Compilerbau

Martin Plümicke

WS 2021/22

Agenda

Literatur


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(in german).


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The Java series. Addison-Wesley, Java SE 8 edition, 2014.


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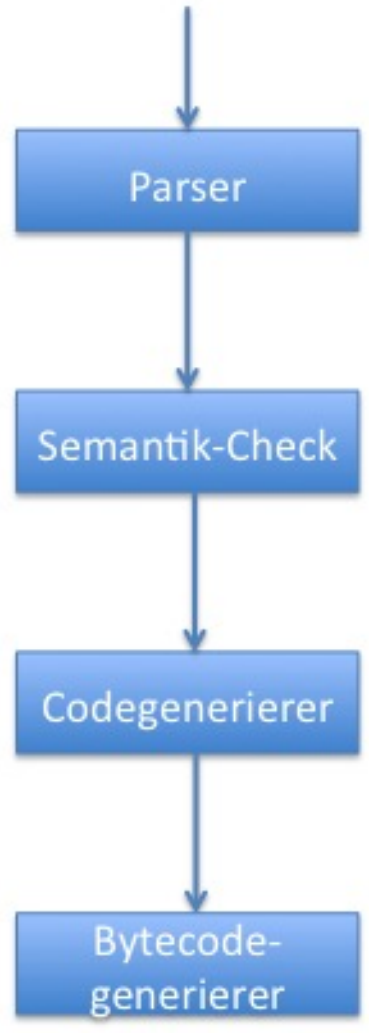
Compiler Überblick



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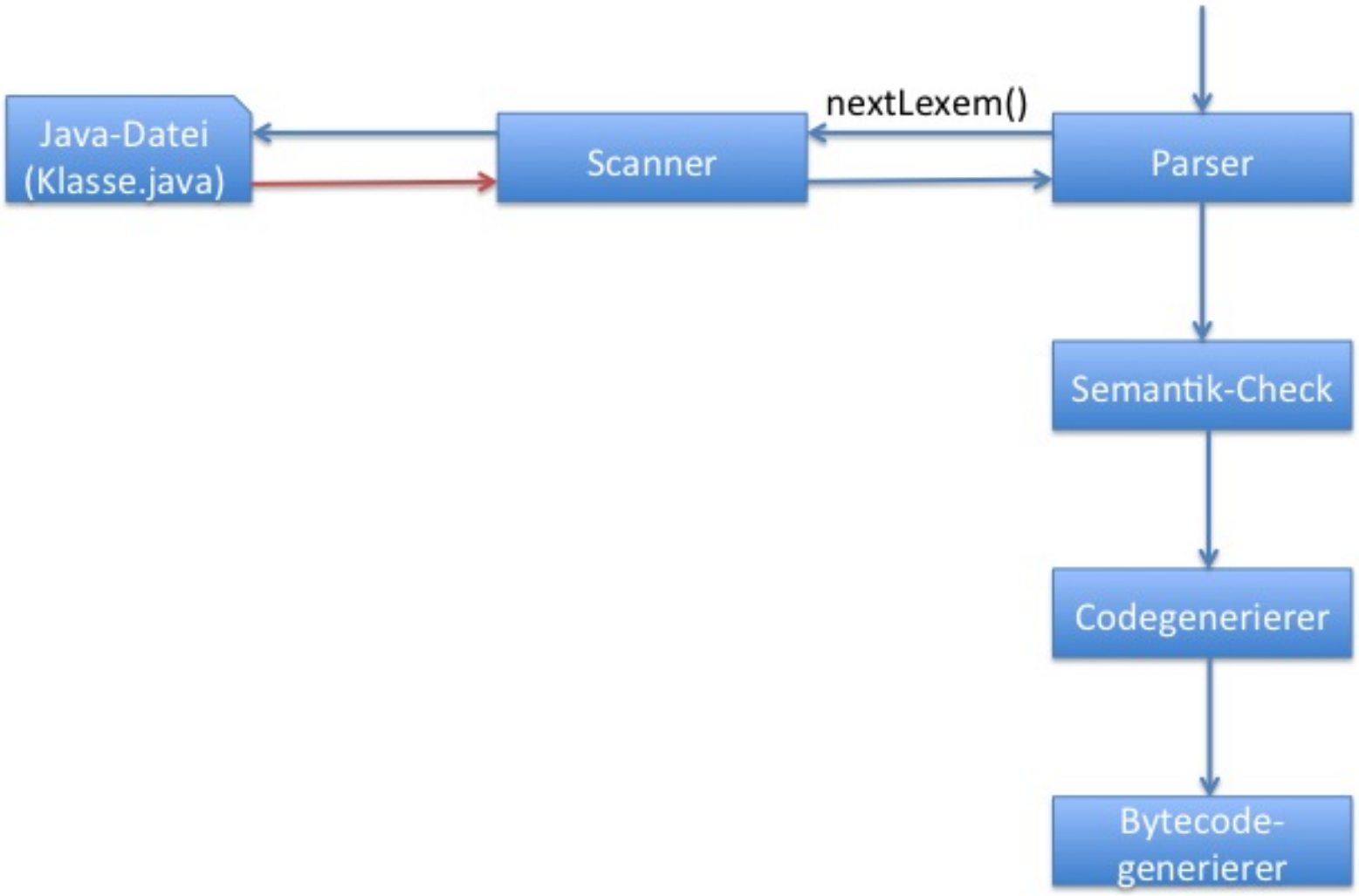

