An Implementation of Type Inference for Featherweight Generic Java

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Syntax

$$T := X \mid N$$

$$N := C{<}\overline{T}{>}$$

$$L := \text{class } C{<}\overline{X} \lhd \overline{N}{>} \lhd D\{\ \overline{T}\ \bar{f}\ [K]\ \overline{M}\ \}$$

$$K := C(\overline{T}\ \bar{f})\{\text{super}(\bar{f});\ \text{this}.\bar{f} = \bar{f};\}$$

$$M := {<}\overline{X} \lhd \overline{N}{>}T\ m(\overline{T}\ \bar{x})\ \{\text{return } e\}$$

$$e := x \mid e.f \mid e.{<}\overline{T}{>}m(\bar{e}) \mid \text{new } C(\bar{e}) \mid (C)e$$

AST

```python
@dataclass
class ClassDef:
    name: str,
    superclass: Type,
    typed_fields: FieldEnv,
    methods: list[MethodDef]
```

Parser

```
# grammar rules

identifier: ...

variable: identifier

[...]

# function for shaping

def variable(tuple_of_elements_of_variable_rule):
    (name, ) = tuple_of_elements_of_variable_rule
    return Variable(name)
```

extended Syntax

$\mathsf{T} := \mathsf{a} \mid \mathsf{X} \mid \mathsf{N}$	type variable, type parameter, non type variable
$\mathsf{N} := \mathsf{C}{<}\overline{\mathsf{T}}{>}$	class type (with type variables)
$\mathsf{sc} := \mathsf{T} < \mathsf{U} \mid \mathsf{T} = \mathsf{U}$	simple constraint: subtype or equality
$\mathsf{oc} := \{\{\overline{\mathsf{sc}}_1\},\ \ldots, \{\overline{\mathsf{sc}}_n\}\}$	or-constraint
$\mathsf{c} := \mathsf{sc} \mid \mathsf{oc}$	constraint
$C := \{\overline{\mathsf{c}}\}$	constraint set
$\lambda := \mathsf{C}{<}\overline{\mathsf{X}} \lhd \overline{\mathsf{N}}{>}.\mathsf{m} : {<}\overline{\mathsf{Y}} \lhd \overline{\mathsf{P}}{>}\overline{\mathsf{T}} \rightarrow \mathsf{T}$	method type assumption
$\eta := \mathsf{x} : \mathsf{T}$	parameter assumption
$\Pi := \Pi \cup \overline{\lambda}$	method type environment
$\Theta := (\Pi; \overline{\eta})$	

Type Inference

$$
\begin{aligned}
&\text{FJTypeInference}(\Pi,\ \text{class C<}\overline{\text{X}} \lhd \overline{\text{N}}\text{>} \lhd \text{N}\{\ldots\}) = \\
&\qquad \text{let } (\overline{\lambda},\ C) \qquad\quad = \text{FJType}(\Pi, \text{class C<}\overline{\text{X}} \lhd \overline{\text{N}}\text{>} \lhd \text{N}\{\ldots\}) \\
&\qquad\quad (\sigma, \text{<}\overline{\text{Y}} \lhd \overline{\text{P}}\text{>}) = \text{Unify}(C, \{\overline{\text{X}} <: \overline{\text{N}}\} \cup \{\text{<}\overline{\text{Z}} \lhd \overline{\text{Q}}\text{>} \mid \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad (\text{C<}\overline{\text{X}} \lhd \overline{\text{N}}\text{>.m} : \text{<}\overline{\text{Z}} \lhd \overline{\text{Q}}\text{>}\overline{T} \to T) \in \overline{\lambda}\}) \\
&\qquad \text{in } \Pi \cup\ \{(\text{C<}\overline{\text{X}} \lhd \overline{\text{N}}\text{>.m}\ :\ \text{<}\overline{\text{Y}} \lhd \overline{\text{P}}\text{>}\ \overline{\sigma(a)} \to \sigma(a)) \mid \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad (\text{C<}\overline{\text{X}} \lhd \overline{\text{N}}\text{>.m} : \overline{a} \to a) \in \overline{\lambda}\}
\end{aligned}
$$

