**Featherweight Java**

Classes \[ C ::= \text{class} \ c \text{ extends} \ c \{ c \ f ; \ k \ d \} \]

Constructors \[ k ::= c (c \ x) \{ \text{super} (x); \ this.\ f = x; \} \]

Methods \[ d ::= c \ m (c \ x) \{ \text{return} \ e \; \} \]

Types \[ \tau ::= c \]

Expressions \[ e ::= x \mid e.\ f \mid e.m(e) \mid \text{new} \ c(e) \mid (c) \ e \]

**Notation:**

- \( f \): field name
- \( c \): class name
- \( m \): method name
- \( x \): variable name
- \( _e \) is an abbreviation for \( e_1, e_2, \ldots, e_k \)
- \( c \_x \) is an abbreviation for \( c_1 \_x_1; \ldots \)
Class expressions:

class $c$ extends $c'$
{
  $c_1 f_1$;
  $c_2 f_2$;
  ...
  $k$
  $d_1$
  $d_2$ ...
}

declares class

$\rightarrow$ $c$ to be a subclass of $c'$
$\rightarrow$ with additional fields $c_i f_i$
$\rightarrow$ a single constructor $k$
$\rightarrow$ methods $d_i$
Constructor expressions:

\[
\begin{align*}
\quad & c\left(c_1 x_1', \ c_2 x_2', \ldots, c_1 x_1, \ c_2 x_2, \ldots\right)\{ \\
\quad & \quad \text{super}(x_1', \ldots) \\
\quad & \quad \text{this}.f_1 = x_1; \\
\quad & \quad \text{this}.f_2 = x_2; \\
\quad & \quad \vdots \\
\quad & \}
\end{align*}
\]

declares a constructor for class \( c \)

\( \rightarrow \) with arguments \( c_1 x_1' \) corresponding to fields of the superclass

\( \rightarrow \) and arguments \( c_i x_i \) corresponding to new fields of the subclass

\( \rightarrow \) \( x_i' \) are initialised via the superclass

\( \rightarrow \) \( \text{this}.f_i = x_i; \) fields initialised in the subclass
Method expressions:

\[ c \cdot m \left( c_1 \ x_1, \ c_2 \ x_2, \ldots \right) \{ \text{return}(e); \} \]

declares a method \( m \)

\( \rightarrow \) which returns a value of class \( c \)
\( \rightarrow \) with arguments \( x_i \) of class \( c_i \)
\( \rightarrow \) and a body returning the value of expression \( e \)
Field selection:

\[ e.f \]

select field \( f \) from instance \( e \)

Method invocation:

\[ e.m(e_1, e_2, \ldots) \]

invoke method \( m \) of instance \( e \) with arguments \( e_1, e_2 \)
Instance creation:

\[
\text{new } c(e_1, e_2, \ldots)
\]

creates a new instance of class \( c \) with arguments \( e_1, e_2 \).

Casting:

\[
(c) \, e
\]

casts value \( e \) to class \( c \).
the set of types is limited to the set of class names
- in examples, we may assume the presence of the types like int, but we will not discuss the semantics of operations on these types

there is a class Object
- all other classes are subclasses of Object

a special variable this referring to the instance itself
SUBCLASSES AND SUBTYPES

- the subclass/superclass relationship is similar to the subtype/supertype relationship with coercion interpretation
- if \( c \) is a subclass of \( c' \), the \( c \) has at least as many fields as \( c' \)
- objects of class \( c \) can be coerced (cast) to \( c' \) by deleting the additional fields
- we therefore write \( c <: c' \)
class Pt extends Object {
    int x;
    int y;
    Pt (int x, int y) {
        super (); this.x = x; this.y = y;
    }
}

class CPt extends Pt {
    color c;
    CPt (int x, it y, color c) {
        super (x,y);
        this.c = c;
    }
    color getc () {return this.c;}
}
The static semantics is defined by the following judgements:

\[ \tau <: \tau' \quad \text{subtyping} \]
\[ \Gamma \vdash e : \tau \quad \text{expression typing} \]
\[ \text{d ok in } c \quad \text{well formed method} \]
\[ \text{C ok} \quad \text{well formed class} \]
\[ \text{T ok} \quad \text{well formed class table} \]
\[ \text{fields}(c) = \{ c_1 f_1, c_2 f_2 \ldots \} \quad \text{field lookup} \]
\[ \text{type } (m, c) = c \rightarrow c \quad \text{method type} \]

A programme consists of a class table $T$ (sequence of class declarations) and an expression $e$.

