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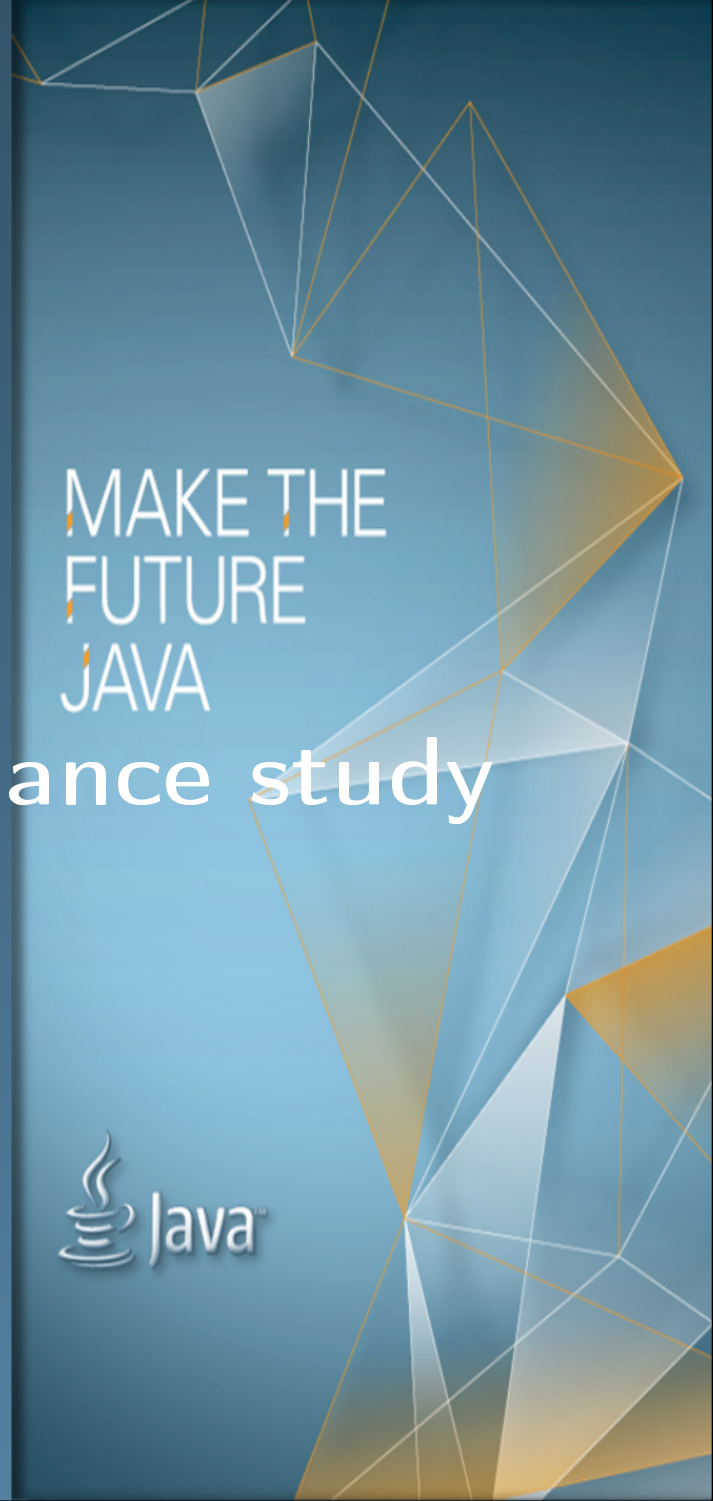

JDK 8: Lambda Performance study

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Lambda

Lambda: performance

Lambda

vs

Anonymous Class

Lambda: performance

Lambda

- linkage

vs

Anonymous Class

- class loading

Lambda: performance

Lambda

- linkage
- capture

vs

Anonymous Class

- class loading
- instantiation

Lambda: performance

Lambda

- linkage
- capture
- invocation

vs

Anonymous Class

- class loading
- instantiation
- invocation

Lambda: SUT[1]

- Intel® Core™ i5-520M (Westmere) [2.0 GHz] 1x2x2
  - Xubuntu 11.10 (64-bits)
- HDD Hitachi 320Gb, 5400 rpm

[1] System Under Test

Linkage

Linkage: How?

```
@GenerateMicroBenchmark
@BenchmarkMode(Mode.SingleShotTime)
@OutputTimeUnit(TimeUnit.SECONDS)
@Fork(value = 5, warmups = 1)
public static Level link() {
    ...
};
```

Linkage: How?

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Linkage: What?

Required:

- lots of lambdas

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e.g. `()->()->()->()->()->...->()->null`

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- lots of different lambdas

e.g. `()->()->()->()->()->...->()->null`

```
@FunctionalInterface
public interface Level {
    Level up();
}
```

Linkage: lambda chain

```
...

public static Level get1023(String p) {
    return () -> get1022(p);
}

public static Level get1024(String p) {
    return () -> get1023(p);
}

...
```

Linkage: anonymous chain

```
...

public static Level get1024(final String p){
    return new Level() {
        @Override
        public Level up() {
            return get1023(p);
        }
    };
}

...
```

Linkage: benchmark

```
@GenerateMicroBenchmark
...
public static Level link() {
    Level prev = null;
    for(Level curr = Chain0.get1024("str");
        curr != null;
        curr = curr.up() ) {
        prev = curr;
    }
    return prev;
}
```

Linkage: results (hot)

	-TieredCompilation		+TieredCompilation	
	anonymous	lambda	anonymous	lambda
1K	0.47	0.80	0.35	0.62
4K	1.58	2.16	1.12	1.58
16K	4.96	5.62	4.22	4.67
64K	16.51	17.53	15.68	16.21

time, seconds

Linkage: results (cold)

