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Dynamic Code Evolution

Coroutines for the JVM

Dynamic Code Evolution

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Dynamic Code Evolution - Past

- Modification of the Java HotSpot™ VM.

- Allows **arbitrary** class redefinition changes:
  - Add/remove methods.
  - Add/remove fields.
  - Change the implemented interfaces or the super class.

- No performance penalty on normal program execution.

Dynamic Code Evolution - Improvements

Stability

- Passes Oracle's internal class redefinition test suite!
- Larger test suite for advanced changes.

Functionality

- Introduction of transformer methods.
- Can call old deleted method and access old deleted static field.

Performance

- Garbage collection run now only necessary if object instances are affected.

Dynamic Code Evolution - Future

Website

- http://ssw.jku.at/dcevm
- Binaries for Linux-32bit, MacOS-32bit, Win-32bit, Win-64bit
- Code available in the MLVM repository

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Integration

- Looking for a sponsoring engineer at Oracle!

JVM Coroutines

part of the MLVM project

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Coroutines

- Old (ancient?) concept
- Extensions of subroutines
    - multiple entry/exit points
- Lightweight threads
- Many variations
    - generators, coexpressions, fibers, iterators, green threads, greenlets, tasklets, …
    - sometimes as generic as coroutines

Variations of coroutines

- Stackless / stackful
  - yield possible outside of main method?
- First-class coroutines
  - not tied to a specific language construct
- (a)symmetric
  - asymmetric: can only return control to their caller
  - symmetric: arbitrary control passing

Coroutines - why?

- Natural control abstraction for some problems
  - scanner/parser (Conway 1963)
  - non-parallel problems
  - do not expose parallelism where there is none!
- Inversion of algorithms
  - converting callback-based algorithms (e.g. SAX parser) into iterative algorithms
  - can be done manually, but coroutines do it for free!

Coroutines - why?

- Language implementations need to emulate coroutines
  - using threads
    - synchronize multiple threads so they look like coroutines
  - compile-time transformations
    - complex compilers
    - smaller chunks: less optimization opportunities for JIT
    - local variables on the heap (less register use, …)
  - that's bad, right?

Goals

- Features:
  - stackful
  - first-class
  - symmetric and asymmetric coroutines
    - it has been shown that these are equivalent
    - but: need both to be useful out of the box
- Performance:
  - fast switching
  - many coroutines
  - implementation complexity (not!)

trade-off

JVM coroutine implementation

- Allocate additional stacks
  - manages multiple stacks within threads
  - migration between threads is not supported (yet?)
- Stacks take lots of space
  - address space: 32-100 kb minimum
  - memory: 16-32 kb minimum
  - worst-case theoretical maximum: 20.000 stacks (32 bit Solaris)
  - not enough!

JVM coroutine implementation

- Suspended coroutines:
  small amount of stack is actually in use
- Sharing stacks if there are too many coroutines
  - copying stack contents to/from the stack
  - bad for performance, but allows many coroutines
  - 1.000.000 coroutines on a 32 bit machine
- Stacks need to be in the same place every time they are executed (native frames)

API

- symmetric coroutines: `Coroutine`

```
public class Coroutine {
    public Coroutine();
    public Coroutine(Runnable target);
    public Coroutine(long stacksize);
    public Coroutine(Runnable target, long stacksize);

    public static void yield();
    public static void yieldTo(Coroutine target);

    protected void run();
}
```

API

- symmetric coroutines: `Coroutine`

```
public class CoroutineTest extends Coroutine {
    @Override
    public void run() {
        System.out.println("Coroutine running 1");
        yield();
        System.out.println("Coroutine running 2");
    }

    public static void main(String[] args) {
        new CoroutineTest();
        System.out.println("start");
        yield();
        System.out.println("middle");
        yield();
        System.out.println("end");
    }
}
```

```
start
Coroutine running 1
middle
Coroutine running 2
end
```

API

- **asymmetric coroutines:** `AsymCoroutine`

```
public abstract class AsymCoroutine<InT, OutT> implements Iterable<OutT>
{
   public AsymCoroutine();
   public AsymCoroutine(long stacksize);

   public InT ret(OutT value);
   public InT ret();
   public OutT call(InT input);
   public OutT call();

   protected abstract OutT run(InT value);

   @Override
   public Iterator<OutT> iterator();
}
```

null as input parameter

API

- **asymmetric coroutines:** `AsymCoroutine`

```
public class CoSAXParser extends AsymCoroutine<Void, String> {
    @Override
    public String run(Void value) {
        SAXParserFactory.newInstance().newSAXParser().parse(..., new DefaultHandler() {
            public void startElement(String uri, String localName, String name, Attributes att) {
                ret(name);
            }
        });
        return null;
    }

    public static void main(String[] args) {
        CoSAXParser parser = new CoSAXParser();

        String element;
        do {
            element = parser.call();
            System.out.println(element);
        } while(element != null);
    }
}
```

```
office:document-content
office:scripts
office:font-face-decls
style:font-face
...
...
```

