Decompiling Java: Problems, Traps, and Pitfalls

Jerome Miecznikowski and **Laurie Hendren**

Sable Research Group
School of Computer Science
McGill University, Montreal, Canada

`http://www.sable.mcgill.ca`

Overview

1. Motivation

2. Basic issues for typed statements

   - simple statements

   - types

3. Advanced issues for restructuring

   - multi-entry point loops

   - labeled blocks and `break` statements

   - exceptions & thread synchronization

4. Putting it all together

5. Conclusions

Motivation

The facts are ...

- Java bytecode is rich in type information, and is much higher level than traditional machine code

- Bytecode generated from `javac` follows specific code generation patterns

So shouldn't decompiling simply be a matter of inverting `javac`'s compilation strategy?

No!

What we found:

- Java bytecode is *much* more flexible that what can be expressed in *any structured language*

- Bytecode optimizers and compilers for other languages will produce radically different patterns in code generation. These patterns can get very complex

- Type information for locals has to be treated carefully regardless of source

Conclusion: We want to show some interesting problems in decompiling to Java, see how other decompilers fare, and suggest our own workable strategies

Background Questions

- What are these “other” decompilers?
  - Jasmine version 1.10, Jad version 1.5.8, Wingdis version 2.16, and SourceAgain version 1.1

- What does Java bytecode look like?
  1. uses an expression stack
  2. has explicit control flow
  3. supports exceptions
  4. supports thread synchronization

Some bytecode (javap -c)

```
Method int f(java.lang.Object, int)
   0 iconst_5
   1 istore_3
   2 goto 32
   5 aload_1
   6 astore 4
   8 aload 4
  10 monitorenter
  11 iload_3
  12 iload_2
  13 iinc
  16 imul
  17 istore_3
  18 aload 4
  20 monitorexit
  21 goto 32
  24 astore 5
  26 aload 4
  28 monitorexit
  29 aload 5
  31 athrow
  32 iload_2
  33 bipush 10
  35 if_icmplt 5
  38 iload_3
  39 ireturn
Exception table:
   from   to  target type
   11    24    24   any
```

Basic Issues for Typed Statements

1. Simple Statements

- The Java virtual machine uses an expression stack

- `javac` compilation pattern: the expression stack will be empty after every program statement

- Even simple optimizations can leave values on the stack after a "program statement" (example is given in paper)

- All other tested decompilers were confused by this and produced incorrect output. (dropped statements, lost locals, error messages in code, etc.)

Our working solution is to ...

1. represent stack positions as locals

2. split locals by using U-D webs

3. build 3-address code using the locals

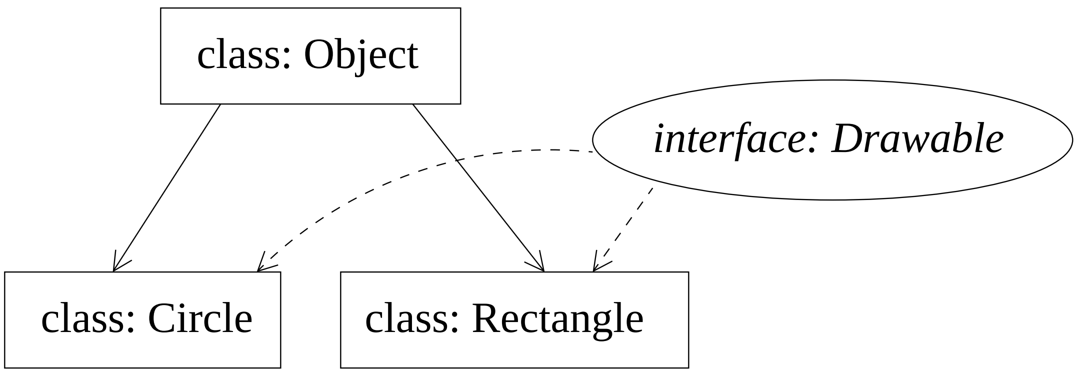
4. aggregate expressions of 3-address code

See Raja Valée-Rai's Master's Thesis:

