Dynamic Proxies in Java

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History of Dynamic Proxies

- **RMI used to need a separate compile step**
  - **Tool "rmic" still found in JDK/bin directory**
    - **Creates *stubs* and *skeletons* to manage remote method invocations**
- **Java 1.3 released in May 2000**
  - **First version with dynamic proxies**
  - **Functional interface of InvocationHandler to service all methods on proxy**
  - **Not necessary to use "rmic" or similar tools for deployment**
  - **Made it possible to build flexible, dynamic systems**

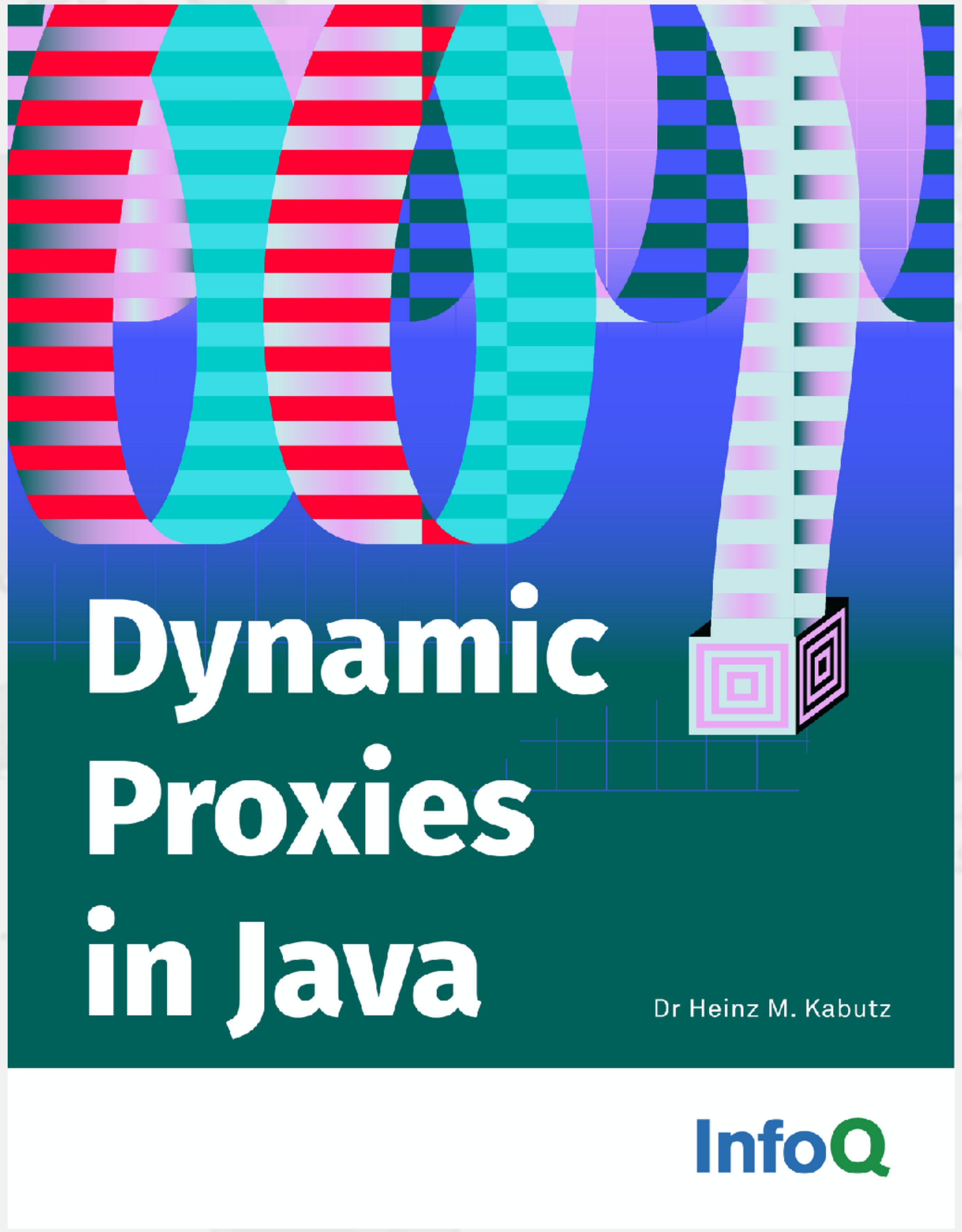
Big Win

- Don't Repeat Yourself (DRY) at its best
  - Write a single InvocationHandler implementation
  - Reuse for hundreds of classes
- We once replaced 600,000 code statements with 1 dynamic proxy
  - Code had been generated, but was maintained by hand
  - Dynamic proxy easier to maintain
  - Less code

Infrastructure Code

- **Dynamic proxies in tools and frameworks**
  - **Spring**
  - **Annotations**
  - **Dependency injection**
  - **Hibernate**
  - **Gradle**

Dynamic Proxies in Java



- Free download from
  - www.infoq.com/minibooks/java-dynamic-proxies

1: Handcrafted Proxies

Handcrafted Proxies

- **Before learning how to avoid duplicate code, we will copy & paste**
  - **And then in next section will use *dynamic proxies* instead**

Virtual Proxy

Virtual Proxy

- **Delays expensive object creation**
  - **placeholder object creates costly object on demand**

CustomMap Interface

- **Reduced version of the Map interface**

```
public interface CustomMap<K, V> {
  int size();
  V get(Object key);
  V put(K key, V value);
  V remove(Object key);
  void clear();
  void forEach(BiConsumer<? super K, ? super V> action);
}
```

CustomHashMap Implementation

- **Delegates methods to a java.util.HashMap**
  - **Repetitive and error prone**

```
public class CustomHashMap<K, V> implements CustomMap<K, V> {
  private final Map<K, V> map = new HashMap<>();
  { System.out.println("CustomHashMap constructed"); }
