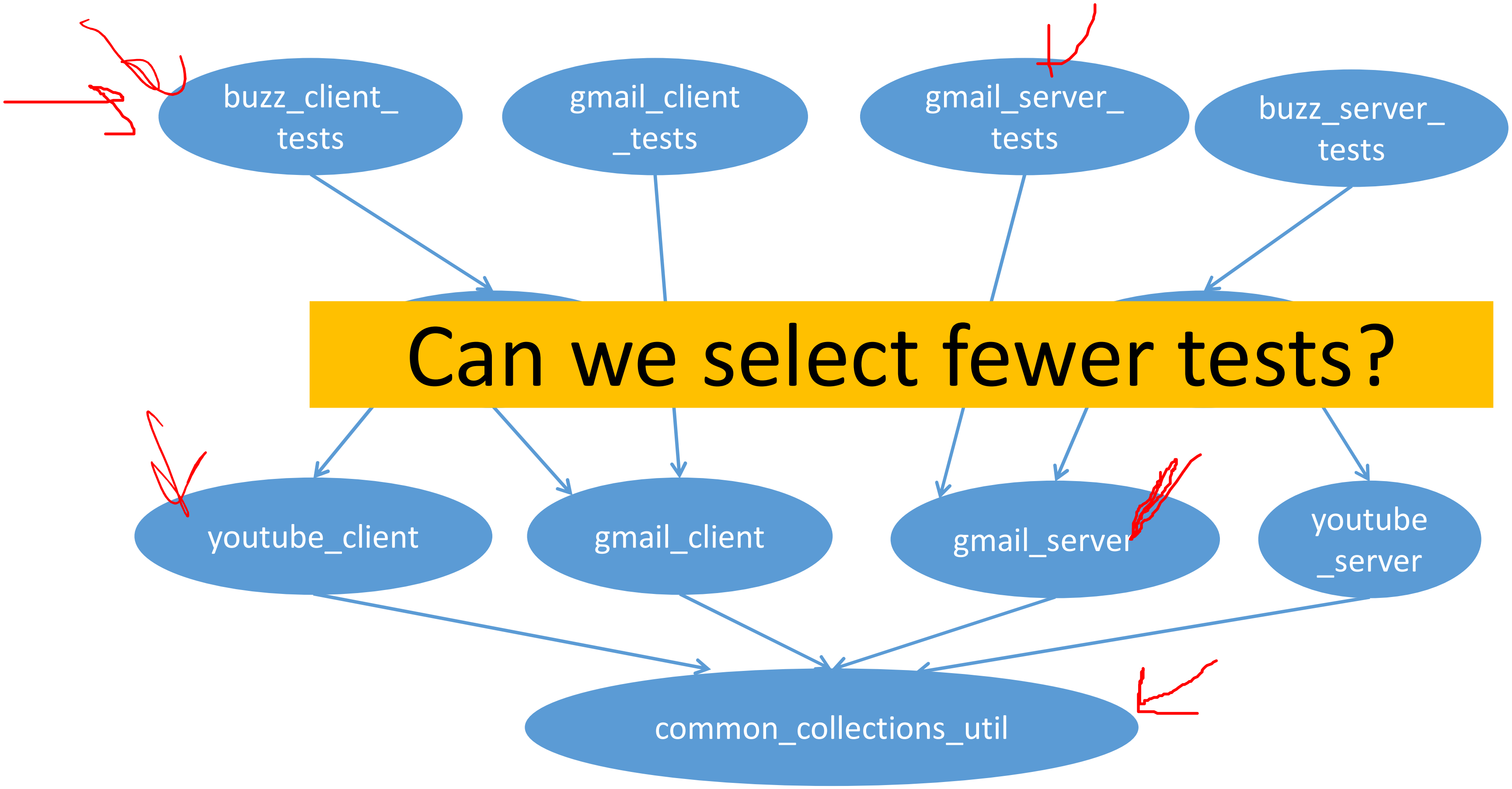
RTS at Google (Target/Module Level)

TAP



Can we select fewer tests?

