The Role of Method Call Optimizations in the Efficiency of Java Generics

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Terminology

Java HotSpot Virtual Machine (JVM)

An application developed by Oracle that interprets a compiled Java program.

Just-in-Time Compiler (JIT)

A part of the JVM that optimizes code through recompilations at run-time.

Java Generics

A type in Java that allow the contents of a container to be bounded to a single, specified type. (E.g. `ArrayList<String>`).

Research Goals

- Describe the influence of Java Generics on run times of Java programs
- Detect the presence of optimizations such as inlining and devirtualization
- Explore tools and methodology for observing JIT optimizations of Java Generics:
    - Profilers such as XProf
    - Internal logging of JIT

Challenges: JVM Complexity

- The HotSpot JVM documentation is not detailed and often not up to date
- Which JIT optimizations matter and why is difficult to assess
- The HotSpot JVM is multi-threaded
- JIT optimizations may be scheduled differently among multiple runs of the same program

Challenges: JVM Diagnostics

- Observer Effect:
    - Profilers can influence JIT optimizations as well as program run times.
- Absence of Relevant Data:
    - Differences among run times for multiple runs of the same program may not be explainable by using the tools at our disposal.
- Presence of Irrelevant Data:
    - Tools can provide overwhelming amounts of information that may or may not be useful in describing observations.

Java Execution Model

Java code is executed through a two-phase compilation process:

- Initial compilation into *bytecode*
- Additional recompilation by the JIT

Three internal representations exist:

- Bytecode
- Native code produced by the JIT
- The Sea of Nodes within the JIT

JIT Optimizations

- During JIT compilation, optimizations are made to increase efficiency and decrease run time of the program

Devirtualization

- The JVM uses *Virtual Method Lookup* to locate the correct method
- JIT replaces these calls with jumps after repeated look-up

Inlining

The method call is replaced by the code it represents

- A method call threshold must be reached before optimizations take place

Java Generics

- `public class ArrayList<T>`
- `ArrayList<String> strArrayList = new ArrayList<String>();`
- `public class ArrayListInteger extends ArrayList<Integer>`

The last example is referred to as *bound narrowing*, where the element type of a class is more specific than that of its superclass

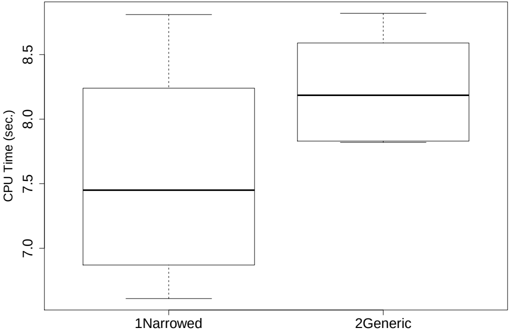
Bound Narrowing

- `public class Generic<K, V> extends HashMap<K, V>`
- `public class Narrowed extends HashMap<Integer, String>`
- `hashMap = new Generic<Integer, String>();`
- `hashMap = new Narrowed();`

Test Examples

```
public boolean containsValue(String value) {
    // some unimportant code removed
    Entry[] tab = table;
    for (int i = 0; i < tab.length; i++)
        for (Entry e = tab[i]; e != null; e = e.next)
            if (value.equals(e.value))
                return true;
    return false;
}
```

Narrowed and Generic Test Runs



Running times for Narrowed and Generic runs.

- 100,000,000 method calls for `containsValue`
- 10 test runs for each of Narrowed and Generic.

