Featherweight Java

Advanced Compiler Construction and Program Analysis

Lecture 9

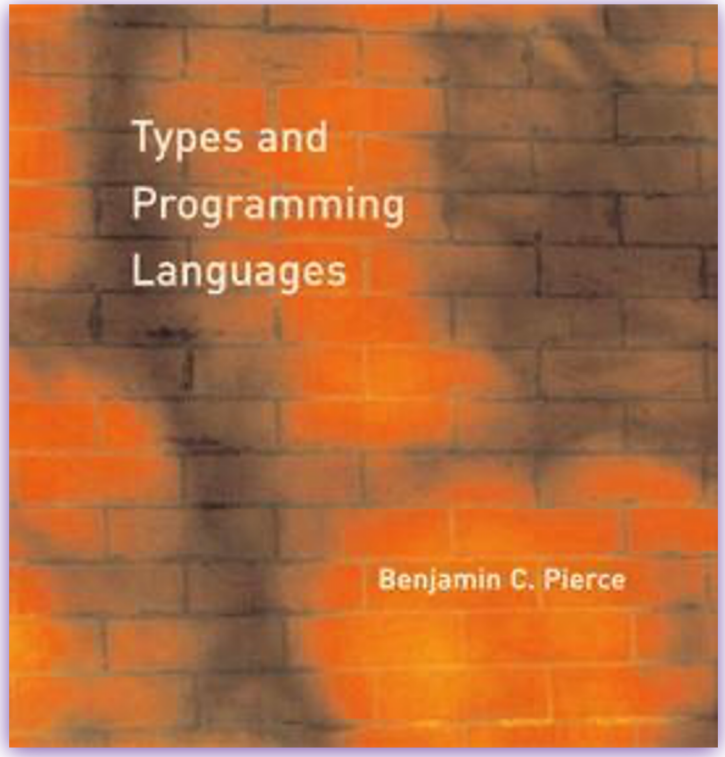
Innopolis University, Spring 2022

The topics of this lecture are covered in detail in…

Benjamin C. Pierce.

Types and Programming Languages

MIT Press 2002



Featherweight Java

1. A simplified core of Java
2. Useful for reasoning and proofs
3. A program in FJ is also a program in Java
4. Primarily useful to study language extensions for Java and how different extensions interoperate with each other

Featherweight Java: A Minimal Core Calculus for Java and GJ

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Several recent studies have introduced lightweight versions of Java: reduced languages in which complex features like threads and reflection are dropped to enable rigorous arguments about key properties such as type safety. We carry this process a step further, omitting almost all features of the full language (including interfaces and even assignment) to obtain a small calculus, Featherweight Java, for which rigorous proofs are not only possible but easy. Featherweight Java bears a similar relation to Java as the lambda-calculus does to languages such as ML and Haskell. It offers a similar computational "feel," providing classes, methods, fields, inheritance, and dynamic typecasts with a semantics closely following Java's. A proof of type safety for Featherweight Java thus illustrates many of the interesting features of a safety proof for the full language, while remaining pleasingly compact. The minimal syntax, typing rules, and operational semantics of Featherweight Java make it a handy tool for studying the consequences of extensions and variations. As an illustration of its utility in this regard, we extend Featherweight Java with *generic classes* in the style of GJ (Bracha, Odersky, Stoutamire, and Wadler) and give a detailed proof of type safety. The extended system formalizes for the first time some of the key features of GJ.

Categories and Subject Descriptors: D.3.1 [**Programming Languages**]: Formal Definitions and Theory; D.3.2 [**Programming Languages**]: Language Classifications—*Object-oriented languages*; D.3.3 [**Programming Languages**]: Language Constructs and Features—*Classes and objects*;

Featherweight Java: overview

```
class A extends Object { A() { super(); } }

class B extends Object { B() { super(); } }

class Pair extends Object {
    Object fst;
    Object snd;

    Pair(Object fst, Object snd) {
        super(); this.fst=fst; this.snd=snd;
    }
    Pair setfst(Object newfst) {
        return new Pair(newfst, this.snd);
    }
}
```

Featherweight Java: overview

```
class A extends Object { A() { super(); } }

class B extends Object { B() { super(); } }

class Pair extends Object {
    Object fst;
    Object snd;

    Pair(Object fst, Object snd) {
        super(); this.fst=fst; this.snd=snd;
    }
    Pair setfst(Object newfst) {
        return new Pair(newfst, this.snd);
    }
}
```

1. Always include superclass

Featherweight Java: overview

```
class A extends Object { A() { super(); } }

class B extends Object { B() { super(); } }

class Pair extends Object {
    Object fst;
    Object snd;

    Pair(Object fst, Object snd) {
        super(); this.fst=fst; this.snd=snd;
    }
    Pair setfst(Object newfst) {
        return new Pair(newfst, this.snd);
    }
}
```