We use the class table as implicit parameter in the following.

We only look at some interesting aspects of the static semantics.
Subclass relationship:

\[ \tau \leq \tau \]

\[ \tau_1 \leq \tau_2 \quad \tau_2 \leq \tau_3 \quad \tau_1 \leq \tau_3 \]

\[ T(c) = \text{class } c \text{ extends } c' \{ \ldots \} \]

\[ c \leq c' \]
Every variable has to be declared

\[
\frac{x : \tau \in \Gamma}{\Gamma \vdash x : \tau}
\]

Types of fields are defined in the class table:

\[
\frac{\Gamma \vdash e_0 : c_0 \quad \text{fields}(c_0) = c_1 f_1 \ldots}{\Gamma \vdash e_0.f_i : c_i}
\]
Argument and result types of methods are defined in the class table:

- methods of superclass can be applied, without explicit cast

\[
\Gamma \vdash e_0 : c_0 \quad \Gamma \vdash e : c \quad \text{type}(m, c_0) = c' \rightarrow c_1 \quad c <: c' \\
\Gamma \vdash e_0.m(e) : c_1
\]
All casts are statically valid:

\[
\frac{\Gamma \vdash e_0 : c'}{
\Gamma \vdash (c)e_0 : c}
\]
Method overriding:

New subclass method must have

- the same argument types
- the same result type

as superclass method

\[
T(c) = \text{class } c \text{ extends } c' \{ \ldots \} \\
\text{type}(m, c') = c \rightarrow c_0 \\
x : c, \text{this} : c \vdash e_0 : c_0 \\
c_0 \ m \ (c \ x) \{ \text{return } e_0 ; \} \ \text{ok in } c
\]
Properties:

- casts may fail at run time: checks required
- method invocation is statically checked
- field selection is statically checked
We discuss the single step or structural operational semantics of Featherweight Java.
Featherweight Java: Dynamic Semantics

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Values: an instance is a value if all of its arguments are values

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\frac{v \text{ value}}{\text{new } c(v) \text{ value}}
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Values: an instance is a value if all of it’s arguments are values

\[
\frac{\text{value} \quad \text{value}}{\text{new } c \ (v) \ \text{value}}
\]

In essence, a instance is just a collection of named fields, labeled with the class name.
Field Selection:

- \( c'_i f'_i \): fields of the super class
- \( c_j f_j \): new fields of the class
- retrieve value of field from either superclass or class itself

\[
\begin{align*}
\text{fields}(c) &= c f', \ c f \\
\text{new } c (v', v) \cdot f'_i &\mapsto v'_i \\
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\end{align*}
\]

Note that in Featherweight Java, the content of fields cannot be changed after initialization.

We could extend the language using techniques described previously.
Field Selection:

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\text{fields}(c) = c'_i f'_i, c f
\]
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\text{new } c (v'_i, v) \rightarrow f'_i \mapsto v'_i
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We could extend the language using techniques described previously.
Method Invocation:

- method invocation relies on an auxiliary predicate, $body$, which provides the list of formal arguments and the body of a method $m$ defined in a class $c$
- replace all formal parameters $x$ by actual parameters $e'$
- replace every occurrence of $\text{this}$ by the instance itself

\[
body(m, c) = \overline{x \rightarrow e_0} \\
\text{new } c(e).m(e') \leftarrow \{e'/x\}\{\text{new } c(e)/\text{this}\}e_0
\]
**Type Cast:**

- if \( c' \) is supertype of \( c \), then cast instance by “ignoring” fields that are not present in \( c' \)
- otherwise, cause a checked run-time error

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\text{otherwise, } & \quad \text{cause a checked run-time error}
\end{align*}
\]

\[
\begin{align*}
\frac{c <: c'}{(c')\text{new } c \ (e) \leftrightarrow \text{new } c \ (e)} \\
\frac{c \not<: c'}{(c')\text{new } c \ (e) \leftrightarrow \text{error}}
\end{align*}
\]

Note the interplay with the static semantic rules for type cast
Dynamic Dispatch:

To find the body $\text{body}(m, c)$ of a method $m$ of a class $c$, we have to search upwards through the class hierarchy for the first definition of $m$.

\[
T(c) = \text{class } c \text{ extends } c'\{\ldots d\} \quad d_i = c_i \quad m(c_i \quad x)\{\text{return}(e);\} \\
\text{body}(m, c) = x \rightarrow e
\]

\[
T(c) = \text{class } c \text{ extends } c'\{\ldots d\} \quad m \notin d \quad \text{body}(m, c') = x \rightarrow e \\
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Dynamic Dispatch:

To find the body \( \text{body}(m, c) \) of a method \( m \) of a class \( c \), we have to search upwards through the class hierarchy for the first definition of \( m \).