API

- **asymmetric coroutines:** `AsymCoroutine`

```
public class CoSAXParser extends AsymCoroutine<Void, String> {
    @Override
    public String run(Void value) {
        SAXParserFactory.newInstance().newSAXParser().parse(..., new DefaultHandler() {
            public void startElement(String uri, String localName, String name, Attributes att) {
                ret(name);
            }
        });
        return null;
    }

    public static void main(String[] args) {
        CoSAXParser parser = new CoSAXParser();

        String element;
        do {
            element = parser.call();
            System.out.println(element);
        } while(element != null);
    }
}
```

```
office:document-content
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...
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```

API

- asymmetric coroutines: `AsymCoroutine`

```
public class CoSAXParser extends AsymCoroutine<Void, String> {
    @Override
    public String run(Void value) {
        SAXParserFactory.newInstance().newSAXParser().parse(..., new DefaultHandler() {
            public void startElement(String uri, String localName, String name, Attributes att) {
                ret(name);
            }
        });
        return null;
    }

    public static void main(String[] args) {
        CoSAXParser parser = new CoSAXParser();

        for (String element : parser)
            System.out.println(element);
    }
}
```

```
office:document-content
office:scripts
office:font-face-decls
style:font-face
...
...
```

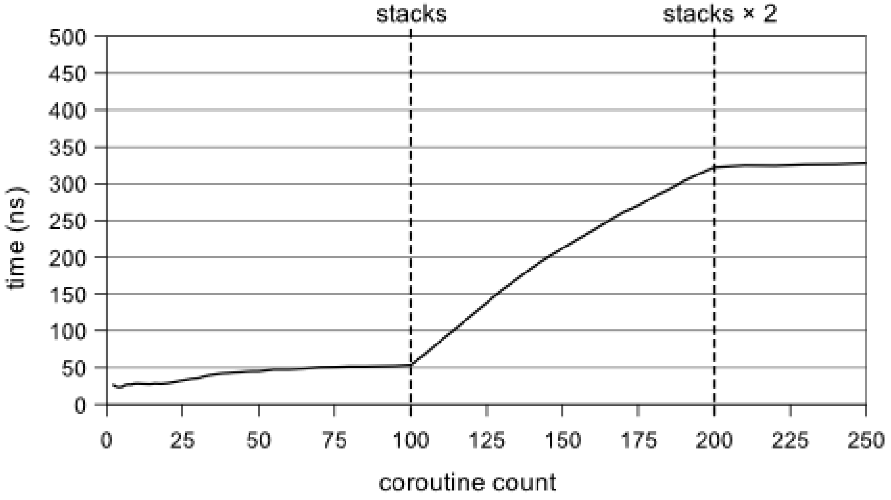
API

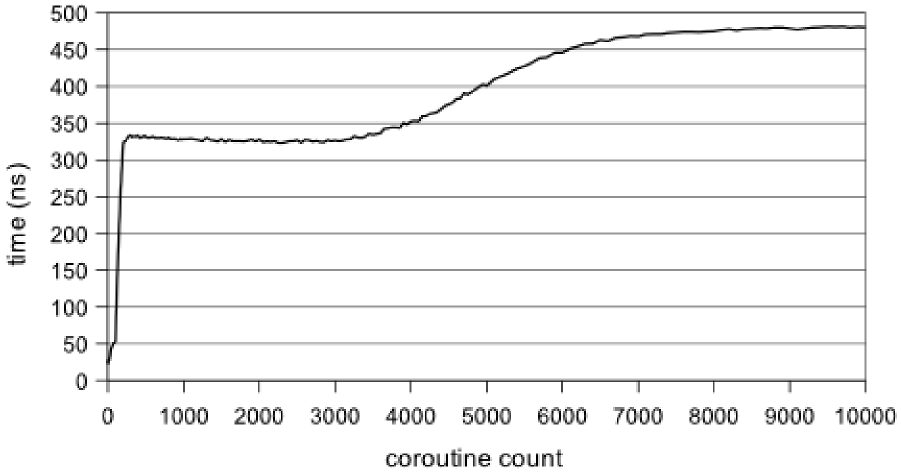
