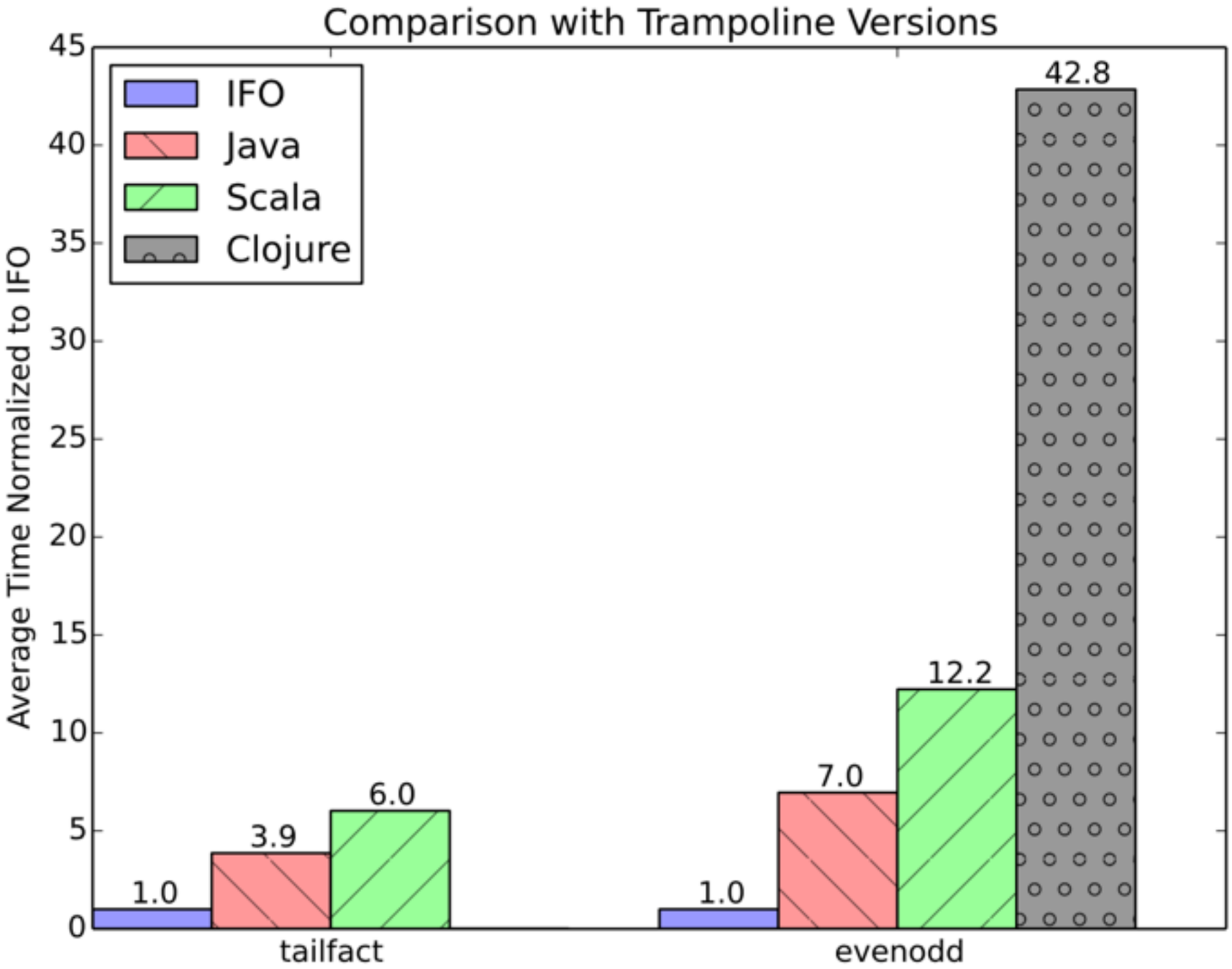
What Makes Our Compiler Fast

Jeremy



A picture is worth a thousand words!

“Avoid method calls at any cost!”

– Anonymous

(CJ-App)

$$\frac{\Gamma \vdash E_1 : \forall(x : T_2)\Delta.T_1 \rightsquigarrow J_1 \textbf{ in } S_1 \qquad \Gamma \vdash E_2 : T_2 \rightsquigarrow J_2 \textbf{ in } S_2 \qquad \Delta; T_1 \Downarrow T_3 \qquad f,\ x_f\ fresh}{\Gamma \vdash E_1\ E_2 : T_3 \rightsquigarrow x_f \textbf{ in } S_1 \uplus S_2 \uplus S_3}$$

S_3 := {
Function f = J_1;
f.arg = J_2;
f.apply();
$\langle T_3 \rangle$ x_f = ($\langle T_3 \rangle$) f.res;}

In base, one method call for one argument

Recap

```
public abstract class Closure
{
    public Object arg;
    public Object res;
    public abstract void apply ();
}
```

```
let add2 (a:Int) (b:Int): Int = a + b
in add2 3 4
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base

```
class Fun1 extends f2j.Closure
{...}
final f2j.Closure x0 = new Fun1();
f2j.Closure x8 = x0;
x8.arg = 3;
x8.apply();
final f2j.Closure x9 = (f2j.Closure) x8.res;
f2j.Closure x10 = x9;
x10.arg = 4;
x10.apply();
final java.lang.Integer x11 = (java.lang.Integer) x10.res;
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apply-opt

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f2j.Closure x8 = x0;
x8.arg = 3;
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Why?