	-TieredCompilation		+TieredCompilation	
	anonymous	lambda	anonymous	lambda
1K	7.24	0.95	6.98	0.77
4K	16.64	2.46	16.16	1.84
16K	22.44	5.92	21.25	4.90
64K	34.52	18.20	33.34	16.33

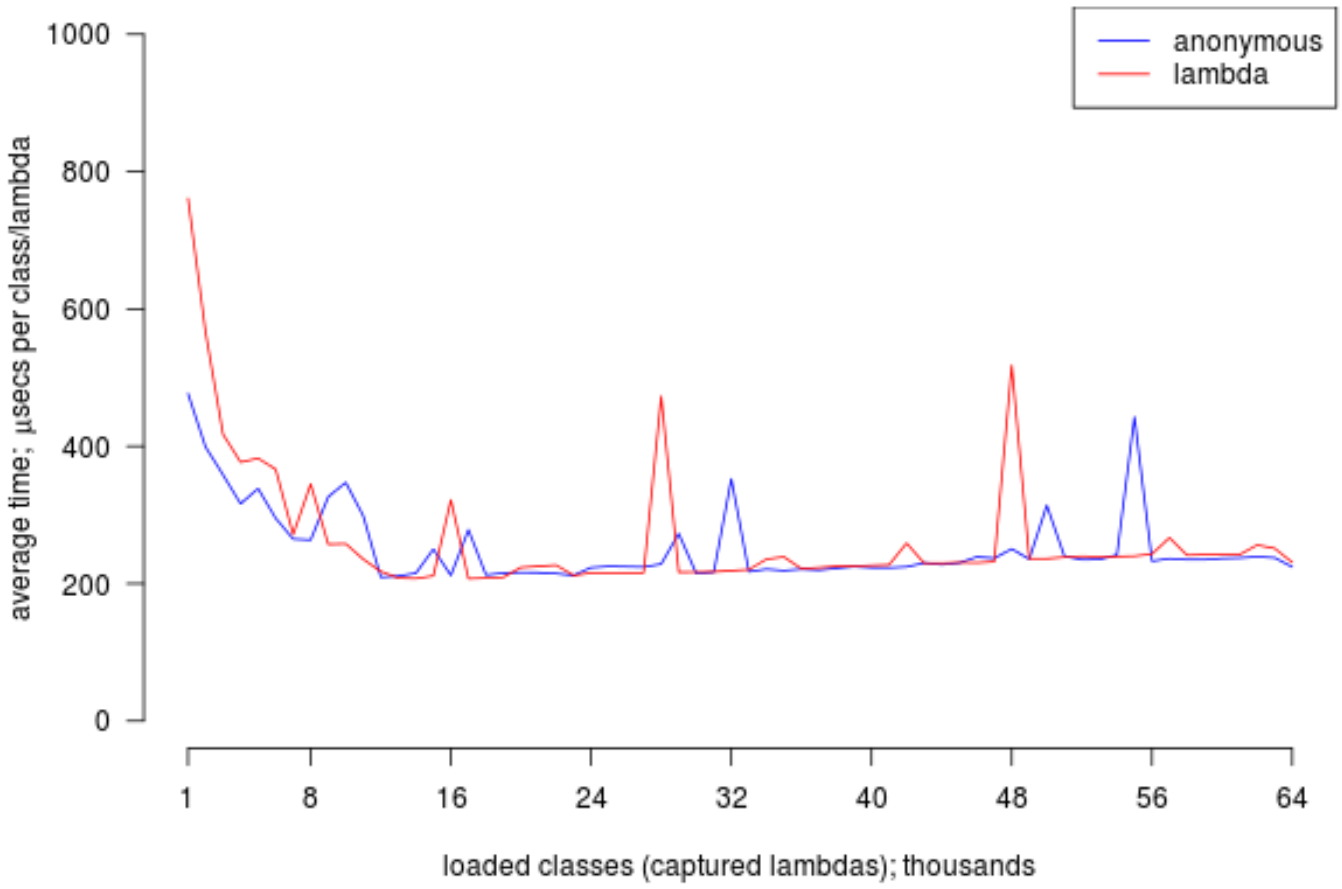
time, seconds

Linkage: results (cold)

	-TieredCompilation		+TieredCompilation	
	anonymous	lambda	anonymous	lambda
1K	1440%	19%	1894%	24%
4K	953%	14%	1343%	16%
16K	352%	5%	404%	5%
64K	109%	4%	113%	1%

performance hit

Linkage: results (hot)