2. Always name the receiver

Featherweight Java: overview

```
class A extends Object { A() { super(); } }

class B extends Object { B() { super(); } }

class Pair extends Object {
    Object fst;
    Object snd;

    Pair(Object fst, Object snd) {
        super(); this.fst=fst; this.snd=snd;
    }
    Pair setfst(Object newfst) {
        return new Pair(newfst, this.snd);
    }
}
```

3. Constructors are simple

Featherweight Java: overview

```
class A extends Object { A() { super(); } }

class B extends Object { B() { super(); } }

class Pair extends Object {
    Object fst;
    Object snd;

    Pair(Object fst, Object snd) {
        super(); this.fst=fst; this.snd=snd;
    }
    Pair setfst(Object newfst) {
        return new Pair(newfst, this.snd);
    }
}
```

4. Method body is **return ...**

Featherweight Java: terms

Object constructors

```
new A()
new B()
new Pair(…, …)
```

Method invocations

```
….setfst(…)
….getsnd()
```

Field access

```
this.fst
….x.setfst(…).z
```

Variables

```
this
newfst
```

Cast

```
(Pair)pair.fst
```

Featherweight Java: example

```
new Pair(new A(), new B()).setfst(new B())
```

Featherweight Java: example

```
new Pair(new A(), new B()).setfst(new B())
```

⇒ `new Pair(new B(), new B())`

Featherweight Java: example

```
new Pair(new A(), new B()).setfst(new B())

⇒ new Pair(new B(), new B())


((Pair)new Pair(new Pair(new A(), new B()),
                new A()).fst
).snd
```

Featherweight Java: example

```
new Pair(new A(), new B()).setfst(new B())
```

⇒ `new Pair(new B(), new B())`

```
((Pair)new Pair(new Pair(new A(), new B()),
                new A()).fst
).snd
```

⇒ `new B()`

Featherweight Java: evaluation preview

```
new Pair(new A(), new B()).snd    ⇒    new B()
```

Featherweight Java: evaluation preview

```
new Pair(new A(), new B()).snd    ⇒    new B()

new Pair(new A(), new B()).setfst(new B())
```

Featherweight Java: evaluation preview

```
new Pair(new A(), new B()).snd    ⇒    new B()

new Pair(new A(), new B()).setfst(new B())
```

Featherweight Java: evaluation preview

```
new Pair(new A(), new B()).snd    ⇒    new B()

new Pair(new A(), new B()).setfst(new B())
⇒              [newfst ↦ new B()]
               [this   ↦ new Pair(new A(), new B())]
               new Pair(newfst, this.snd)
```

Featherweight Java: evaluation preview

```
new Pair(new A(), new B()).snd    ⇒    new B()

new Pair(new A(), new B()).setfst(new B())
⇒              [newfst ↦ new B()]
               [this   ↦ new Pair(new A(), new B())]
               new Pair(newfst, this.snd)
⇒              new Pair(new B(), (new Pair(new A(), new
B())).snd)
```

Featherweight Java: evaluation preview

```
new Pair(new A(), new B()).snd    ⇒    new B()

new Pair(new A(), new B()).setfst(new B())
⇒              [newfst ↦ new B()]
               [this   ↦ new Pair(new A(), new B())]
               new Pair(newfst, this.snd)
⇒              new Pair(new B(), (new Pair(new A(), new
B()))).snd)
```

Featherweight Java: evaluation preview

```
new Pair(new A(), new B()).snd    ⇒    new B()

new Pair(new A(), new B()).setfst(new B())
⇒              [newfst ↦ new B()]
               [this   ↦ new Pair(new A(), new B())]
               new Pair(newfst, this.snd)
⇒              new Pair(new B(), (new Pair(new A(), new
B()))).snd)

(Pair)new Pair(new A(), new B())
⇒              new Pair(new A(), new B())
```

Nominal vs Structural Type Systems

Structural	Nominal
`NatPair = {fst:Nat, snd:Nat}`	`class NatPair extends Object { Nat fst; Nat snd; … }`
`{fst:Nat, snd:Nat, thd:Nat} <: {fst:Nat, snd:Nat}`	`class NatTriple extends NatPair … NatTriple <: NatPair`
Difficult to typecheck at runtime	Easy to typecheck at runtime (`instanceOf`, downcasting, printing, serializing, reflection, …)
Fixpoint combinator for recursive types	Easy recursive types
Non-trivial subtyping tests	Easy subtyping test
Single-constructor types (wrappers)	Explicit subtyping

Featherweight Java: syntax

```
CL ::= class C extends C {C f; K; M}
K ::= C(C f) { super(f); this.f = f}
M ::= C m(C x) { return t; }

t ::=
  x
  t.f
  t.m(t)
  new C(t)
  (C) t

v ::=
  new C(v)
```

class declaration
constructor declaration
method declaration

terms
variable
field access
method invocation
object construction
cast

values
object construction

Featherweight Java: subtyping

$$S <: S$$

$$\frac{S <: U \qquad U <: T}{S <: T}$$

$$\frac{CT(C) = \texttt{class } C \texttt{ extends } D \{\ldots\}}{C <: D}$$

Featherweight Java: subtyping with Object

Exercise 9.1. Explain why we do not need a special subtyping rule for `Object`, like we did for the `Top` type.