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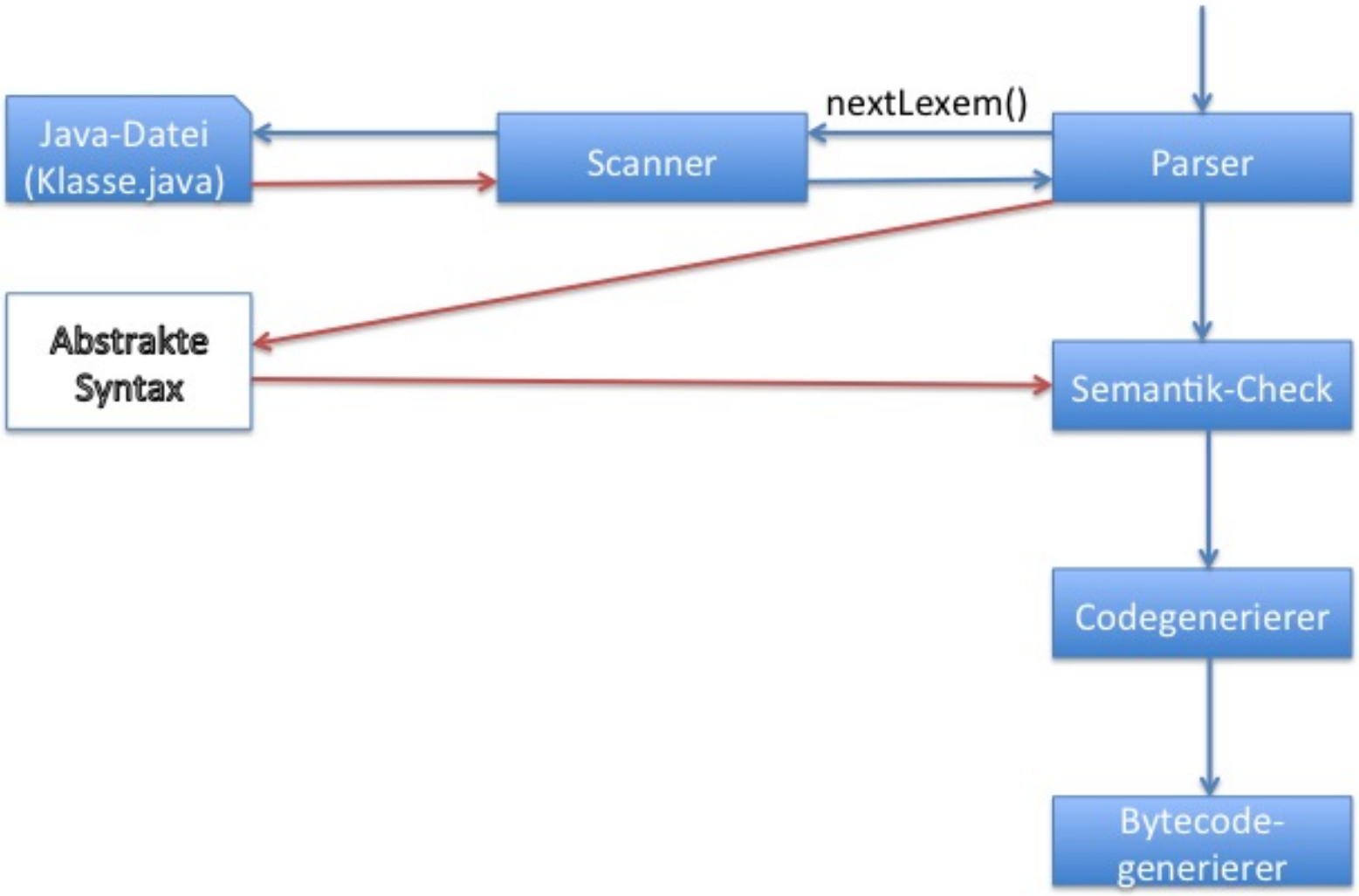