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T(c) = \text{class } c \text{ extends } c' \{ \ldots d \} \quad d_i = c_i \text{ } m(c_i \ x) \{ \text{return } (e); \} \\
\text{body}(m, c) = x \rightarrow e
\]

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T(c) = \text{class } c \text{ extends } c' \{ \ldots d \} \quad m \notin d \quad \text{body}(m, c') = x \rightarrow e \\
\text{body}(m, c) = x \rightarrow e
\]

And finally, we need rules to determine the evaluation order
SUBTYPING REVISITED

For records (or n-tuples) two types of subtyping:

→ Width Subtyping

\[
\begin{align*}
\text{If } m & > n, \\
\{l_1 : \tau_1, \ldots l_m : \tau_m\} & <: \{l_1 : \tau_1, \ldots l_n : \tau_n\}
\end{align*}
\]

Note: ordering of fields in records immaterial, rule allows us to “drop” arbitrary subset of fields

→ Depth Subtyping

\[
\begin{align*}
\sigma_1 & <: \tau_1, \sigma_2 <: \tau_2, \ldots, \\
\{l_1 : \sigma_1, \ldots l_n : \sigma_n\} & <: \{l_1 : \tau_1, \ldots l_n : \tau_n\}
\end{align*}
\]
IMPLEMENTATION OF SUBTYPING

For the implementation, we need to synthesize the coercion functions if we want to avoid runtime checks.
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We define a new relation $\tau_1 <: \tau_2 \rightsquigarrow f$

$\Rightarrow \tau_1$ is subclass of $\tau_2$, and $f$ is the coercion function of type $\tau_1 \rightarrow \tau_2$
\[
\text{Int} <: \text{Float} \leadsto \text{intToFloat}
\]

\[
\tau <: \tau \leadsto \text{id}
\]

\[
\frac{\tau_1 <: \tau_2 \leadsto f_1 \quad \tau_2 <: \tau_3 \leadsto f_2}{\tau_1 <: \tau_3 \leadsto}
\]

\[
\frac{\tau_1' <: \tau_1 \leadsto f_1 \quad \tau_2 <: \tau_2' \leadsto f_2}{\tau_1 \to \tau_2 <: \tau_1' \to \tau_2' \leadsto}
\]
\[
\text{Int} <: \text{Float} \rightsquigarrow \text{intToFloat}
\]

\[
\tau <: \tau \rightsquigarrow \text{id}
\]

\[
\begin{array}{c}
\tau_1 <: \tau_2 \rightsquigarrow f_1 & \quad \tau_2 <: \tau_3 \rightsquigarrow f_2 \\
\hline
\tau_1 <: \tau_3 \rightsquigarrow f_2 \cdot f_1
\end{array}
\]

\[
\begin{array}{c}
\tau_1' <: \tau_1 \rightsquigarrow f_1 & \quad \tau_2 <: \tau_2' \rightsquigarrow f_2 \\
\hline
\tau_1 \rightarrow \tau_2 <: \tau_1' \rightarrow \tau_2' \rightsquigarrow
\end{array}
\]

\textbf{IMPLEMENTATION OF SUBTYPING}
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\[ \tau <: \tau \leadsto \text{id} \]

\[
\begin{align*}
\tau_1 <: \tau_2 \leadsto f_1 & \quad \tau_2 <: \tau_3 \leadsto f_2 \\
\tau_1 <: \tau_3 \leadsto f_2 \cdot f_1
\end{align*}
\]

\[
\begin{align*}
\tau'_1 <: \tau_1 \leadsto f_1 & \quad \tau_2 <: \tau'_2 \leadsto f_2 \\
\tau_1 \rightarrow \tau_2 <: \tau'_1 \rightarrow \tau'_2 \leadsto f, \text{ where } f \ g \ x = f_2(g(f_1 \ x))
\end{align*}
\]
Subtyping complicates efficient implementation of field selection
Record type no longer reveals fields and types of fields of record
Possible solution: coercion creates a new copy of the record with adjusted number of fields
- drop: create a copy of record, delete fields
- copy: create a copy of record, apply respective coercion function to all components
Problematic for mutable records
Possible solution: separation of view from contents