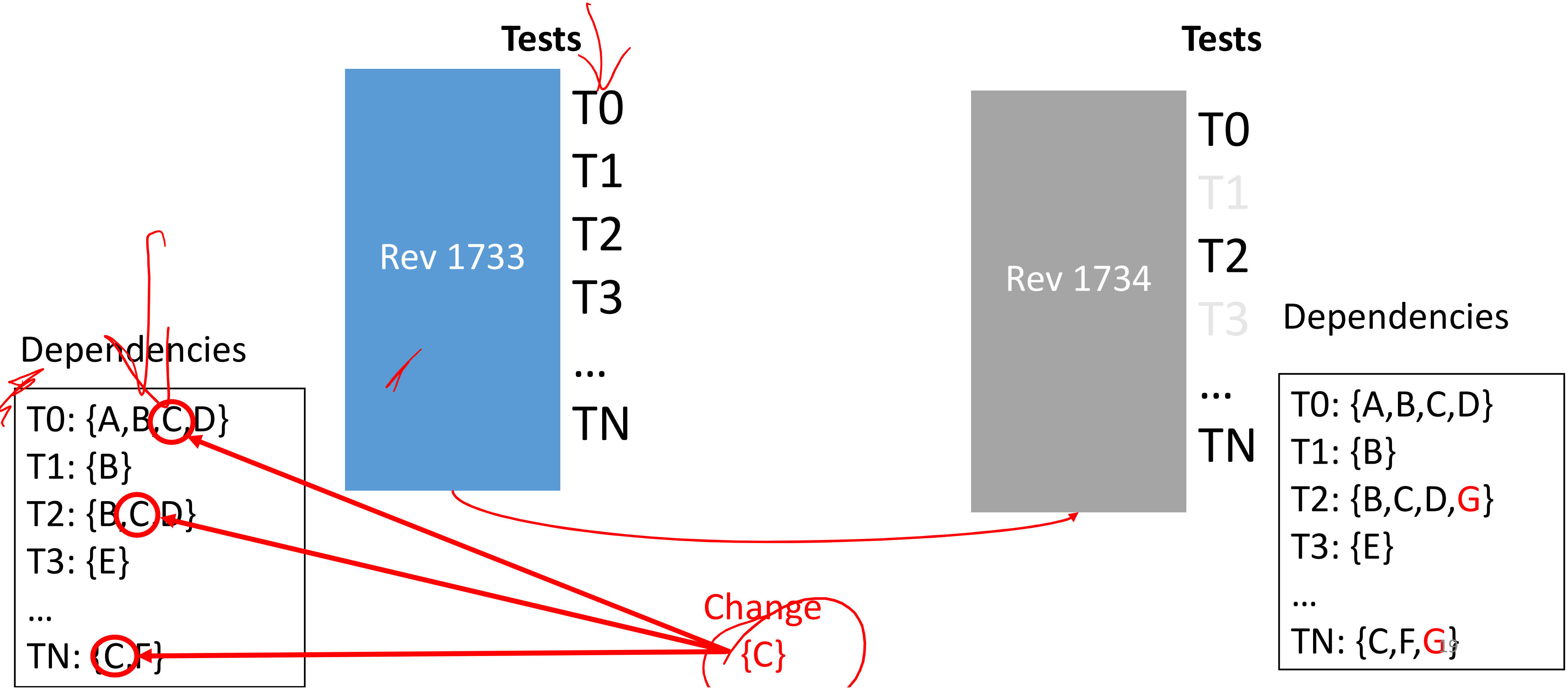
Class-level RTS

- Track dependencies between classes (in Java)
    - Collect changes at class level
    - Connect related classes
    - Select test classes (run all test methods in selected test class)

- How do we track test dependencies?

- How do we track changes?