  public int size() { return map.size();}
  public V get(Object key) { return map.get(key); }
  public V put(K key, V value) { return map.put(key, value); }
  public V remove(Object key) { return map.remove(key); }
  public void clear() { map.clear(); }
  public void forEach(BiConsumer<? super K, ? super V> action) {
    map.forEach(action);
  }
  public String toString() { return map.toString(); }
}
```

VirtualCustomMap Virtual Proxy

- **Has a reference to a Supplier for CustomMap**
  - **Is created in the getRealMap() method**

```java
public class VirtualCustomMap<K, V>
    implements CustomMap<K, V> {
  private final Supplier<CustomMap<K, V>> mapSupplier;
  private CustomMap<K, V> realMap;
  public VirtualCustomMap(
      Supplier<CustomMap<K, V>> mapSupplier) {
    this.mapSupplier = mapSupplier;
  }
  private CustomMap<K, V> getRealMap() {
    // not thread-safe
    if (realMap == null) realMap = mapSupplier.get();
    return realMap;
  }
```

VirtualCustomMap Methods

```
  public int size() {
    return getRealMap().size();
  }
  public V get(Object key) {
    return getRealMap().get(key);
  }
  public V put(K key, V value) {
    return getRealMap().put(key, value);
  }
  public V remove(Object key) {
    return getRealMap().remove(key);
  }
  public void clear() { getRealMap().clear(); }
  public void forEach(
        BiConsumer<? super K, ? super V> action) {
    getRealMap().forEach(action);
  }
}
```

Using VirtualCustomMap

- **CustomHashMap made when method called**
  - **Does not matter which method we call first**

```java
CustomMap<String, Integer> map =
    new VirtualCustomMap<>(CustomHashMap::new);
System.out.println("Virtual Map created");
map.put("one", 1);
map.put("life", 42);
System.out.println("get(\"life\") = " + map.get("life"));
System.out.println("size() = " + map.size());
System.out.println("clearing map");
map.clear();
System.out.println("size() = " + map.size());
```

```
Virtual Map created
CustomHashMap constructed
get("life") = 42
size() = 2
clearing map
size() = 0
```