Soot: A Java Bytecode Optimization Framework

2. Types

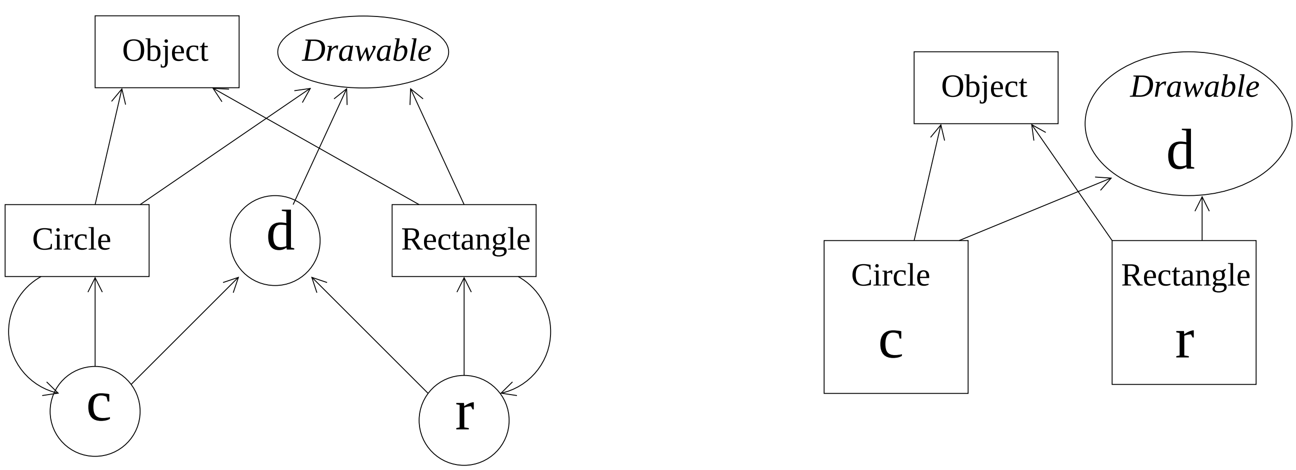
In bytecode, **fields** have types but **locals** don't




```
public static void f(short i)
{  <unknown> c; <unknown> r; <unknown> d;
   <unknown> is_fat;

   if (i>10)
   {  r =  new Rectangle(i, i);
      is_fat = r.isFat();
      d = r;
   }
   else
   {  c = new Circle(i);
      is_fat = c.isFat();
      d = c;
   }
   if (is_fat == 0) d.draw();
}
```

Problem: Given the following class hierarchy, how to determine the type of "`d`"?

Solution:
1) Create a type constraint graph based on the class hierarchy, local assignments, and local uses
2) Prune and collapse the graph to get precise types



See Gagnon, et.al. from SAS2000:

Efficient Inference of Static Types for Java Bytecode

All other decompilers failed in *both*:

- Handling simple statement creation on stack optimized code

- Correctly finding that `d` is of type *Drawable*

The following 5 slides show all tested decompilers' output on this example.

1. The class was first compiled with `javac`

2. Then it was optimized by a simple peephole optimizer

Output for: Jasmine

```
public static void f(short s)
{ Object object;
  if (s <= 10) goto 24 else 6;
  expression new Rectangle
  dup 1 over 0
  expression s
  dup 1 over 0
  invoke Rectangle.<init>
  dup 1 over 0
  invoke isFat
  swap
  pop object
  expression new Circle(s)
  dup 1 over 0
  invoke isFat
  swap
  pop object
  if != goto 47
  object.draw();
}
```

Output for: Wingdis

```
public static void f(short short0)
{ if ((((byte)short0) <= 10)?
       (Circle circle1= new Circle(short0)):
       (Rectangle rectan1=
           new Rectangle(
             ((short)short0), ((short)short0)))
       == false)
      { Drawable.draw();
      }
}
```