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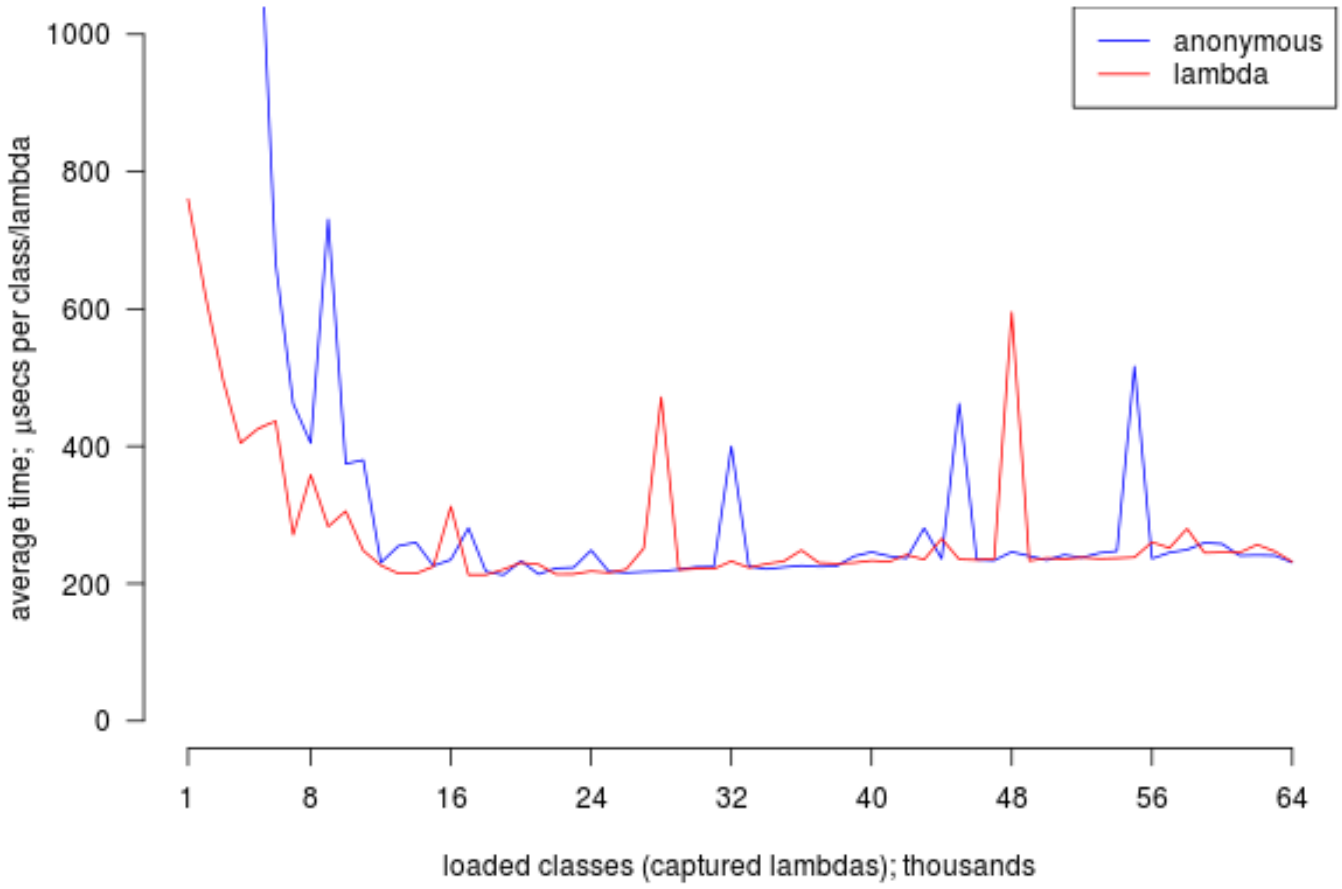
Linkage: results (cold)



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Linkage: Main contributors (lambda)

25% - resolve_indy
    13% - link_MH_constant
44% - LambdaMetaFactory
    20% - Unsafe.defineClass

Capture

Non-capture lambda: benchmarks

```
public static Supplier<String> lambda(){
    return () -> "42";
}
```

Non-capture lambda: benchmarks

```
public static Supplier<String> lambda(){
    return () -> "42";
}

public static Supplier<String> anonymous(){
    return new Supplier<String>() {
        @Override
        public String get() {
            return "42";
        }
    };
}
```

Non-capture lambda: benchmarks

```
public static Supplier<String> lambda(){
    return () -> "42";
}

public static Supplier<String> anonymous(){
    return new Supplier<String>() {
        @Override
        public String get() {
            return "42";
        }
    };
}

public static Supplier<String> baseline(){
    return null;
}
```

Non-capture lambda: results

	single thread	
baseline	5.29 ± 0.02	
anonymous	6.02 ± 0.02	
cached anonymous	5.36 ± 0.01	
lambda	5.31 ± 0.02	

average time, nsecs/op

Non-capture lambda: results

	single thread	max threads (4)
baseline	5.29 ± 0.02	5.92 ± 0.02
anonymous	6.02 ± 0.02	12.40 ± 0.09
cached anonymous	5.36 ± 0.01	5.97 ± 0.03
lambda	5.31 ± 0.02	5.93 ± 0.07

average time, nsecs/op

Capture: lambda

```
public Supplier<String> lambda() {
    String localString = someString;
    return () -> localString;
}
```

Instance size = 16 bytes [2]

[2] 64-bits VM, -XX:+CompressedOops

Capture: anonymous (static context)

```
public static Supplier<String> anonymous() {
    String localString = someString;
    return new Supplier<String>() {
        @Override
        public String get() {
            return localString;
        }
    };
}
```

Instance size = 16 bytes [3]

[3] 64-bits VM, -XX:+CompressedOops

Capture: anonymous (non-static context)

```
public Supplier<String> anonymous() {
    String localString = someString;
    return new Supplier<String>() {
        @Override
        public String get() {
            return localString;
        }
    };
}
```

Instance size = 24 bytes [3]

[3] 64-bits VM, -XX:+CompressedOops

Capture: results

	single thread	max threads
anonymous(static)	6.94 ± 0.03	13.4 ± 0.33
anonymous(non-static)	7.88 ± 0.09	18.7 ± 0.17
lambda	8.29 ± 0.04	16.0 ± 0.28

average time, nsec/op

Capture: results

	single thread	max threads
anonymous(static)	6.94 ± 0.03	13.4 ± 0.33
anonymous(non-static)	7.88 ± 0.09	18.7 ± 0.17
lambda	8.29 ± 0.04	16.0 ± 0.28

average time, nsec/op

Capture: exploring asm

```
...
mov     0x68(%r10),%ebp
                  ; *getstatic someString
mov     $0xefe53110,%r10d
                  ; metadata('Capture1$$Lambda$1')
movzbl 0x186(%r12,%r10,8),%r8d
add     $0xfffffffffffffffc,%r8d
test    %r8d,%r8d
jne     allocation_slow_path
mov     0x60(%r15),%rax
mov     %rax,%r11
add     $0x10,%r11
cmp     0x70(%r15),%r11
jae     allocation_slow_path
mov     %r11,0x60(%r15)
prefetchnta 0xc0(%r11)
mov     0xa8(%r12,%r10,8),%r10
mov     %r10,(%rax)
movl    $0xefe53110,0x8(%rax)
                  ; {metadata('Capture1$$Lambda$1')}
mov     %ebp,0xc(%rax)
                  ;*invokevirtual allocateInstance
...
```