2: Dynamic Proxy

2: Dynamic Proxy

- **Avoid copy and paste programming**
  - **A bug needs to be fixed everywhere**
- **Better is static or dynamic code generation**

Proxy.newProxyInstance()

Proxy.newProxyInstance()

- **Takes three parameters**
  - **ClassLoader where the new proxy class is loaded**
  - **Class<?>[] an array containing all interfaces our proxy object must implement**
  - **InvocationHandler a handler that's called when any proxy method is invoked**

InvocationHandler

- **Invoked when *any* method is called on proxy**

```
public interface InvocationHandler {
  Object invoke(Object proxy, Method method,
      Object[] args) throws Throwable;
}
```

  - Object proxy **is the instance of the dynamic proxy class that is calling invoke()**
  - Method method **is a java.lang.reflect.Method**
    - **Either interface method or equals(), hashCode(), or toString()**
  - Object[] args **is an array of parameters passed into the method**
    - **This is** null **when method has no parameters**

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LoggingInvocation Handler

LoggingInvocationHandler

- **We will log all method calls**
  - **Optionally measuring how long they take**
- **The constructor parameters are**
  - Logger log **a java.util.Logger to log to**
  - Object obj **the object that we want to delegate the calls to**
    - **Must implement the same interfaces as the proxy**

```
public final class LoggingInvocationHandler implements InvocationHandler {
  private final Logger log;
  private final Object obj;
  public LoggingInvocationHandler(Logger log, Object obj) {
    this.log = log;
    this.obj = obj;
  }
```

invoke() Method for Logging

```java
public Object invoke(
    Object proxy, Method method, Object[] args)
    throws Throwable {
  log.info(() -> "Entering " + toString(method, args));
  // optimization - nanoTime() is expensive native call
  final boolean logFine = log.isLoggable(Level.FINE);
  long start = logFine ? System.nanoTime() : 0;
  try {
    return method.invoke(obj, args);
  } finally {
    long nanos = logFine ? System.nanoTime() - start:0;
    log.info(() -> "Exiting " + toString(method, args));
    if (logFine) log.fine(() -> "Time " + nanos + "ns");
  }
}
```

toString() Prints Methods with Args

```
  private String toString(Method method,
                          Object[] args) {
    return String.format("%s.%s(%s)",
        method.getDeclaringClass().getCanonicalName(),
        method.getName(),
        args == null ? "" :
            Stream.of(args).map(String::valueOf)
                .collect(Collectors.joining(", ")));
  }
}
```

Demo of LoggingInvocationHandler

```
@SuppressWarnings("unchecked")
var map = (Map<String, Integer>)
  Proxy.newProxyInstance(Map.class.getClassLoader(),
    new Class<?>[] {Map.class},
    new LoggingInvocationHandler(
      Logger.getGlobal(), new ConcurrentHashMap<>()));
map.put("one", 1);
map.put("two", 2);
System.out.println(map);
map.clear();
```

```
Jan 24, 2020 7:32:20 AM
eu.javaspecialists.books.dynamicproxies.ch03.logging.LoggingInvocationHandler invoke
INFO: Entering java.util.Map.put(one, 1)
Jan 24, 2020 7:32:21 AM
eu.javaspecialists.books.dynamicproxies.ch03.logging.LoggingInvocationHandler invoke
INFO: Exiting java.util.Map.put(one, 1)
Jan 24, 2020 7:32:21 AM
eu.javaspecialists.books.dynamicproxies.ch03.logging.LoggingInvocationHandler invoke
FINE: Time 61622ns
```

Dissecting a Dynamic Proxy

Dissecting a Dynamic Proxy

- **We will start with a simple interface**

```
public interface ISODateParser {
  LocalDate parse(String date) throws ParseException;
}
```