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```
class Fun1 extends f2j.Closure
{
    f2j.Closure x2 = this;
    public void apply ()
    {
        final java.lang.Integer x3 = (java.lang.Integer) x2.arg;
        class Fun4 extends f2j.Closure
        {...}
        res = new Fun4();
    }
}
```

base

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class Fun1 extends f2j.Closure
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apply-opt

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class Fun1 extends f2j.Closure
{
    f2j.Closure x2 = this;
    {
        class Fun4 extends f2j.Closure
        {...}
        res = new Fun4();
    }
    public void apply ()
    {
    }
    public f2j.Closure clone ()
    {...}
}
```

What about unknown function?

\(f : Int -> Int -> Int) (a : Int) (b : Int). f a b

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\(f : Int -> Int -> Int) (a : Int) (b : Int). f a b

```
f.arg = a;
f.apply();
final f2j.Closure x10 = (f2j.Closure) f.res;
f2j.Closure x11 = x10;
x11.arg = b;
x11.apply();
final java.lang.Integer x12 = (java.lang.Integer) x11.res;
```

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f.arg = a;
final f2j.Closure x10 = (f2j.Closure) f.res;
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x11.arg = b;
x11.apply();
final java.lang.Integer x12 = (java.lang.Integer) x11.res;
```

We don’t know!

The statically unknown function *f* can be like *add2*, which takes two arguments, and returns the result.

Or it might be some function that takes one argument, compute for a while before returning a function that consumes the next argument, like the following one

\(a : Int). if a == 0 then \(b : Int). b + 1 else \(b : Int). b + 2

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\(a : Int). if a == 0 then \(b : Int). b + 1 else \(b : Int). b + 2

In either case, they all have the same type: **Int -> Int -> Int**

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```
Exception in thread "main" java.lang.NullPointerException
        at Test$1Fun1$1Fun4$1Fun7.apply(Test.java:27)
        at Test.apply(Test.java:138)
        at Test.main(Test.java:145)
```

Insight

The idea is simple. When a function of statically-unknown arity is applied, two pieces of information come together:

1. The arity of the function
2. The number of arguments in the call

Let the function itself tells us how many arguments it needs.

Insight

The idea is simple. When a function of statically-unknown arity is applied, two pieces of information come together:

1. The arity of the function
2. The number of arguments in the call

Let the function itself tells us how many arguments it needs.

Boolean to Rescue!

Run-time check

When translating a function, we set a *boolean flag* to indicate whether it needs to call apply method or not.

This is feasible because the function itself statically knows its arity.

\(a:Int) (b:Int): Int = a + b

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```
class Fun0 extends f2j.Closure
{
    f2j.Closure x1 = this;
    public void apply ()
    {
        final java.lang.Integer x2 = (java.lang.Integer) x1.arg;
        final java.lang.Boolean x4 = x2 == 0;
        f2j.Closure ifres3;
        if (x4)
        {
            class Fun5 extends f2j.Closure
            {...}
            ifres3 = new Fun5();
        }
        else
        {
            class Fun9 extends f2j.Closure
            {...}
            ifres3 = new Fun9();
        }
        res = ifres3;
    }
    public f2j.Closure clone ()
    {...}
}
```

```
public abstract class Closure
{
    public Object arg;
    public Object res;
    public boolean hasApply = true;
    public abstract void apply ();
}
```

\(a:Int) (b:Int): Int = a + b

```
class Fun0 extends f2j.Closure
{
    f2j.Closure x1 = this;
    {
        x1.hasApply = false;
        class Fun3 extends f2j.Closure
        {...}
        res = new Fun3();
    }
    public void apply ()
    {
    }
    public f2j.Closure clone ()
    {...}
}
```

\(a : Int). if a == 0 then \(b : Int). b + 1 else \(b : Int). b + 2

```
class Fun0 extends f2j.Closure
{
    f2j.Closure x1 = this;
    public void apply ()
    {
        final java.lang.Integer x2 = (java.lang.Integer) x1.arg;
        final java.lang.Boolean x4 = x2 == 0;
        f2j.Closure ifres3;
        if (x4)
        {
            class Fun5 extends f2j.Closure
            {...}
            ifres3 = new Fun5();
        }
        else
        {
            class Fun9 extends f2j.Closure
            {...}
            ifres3 = new Fun9();
        }
        res = ifres3;
    }
    public f2j.Closure clone ()
    {...}
}
```

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public abstract class Closure
{
    public Object arg;
    public Object res;
    public boolean hasApply = true;
    public abstract void apply ();
}
```