FJType

$$
\begin{aligned}
&\mathsf{FJType}(\Pi, \text{class } C{<}\overline{X} \lhd \overline{N}{>} \lhd N\{\overline{T}\ \bar{f};\ \overline{M}\}) = \\
&\qquad \text{let } \overline{a}_m \text{ be fresh type variables for each } m \in \overline{M} \\
&\qquad\quad \overline{\lambda}_0 = \{C{<}\overline{X} \lhd \overline{N}{>}.m :\ {<}\overline{Y} \lhd \overline{P}{>}\overline{T} \to a_m \\
&\qquad\qquad\qquad\qquad \mid m \in \overline{M},\ \mathsf{mtype}(m,\ N,\ \Pi) = {<}\overline{Y} \lhd \overline{P}{>}\overline{T} \to T\} \\
&\qquad\quad C_0 = \{a_m < T \mid m \in \overline{M},\ \mathsf{mtype}(m,\ N,\ \Pi) = {<}\overline{Y} \lhd \overline{P}{>}\overline{T} \to T\} \\
&\qquad\quad \overline{\lambda}' = \{(C{<}\overline{X} \lhd \overline{N}{>}.m :\ \overline{a} \to a_m) \\
&\qquad\qquad\qquad\qquad \mid m \in \overline{M},\ \mathsf{mtype}(m,\ N,\ \Pi) \text{ not defined},\ \overline{a} \text{ fresh}\} \\
&\qquad\quad C_m = \{\{a_m < \mathsf{Object}, \overline{a} < \overline{\mathsf{Object}}\} \mid (C{<}\overline{X} \lhd \overline{N}{>}.m :\ \overline{a}\ \to a_m) \in \overline{\lambda}'\} \\
&\qquad\quad \Pi = \Pi \cup \overline{\lambda}' \cup \overline{\lambda}_0 \\
&\qquad \text{in } (\Pi, C_0 \cup C_m \cup \bigcup_{m \in \overline{M}} \mathsf{TYPEMethod}(\Pi, C{<}\overline{X}{>}, m))
\end{aligned}
$$

TYPEMethod

$$
\begin{aligned}
&\text{TYPEMethod}(\Pi,\ \text{C<}\overline{\text{X}}\text{>},\ \text{m}(\bar{\text{x}})\{\ \text{return e;}\ \}) = \\
&\qquad\qquad \text{let}\ \text{<}\overline{\text{Y}} \lhd \overline{\text{P}}\text{>}\overline{\text{T}} \to \text{T} = \Pi(\text{C<}\overline{\text{X}} \lhd \overline{\text{N}}\text{>.m}) \\
&\qquad\qquad\quad (\text{R}, C) = \text{TYPEExpr}((\Pi; \{\text{this} : \text{C<}\overline{\text{X}}\text{>}\} \cup \{\bar{\text{x}} : \overline{\text{T}}\}), \text{e}) \\
&\qquad\qquad \text{in}\quad C \cup \{\text{R} < \text{T}\}
\end{aligned}
$$

TYPEExpr | Variable

$$\mathsf{TYPEExpr}((\Pi; \overline{\eta}), \mathsf{x}) = (\overline{\eta}(\mathsf{x}), \emptyset)$$