Dynamic Proxy Class Name

- **Dynamic proxy with empty InvocationHandler**

```
System.out.println(
    Proxy.newProxyInstance(
        ISODateParser.class.getClassLoader(),
        new Class<?>[] {ISODateParser.class},
        (proxy, method, arguments) -> null
    ).getClass()
);
```

```
class com.sun.proxy.$Proxy0
```

Decompiling $Proxy0

- **We can dump generated proxy classes**
  - Java 9+:
    -Djdk.proxy.ProxyGenerator.saveGeneratedFiles=true
  - Earlier versions:
    -Dsun.misc.ProxyGenerator.saveGeneratedFiles=true
- **And then decompile with a tool like CFR**
  - https://www.benf.org/other/cfr

Dynamic Proxies in Java

```java
public final class $Proxy0 extends Proxy
    implements ISODateParser {
  private static Method m0;
  private static Method m1;
  private static Method m2;
  private static Method m3;
  static {
    try {
      m0 = Class.forName("java.lang.Object").getMethod("hashCode");
      m1 = Class.forName("java.lang.Object").getMethod("equals",
            Class.forName("java.lang.Object"));
      m2 = Class.forName("java.lang.Object").getMethod("toString");
      m3 = Class.forName("eu.javaspecialists.books.dynamicproxies."
          + "ch03.ISODateParser").getMethod("parse",
          Class.forName("java.lang.String"));
    } catch (NoSuchMethodException e) {
      throw new NoSuchMethodError(e.getMessage());
    } catch (ClassNotFoundException e) {
      throw new NoClassDefFoundError(e.getMessage());
    }
  }
```

Dynamic Proxies in Java

```
public $Proxy0(InvocationHandler h) {super(h);}

public final int hashCode() {
  try {
    return (Integer) h.invoke(this, m0,
      (Object[]) null);
  } catch (RuntimeException | Error e) {
    throw e;
  } catch (Throwable e) {
    throw new UndeclaredThrowableException(e);
  }
}
public final boolean equals(Object o) {
  try {
    return (Boolean) h.invoke(this, m1, new Object[] {o});
  } catch (RuntimeException | Error e) {
    throw e;
  } catch (Throwable e) {
    throw new UndeclaredThrowableException(e);
  }
}
```

Dynamic Proxies in Java

```
    public final String toString() {
      try {
        return (String) h.invoke(this, m2,
          (Object[]) null);
      } catch (RuntimeException | Error e) {
        throw e;
      } catch (Throwable e) {
        throw new UndeclaredThrowableException(e);
      }
    }

    public final LocalDate parse(String s) throws ParseException {
      try {
        return (LocalDate) h.invoke(this, m3, new Object[] {s});
      } catch (RuntimeException | ParseException | Error e) {
        throw e;
      } catch (Throwable e) {
        throw new UndeclaredThrowableException(e);
      }
    }
  }
```