Output for: Jad

```
public static void f(short word0)
{ Rectangle rectangle;
  if(word0 <= 10)
    break MISSING_BLOCK_LABEL_24;
  rectangle =
    new Rectangle(word0, word0);
  rectangle.isFat();
  Object obj;
  obj = rectangle;
  break MISSING_BLOCK_LABEL_38;
  Circle circle =
    new Circle(word0);
  circle.isFat();
  obj = circle;
  JVM INSTR ifne 47;
  goto _L1 _L2
_L1:
  break MISSING_BLOCK_LABEL_41;
_L2:
  break MISSING_BLOCK_LABEL_47;
  ((Drawable) (obj)).draw();
}
```

Output for: SourceAgain

```
public static void f(short si)
{ Object obj;
  Object tobj;
  Object tobj1;

  if( si > 10 )
    { Object tobj2;
      tobj = new Rectangle( si, si );
      tobj2 = ((Rectangle) tobj).isFat();
      obj = new Rectangle( si, si );
     }
  else
    { tobj = new Circle( si );
      tobj1 = ((Circle) tobj).isFat();
      obj = new Circle( si );
     }
  if( tobj1 == 0 )
     ((Drawable) obj).draw();
}
```

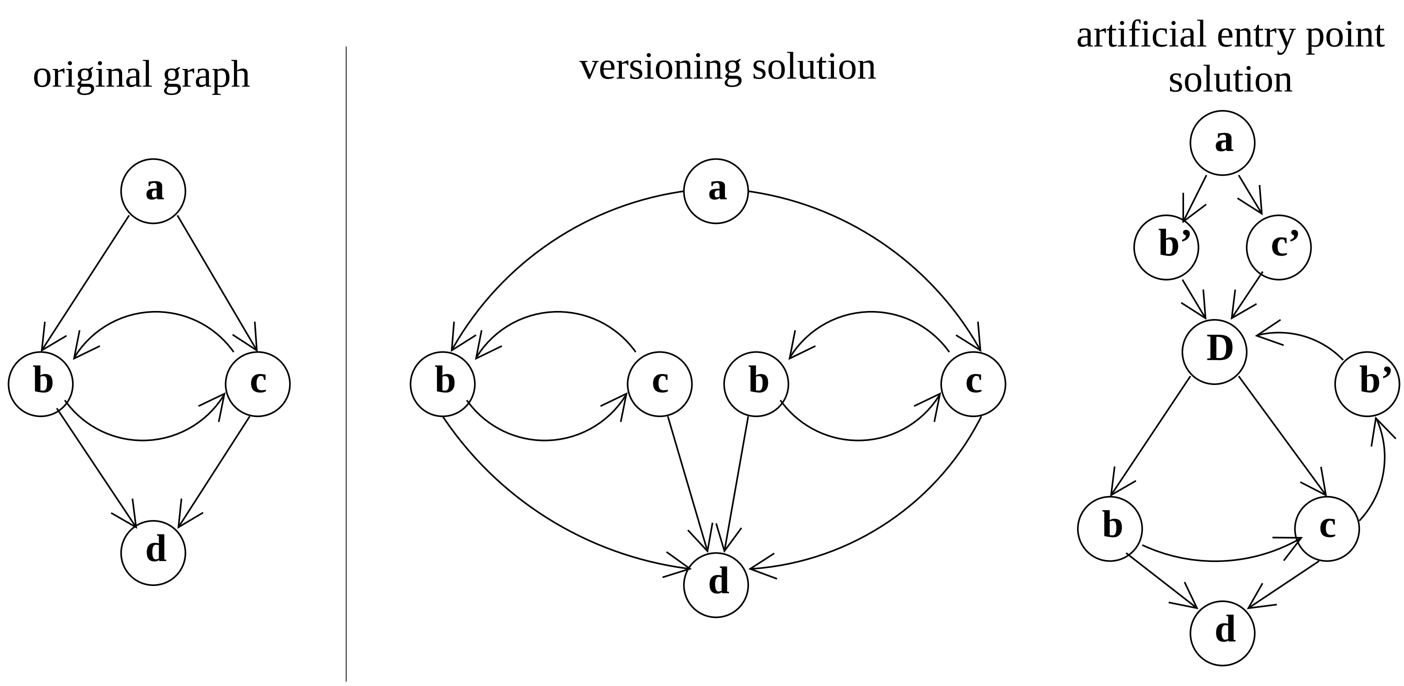
Output from our decompiler: Dava

```
public static void f(short s0)
{ boolean $z0;
  Drawable r0;
  Rectangle $r1;
  Circle $r2;

  if (s0 <= 10)
    { $r2 = new Circle(s0);
      $z0 = $r2.isFat();
      r0 = $r2;
    }
  else
    { $r1 = new Rectangle(s0, s0);
      $z0 = $r1.isFat();
      r0 = $r1;
    }
  if ($z0 == false)
    r0.draw();
  return;
}
```