\(a:Int) (b:Int): Int = a + b

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class Fun0 extends f2j.Closure
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    f2j.Closure x1 = this;
    {
        x1.hasApply = false;
        class Fun3 extends f2j.Closure
        {...}
        res = new Fun3();
    }
    public void apply ()
    {
    }
    public f2j.Closure clone ()
    {...}
}
```

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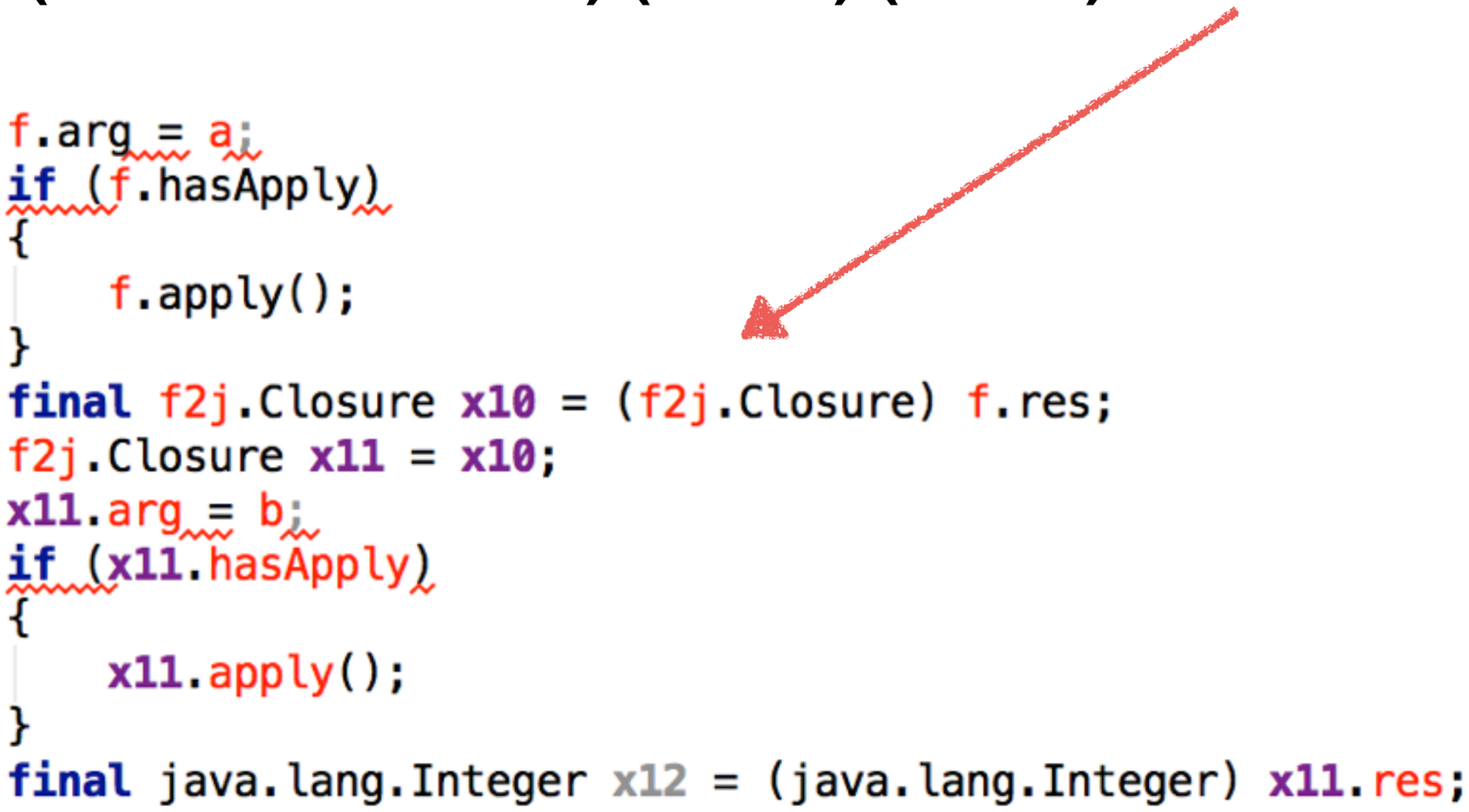

```
f.arg = a;
if (f.hasApply)
{
    f.apply();
}
final f2j.Closure x10 = (f2j.Closure) f.res;
f2j.Closure x11 = x10;
x11.arg = b;
if (x11.hasApply)
{
    x11.apply();
}
final java.lang.Integer x12 = (java.lang.Integer) x11.res;
```

Now we can rest assured that the function f takes care of whether it needs to call apply method or not.

Life is all too wonderful if we don’t …

```
let add2 (a:Int) (b:Int): Int = a + b
in add2 3 (add2 4 5)
```

Which one produces the correct result?

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⇒  f2j test.sf -m naive -r
test using [Naive]
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```
let add2 (a:Int) (b:Int): Int = a + b
in add2 3 (add2 4 5)
```

Which one produces the correct result?