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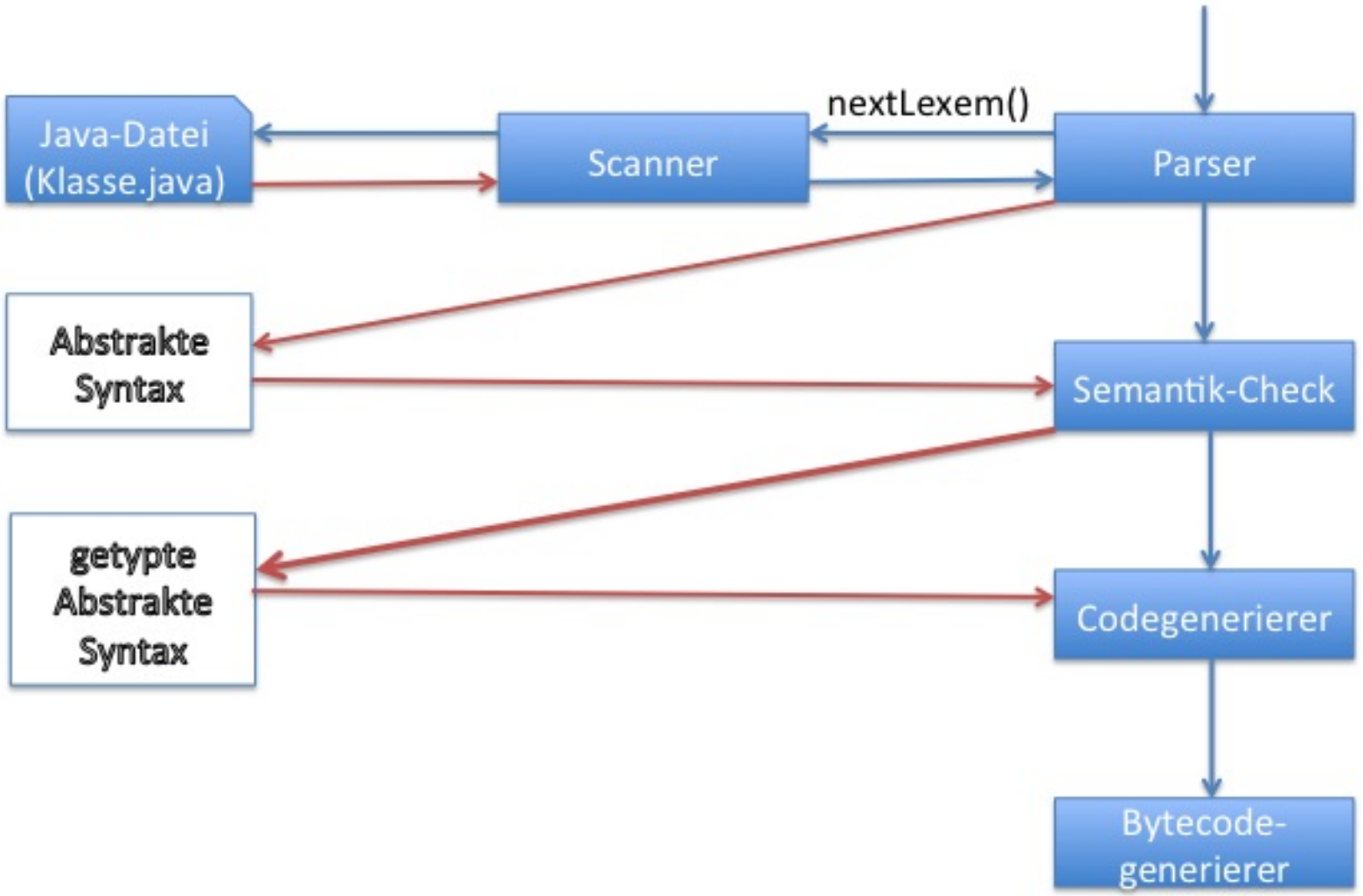