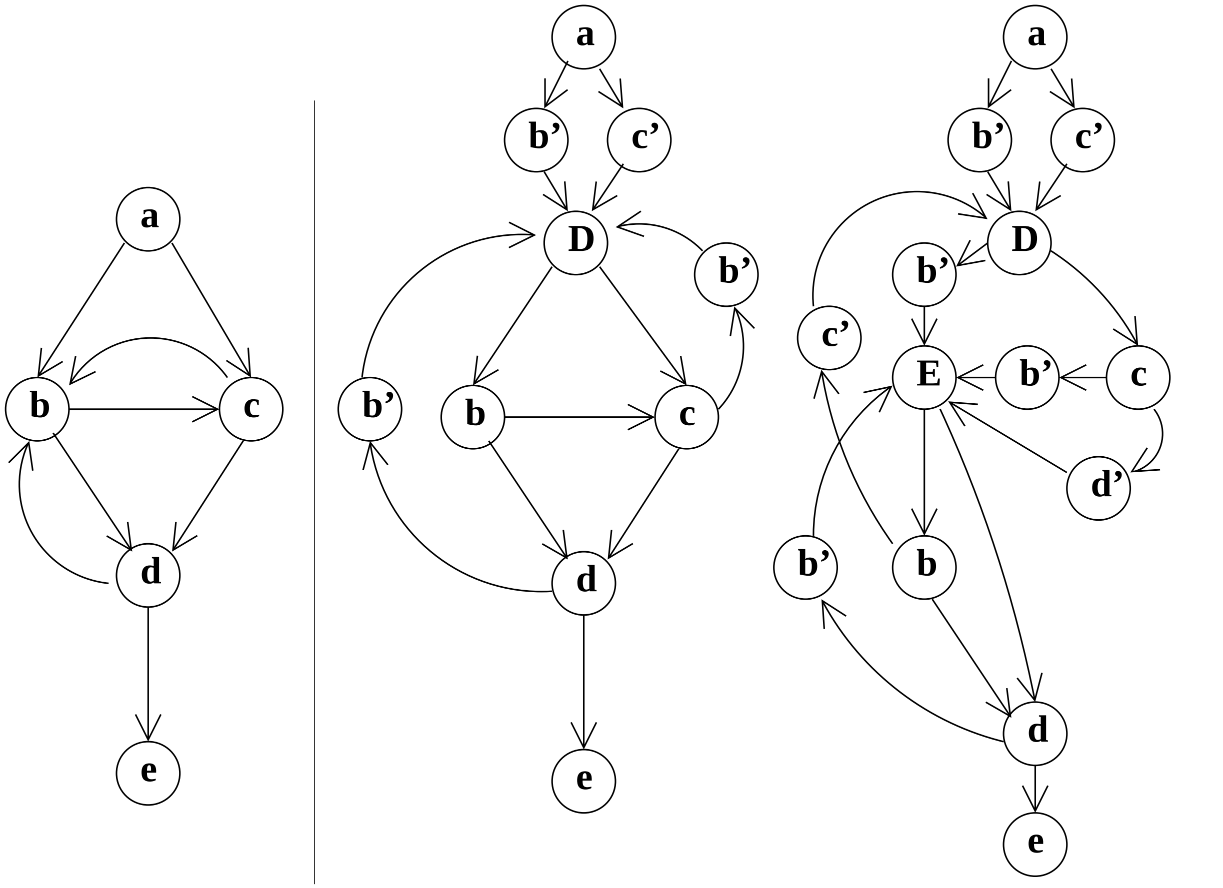
Advanced Issues for Restructuring

1. Multi-entry point loops

- **Problem:** Loops in the control flow graph may have more than one entry point
- **Two solutions:** both perform a transform on the control flow graph