base

```
⇒  f2j test.sf -m naive -r
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```

apply-opt

```
⇒  f2j test.sf -m apply -r
test using [Apply,Naive]
  Compiling to Java source code ( ./Test.java )
13
```

Apparently something terrible happens …

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$$\text{(CJD-Bind1)}\qquad \frac{\Gamma\,(y : T_1 \mapsto x_2); \Delta \vdash E : T \rightsquigarrow J \textbf{ in } S \qquad FC,\ x_1,\ x_2,\ f\ fresh}{\Gamma; (y : T_1)\ \Delta \vdash E : T \rightsquigarrow f \textbf{ in } S'}$$

S' := {
```
  class FC extends Function {
    Function x1 = this;
    void apply() {
      ⟨T1⟩ x2 = (⟨T1⟩) x1.arg;
      S;
      res = J;
    }
  };
  Function f = new FC();}
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    }
  };
Function f = new FC();}
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      S;
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Function f = new FC();}
```

Wherever there is a function definition, we immediately allocate memory for that.

This is no problem for base, because each apply call will create fresh copies of all the variables.

But for apply-opt, this is not the case …

let add2 (a:Int) (b:Int): Int = a + b
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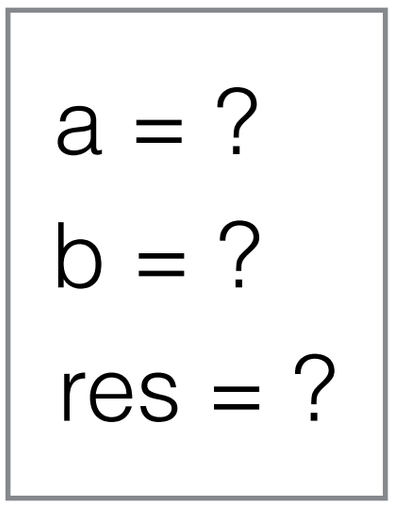