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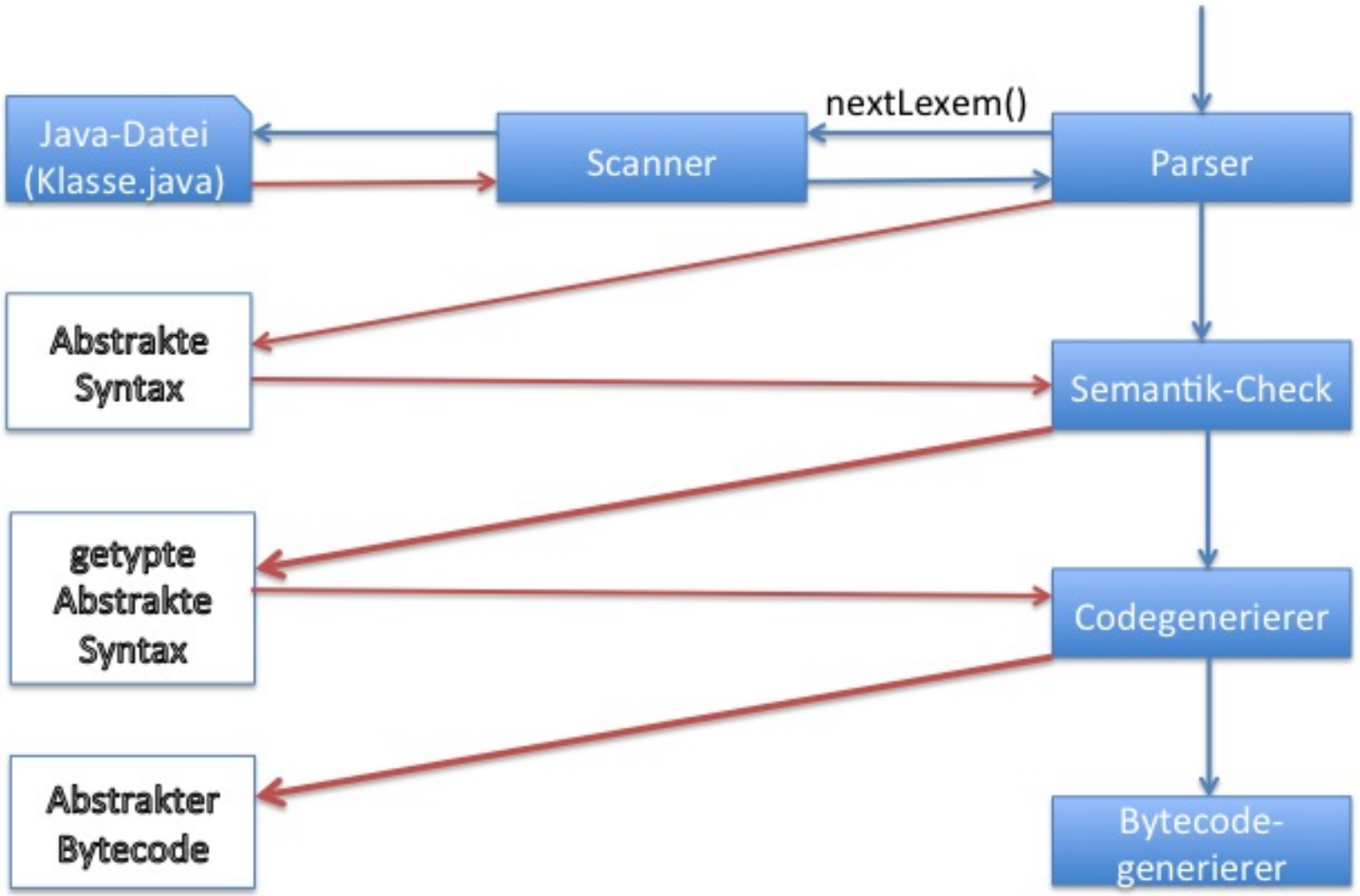