Capture: exploring asm

```
...
mov     0x68(%r10),%ebp
                  ; *getstatic someString
mov     $0xefe53110,%r10d
                  ; metadata('Capture1$$Lambda$1')
movzbl 0x186(%r12,%r10,8),%r8d
add     $0xfffffffffffffffc,%r8d
test    %r8d,%r8d
jne     allocation_slow_path
mov     0x60(%r15),%rax
mov     %rax,%r11
add     $0x10,%r11
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jae     allocation_slow_path
mov     %r11,0x60(%r15)
prefetchnta 0xc0(%r11)
mov     0xa8(%r12,%r10,8),%r10
mov     %r10,(%rax)
movl    $0xefe53110,0x8(%rax)
                  ; {metadata('Capture1$$Lambda$1')}
mov     %ebp,0xc(%rax)
                  ;*invokevirtual allocateInstance
...
```

← check
if class was initialized
(Unsafe.allocateInstance from jsr292 LF's)

Capture: benchmark

Can we find a benchmark or/and JVM environment where allocation size difference is significant?

Capture: benchmark

```
@GenerateMicroBenchmark
@BenchmarkMode(Mode.AverageTime)
@OutputTimeUnit(TimeUnit.NANOSECONDS)
@OperationsPerInvocation(SIZE)[4]
public Supplier<Supplier> chain_lambda() {
    Supplier<Supplier> top = null;
    for (int i = 0; i < SIZE; i++) {
        Supplier<Supplier> current = top;
        top = () -> current;
    }
    return top;
}
```

[4] SIZE==1048576

Capture: chain results

- out of the box

	1 thread	
anonymous	8.4 ± 1.1	
lambda	6.7 ± 0.6	

- -Xmx1g

anonymous	11 ± 1.2	
lambda	7.6 ± 0.4	

- -Xmx1g -Xmn800m

anonymous	8.1 ± 0.9	
lambda	6.0 ± 0.7	

average time, nsecs/op

Capture: beware of microbenchmarks

- out of the box

	1 thread	4 threads
anonymous	8.4 ± 1.1	47 ± 16
lambda	6.7 ± 0.6	28 ± 10

- -Xmx1g

anonymous	11 ± 1.2	84 ± 9
lambda	7.6 ± 0.4	47 ± 20

- -Xmx1g -Xmn800m

anonymous	8.1 ± 0.9	123 ± 18
lambda	6.0 ± 0.7	28 ± 14

average time, nsecs/op

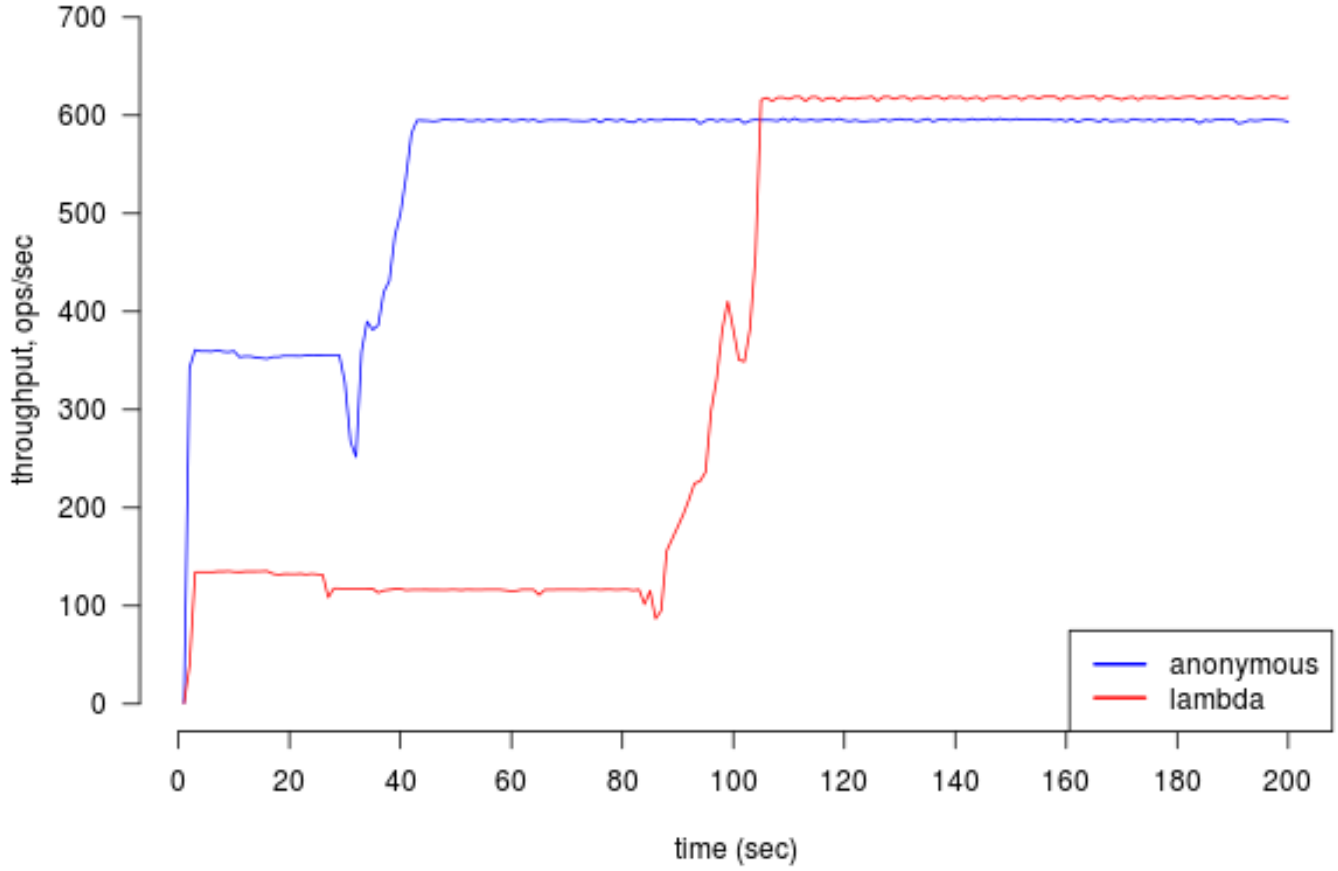
Capture warmup (time-to-performance)