Virtual Dynamic Proxy

Virtual Dynamic Proxy

- **InvocationHandler for virtual proxies**

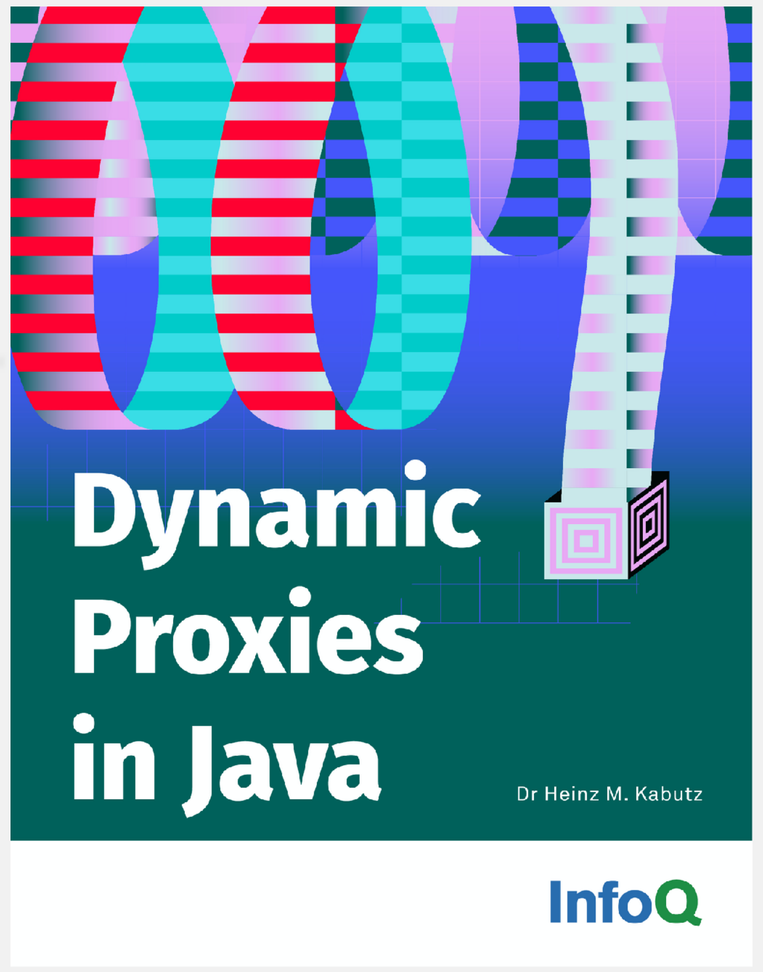
```
public final class VirtualProxyHandler<S>
    implements InvocationHandler, Serializable {
  private final Supplier<? extends S> supplier;
  private S subject;
  public VirtualProxyHandler(Supplier<? extends S> supplier) {
    this.supplier = supplier;
  }
  private S getSubject() {
    if (subject == null) subject = supplier.get();
    return subject;
  }
  public Object invoke(Object proxy, Method method,
                       Object[] args) throws Throwable {
    return method.invoke(getSubject(), args);
  }
}
```

Proxies Facade virtualProxy()

- **Facade has a virtualProxy() method**

```
public static <S> S virtualProxy(
    Class<? super S> subjectInterface,
    Supplier<? extends S> subjectSupplier) {
  Objects.requireNonNull(subjectSupplier,
    "subjectSupplier==null");
  return castProxy(subjectInterface,
      new VirtualProxyHandler<>(subjectSupplier));
}
```

- **More details in book**
  - **www.infoq.com/minibooks/java-dynamic-proxies/**



Creating Virtual Proxy

- **We can create virtual proxies of anything**
  - **Here we replace the handcrafted proxy with dynamic**
    - **Less code, less chance of bugs**

```
CustomMap<String, Integer> map =
    Proxies.virtualProxy(CustomMap.class,
CustomHashMap::new);
System.out.println("Virtual Map created");
map.put("one", 1); // creating map as side effect
map.put("life", 42);
System.out.println("map.get(\"life\") = " +
  map.get("life"));
System.out.println("map.size() = " + map.size());
System.out.println("clearing map");
map.clear();
System.out.println("map.size() = " + map.size());
```

```
Virtual Map created
CustomHashMap constructed
map.get("life") = 42
map.size() = 2
clearing map
map.size() = 0
```

Dynamic Proxy Restrictions

Interfaces Only

- **Dynamic proxies cannot extend classes**
  - **All proxies are subclasses of java.lang.reflect.Proxy**
    - **No multiple inheritance in Java**
  - **Might need to use tools like CGLib or ByteBuddy**

UndeclaredThrowableException

- **InvocationHandler.invoke() throws Throwable**
  - **However, we should only throw declared exceptions**
    - **Error and RuntimeException always allowed**

```
Runnable job = Proxies.castProxy(
  Runnable.class,
  (proxy, method, params) -> {
    // will be wrapped with UndeclaredThrowableException
    throw new IOException("bad exception");
  });
job.run();
```

```
Exception in "main" java.lang.reflect.UndeclaredThrowableException at
com.sun.proxy.$Proxy0.run(Unknown Source)
at UndeclaredExceptionThrown.main()
Caused by: java.io.IOException: bad exception
at UndeclaredExceptionThrown.lambda$main$0() ... 2 more
```