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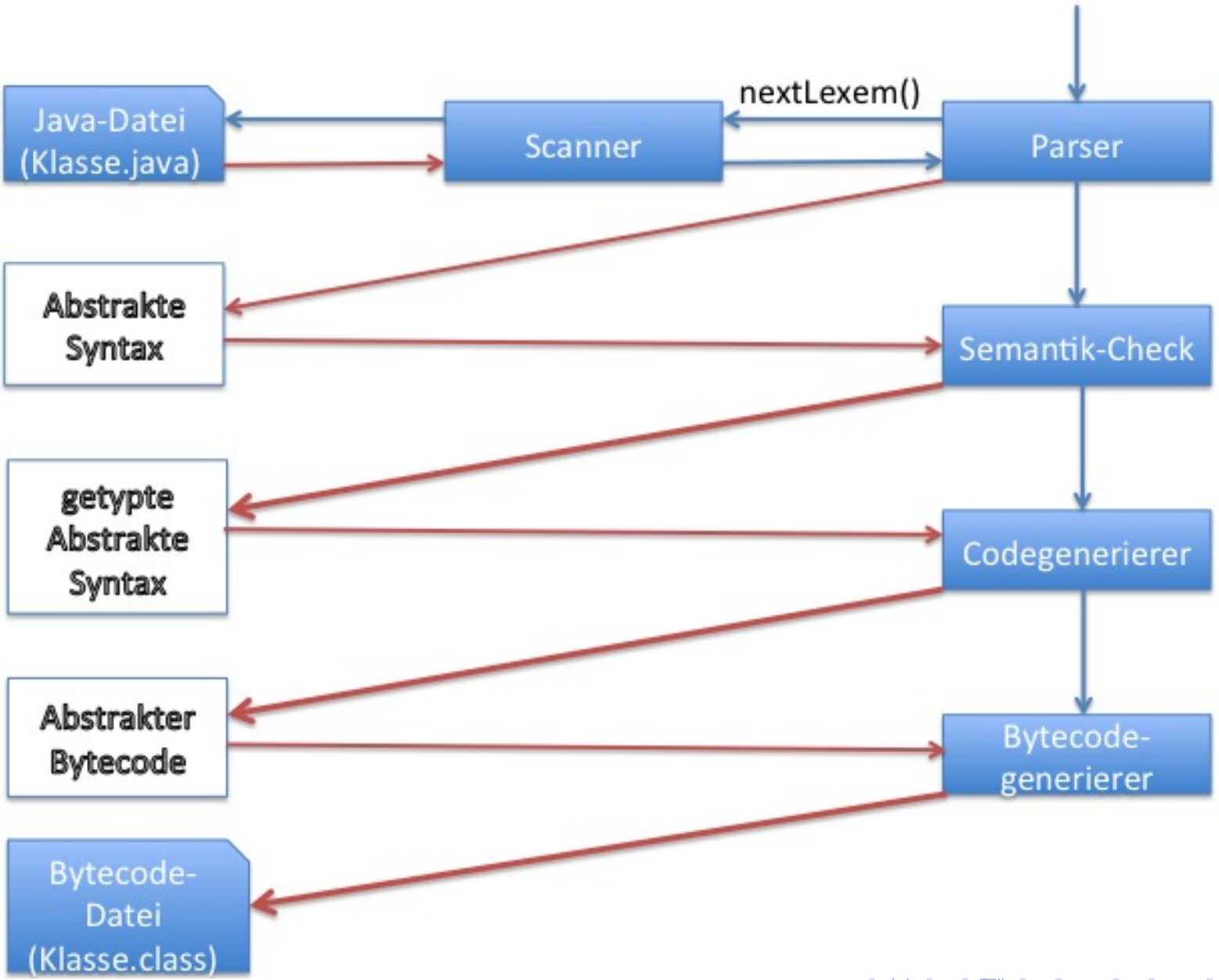
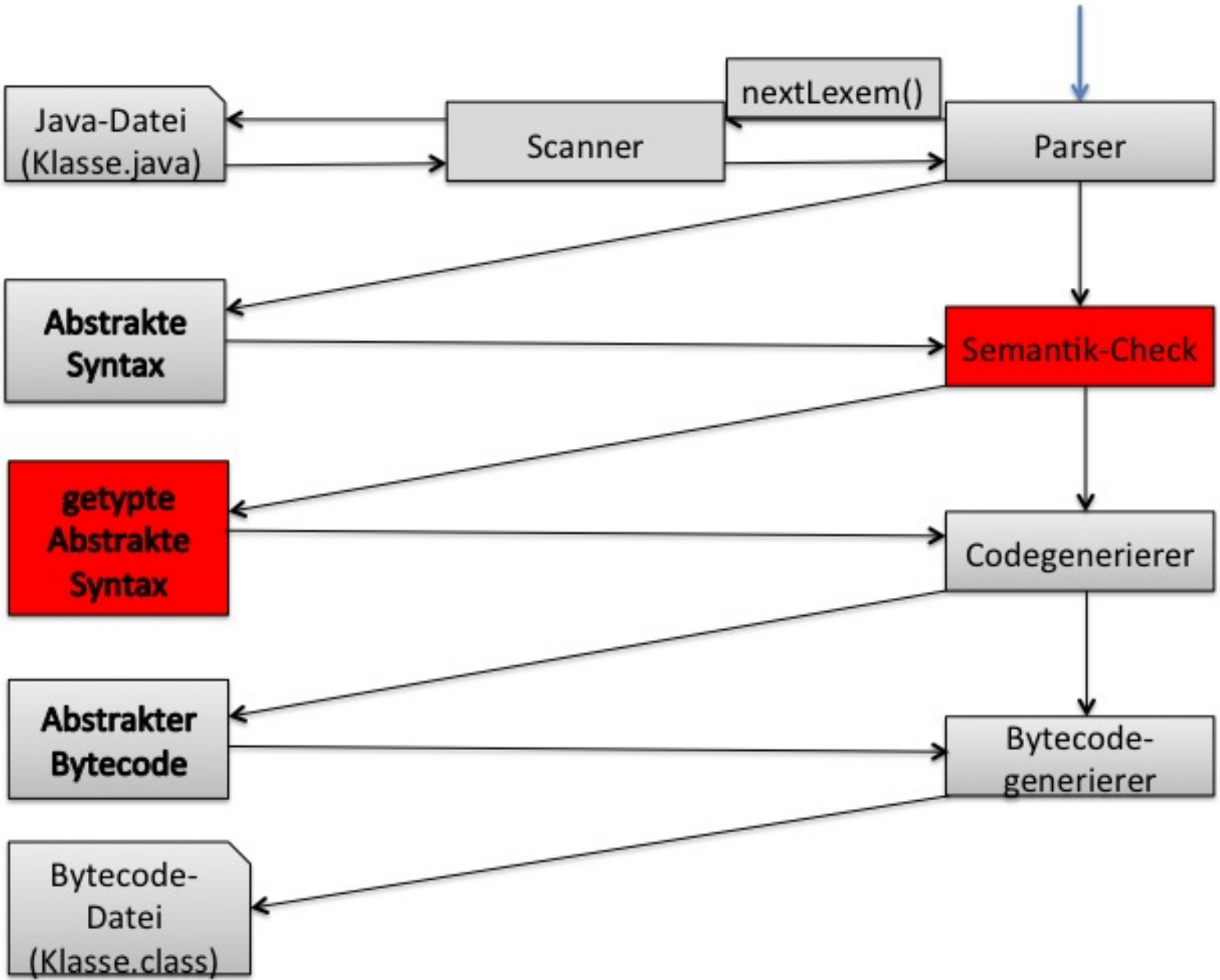