Capture: time-to-performance

- lots of different lambdas (e.g. linkage benchmark)
- throughput (-bm Throughput)
- no warmup (-wi 0)
- get throughput each second (-r 1)
- large amount of iterations (-i 200)

Capture: time-to-performance

4K chain; -XX:-TieredCompilation



Capture: lambda slow warmup

Main culprits:

- jsr292 LF implementation
  - layer of LF's generated methods

Capture: LF's inline tree

```
@ 1   oracle.micro.benchmarks.jsr335.lambda.chain.lamb.cap1.common.Chain3:get3161
  @ 1   java.lang.invoke.LambdaForm$MH/1362679684::linkToCallSite
    @ 1   java.lang.invoke.Invokers::getCallSiteTarget
      @ 4   java.lang.invoke.ConstantCallSite::getTarget
    @ 10   java.lang.invoke.LambdaForm$MH/90234171::convert
      @ 9   java.lang.invoke.LambdaForm$DMH/1041177261::newInvokeSpecial_L_L
        @ 1   java.lang.invoke.DirectMethodHandle::allocateInstance
          @ 12   sun.misc.Unsafe::allocateInstance (0 bytes)   (intrinsic)
        @ 6   java.lang.invoke.DirectMethodHandle::constructorMethod
        @ 16   ...$$Lambda$936::<init>
          @ 1   java.lang.invoke.MagicLambdaImpl::<init> (5 bytes)
            @ 1   java.lang.Object::<init> (1 bytes)
```

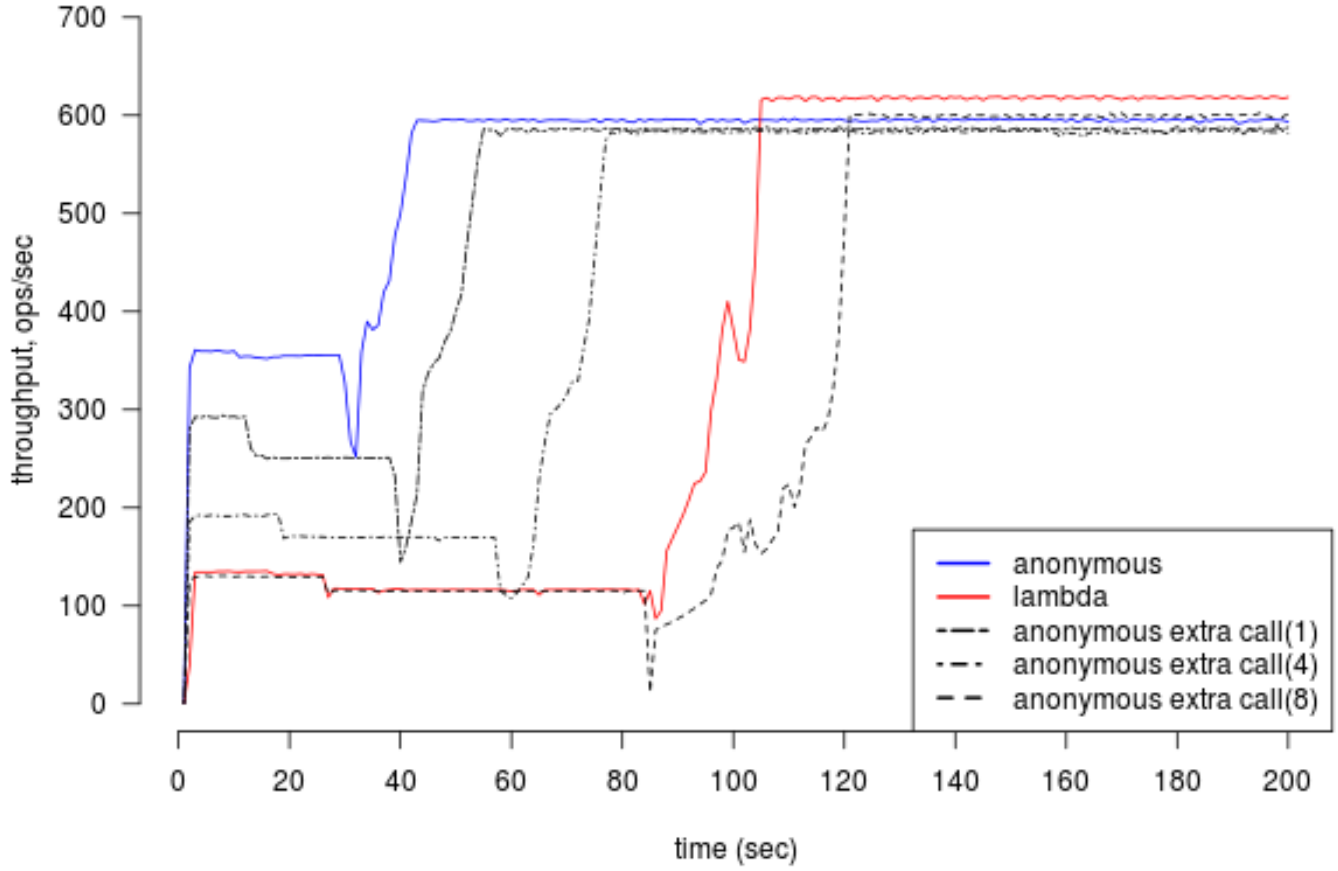
Capture: lambda slow warmup

Main culprits:

- jsr292 LF implementation
  - layer of LF's generated methods
- HotSpot (interpreter)
  - calling a method is hard (even simple delegating methods)

Capture: time-to-performance

`extra invocations for anonymous`



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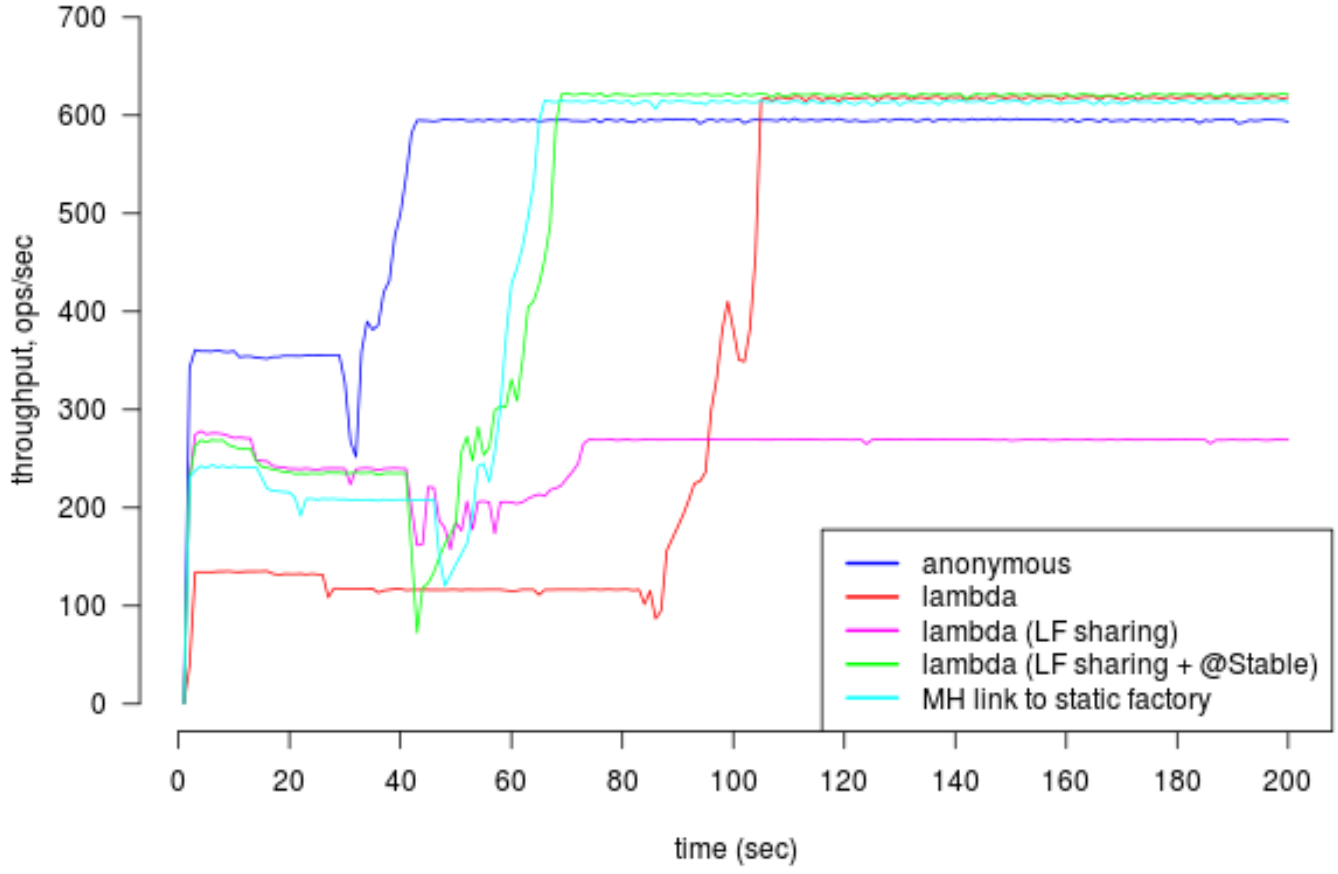
Capture: lambda slow warmup

Areas for improvement:

- Lambda runtime representation?
- jsr292 LF implementation?
- Tiered Compilation?
- HotSpot (interpreter)?