TYPEExpr | Field Lookup

$$
\begin{aligned}
&\mathsf{TYPEExpr}((\Pi;\overline{\eta}), e.f) = \\
&\qquad \text{let } (\mathsf{R}, C_R) = \mathsf{TYPEExpr}((\Pi;\overline{\eta}), e) \\
&\qquad\quad a \text{ fresh} \\
&\qquad\quad \mathsf{c} = \mathsf{oc}\{\{\mathsf{R} < \mathsf{C}\text{<}\overline{\mathsf{a}}\text{>}, \mathsf{a} = [\overline{\mathsf{a}}/\overline{\mathsf{X}}]\mathsf{T}, \overline{\mathsf{a}} < [\overline{\mathsf{a}}/\overline{\mathsf{X}}]\overline{\mathsf{N}} \mid \overline{\mathsf{a}} \text{ fresh}\} \\
&\qquad\qquad\qquad \mid \mathsf{T}\ \mathsf{f} \in \mathsf{class}\ \mathsf{C}\text{<}\overline{\mathsf{X}} \lhd \overline{\mathsf{N}}\text{>} \lhd \mathsf{N}\ \{\ \overline{\mathsf{X}}\ \overline{\mathsf{N}};\ [\mathsf{K}]\ \overline{\mathsf{M}}\ \}\} \\
&\qquad \text{in } (\mathsf{a}, (C_R \cup \{\mathsf{c}\}))
\end{aligned}
$$

Solved Form

1. $a < b$
2. $a = b$
3. $a <$ C<$\overline{T}$>
4. $a =$ C<$\overline{T}$> with $a \notin \overline{T}$

No variable is allowed to occur twice on the left side of rules 3 and 4.

Step 1

$$\frac{C \cup \{a < \mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>},\ a < \mathtt{D}\texttt{<}\overline{\mathtt{V}}\texttt{>}\}}{C \cup \{a < \mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>},\ \mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>} < \mathtt{D}\texttt{<}\overline{\mathtt{V}}\texttt{>}\}} \quad \Delta \vdash \mathtt{C}\texttt{<}\overline{\mathtt{X}}\texttt{>} <: \mathtt{D}\texttt{<}\overline{\mathtt{N}}\texttt{>} \qquad \text{match}$$

$$\frac{C \cup \{\mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>} < a,\ \mathtt{D}\texttt{<}\overline{\mathtt{V}}\texttt{>} < a\}}{C \cup \mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>} < \mathtt{D}\texttt{<}\overline{\mathtt{V}}\texttt{>},\ \mathtt{D}\texttt{<}\overline{\mathtt{V}}\texttt{>} < a} \quad \Delta \vdash \mathtt{C}\texttt{<}\overline{\mathtt{X}}\texttt{>} <: \mathtt{D}\texttt{<}\overline{\mathtt{N}}\texttt{>} \qquad \text{match reverse}$$

$$\frac{C \cup \{a < \mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>},\ b <^* a, b < \mathtt{D}\texttt{<}\overline{\mathtt{U}}\texttt{>}\}}{C \cup \{a < \mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>},\ b <^* a,\ b < \mathtt{D}\texttt{<}\overline{\mathtt{U}}\texttt{>},\ b < \mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>}\}} \qquad \text{adopt}$$

$$\frac{C \cup \{\mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>} < a,\ a <^* b, \mathtt{D}\texttt{<}\overline{\mathtt{U}}\texttt{>} < b\}}{C \cup \{\mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>} < a,\ a <^* b,\ \mathtt{D}\texttt{<}\overline{\mathtt{U}}\texttt{>} < b,\ \mathtt{C}\texttt{<}\overline{\mathtt{T}}\texttt{>} < b\}} \qquad \text{reverse adopt}$$