Class-level Dynamic RTS (Ekstazi[1])



Tests

Rev 1733

T0

T1

T2

T3

…

TN

Dependencies

T0: {A,B,C,D}
T1: {B}
T2: {B,C,D}
T3: {E}
…
TN: {C,F}

Change

{C}

Tests

Rev 1734

T0

T1

T2

T3

…

TN

Dependencies

T0: {A,B,C,D}
T1: {B}
T2: {B,C,D,G}
T3: {E}
…
TN: {C,F,G}

[1] Gligoric et al., *Practical Regression Test Selection with Dynamic File Dependencies.* ISSTA 2015, https://github.com/gliga/ekstazi

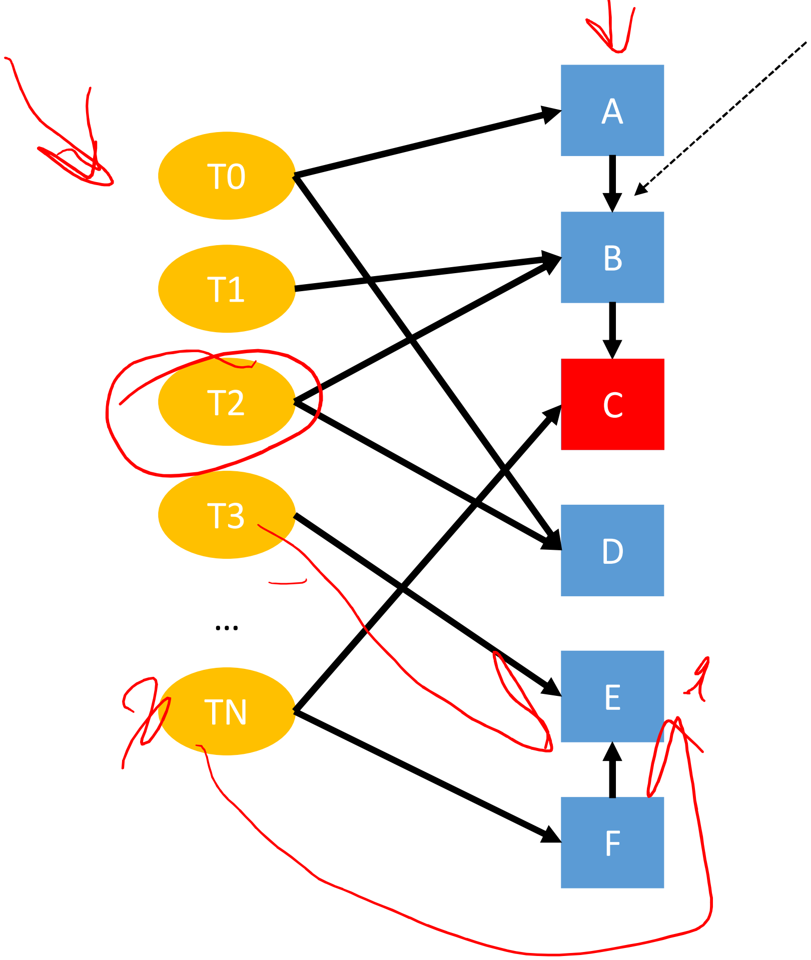
How Ekstazi works

A.class 544

A$B.class 54e

- **Find Dependencies**: dynamically track classes used while running each test class
    - Instrument classes to figure out which classes are used/loaded when running tests in some test class
- **Changes**: classes whose .class (bytecode) files differ
- **Analyze Dependencies**: select test classes for which any of its dependencies changed
    - Maintain dependencies between versions

Class-level STAtic RTS (STARTS[1])



Use edge or inheritance edge

STARTS Dependencies

T0: {A,B,C,D}
T1: {B,C}
T2: {B,C,D}
T3: {E}
…
TN: {C,E,F}

Transitive closure

Is the transitive closure sufficient?

reflexive closure

[1] Legunsen et al., *An Extensive Study of Static Regression Test Selection in Modern Software Evolution.* FSE 2016, https://github.com/TestingResearchIllinois/starts

How STARTS works

- First, build a class dependency graph at compile time
  - Each class has an edge to direct superclass/interface and referenced classes

- **Find Dependencies**: classes reachable from each test class in the graph

- **Changes**: computed in same way as Ekstazi

- **Analyze Dependencies**: select test classes that reach a changed class in the graph