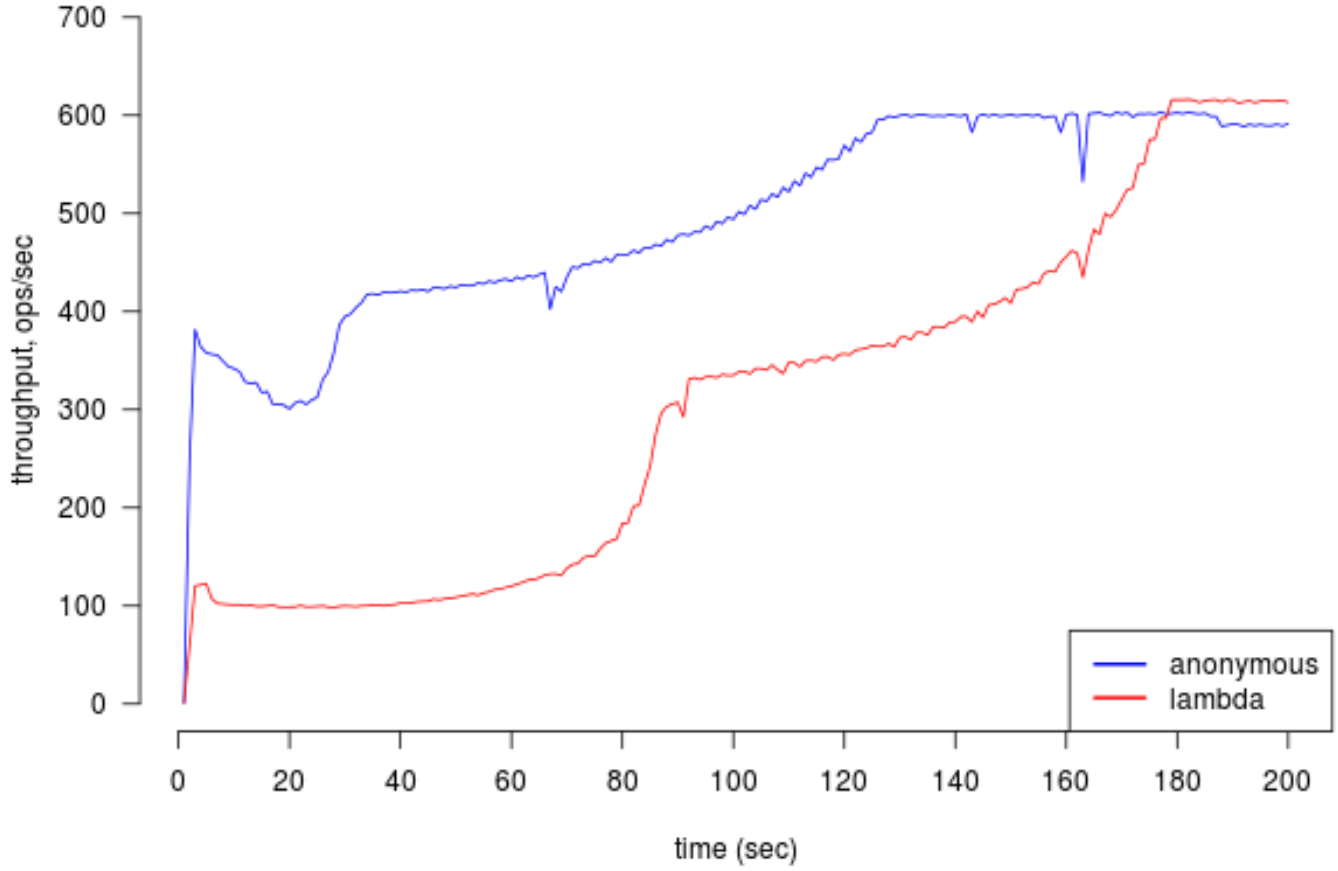
Capture: time-to-performance

`4K chain; -XX:-TieredCompilation`



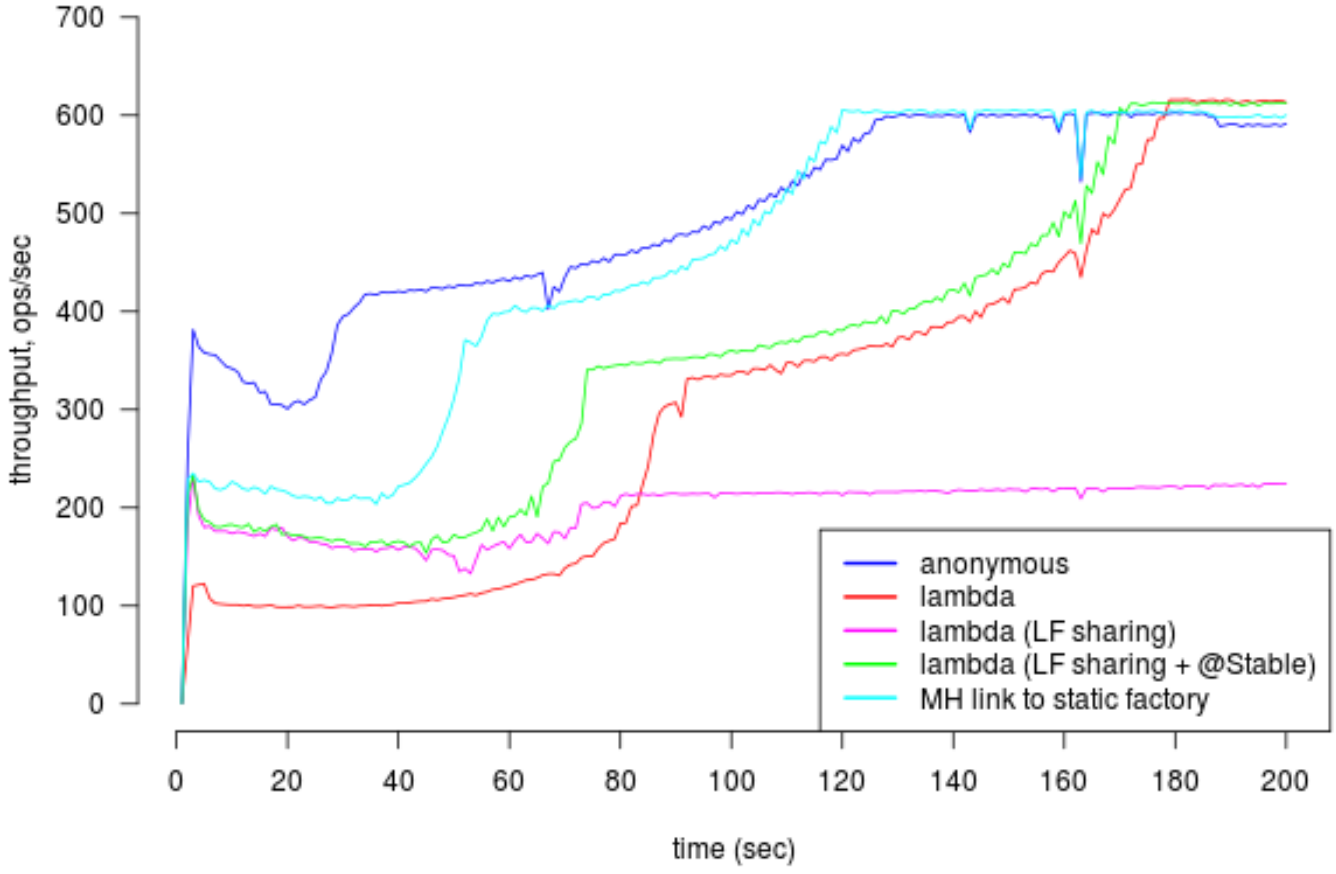
Capture: time-to-performance

`4K chain; -XX:+TieredCompilation`



Capture: time-to-performance

`4K chain; -XX:+TieredCompilation`



Invocation

Invocation: performance

Lambda invocation behaves
exactly as anonymous class invocation

Invocation: performance

Lambda[5] invocation behaves exactly as anonymous class invocation

[5] current implementation

Lambda and optimizations

Inline: benchmark

```
public String id_lambda(){
    String str = "string";
    Function<String, String> id = s -> s;
    return id.apply(str);
}
```

Inline: benchmark

```
public String id_lambda(){
    String str = "string";
    Function<String, String> id = s -> s;
    return id.apply(str);
}

public String id_ideal(){
    String str = "string";
    return str;
}
```

Inline: results

ideal	5.38 ± 0.03
anonymous	5.40 ± 0.02
cached anonymous	5.37 ± 0.03
lambda	5.38 ± 0.02

average time, nsecs/op

Inline: asm

ideal, anonymous, cached anonymous:

```
...
mov   $0x7d75cd018,%rax   ;   {oop("string")}
...
```

lambda:

```
...
mov   $0x7d776c8b0,%r10   ;   {oop(a 'TestOpt0$$Lambda$1')}
mov   0x8(%r10),%r11d
cmp   $0xefe56908,%r11d   ;   {metadata('TestOpt0$$Lambda$1')}
jne   <invokeinterface_slowpath>
mov   $0x7d75cd018,%rax   ;   {oop("string")}
...
```

Scalar replacement: benchmark

```
public String sup_lambda(){
    String str = "string";
    Supplier<String> sup = () -> str;
    return sup.get();
}
```

Scalar replacement: benchmark

```
public String sup_lambda(){
    String str = "string";
    Supplier<String> sup = () -> str;
    return sup.get();
}

public String sup_ideal(){
    String str = "string";
    return str;
}
```

Scalar replacement: results

ideal	5.49 ± 0.03
anonymous	5.52 ± 0.02
lambda	5.53 ± 0.02

average time, nsecs/op

Scalar replacement: asm

ideal, anonymous, lambda:

```
...
mov   $0x7d75cd018,%rax   ;   {oop("string")}
