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

Version Control

1. Commit Changes
2. Fetch Changes
3. Build
4. Test
5. Pass/Fail
6. Release/Deploy

Developers

CI Server

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

Releases per day
- Etsy: 50

What we’ll talk about today

Problem: Regression testing can be very slow

Solution: Techniques to speed up regression testing

Regression testing can be very slow

<table>
<thead>
<tr>
<th>Test Execution Time</th>
<th>Number of Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>~5min</td>
<td>1667</td>
</tr>
<tr>
<td>~10min</td>
<td>641534</td>
</tr>
<tr>
<td>~45min</td>
<td>1296</td>
</tr>
<tr>
<td>~45min</td>
<td>361</td>
</tr>
<tr>
<td>~45min</td>
<td>631</td>
</tr>
<tr>
<td>~4h</td>
<td>4975</td>
</tr>
<tr>
<td>~17h</td>
<td>8663</td>
</tr>
</tbody>
</table>

Re-run many times each day
The cost of regression testing is growing!

• 2015: ~10min 641,534 tests

• Today: ~24min 1,713,729 tests
Testing Google Guava locally: ~1/2 of lecture time

```
INFO Reactor Summary for Guava Maven Parent HEAD-jre-SNAPSHOT:
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 BUILD FAILURE
INFO Total time: 33:38 min
INFO Finished at: 2021-11-22T20:27:28-05:00
```
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

In 2011,

• 75+ million tests run per day

• 20+ revisions per minute

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
- Write fewer tests that satisfy stronger criteria
- Pick and choose test based on how long they take and budget
- 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 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

- An affected test can behave differently due to code changes
- A test is affected if any of its dependencies changed

Diagram:

1. Code + Tests
2. Find Dependencies
3. Dependencies
4. Analyze Dependencies
5. Affected Tests
CS 5154: Software Testing

Regression Testing

Instructor: Owolabi Legunsen

Fall 2021
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\textsuperscript{1})

\begin{itemize}
\item T0: \{A,B,C,D\}
\item T1: \{B\}
\item T2: \{B,C,D\}
\item T3: \{E\}
\item \ldots
\item TN: \{C,F\}
\end{itemize}

\begin{itemize}
\item T0: \{A,B,C,D\}
\item T1: \{B\}
\item T2: \{B,C,D,G\}
\item T3: \{E\}
\item \ldots
\item TN: \{C,F,G\}
\end{itemize}

\textsuperscript{1}Gligoric et al., \textit{Practical Regression Test Selection with Dynamic File Dependencies}. ISSTA 2015, https://github.com/gliga/ekstazi
How Ekstazi works

- **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\(^1\))

STARTS Dependencies

\[\begin{align*}
T0: & \{A, B, C, D\} \\
T1: & \{B, C\} \\
T2: & \{B, C, D\} \\
T3: & \{E\} \\
\vdots \\
TN: & \{C, E, F\}
\end{align*}\]

Is the transitive closure sufficient?

\[\text{Reflexive closure}\]

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
CS 5154: Software Testing

Regression Testing

Instructor: Owolabi Legunsen

Fall 2021
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

For Ekstazi, includes time to run and collect dependencies
Benefit of RTS is measured across many versions

Reduces number of tests: \( \sim 15x \) (10% more than dynamic method-level RTS)
Reduces test execution time: \( \sim 8x \)
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

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

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

Revision 1

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

Revision 1
```java
class A {
    A() {}
    public void m() { ... }
    + public void n() { ... }
}
```

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

Would “Test” be selected?

Should “Test” be selected?
Safety Example (1) – Static Class-Level RTS

Revision 0

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

Revision 1

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

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

Would “Test” be selected?

Should “Test” be selected?
Safety Example (1) – Dynamic Method-Level RTS

Revision 0
```java
class A {
    A() {}
    public void m() { ... }
}
```

Revision 1
```java
class A {
    A() {}
    public void m() { ... }
    + public void n() { ... }
}
```

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

Would “test” be selected?

Should “test” be selected?

Test → ? Object::getDeclaredMethods()}
Safety Example (1) – Static Method-Level RTS

Revision 0

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

Revision 1

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

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

Would “test” be selected?

Should “test” be selected?
Safety Example (2)

Revision 0

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

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

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

Revision 1

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

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

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

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

Revision 1

```java
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

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

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

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

Revision 1

```java
class A {
    A() {}  // added @Override annotation
    int m() { return 1; }
}

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

Would “test” be selected?  

Should “test” be selected?
Safety Example (2) – Static Method-Level RTS

Revision 0

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

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

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

Revision 1

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

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

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
  • Open Clover Test Optimization
  • Ekstazi Gradle Plugin
Ekstazi “in the wild”

“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