1. No other decompiler produced correct output, they generally ignore this possibility
2. We chose to use the artificial entry point solution due to scaling issue.
3. Artificial entry point problem: One entry point is selected as *natural* and the other are treated as the product of `goto`s. Which do we select as natural?



original graph

b is chosen as natural entry point (1 target of back−edges)

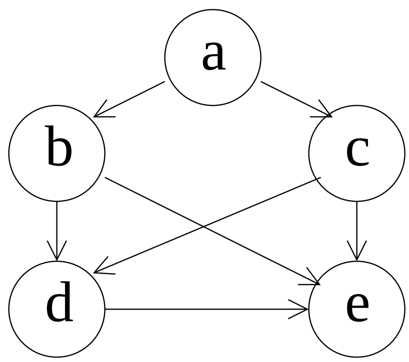
c is chosen as natural entry point (2 targets of back−edges)

1. For each entry point, do a DFS

2. Select the entry point that yields the minimum number of targets of back-edges

2. Labeled blocks and `break` statements

A combination of labeled blocks and `break` statements can act like a limited goto!




```
L1:
{
   if (a) {
      if (b)
         break L1;
   }
   else {
      if (c)
         break L1;
   }
   d;
}
e;
```

Any control flow DAG can be represented in pure Java.

1. Topologically sort the DAG

2. Place labeled blocks around the statements of the DAG

3. Represent all control flow with **`break`** statements

```
a b c d e ...

{a} b c d e ...

{{a} b} c d e ...

{{{a} b} c} d e ...

{{{{a} b} c} d} e ...
```