...
```

Streams

Lazy vs Eager: benchmark

```
List<Integer> list = new ArrayList<>();

@GenerateMicroBenchmark
public int forEach_4filters() {
    Counter c = new Counter();
    list.stream()
        .filter(i -> (i & 0xf) == 0)
        .filter(i -> (i & 0xff) == 0)
        .filter(i -> (i & 0xfff) == 0)
        .filter(i -> (i & 0xffff) == 0)
        .forEach(c::add);
    return c.sum;
}
```

Lazy vs Eager: benchmark

```
List<Integer> list = new ArrayList<>();

@GenerateMicroBenchmark
public int forEach_3filters() {
    Counter c = new Counter();
    list.stream()

        .filter(i -> (i & 0xff) == 0)
        .filter(i -> (i & 0xfff) == 0)
        .filter(i -> (i & 0xffff) == 0)
        .forEach(c::add);
    return c.sum;
}
```

Lazy vs Eager: benchmark

```
List<Integer> list = new ArrayList<>();

@GenerateMicroBenchmark
public int forEach_2filters() {
    Counter c = new Counter();
    list.stream()


        .filter(i -> (i & 0xfff) == 0)
        .filter(i -> (i & 0xffff) == 0)
        .forEach(c::add);
    return c.sum;
}
```

Lazy vs Eager: benchmark

```
@GenerateMicroBenchmark
public int iterator_4filters() {
    Counter c = new Counter();
    Iterator<Integer> iterator = list
            .stream()
            .filter(i -> (i & 0xf) == 0)
            .filter(i -> (i & 0xff) == 0)
            .filter(i -> (i & 0xfff) == 0)
            .filter(i -> (i & 0xffff) == 0)
            .iterator();
    while (iterator.hasNext()) {
            c.add(iterator.next());
    }
    return c.sum;
}
```

Lazy vs Eager: benchmark

```
@GenerateMicroBenchmark
public int for_4filters() {
    Counter c = new Counter();
    for(Integer i : list) {
        if((i & 0xf) == 0 &&
           (i & 0xff) == 0 &&
           (i & 0xfff) == 0 &&
           (i & 0xffff) == 0) {
            c.add(i);
        }
    }
    return c.sum;
}
```

Lazy vs Eager: results

	2 filters	3 filters	4 filters
forEach	3.0	1.8	1.7
iterator	1.1	0.7	0.6
for	2.4	2.4	2.3

throughput, ops/sec

Q&A?