Instability

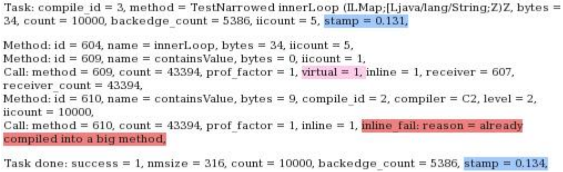
Running the same code multiple times may result in differing run times: instability

	Run 1	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Run 7**	**Run 8**	**Run 9**	**Run 10**
Narrowed	6.87	8.09	8.24	8.81	6.87	8.58	6.87	8.03	6.87	6.61
Generic	8.55	8.53	7.84	7.83	8.59	8.82	7.82	7.83	7.83	8.60

- In some cases two runs may produce identical logs (Generic)
- In other cases there are differences in logs (Narrowed)
- We can use the differences in logs to explain the second type of instability

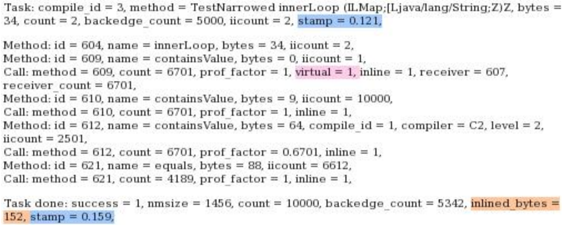
LogCompilation of Two Narrowed Test Runs: Compilations

- Slow Run: 8.87 s



```
Task: compile_id = 3, method = TestNarrowed innerLoop (ILMap;[Ljava/lang/String;Z)Z, bytes =
34, count = 10000, backedge_count = 5386, iicount = 5, stamp = 0.131,

Method: id = 604, name = innerLoop, bytes = 34, iicount = 5,
Method: id = 609, name = containsValue, bytes = 0, iicount = 1,
Call: method = 609, count = 43394, prof_factor = 1, virtual = 1, inline = 1, receiver = 607,
receiver_count = 43394,
Method: id = 610, name = containsValue, bytes = 9, compile_id = 2, compiler = C2, level = 2,
iicount = 10000,
Call: method = 610, count = 43394, prof_factor = 1, inline = 1, inline_fail: reason = already
compiled into a big method,

Task done: success = 1, nmsize = 316, count = 10000, backedge_count = 5386, stamp = 0.134,
```

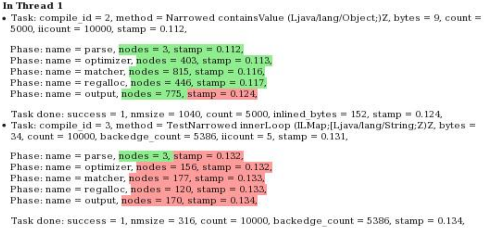
- Fast Run: 6.97 s



```
Task: compile_id = 3, method = TestNarrowed innerLoop (ILMap;[Ljava/lang/String;Z)Z, bytes =
34, count = 2, backedge_count = 5000, iicount = 2, stamp = 0.121,

Method: id = 604, name = innerLoop, bytes = 34, iicount = 2,
Method: id = 609, name = containsValue, bytes = 0, iicount = 1,
Call: method = 609, count = 6701, prof_factor = 1, virtual = 1, inline = 1, receiver = 607,
receiver_count = 6701,
Method: id = 610, name = containsValue, bytes = 9, iicount = 10000,
Call: method = 610, count = 6701, prof_factor = 1, inline = 1,
Method: id = 612, name = containsValue, bytes = 64, compile_id = 1, compiler = C2, level = 2,
iicount = 2501,
Call: method = 612, count = 6701, prof_factor = 0.6701, inline = 1,
Method: id = 621, name = equals, bytes = 88, iicount = 6612,
Call: method = 621, count = 4189, prof_factor = 1, inline = 1,

Task done: success = 1, nmsize = 1456, count = 10000, backedge_count = 5342, inlined_bytes =
152, stamp = 0.159,
```

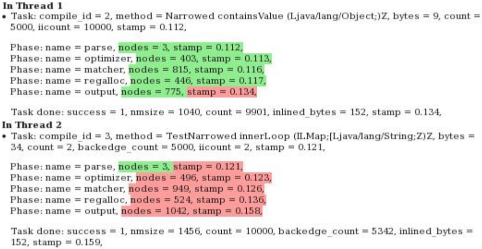
LogCompilation of Two Narrowed Test Runs: Nodes