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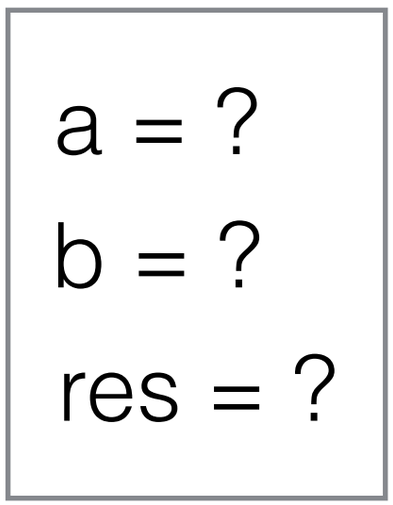

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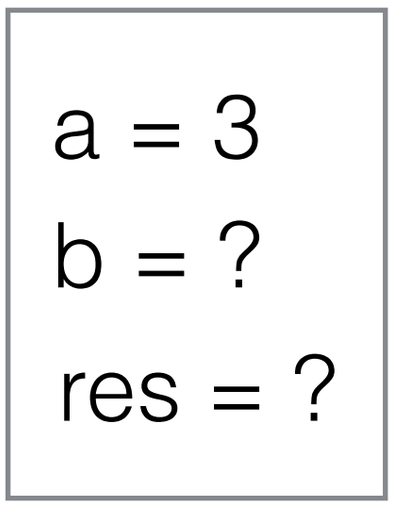

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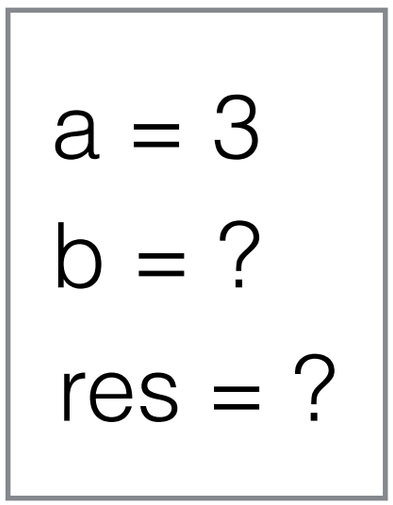

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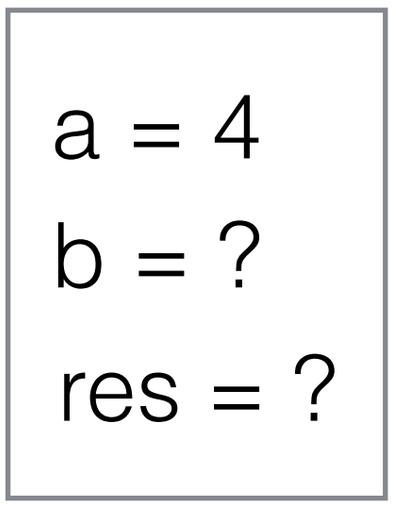

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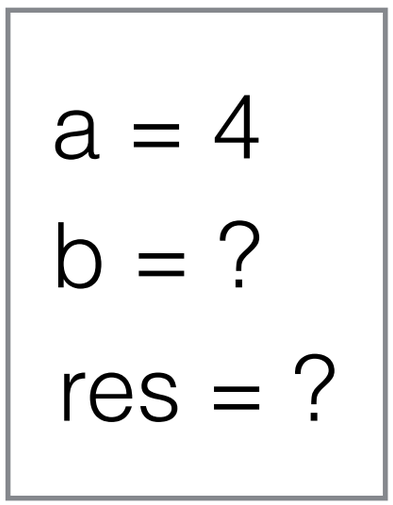

Overriding happens!

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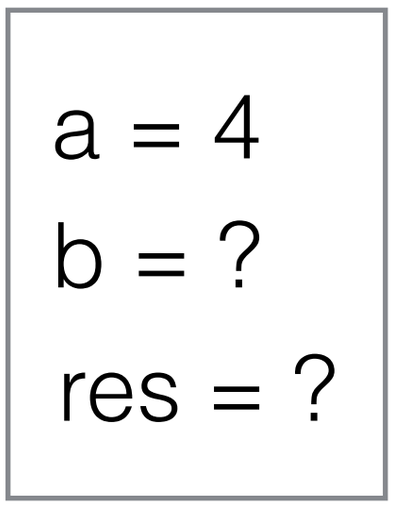

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a = 4

b = 5

res = ?

add2

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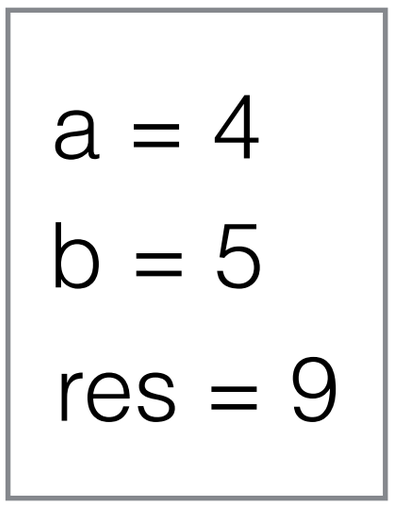

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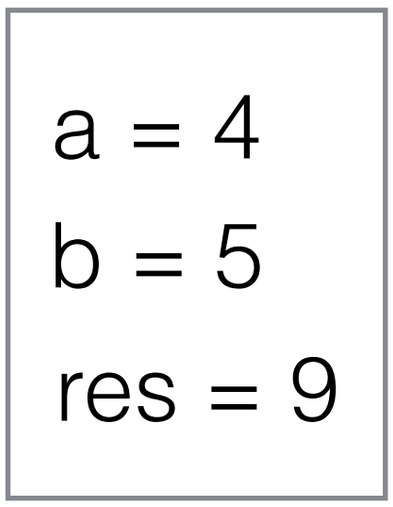

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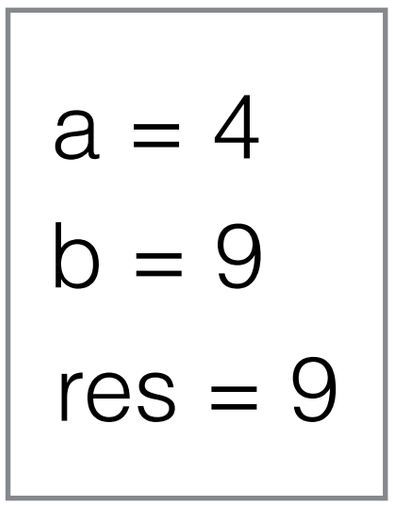

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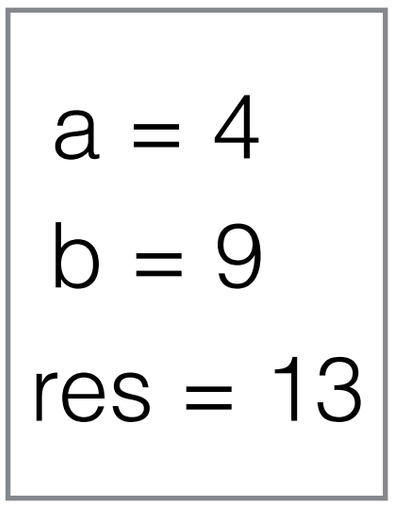

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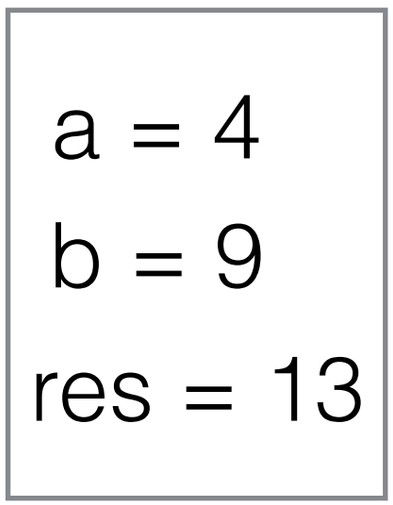

Observation is that, those two *add2* applications should use two different instances in memory instead of sharing one.

Non-Solution

Use a set to record all function names which have been used before.

