JVM Continuations

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Agenda

- Continuations
- Uses for continuations
- Common implementation techniques
- Our lazy approach
- Implementation
- Summary
Continuations

- Functional / dynamic languages
- “the rest of the computation”
- “everything thats going to happen from now on”
- In Java terminology: (part of) the contents of the stack of activation frames (method, bci, variables, expressions)
- Can be stored
- Can be reinstated (possibly more than once)
- Different types with different semantics
Continuations

Continuation alpha;

```java
void method() {
    int value = 0;
    alpha.capture();
    System.out.println("current value: "+value);
    value += 1;
    alpha.resume();
}
```
Continuations

Continuation alpha;

void method() {
    int value = 0;
    alpha.capture();
    System.out.println("current value: " + value);
    value += 1;
    alpha.resume();
}

...
Uses for continuations

- Functional languages: basic language features
  - return, exception handling, etc.
- Java: advanced features
  - green threads, coroutines, fibers, etc.
- Web servers
  - linearize complex interactions
  - “back button” problem
- Checkpointing, portable agents, etc.
Common Techniques

- One-shot continuations (via exceptions)
- Activation frames as objects (Smalltalk)
- Segments containing many activation frames allocated on heap (some Scheme environments)
- Most implementations: *Copy-all* approach
Common Techniques

- Copy-all approach: example

```java
Continuation alpha;
Continuation beta;

void a() {
    b();
}
void b() {
    alpha.capture();
    beta.capture();
}
```
Common Techniques

- Copy-all approach: example

```java
Continuation alpha;
Continuation beta;

void a() {
    b();
}
void b() {
    alpha.capture();
    beta.capture();
}
```

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Common Techniques

• Copy-all approach: example

Continuation alpha;
Continuation beta;

void a() {
  b();
}
void b() {
  alpha.capture();
  beta.capture();
}

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Common Techniques

• Problems:
  • Immediate cost of continuation capture
  • Continuations often share activation frames
  • No way to tell if an activation frame needs to be restored

• Be Lazy!
Lazy Continuations

- Store activation frames as late as possible
- Intercept the return to an activation frame by patching the return address
- Call site - specific trampoline
- One Object per activation frame (called activation object): linked list
- The activation object for the next activation frame stored in the thread
Lazy Continuations

- Continuations joined into tree structure
Lazy Continuations

- Continuations joined into tree structure
Lazy Continuations

- Continuations joined into tree structure

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Implementation tricks

Continuation alpha;

```c
void a() {
    b();
}

void b() {
    alpha.capture();
}
```

Stack

- a()
- b()
- capture()
Implementation tricks

Continuation alpha;

```c
void a() {
    b();
}
storeFrame();
goto;
```

```c
void b() {
    alpha.capture();
}
storeFrame();
goto;
```

`native void storeFrame();`
Implementation tricks

- Assembly fast path, C++ slow paths
- Where to put / how to connect all this?

- Patching
  - One extra trampoline per call site
  - Keeps stack walking, etc. simple

- Interfacing asm/C++
  - JNI method called by trampoline
  - Stackless, no-safepoint asm fast path
Java Interface

```java
public class Continuation {
    public static final Object CAPTURED;
    public native Object capture();
    public native void resume(Object retVal);
}

public @interface Continuable {
}
```

- Passing a return value on resume
- Annotation to mark methods continuation - safe
class Test {
    Continuation alpha = new Continuation();

    @Continuable
    public static void main() {
        System.out.println("start");
        if (alpha.capture() == Continuation.CAPTURED) {
            System.out.println("captured");
            alpha.resume(null);
        } else {
            System.out.println("resumed");
        }
        System.out.println("end");
    }
}
Summary, Future

- Saves time
- Saves memory
  (break even at ~30%)

Future:
- C2 implementation
- Serialization
- Other uses
Thank you.
Questions?

For details on the algorithm see:
Lazy Continuations for Java Virtual Machines
Conference on Principles and Practice of Programming in Java 2009

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Copy cases

(1) 

before 

after 

(2) 

(3) 

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Frame storing cases

before

after

(1)       CAO     b       CAO     a
           ---      ---      ---

(2)       a         CAO     b       a         b
           ---      ---      ---

(3)       a         CAO     c       a         c
           ---      ---      ---

(4)       a         CAO     c       a         b
           ---      ---      ---

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Resume cases