- Slow Run: 8.87 s



```
In Thread 1
• Task: compile_id = 2, method = Narrowed containsValue (Ljava/lang/Object;)Z, bytes = 9, count =
  5000, iicount = 10000, stamp = 0.112,

  Phase: name = parse, nodes = 3, stamp = 0.112,
  Phase: name = optimizer, nodes = 403, stamp = 0.113,
  Phase: name = matcher, nodes = 815, stamp = 0.116,
  Phase: name = regalloc, nodes = 446, stamp = 0.117,
  Phase: name = output, nodes = 775, stamp = 0.124,

  Task done: success = 1, nmsize = 1040, count = 5000, inlined_bytes = 152, stamp = 0.124,
• Task: compile_id = 3, method = TestNarrowed innerLoop (ILMap;[Ljava/lang/String;Z)Z, bytes =
  34, count = 10000, backedge_count = 5386, iicount = 5, stamp = 0.131,

  Phase: name = parse, nodes = 3, stamp = 0.132,
  Phase: name = optimizer, nodes = 156, stamp = 0.132,
  Phase: name = matcher, nodes = 177, stamp = 0.133,
  Phase: name = regalloc, nodes = 120, stamp = 0.133,
  Phase: name = output, nodes = 170, stamp = 0.134,

  Task done: success = 1, nmsize = 316, count = 10000, backedge_count = 5386, stamp = 0.134,
```

- Fast Run: 6.97 s



```
In Thread 1
• Task: compile_id = 2, method = Narrowed containsValue (Ljava/lang/Object;)Z, bytes = 9, count =
  5000, iicount = 10000, stamp = 0.112,

  Phase: name = parse, nodes = 3, stamp = 0.112,
  Phase: name = optimizer, nodes = 403, stamp = 0.113,
  Phase: name = matcher, nodes = 815, stamp = 0.116,
  Phase: name = regalloc, nodes = 446, stamp = 0.117,
  Phase: name = output, nodes = 775, stamp = 0.134,

  Task done: success = 1, nmsize = 1040, count = 9901, inlined_bytes = 152, stamp = 0.134,
In Thread 2
• Task: compile_id = 3, method = TestNarrowed innerLoop (ILMap;[Ljava/lang/String;Z)Z, bytes =
  34, count = 2, backedge_count = 5000, iicount = 2, stamp = 0.121,

  Phase: name = parse, nodes = 3, stamp = 0.121,
  Phase: name = optimizer, nodes = 496, stamp = 0.123,
  Phase: name = matcher, nodes = 949, stamp = 0.126,
  Phase: name = regalloc, nodes = 524, stamp = 0.136,
  Phase: name = output, nodes = 1042, stamp = 0.158,

  Task done: success = 1, nmsize = 1456, count = 10000, backedge_count = 5342, inlined_bytes =
  152, stamp = 0.159,
```

XProf

- Slow Run: 8.87 s

```
    Compiled + native   Method
77.0%    676  +      0   Narrowed.containsValue
21.8%    191  +      0   TestNarrowed.innerLoop
98.7%    867  +      0   Total compiled
```

- Fast Run: 6.97 s

```
    Compiled + native   Method
99.1%    672  +      0   TestNarrowed.innerLoop
 0.1%      1  +      0   Narrowed.containsValue
99.3%    673  +      0   Total compiled
```

Conclusions

- Able to classify and distinguish instability through:
  - Differences in LogCompilation
  - Differences in XProf output
- Observed evidence of specific methods being inlined
- Developed strategies for describing specific behaviors of JIT

Open Problems and Future Work

- Use these strategies to explain other behaviors associated with Java generics
- More recent versions of Java SE 6
- Extend to Java SE 7