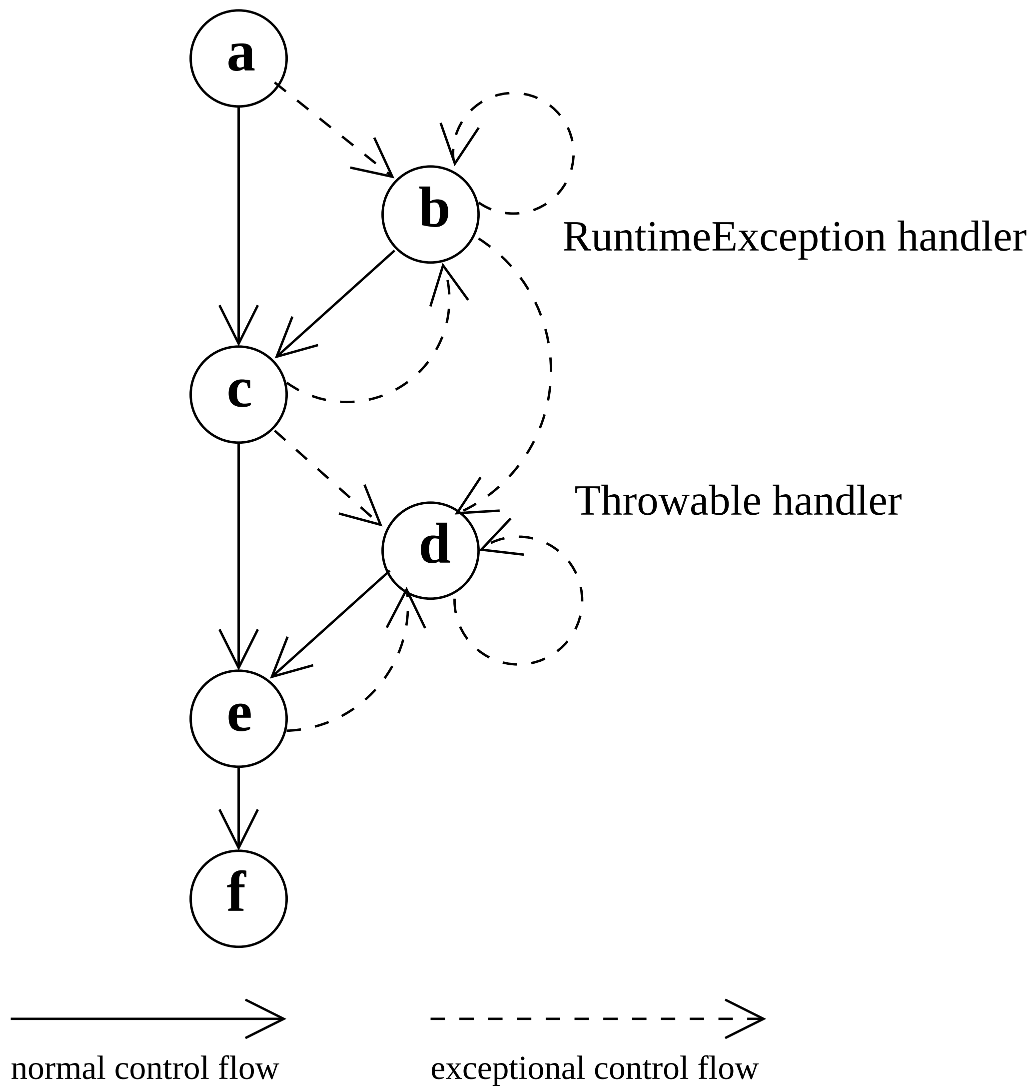
3. Exceptions

Problems:

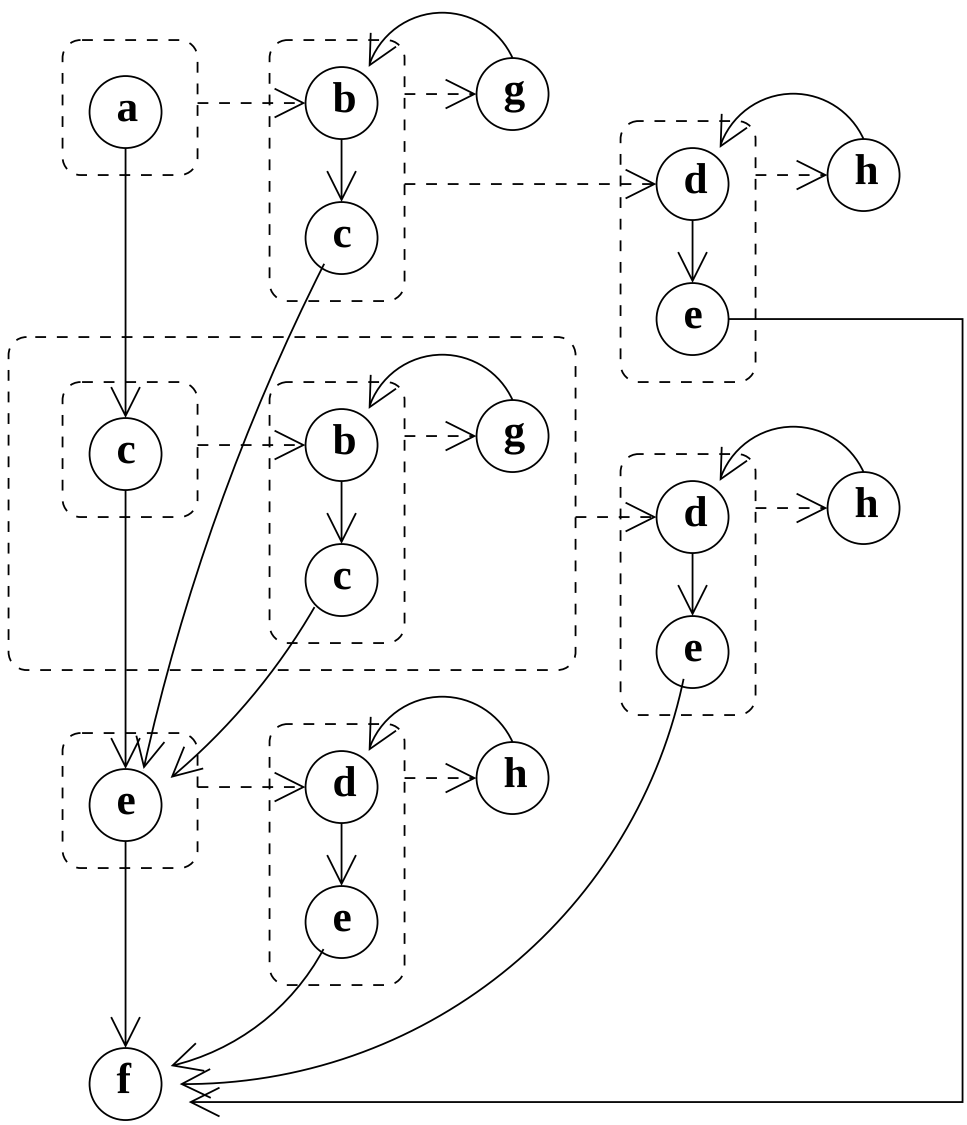
- Areas of protection may overlap, but not nest
- An area of protection may have several entry points
- Several areas might share the same handler statement
- Their handlers may reside in the area of protection itself!
- Any combination of the above all at once.

```
public void m()
{
    mException r0;
    java.lang.RuntimeException r1;
    java.lang.Throwable r2;

    r0 := @this;

  label_a:
    java.lang.System.out.println("a");
    goto label_c;

  label_b:
    r1 := @caughtexception;
    java.lang.System.out.println("b");

  label_c:
    java.lang.System.out.println("c");
    goto label_e;

  label_d:
    r2 := @caughtexception;
    java.lang.System.out.println("d");

  label_e:
    java.lang.System.out.println("e");

  label_f:
    java.lang.System.out.println("f");

  catch java.lang.RuntimeException from label_a to label_d with label_b;
  catch java.lang.Throwable from label_b to label_f with label_d;
}
```