Step 2

1. $\text{C<}\overline{\text{T}}\text{>} < \text{D<}\overline{\text{U}}\text{>}$ where C cannot be a subtype of D.
2. $a < \text{C<}\overline{\text{T}}\text{>},\ a < \text{D<}\overline{\text{U}}\text{>}$ where C cannot be a subtype of D and vice versa.
3. $\text{C<}\overline{\text{T}}\text{>} < a$

expandLB

$$\text{expandLB}(\text{C<}\overline{\text{T}}\text{>} < a,\ a < \text{D<}\overline{\text{U}}\text{>}) = \{\{a = [\overline{\text{T}}/\overline{\text{X}}]\text{N}\}$$
$$\mid \Delta \vdash \text{C<}\overline{\text{X}}\text{>} < \text{N},\ \Delta \vdash \text{N} < \text{D<}\overline{\text{P}}\text{>}\}$$
$$\text{where } \overline{\text{P}} \text{ is determined by } \Delta \vdash \text{C<}\overline{\text{X}}\text{>} < \text{D<}\overline{\text{P}}\text{>} \text{ and } [\overline{\text{T}}/\overline{\text{X}}]\overline{\text{P}} = \overline{\text{U}}$$

Step 3

$$\frac{C \cup \{\mathsf{a} = \mathsf{T}\}}{[\mathsf{T}/\mathsf{a}]\mathsf{C} \cup \{\mathsf{a} = \mathsf{T}\}} \quad \text{where a occurs in C but not in T}$$

Step 4

If C" has changed, then start again from Step 1.

Step 5

$$\frac{C \cup \{\mathsf{C} \cup \mathsf{a} < \mathsf{b}\}}{[\mathsf{a}/\mathsf{b}]\mathsf{C} \cup \{\mathsf{b} = \mathsf{a}\}} \quad \text{sub elim}$$

$$\frac{C \cup \{\mathsf{a} = \mathsf{a}\}}{C} \quad \text{erase}$$

Step 6

$$\sigma = \{\mathsf{b} \rightarrow [\overline{\mathsf{Y}}/\overline{\mathsf{a}}]\mathsf{T} \mid (\mathsf{b} = \mathsf{T}) \in C_{=}\} \cup \{\overline{\mathsf{a}} \rightarrow \overline{\mathsf{Y}}\} \cup \{\mathsf{b} \rightarrow \mathsf{X} \mid (\mathsf{b} < \mathsf{X}) \in C_{<}\}$$

$$\gamma = \{\mathsf{Y} \lhd [\overline{\mathsf{Y}}/\overline{\mathsf{a}}]\mathsf{N} \mid (\mathsf{a} < \mathsf{N}) \in C_{<}\}$$

Type Infernece

$$
\begin{aligned}
&\mathsf{FJTypeInference}(\Pi,\ \mathsf{class}\ \mathsf{C{<}\overline{X} \lhd \overline{N}{>} \lhd N\{...\}}) = \\
&\quad \mathsf{let}\ (\overline{\lambda},\ C) \qquad\qquad = \mathsf{FJType}(\Pi, \mathsf{class}\ \mathsf{C{<}\overline{X} \lhd \overline{N}{>} \lhd N\{...\}}) \\
&\qquad (\sigma, \mathsf{{<}\overline{Y} \lhd \overline{P}{>}}) = \mathsf{Unify}(C, \{\overline{\mathsf{X}} <: \overline{\mathsf{N}}\} \cup \{\mathsf{{<}\overline{Z} \lhd \overline{Q}{>}} \mid \\
&\qquad\qquad\qquad\qquad\qquad\qquad (\mathsf{C{<}\overline{X} \lhd \overline{N}{>}.m} : \mathsf{{<}\overline{Z} \lhd \overline{Q}{>}}\overline{T} \to T) \in \overline{\lambda}\}) \\
&\quad \mathsf{in}\ \Pi \cup\ \{(\mathsf{C{<}\overline{X} \lhd \overline{N}{>}.m}\ :\ \mathsf{{<}\overline{Y} \lhd \overline{P}{>}}\ \overline{\sigma(a)} \to \sigma(a)) \mid \\
&\qquad\qquad\qquad\qquad\qquad\qquad (\mathsf{C{<}\overline{X} \lhd \overline{N}{>}.m} : \overline{a} \to a) \in \overline{\lambda}\}
\end{aligned}
$$