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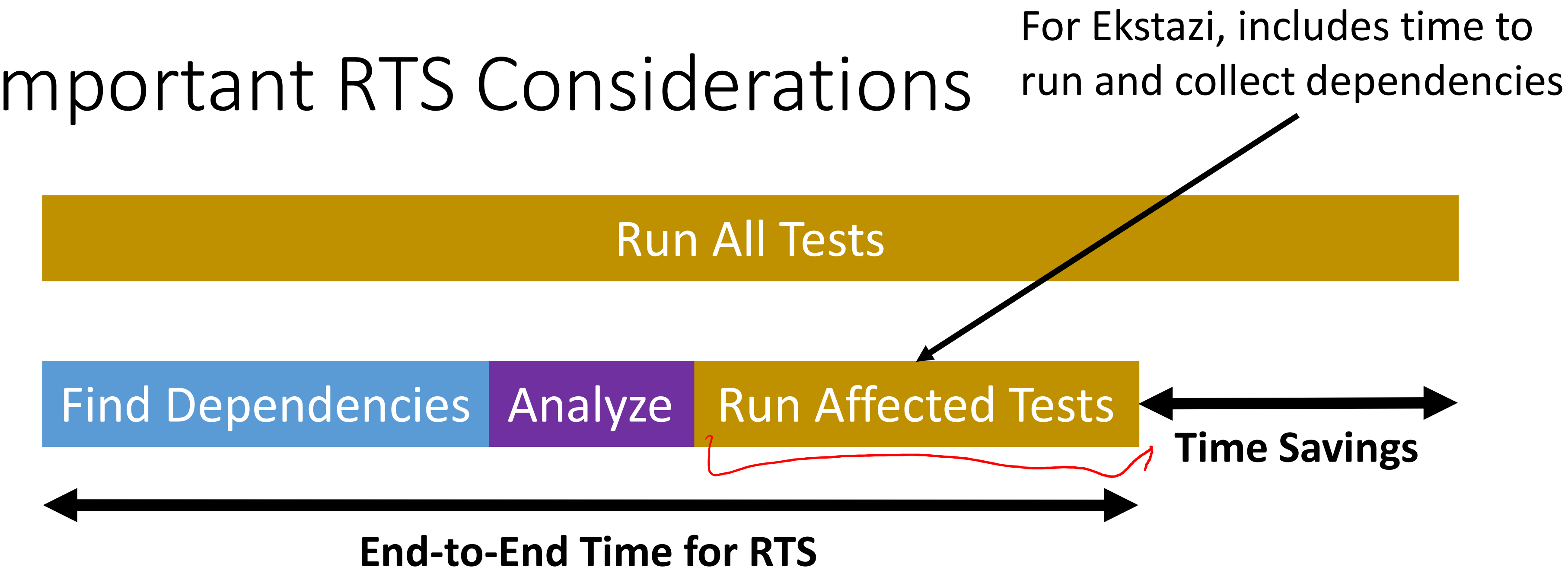
A conversation from the last lecture

Owolabi : For an RTS technique to be useful, the end-to-end time of finding dependencies, analyzing dependencies+changes, and rerunning affected tests must be less than the time to simply re-run all tests

Student : What if RTS selects all tests to be re-run?

