CS 4110

Programming Languages & Logics

Lecture 29
Featherweight Java

Roadmap

We've been building up from the λ-calculus to get languages resembling "real" functional programming languages like ML.

Can we use the same tools to formalize a very different kind of language?

Object-Oriented Features

Today we'll study a core calculus called *Featherweight Java*, developed by Igarashi, Pierce, and Wadler in 2002.

Featherweight Java : Java

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polymorphic λ-calculus with references : OCaml

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Featherweight Java is small: it just has classes, inheritance, constructors, fields, methods, and casts, and it omits everything else.

Its simplicity makes its type soundness proof short and easy to extend.

Question

What *is* Object-Oriented Programming?

Syntax

$P \quad ::= \quad \overline{CL}\ e$ *programs*

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e	$::=$	x	*expressions*
	$\mid$	$e.f$	
	$\mid$	$e.m(\overline{e})$	
	$\mid$	$\texttt{new}\, C(\overline{e})$	
	$\mid$	$(C)\, e$	

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	$\mid$	$(C)\, e$	
v	$::=$	$\texttt{new}\, C(\overline{v})$	*values*
E	$::=$	$[\cdot]$	*evaluation contexts*
	$\mid$	$E.f$	
	$\mid$	$E.m(\overline{e})$	
	$\mid$	$v.m(\overline{v}, E, \overline{e})$	
	$\mid$	$\texttt{new}\, C(\overline{v}, E, \overline{e})$	
	$\mid$	$(C)\, E$	

Example

```
class A extends Object { A() { super(); } }
class B extends Object { A() { super(); } }
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```
class A extends Object { A() { super(); } }
class B extends Object { A() { super(); } }
 class Pair extends Object {
  Object fst;
  Object snd;
  Pair(Object fst, Object snd) {
    super();
    this.fst = fst;
    this.snd = snd;
  }
  Pair swap() {
    return new Pair(this.snd, this.fst);
  }
}
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}
new Pair(new A(), new B()).swap()
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$$\frac{P(C) = \texttt{class}\ C\ \texttt{extends}\ D\ \{\overline{C\ f};\ K\ \overline{M}\}}{C \leq D}\ \textsc{S-Class}$$

Field Lookup

$$\frac{}{\mathit{fields}(\texttt{Object}) = []}\ \textsc{F-Object}$$

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Method Body Lookup

$$\frac{P(C) = \texttt{class}\ C\ \texttt{extends}\ D\ \{\overline{C\ f};\ K\ \overline{M}\} \qquad B\ m\ (\overline{B\ x})\ \{\texttt{return}\ e\} \in \overline{M}}{mbody(m, C) = (\overline{x}, e)}\ \text{MB-Class}$$

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Operational Semantics

$$E ::= [\cdot] \mid E.f \mid E.m(\overline{e}) \mid v.m(\overline{v}, E, \overline{e}) \mid \texttt{new}\, C(\overline{v}, E, \overline{e}) \mid (C)\, E$$

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$$\frac{C \leq D}{(D)\, \texttt{new}\, C(\overline{v}) \to \texttt{new}\, C(\overline{v})}\ \textsc{E-Cast}$$

Method Type Lookup

$$\frac{P(C) = \texttt{class}\ C\ \texttt{extends}\ D\ \{\overline{C\ f};\ K\ \overline{M}\} \qquad B\ m\ (\overline{B\ x})\ \{\texttt{return}\ e\} \in \overline{M}}{mtype(m, C) = \overline{B} \to B}\ \text{MT-Class}$$

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Typing Rules

$$\frac{\Gamma(x) = C}{\Gamma \vdash x : C}\ \textsc{T-Var}$$

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$$\frac{\Gamma \vdash e : C \qquad \mathit{mtype}(m, C) = \overline{B} \to B \qquad \Gamma \vdash \overline{e} : \overline{A} \qquad \overline{A} \leq \overline{B}}{\Gamma \vdash e.m(\overline{e}) : B}\ \textsc{T-Invk}$$

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$$\frac{\Gamma \vdash e : D \qquad D \leq C}{\Gamma \vdash (C)\, e : C}\ \text{T-UCast}$$

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$$\frac{\Gamma \vdash e : C \qquad \mathit{mtype}(m, C) = \overline{B} \to B \qquad \Gamma \vdash \overline{e} : \overline{A} \qquad \overline{A} \leq \overline{B}}{\Gamma \vdash e.m(\overline{e}) : B}\ \text{T-INVK}$$

$$\frac{\mathit{fields}(C) = \overline{C\ f} \qquad \Gamma \vdash \overline{e} : \overline{B} \qquad \overline{B} \leq \overline{C}}{\Gamma \vdash \texttt{new}\ C(\overline{e}) : C}\ \text{T-NEW}$$

$$\frac{\Gamma \vdash e : D \qquad D \leq C}{\Gamma \vdash (C)\, e : C}\ \text{T-UCAST} \qquad \frac{\Gamma \vdash e : D \qquad C \leq D \qquad C \neq D}{\Gamma \vdash (C)\, e : C}\ \text{T-DCAST}$$

$$\frac{\Gamma \vdash e : D \qquad C \not\leq D \qquad D \not\leq C \qquad \textit{stupid warning}}{\Gamma \vdash (C)\, e : C}\ \text{T-SCAST}$$

Method Typing

$$\frac{mtype(m, D) = \overline{A} \to A \text{ implies } \overline{A} = \overline{B} \text{ and } A = B}{override(m, D, \overline{B} \to B)} \textsc{Override}$$

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$$\frac{\begin{array}{c}\overline{x : B}, \texttt{this} : C \vdash e : A \qquad A \leq B \\ P(C) = \texttt{class } C \texttt{ extends } D \, \{\overline{C\ f};\ K\ \overline{M}\} \\ override(m, D, \overline{B} \to B)\end{array}}{B\ m(\overline{B\ x})\{\texttt{return } e\}\ OK \text{ in } C} \textsc{Method-OK}$$

Class Typing

$$\frac{\begin{array}{c} K = C(\overline{D\ g}, \overline{C\ f})\ \{\texttt{super}(\overline{g}); \overline{\texttt{this}.f = \bar{f};}\ \} \\ \mathit{fields}(D) = \overline{D\ g} \qquad \overline{M\ OK\ \mathit{in}\ C} \end{array}}{\texttt{class}\ C\ \texttt{extends}\ D\ \{\overline{C\ f};\ K\ \overline{M}\}\ OK}\ \textsc{Class-OK}$$

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Lemma (Preservation)

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Lemma (Progress)

Let e be an expression such that $\vdash e : C$. *Then either:*

1. *e is a value,*
2. *there exists an expression* e' *such that* $e \to e'$, *or*
3. $e = E[(B)\ (\mathit{new}\ A(\overline{v}))]$ *with* $A \not\leq B$.