Control flow graph



Solution: Version the control flow graph



4. Thread Synchronization

Problems:

- Object lock releases may be unstructured
- Critical sections may intersect but not nest
- Multiple entry points, etc.

Solution:

- Restructure only nice candidates
- Use a fallback mechanism for all other cases

Fallback mechanism: Replace monitor instructions with static method calls to a class that implements monitors in pure Java.

Example of fallback mechanism

```
...                          ...
monitorenter a;              synchronized (a) {
...                             ...
monitorenter b;                 Monitor.v().enter( b);
...                             ...
monitorexit a;               }
...                          ...
monitorexit b;               Monitor.v().exit( b);
...                          ...
```

Putting it All Together

Problem: Since it is difficult to resolve these issues singly, solving them simultaneously would likely be *extremely* difficult, maybe impossible

Solution: Deal with issues one at a time

Our decompiler uses an ordering of phases that allows us to tackle each problem on it's own.

For example, all Java loops are found in a single phase. The benefit is that once we have completed this phase, we know we have solved all the potential restructuring problems caused by multi-entry point loops.

See Miecznikowski et.al. from WCRE2001:

Decompiling Java using Staged Encapsulation

The ordering of phases in Dava:

1. Find simple statements
2. Perform local typing
3. Create a control flow graph of typed simple statements
4. Modify control flow graph to accommodate exceptional problems
5. Find loops
6. Find `if` and `switch` statements
7. Find exceptions
8. Find `synchronized` statements and their fallbacks
9. Determine if we need labeled blocks and `break` statements
10. Emit Java source

Conclusions

- The Java bytecode specification is much more flexible than the Java language specification

- There are plenty more problems that I haven't shown (`throws` declarations, spurious `try` block removal, class literals, package and class resolution, etc.)

- Even bytecode that comes from `javac` can pose difficulties

- Many sources can produce bytecode which doesn't follow `javac`'s code production patterns

- All these problems have been solved in our decompiler!

If you'ld like to try it out

- Our website:
  `http://www.sable.mcgill.ca`

- My public directory:
  `http://www.sable.mcgill.ca/~jerome/public/`

Thank you!