Owolabi : ☹

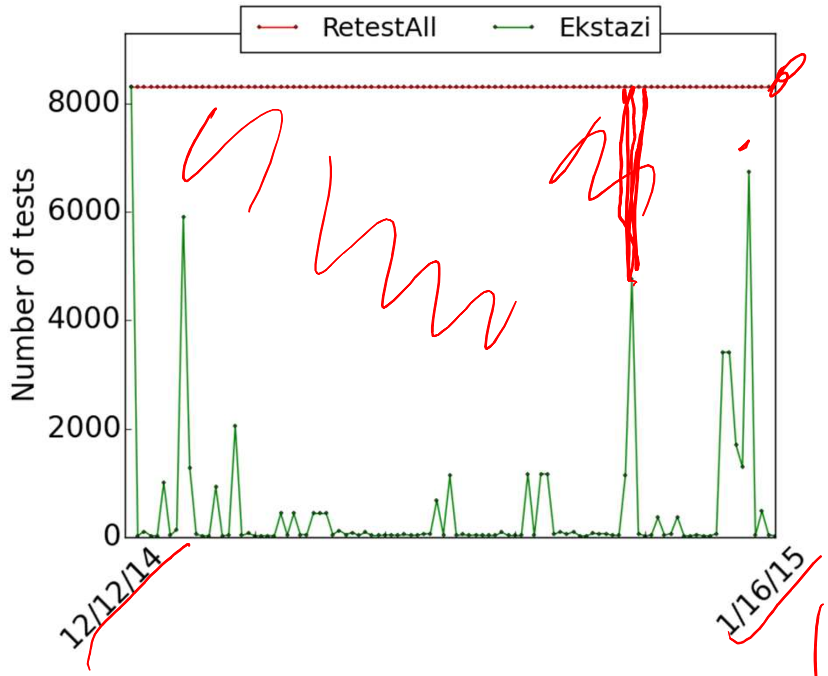
Important RTS Considerations

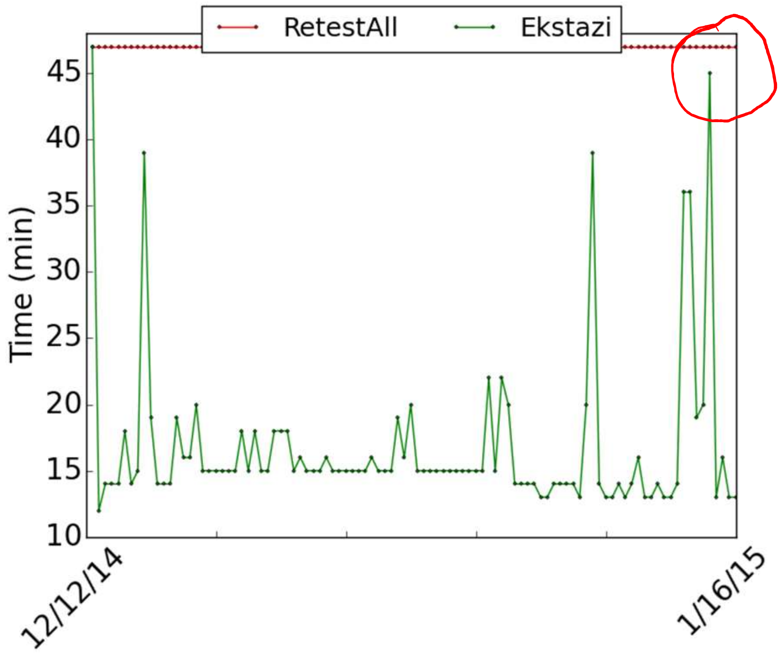


- End-to-end time for RTS must be less than time to run all tests
- RTS should be **safe:** it should select to rerun *all* affected tests
- RTS should be **precise**: it should select to rerun *only* affected tests

Apache CXF

Benefit of RTS is measured across many versions





Reduces number of tests: ~15x (10% more than dynamic method-level RTS)

Reduces test execution time: ~8x

Dynamic vs Static

- Dynamic:
  - Pro
    - Gets exactly what tests depends on
  - Con
    - Requires executing tests to collect dependencies (overhead)
- Static:
  - Pro
    - Quick analysis without needing to execute tests
  - Con
    - Can over-approximate affected tests due to static analysis
    - May miss dependencies (reflection!)

A conversation from last lecture

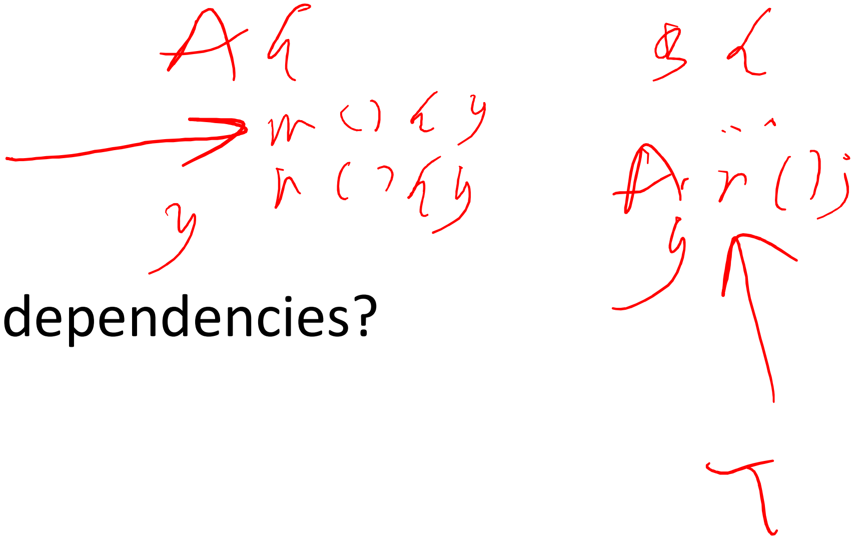
Owolabi: Module-level RTS saves costs but still runs too many tests because classes that changed may not be used by all modules that depend on changed module