Return Types Have to be Correct

```
public interface FooBar {
  void foo();
  boolean bar();
  int baz();
}
public class FooBarInvocationHandler
    implements InvocationHandler {
  public Object invoke(Object proxy, Method method,
                       Object[] args) throws Throwable {
    switch (method.getName()) {
      case "foo": return true; // ignored
      case "bar": return 42; // ClassCastException
      case "baz": return null; // NullPointerException
      default: throw new UnsupportedOperationException();
    }
  }
}
```

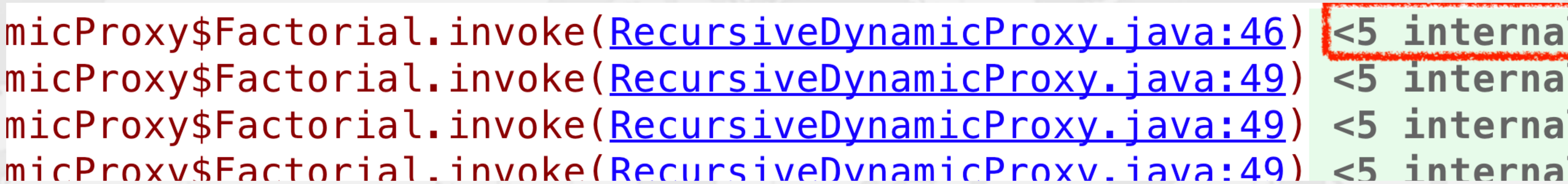
Naming Mysteries

```
public class ProxyNaming {
  public interface PublicNotExported {
    void open();
  }
  interface Hidden {
    void mystery();
  }
  public static void main(String... args) {
    show(BaseComponent.class); // exported from module
    show(PublicNotExported.class);
    show(Hidden.class);
  }
  private static void show(Class<?>... intf) {
    System.out.println(Proxy.newProxyInstance(
      intf[0].getClassLoader(), intf,
      (p, m, a) -> null).getClass());
  }
}
```

```
class com.sun.proxy.$Proxy0
class com.sun.proxy.jdk.proxy1.$Proxy1
class eu.javaspecialists.books.dynamicproxies.ch03.gotchas.$Proxy2
```

Deeper Call Stacks

- **Call stacks have references to $Proxy0**
  - **Can increase each call by an additional 5 layers**
  - **IntelliJ IDEA folds this information away**



```
micProxy$Factorial.invoke(RecursiveDynamicProxy.java:46) <5 interna
micProxy$Factorial.invoke(RecursiveDynamicProxy.java:49) <5 interna
micProxy$Factorial.invoke(RecursiveDynamicProxy.java:49) <5 interna
micProxy$Factorial.invoke(RecursiveDynamicProxy.java:49) <5 interna
```

- **Actual stack trace contains all the gory details**

```
at RecursiveDynamicProxy$Factorial.invoke()
at com.sun.proxy.$Proxy0.apply(Unknown Source)
at java.base/NativeMethodAccessorImpl.invoke0()
at java.base/NativeMethodAccessorImpl.invoke()
at java.base/DelegatingMethodAccessorImpl.invoke()
at java.base/Method.invoke()
at RecursiveDynamicProxy$Factorial.invoke()
```

Shared Proxy Classes

- **Java tries to minimize dynamic proxy classes**
  - **When we call Proxy.newProxyInstance() it checks**
    - **Have we had the same interfaces (in that order)?**
    - **And for the same class loader?**
  - **If it has seen it before, it returns a cached class**
    - **This is stored inside weak references to prevent memory leaks**

Performance

Performance

- Dynamic proxies used in infrastructure code
  - Some methods called billions of times
- Calling methods on dynamic proxies may be slower
  - Primitive return types and parameters might be boxed
  - Parameters are wrapped with Object[]
    - Object[] can be eliminated if it does not escape from invoke()
  - Method has amnesia and checks our permission every call