Featherweight Java: field lookup

$$\mathit{fields}(\mathtt{Object}) = \emptyset$$

$$\frac{\mathtt{CT(C) = class\ C\ extends\ D\ \{A\ f;\ K;\ M\}} \qquad \mathit{fields}(\mathtt{D}) = \mathtt{B\ g}}{\mathit{fields}(\mathtt{C}) = \mathtt{A\ f,\ B\ g}}$$

Featherweight Java: method type lookup

$$\frac{\texttt{CT(C) = class C extends D \{A f; K; M\}} \quad \texttt{B m(E x) \{…\}} \in \texttt{M}}{\textit{mtype}\texttt{(m, C) = E} \rightarrow \texttt{B}}$$

$$\frac{\texttt{CT(C) = class C extends D \{A f; K; M\}} \quad \texttt{m not in M}}{\textit{mtype}\texttt{(m, C) = }\textit{mtype}\texttt{(m, D)}}$$

Featherweight Java: method body lookup

$$\frac{CT(C) = \textbf{class } C \textbf{ extends } D \ \{\underline{A\ f};\ K;\ \underline{M}\} \qquad B\ m(\underline{E\ x})\ \{\ \textbf{return } t;\ \} \in \underline{M}}{\mathit{mbody}(m, C) = (\underline{x}, t)}$$

$$\frac{CT(C) = \textbf{class } C \textbf{ extends } D \ \{\underline{A\ f};\ K;\ \underline{M}\} \qquad m \text{ not in } \underline{M}}{\mathit{mtype}(m, C) = \mathit{mbody}(m, D)}$$

Featherweight Java: valid method overloading

$$\frac{\mathit{mtype}(\mathtt{m},\ \mathtt{D}) = \underline{\mathtt{E}} \to \mathtt{F} \text{ implies } \underline{\mathtt{E}}=\underline{\mathtt{A}} \text{ and } \mathtt{F}=\mathtt{B}}{\mathit{override}(\mathtt{m},\ \mathtt{D},\ \underline{\mathtt{A}} \to \mathtt{B})}$$

Featherweight Java: evaluation

$$\frac{\mathit{fields}(C) = \underline{A\ f}}{(\textbf{new}\ C(\underline{v})).f_n \longrightarrow v_n}$$

$$\frac{\mathit{mbody}(m, C) = (\underline{x}, t)}{(\textbf{new}\ C(\underline{v})).m(\underline{u}) \longrightarrow [\text{this} \mapsto \textbf{new}\ C(\underline{v}),\ \underline{x} \mapsto \underline{u}]t}$$

$$\frac{C <: D}{(D)(\text{new}\ C(\underline{v})) \longrightarrow \text{new}\ C(\underline{v})}$$

Featherweight Java: term typing

$$\frac{\Gamma \vdash t : C \qquad \mathit{fields}(C) = \underline{A\ f}}{\Gamma \vdash t.f_n : A_n}$$

$$\Gamma, x{:}T \vdash x : T$$

$$\frac{\Gamma \vdash t : C \qquad \mathit{mtype}(m, C) = \underline{A} \to B \qquad \Gamma \vdash \underline{s} : \underline{D} \qquad \underline{D} <: \underline{A}}{\Gamma \vdash t.m(\underline{s}) : B}$$

$$\frac{\mathit{fields}(C) = \underline{A\ f} \qquad \Gamma \vdash \underline{t} : \underline{B} \qquad \underline{B} <: \underline{A}}{\Gamma \vdash \mathbf{new}\ C(\underline{t}) : C}$$

Featherweight Java: term typing (casts)

$$\frac{\Gamma \vdash t : D \qquad D <: C}{\Gamma \vdash (C)t : C}$$

$$\frac{\Gamma \vdash t : D \qquad C <: D \qquad C \neq D}{\Gamma \vdash (C)t : C}$$

$$\frac{\Gamma \vdash t : D \qquad D \not<: C \qquad D \not<: C \qquad \textit{issue a warning}}{\Gamma \vdash (C)t : C}$$

Featherweight Java: “stupid” cast example

```
(A) ((Object) new B())   ⇒   (A) (new B())
```

Featherweight Java: “stupid” cast example

Exercise 9.2. Extend FJ with means to assign new values to the fields in the bodies of methods. Use references.

Exercise 9.3. Extend FJ with versions of **`raise`** and **`try`**.

Exercise 9.4. Show how to extend FJ with interfaces.

Summary

- ❏ Featherweight Java

See you next time!