```
let add2 (a:Int) (b:Int): Int = a + b
in add2 3 (add2 4 5)
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add2 is in the set!
Cloning is needed…

let add2 (a:Int) (b:Int): Int = a + b
in add2 3 (add2 4 5)

```
class Fun1 extends f2j.Closure
{
    f2j.Closure x2 = this;
    {
        x2.hasApply = false;
        class Fun4 extends f2j.Closure
        {...}
        res = new Fun4();
    }
    public void apply ()
    {...}
    public f2j.Closure clone ()
    {
        f2j.Closure c = new Fun1();
        return (f2j.Closure) c;
    }
}
```

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We get a fresh copy of *add2* :)

Problem solved?

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let add2 (a : Int) (b : Int): Int = a + b
in let g (a : Int) (b : Int) : Int = add2 a b
    in let f = add2
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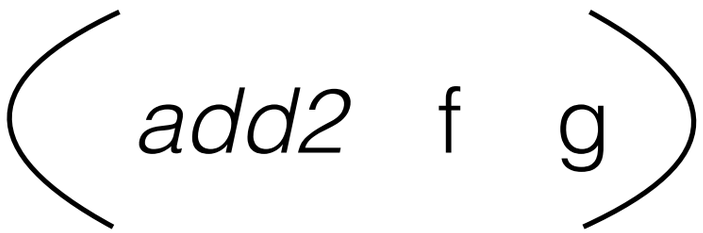

set

Overriding happens!

Even worse …

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\(f : Int -> Int -> Int) (g -> Int -> Int -> Int). f 3 (g 4 5)

We have no clue at all whether *g* will have a call to *f* or not!

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Cloning everywhere is possible, but slows down performance.

Potential Solution

The problem boils down to allocating memory immediately after function definition.

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$$\text{(CJD-Bind1)}\quad \frac{\Gamma\ (y : T_1 \mapsto x_2); \Delta \vdash E : T \rightsquigarrow J\ \textbf{in}\ S \qquad FC,\ x_1,\ x_2,\ f\ fresh}{\Gamma; (y : T_1)\ \Delta \vdash E : T \rightsquigarrow f\ \textbf{in}\ S'}$$

S' := {
  class FC **extends** Function {
    Function x_1 = **this**;
    void apply() {
      $\langle T_1 \rangle$ x_2 = ($\langle T_1 \rangle$) x1.arg;
      S;
      res = J;
    }
  };
  Function f = **new** FC();}

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let add2 (a:Int) (b:Int): Int = a + b
in add2 3 (add2 4 5)

new FC() new FC()

Still …

let f = ...
in f 2 (f 3 4)

```
f = new FC();
f.arg = 2;
...
f.arg = 3;
...
```

Aliasing still causes the same problem …

Contributions

- Propose a run-time check solution to solve the problem in apply-opt.
- Propose a potential solution which could possibly solve field-overriding problem.
- Build a working prototype compiler that uses apply-opt, which produces reasonably fast code.

Related work

- Marlow, Simon, and Simon Peyton Jones. "Making a fast curry: push/enter vs. eval/apply for higher-order languages." *ACM SIGPLAN Notices*. Vol. 39. No. 9. ACM, 2004.
- Shao, Zhong, and Andrew W. Appel. *Space-efficient closure representations*. Vol. 7. No. 3. ACM, 1994.

Future work

- Continue improving apply-opt to fully solve the field-overriding problem
- Investigate *tail recursive optimisation*