Model for Benchmark using JMH

```
public interface Worker {
  long increment();
  void consumeCPU();
}

public class RealWorker implements Worker {
  private long counter = 0;

  public long increment() { return counter++; }
  public void consumeCPU() { Blackhole.consumeCPU(2); }
}

public class ProxyWorker implements Worker {
  private final RealWorker worker = new RealWorker();

  public long increment() { return worker.increment(); }
  public void consumeCPU() { worker.consumeCPU(); }
}
```

increment() and consumeCPU()

- **We use five ways of calling these methods**
  - **directCall**
  - **staticProxy**
  - **dynamicProxyThenDirectCall**
    - **Avoids cost of reflective method calls, but might need to box return value**
  - **dynamicProxyThenReflectiveCall**
    - **Delegates all calls to the RealWorker using reflection**
    - **Method call might be turbo-boosted by turning off accessibility checks**

Benchmark increment() Results

- **Analysis of results**
  - dynamicProxyDirectCall 2.1 ns slower than staticProxy
  - dynamicProxyReflectiveCall is another 4.1 ns slower
    - Also allocates 24 bytes
  - Without our method turbo boost, it is another 2.3 ns slower

Benchmark increment()	Best ns/op	Bytes/op EA on/off
directCall	2.9	0 / 0
staticProxy	3.5	0 / 0
dynamicProxyDirectCall	5.6	0 / 24
dynamicProxyReflectiveCall (turbo)	9.7	24 / 24
dynamicProxyReflectiveCall (no turbo)	12	24 / 24

Benchmark consumeCPU() Results

- **Analysis of results**
  - dynamicProxyDirectCall 1.1 ns slower than staticProxy
  - dynamicProxyReflectiveCall is another 1 ns slower
  - Without our turbo boost, it is a further 3.4 ns slower

Benchmark consumeCPU()	Best ns/op
directCall	4.8
staticProxy	5.5
dynamicProxyDirectCall	6.6
dynamicProxyReflectiveCall (turbo)	7.6
dynamicProxyReflectiveCall (no turbo)	11

Summary of Benchmark Results

- **Method call overhead for our experiments**
  - **6.2 nanoseconds for increment()**
  - **2.1 nanoseconds for consumeCPU()**
- **Overheads negligible in typical business application**
  - **Unless called in performance sensitive code**

3: Related Patterns

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3: Related Patterns

- **Proxy has a similar structure to**
  - **Decorator / Filter**
  - **Composite**

Filtering for Immutability

ImmutableCollection

```
public interface ImmutableCollection<E> {
  void forEach(Consumer<? super E> action);
  Spliterator<E> spliterator();
  int size();
  boolean isEmpty();
  boolean contains(Object o);
  Object[] toArray();
  <T> T[] toArray(T[] a);
  <T> T[] toArray(IntFunction<T[]> generator);
  boolean containsAll(Collection<?> c);
  Stream<E> stream();
  Stream<E> parallelStream();
  // to try out default methods
  default void printAll() {
    forEach(System.out::println);
  }
}
```

HandcodedFilter

- **We only offer methods that do not mutate**

```
public class HandcodedFilter<E>
    implements ImmutableCollection<E> {
  private final Collection<E> c;

  public HandcodedFilter(Collection<E> c) { this.c = c; }

  public int size() { return c.size(); }
  public boolean isEmpty() { return c.isEmpty(); }
  public boolean contains(Object o) { return c.contains(o); }
  public Object[] toArray() { return c.toArray(); }
  // etc.
  // No mutable methods are offered to client
}
```

FilterHandler

```java
public final class FilterHandler
    implements InvocationHandler {
  private final ChainedInvocationHandler chain;

  public FilterHandler(Class<?> filter, Object component) {
    VTable vt = VTables.newVTable(component.getClass(), filter);
    VTable defaultVT = VTables.newDefaultMethodVTable(filter);

    chain = new VTableHandler(component, vt,
        new VTableDefaultMethodsHandler(defaultVT, null));
    chain.checkAllMethodsAreHandled(filter);
  }
  public Object invoke(Object proxy, Method method, Object[] args)
      throws Throwable {
    return chain.invoke(proxy, method, args);
  }
}
```