Example

```
class Pair<X extends Object<>,
           Y extends Object<>> extends Object<>{
  X fst;
  Y snd;

  setfst(newfst) {
    return new Pair(newfst, this.snd);
  }
}
```

Example

$$\lambda = \{(\text{Pair<X} \lhd \text{Object>.setfst}) : \ [a_1] \to a_0\}$$
$$C = \{a_0 < \text{Object}, \ a_1 < \text{Object}\}$$

$$\begin{aligned} C = \{&a_0 < \text{Object}, \ a_1 < \text{Object}, \\ &a_1 < a_5, \ a_5 < \text{Object}, \ a_2 < a_6, \ a_6 < \text{Object}, \\ &\{\{\text{Pair<X, Y>} < \text{Pair<}a_3, a_4\text{>}, \ a_2 = a_4, \ a_3 < \text{Object}, \ a_4 < \text{Object}\}\} \\ &\} \end{aligned}$$

Example

$$
\begin{aligned}
\lambda &= \{(\mathsf{Pair{<}X} \lhd \mathsf{Object{>}.setfst}) : \ [\mathsf{a}_1] \to \mathsf{a}_0\} \\
C &= \{\mathsf{a}_0 < \mathsf{Object},\ \mathsf{a}_1 < \mathsf{Object}, \\
&\qquad \mathsf{a}_1 < \mathsf{a}_5,\ \mathsf{a}_5 < \mathsf{Object},\ \mathsf{a}_2 < \mathsf{a}_6,\ \mathsf{a}_6 < \mathsf{Object}, \\
&\qquad \{\{\mathsf{Pair{<}X,\ Y{>}} < \mathsf{Pair{<}a_3, a_4{>}},\ \mathsf{a}_2 = \mathsf{a}_4,\ \mathsf{a}_3 < \mathsf{Object},\ \mathsf{a}_4 < \mathsf{Object}\}\}, \\
&\qquad \mathsf{Pair{<}a_5, a_6{>}} < \mathsf{a}_0 \\
&\qquad \}
\end{aligned}
$$

Example

$$\frac{C \cup \{\text{Pair<X<>, Y<>>} < \text{Pair<}a_3, a_4\text{>}\}}{C \cup \{\text{Pair<X<>, Y<>>} = \text{Pair<}a_3, a_4\text{>}\}} \quad \text{adapt}$$

$$\frac{C \cup \{\text{Pair<X<>, Y<>>} = \text{Pair<}a_3, a_4\text{>}\}}{C \cup \{\text{X<>} = a_3,\ \text{Y<>} = a_4\}} \quad \text{reduce}$$

$$\frac{C \cup \{\text{X<>} = a_3\}}{C \cup \{a_3 = \text{X<>}\}} \quad \text{and} \quad \frac{C \cup \{\text{Y<>} = a_3\}}{C \cup \{a_3 = \text{Y<>}\}} \quad \text{swap}$$

Example

$$
\begin{aligned}
C = \{&\text{Y<>} < a_6,\ a_1 < a_5,\ a_6 < \text{Object<>},\ a_1 < \text{Object<>},\\
&\text{X<>} < \text{Object<>},\ a_4 = \text{Y<>},\ \text{Y<>} < \text{Object<>},\\
&a_0 = \text{Pair<}a_5,\ a_6\text{>},\ a_3 = \text{X<>}, a_2 = \text{Y<>},\ a_5 < \text{Object<>}\\
&\}
\end{aligned}
$$

$$
\begin{aligned}
C_{=} &= \{a_0 = \text{Pair<}a_1,\ \text{Y>},\ a_6 = \text{Y},\ a_5 = a_1,\ a_4 = \text{Y},\ a_3 = \text{X},\ a_2 = \text{Y}\}\\
C_{<} &= \{a_1 < \text{Object<>}\}
\end{aligned}
$$

Vielen Dank für Ihre Aufmerksamkeit!