Owolabi: So, we need to investigate class-level RTS

Student: But doesn’t the same argument apply to class-level RTS?

Owolabi: ☺

Finer Granularity?



- Why not go even finer granularity of dependencies?
  - Method-level?
  - Statement-level?

- Collecting such dependencies (correctly) is harder/costlier

- More time to collect dependencies
  - Is the extra time worth it?

- Can be unsafe!

Safety Example (1)

Revision 0

```
 class A {
   A() {}
   public void m() { ... }

}
```

Revision 1

```
 class A {
   A() {}
   public void m() { ... }
+  public void n() { ... }
 }
```

```
Class Test {
  @Test test() {
    Method[] methods = A.class.getDeclaredMethods();
    assertEquals(1, methods.length);
  }
}
```

Safety Example (1) – Dynamic Class-Level RTS

Revision 0

```
 class A {
   A() {}
   public void m() { ... }

}
```

Revision 1

```
 class A {
   A() {}
   public void m() { ... }
+  public void n() { ... }
 }
```

Would "Test" be selected?

```
Class Test {
  @Test test() {
    Method[] methods = A.class.getDeclaredMethods();
    assertEquals(1, methods.length);
  }
}
```

t → {A}

Should **"Test" be selected?**

Safety Example (1) – Static Class-Level RTS

Revision 0

```
 class A {
   A() {}
   public void m() { ... }

}
```

Revision 1

```
 class A {
   A() {}
   public void m() { ... }
+  public void n() { ... }
 }
```

```
Class Test {
  @Test test() {
    Method[] methods = A.class.getDeclaredMethods();
    assertEquals(1, methods.length);
  }
}
```

T → {A}

Would "Test" be selected?

***Should* "Test" be selected?**

Safety Example (1) – Dynamic Method-Level RTS

Revision 0

```
class A {
  A() {}
  public void m() { ... }

}
```

Revision 1

```
 class A {
   A() {}
   public void m() { ... }
+  public void n() { ... }
 }
```

Would "test" be selected?

```
@Test test() {
  Method[] methods = A.class.getDeclaredMethods();
  assertEquals(1, methods.length);
}
```

***Should* "test" be selected?**

test → { Object.getDeclaredMethods() }

Safety Example (1) – Static Method-Level RTS

Revision 0

```
 class A {
   A() {}
   public void m() { ... }

}
```

Revision 1

```
 class A {
   A() {}
   public void m() { ... }
+  public void n() { ... }
 }
```

Would “test” be selected?

```
@Test test() {
  Method[] methods = A.class.getDeclaredMethods();
  assertEquals(1, methods.length);
}
```

Should **“test” be selected?**

Safety Example (2)

Revision 0

```
class A {
  A() {}
  int m() { return 1; }
}

class B extends A {
  B() {} // calls A()


}
```

Revision 1

```
 class A {
   A() {}
   int m() { return 1; }
 }

 class B extends A {
   B() {} // calls A()
+  @Override
+  int m() { return 2; }
 }
```

```
@Test test() {
  B b = new B();
  assertEquals(1, b.m());
}
```

Safety Example (2) – Dynamic Class-Level RTS

Revision 0

```
class A {
  A() {}
  int m() { return 1; }
}

class B extends A {
  B() {} // calls A()


}
```

Revision 1

```
class A {
  A() {}
  int m() { return 1; }
}

class B extends A {
  B() {} // calls A()
+ @Override
+ int m() { return 2; }
}
```

```
Class Test {
  @Test test() {
    B b = new B(); assertEquals(1, b.m());
  }
}
```

Would “Test” be selected?