Dynamic Filter

- **We can filter away the mutating methods**

```
ImmutableCollection<String> names =
    Proxies.filter(ImmutableCollection.class,
        Arrays.asList("Peter", "Paul", "Mary"));
// names.remove("Peter"); // does not compile
System.out.println(names);
System.out.println("Is Mary in? " +
  names.contains("Mary"));
System.out.println("Class: " +
  names.getClass().getSimpleName());
names.printAll();
```

```
[Peter, Paul, Mary]
Is Mary in? true
Class: $Proxy0
Peter
Paul
Mary
```

Questions?

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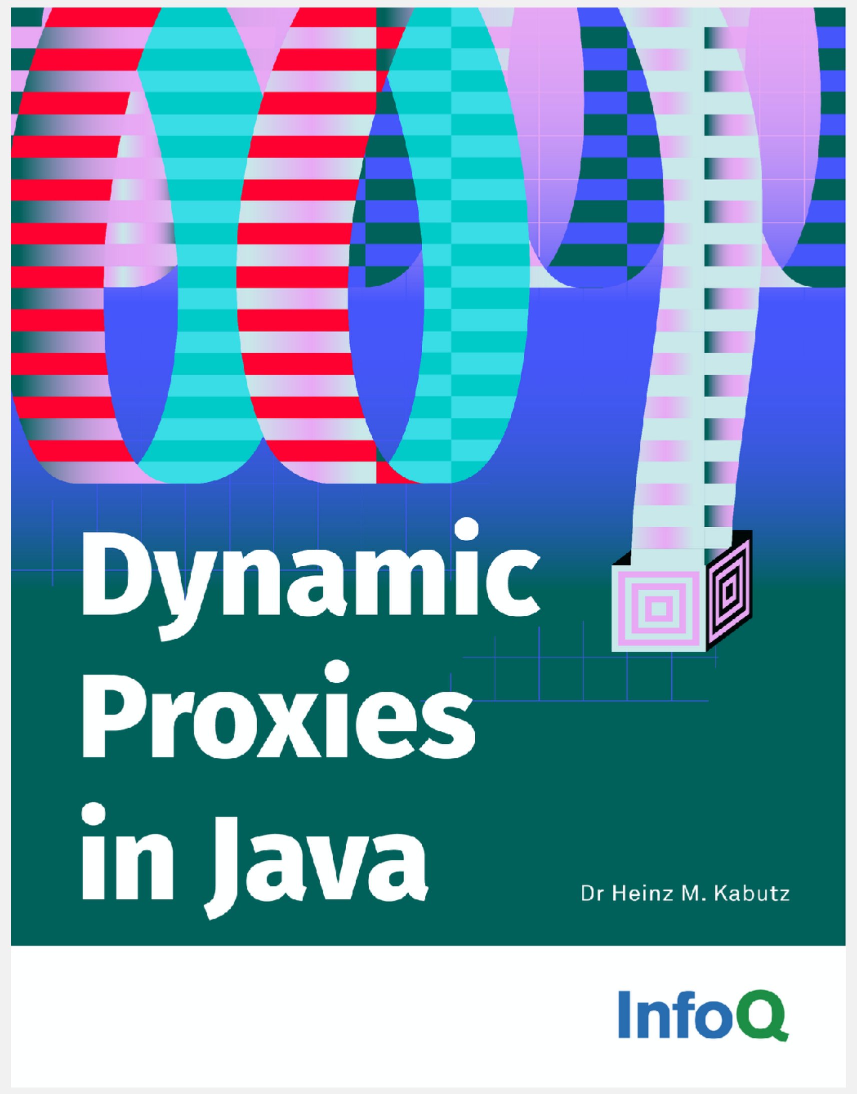

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