- Coroutine locals: `CoroutineLocal`
- … similar to `ThreadLocal`
- What to do with coroutines when a thread ends?
  - *“no coroutine left behind”*
  - `AsymCoroutines` will receive CoroutineDeath as soon as there are no more (symmetric) `Coroutines`

Performance

- Memory:
  - stacks + storage for rescued coroutines
- Run time: (Intel i5 750 CPU)
  - create: 1.5 µs / 0.3 µs (Thread: 2.5 µs)
  - start: 3 µs (Thread: 60 µs)
  - switch: 20 ns (best case)
    - difficult to get reliable thread switch time

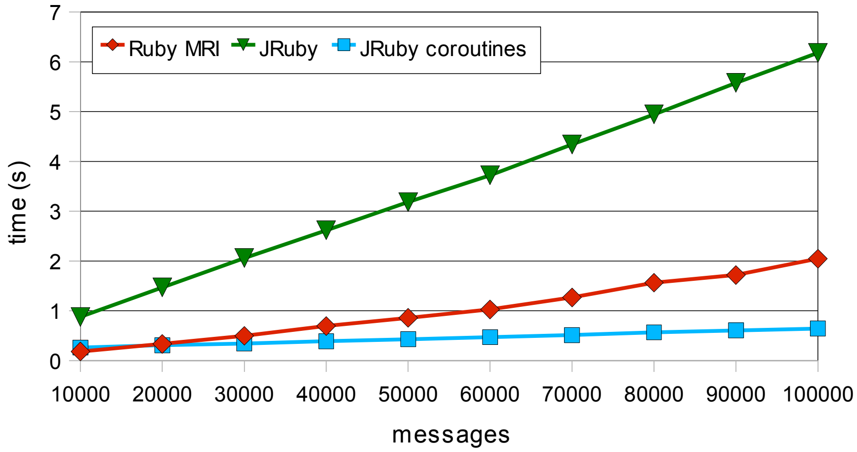
Performance



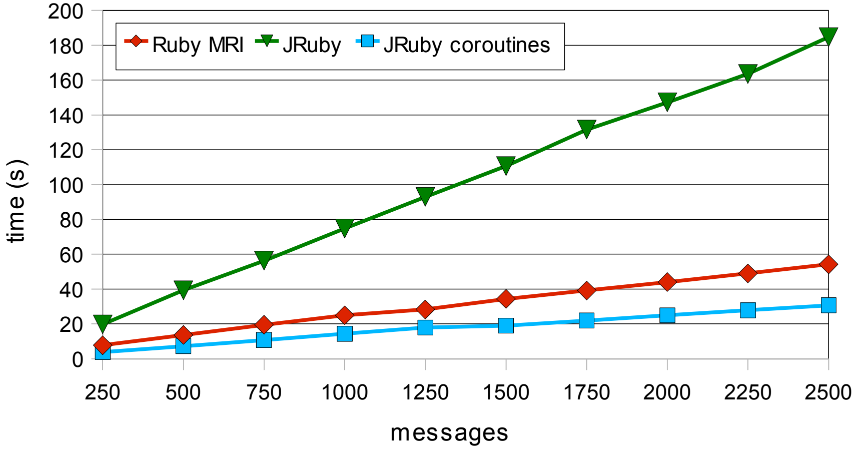


- Time per switch, depending on coroutine count
  - working set outgrows L1 and L2 caches
  - 500 ns even for large numbers of coroutines
- 100 coroutine stacks per thread

Performance: JRuby



5 fiber chain



5000 fiber chain

- Small contrived benchmark
- Passes messages through a chain of fibers
- Improvement from 3 x slower to 2 x faster!
  - won't convert to real-world applications

Weak spots

- Not quite stable
  - reliable `StackOverflowError`
  - occasional GC errors
- Rescuing stack frames with locks
- Large scale tests

Future, Ideas, ...

- Paper at PPPJ 2010 in Vienna:
  Efficient Coroutines for the Java Platform
  - I'll be happy to provide a preprint copy
- Seralizable coroutines?
  - some of the continuation use cases
  - ... along with many of the problems
- Code available in the MLVM repository

Thank you.
Questions?

For details see:
Efficient Coroutines for the Java Platform
Conference on Principles and Practice of Programming in Java 2010

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