***Should* “Test” be selected?**

Safety Example (2) – Static Class-Level RTS

Revision 0

```
class A {
  A() {}
  int m() { return 1; }
}

class B extends A {
  B() {} // calls A()


}
```

Revision 1

```
 class A {
   A() {}
   int m() { return 1; }
 }

 class B extends A {
   B() {} // calls A()
+  @Override
+  int m() { return 2; }
 }
```

```
Class Test {
  @Test test() {
    B b = new B(); assertEquals(1, b.m());
  }
}
```

Would “Test” be selected?

***Should* “Test” be selected?**

Safety Example (2) – Dynamic Method-Level RTS

Revision 0

```
class A {
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  int m() { return 1; }
}

class B extends A {
  B() {} // calls A()


}
```

Revision 1

```
 class A {
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 class B extends A {
   B() {} // calls A()
+  @Override
+  int m() { return 2; }
 }
```

```
@Test test() {
  B b = new B();
  assertEquals(1, b.m());
}
```

Would "test" be selected?

***Should* "test" be selected?**

Safety Example (2) – Static Method-Level RTS

Revision 0

```
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}

class B extends A {
  B() {} // calls A()


}
```

Revision 1

```
class A {
  A() {}
  int m() { return 1; }
}

class B extends A {
  B() {} // calls A()
+ @Override
+ int m() { return 2; }
}
```

```
@Test test() {
  B b = new B();
  assertEquals(1, b.m());
}
```

Would "test" be selected?

Should **"test" be selected?**

Class-level vs Target/Module-level

- Class-level test selection should be more precise than target/module-level test selection
    - Selects to run all tests in affected test class, not all tests in affected test target/module

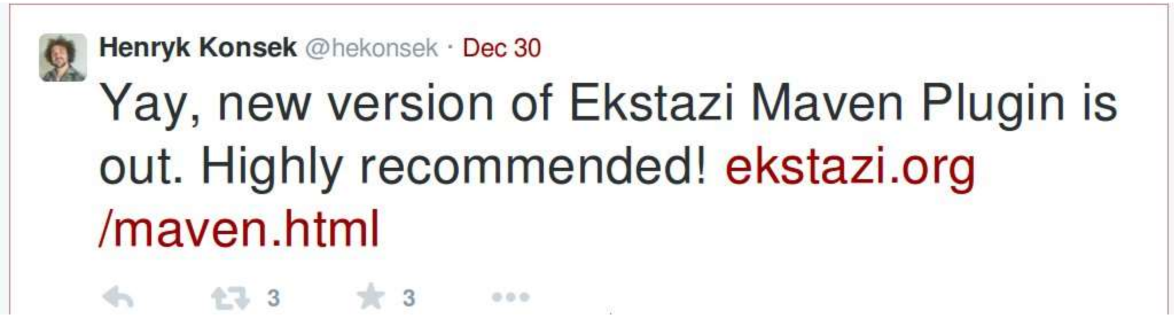
- Why do companies not use class-level test selection?

Some RTS tools you can use today

- Built by researchers (click on links below)
  - STARTS ✓
  - Ekstazi ✓

- Built by industry (click on links below)
  - Microsoft Test Impact Analysis ✓
  - OpenClover Test Optimization ✓
  - Ekstazi Gradle Plugin

Ekstazi “in the wild”



Henryk Konsek @hekonsek · Dec 30

Yay, new version of Ekstazi Maven Plugin is out. Highly recommended! ekstazi.org/maven.html

“Your tool is quite impressive; congratulations!”

an Apache Commons Math developer

Hangout with Google managers and developers

Several feature requests from various (Apache) developers

STARTS “in the wild”

- At least 6 dissertations built on or used STARTS
  - UIUC
  - KTH in Sweden
  - Hacettepe University in Turkey
  - Colorado State University

Questions

?