To be continued …

Paper Reading

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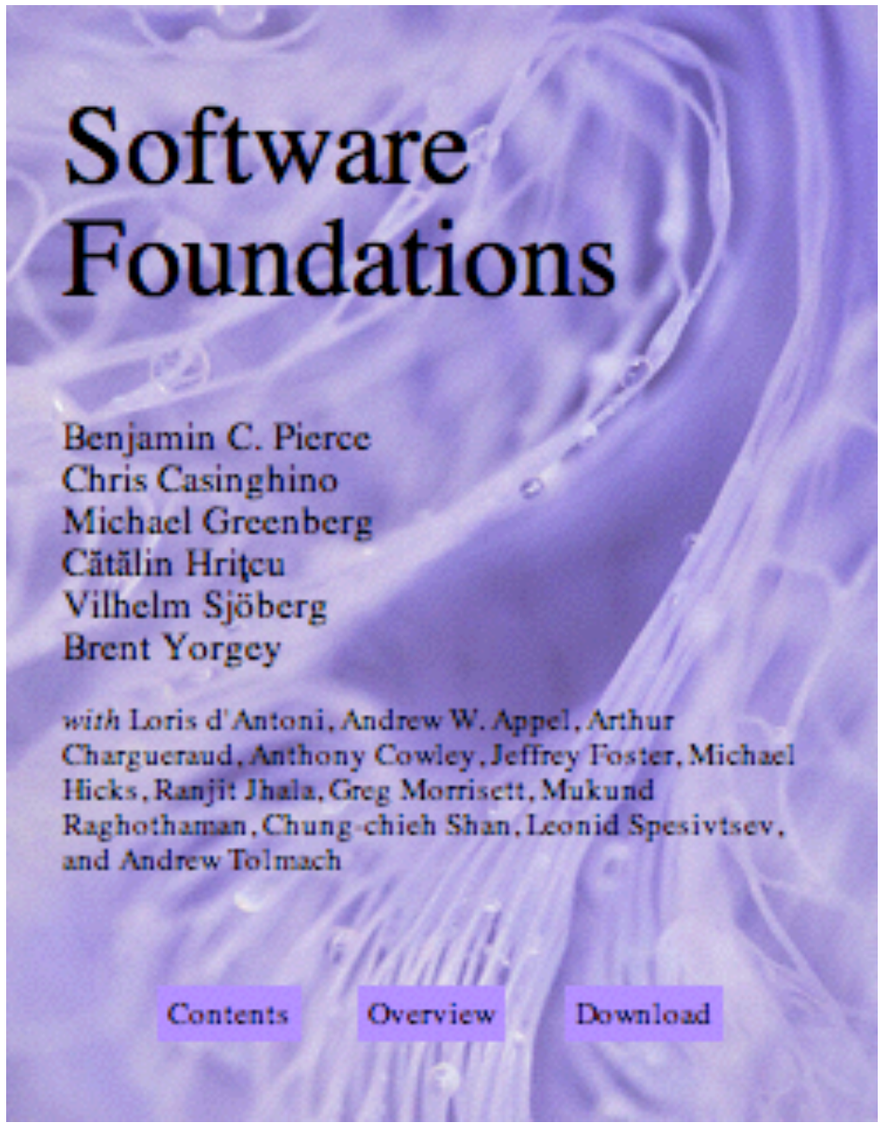
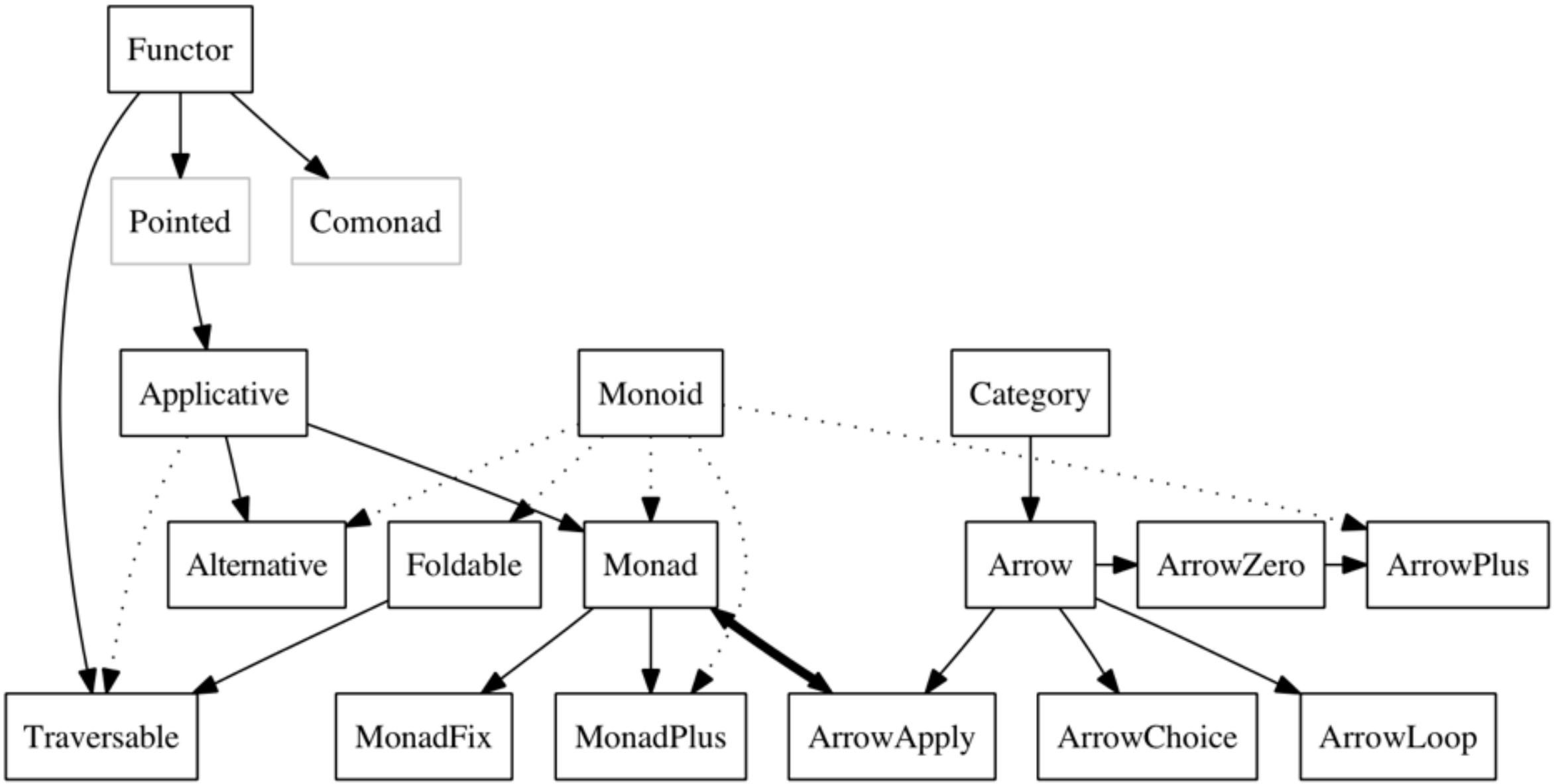
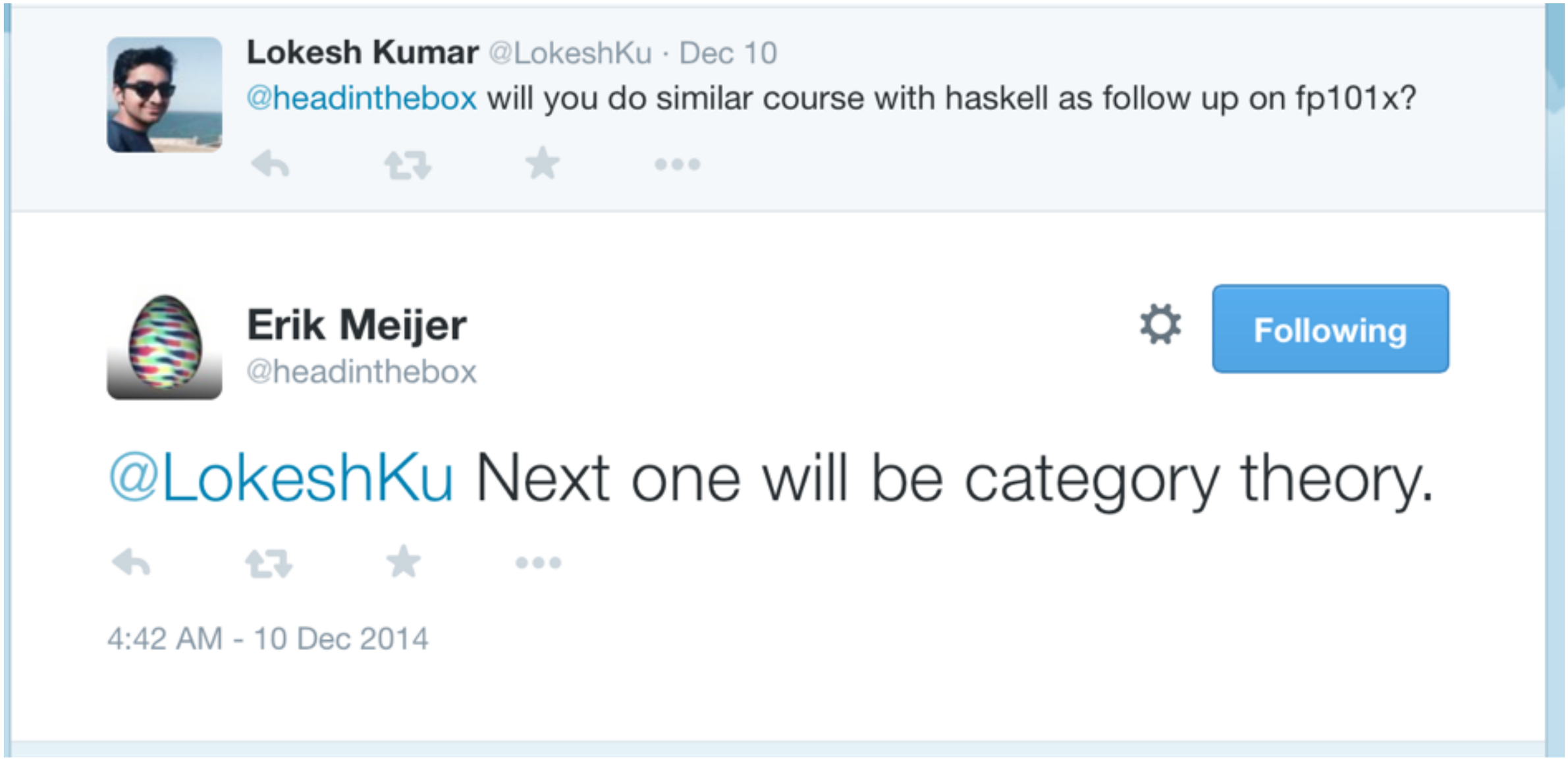


About Author

Note to headhunters: I am not interested in positions in industry, especially in the financial sector. Please don't contact me about job opportunities.

All about type class




Lokesh Kumar @LokeshKu · Dec 10
@headinthebox will you do similar course with haskell as follow up on fp101x?
Erik Meijer
@headinthebox
Following
@LokeshKu Next one will be category theory.
4:42 AM - 10 Dec 2014