Semantische Analyse/Typecheck



Semantische Analyse/Typecheck

- Überprüfen der Kontextsensitiven Nebenbedingungen:
  - alle Variablen/Methoden deklariert/sichtbar?
  - Typen korrekt?
- Typisierung aller Sub–Terme

Ungetypte abstrakte Syntax für *Mini*–Java I

```
data Class = Class(Type, [FieldDecl], [MethodDecl])

data FieldDecl = Field(Type, String)

data MethodDecl = Method(Type, String,[(Type,String)], Stmt)

data Stmt = Block([Stmt])
          | Return( Expr )
          | While( Expr , Stmt )
          | LocalVarDecl(Type, String)
          | If(Expr, Stmt , Maybe Stmt)
          | StmtExprStmt(StmtExpr)

data StmtExpr = Assign(String, Expr)
              | New(Type, [Expr])
              | MethodCall(Expr, String, [Expr])
```

Ungetypte abstrakte Syntax für *Mini*–Java II

```
data Expr = This
          | Super
          | LocalOrFieldVar(String)
          | InstVar(Expr, String)
          | Unary(String, Expr)
          | Binary(String, Expr, Expr)
          | Integer(Integer)
          | Bool(Bool)
          | Char(Char)
          | String(String)
          | Jnull
          | StmtExprExpr(StmtExpr)

type Prg = [Class]
```

Formale Definitionen I

Typableitungen

Menge von Typannahmen: $O = \{ id_1 : ty_1, \ldots, id_n : ty_n \}$

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$$O \rhd_{Id} id : ty$$

Aus der Menge der Typannahmen O ist für den Bezeichner id der Typ ty ableitbar.

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$$O \rhd_{Stmt} s : ty$$

Aus der Menge der Typannahmen O ist für das Statement s der Typ ty ableitbar.

Formale Definitionen II

Typurteile

$$[\textbf{Regelname}]\ \frac{O1 \rhd x : ty1}{O2 \rhd y : ty2}$$

Aus der Regel *Regelname* folgt, wenn man aus $O1$ ableiten kann, dass x den Typ ty1 hat, dann kann man aus $O2$ ableiten dass y den Typ $ty2$ hat.

Ident–Rule

$$[\textbf{Ident}]\ \frac{(f : ty) \in O_\tau}{O_\tau \ \rhd_{Id}\ f : ty}$$

O_τ: Menge aller in der Klasse τ sichtbaren Methoden und Attribute

Beispiel Ident–Rule

```
class A {
    int attr;
    A meth(Boolean x) { ... }
}
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$$[\textbf{Ident}]\ \frac{O_{\mathtt{A}}}{O_{\mathtt{A}} \rhd_{Id} \mathtt{attr} : \mathtt{int}}$$

Beispiel Ident–Rule

```
class A {
    int attr;
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- $O_{\mathtt{A}} = \{\, \mathtt{attr} : \mathtt{int},\ \mathtt{meth} : \mathtt{Boolean} \to \mathtt{A} \,\}$

$$[\textbf{Ident}]\ \frac{O_{\mathtt{A}}}{O_{\mathtt{A}} \rhd_{Id} \mathtt{attr} : \mathtt{int}}$$

$$[\textbf{Ident}]\ \frac{O_{\mathtt{A}}}{O_{\mathtt{A}} \rhd_{Id} \mathtt{meth} : \mathtt{Boolean} \to \mathtt{A}}$$

Literal–Regeln

$$[\textbf{IntLiteral}] \quad O \rhd_{Expr} \text{Integer}(\, n \,) : \texttt{int}$$

$$[\textbf{BoolLiteral}] \quad O \rhd_{Expr} \text{Bool}(\, b \,) : \texttt{boolean}$$

$$[\textbf{CharLiteral}] \quad O \rhd_{Expr} \text{Char}(\, c \,) : \texttt{char}$$

$$[\textbf{NullLiteral}] \quad O \rhd_{Expr} \text{Null} : \theta'$$

Expression–Regel: Simple–Expressions

$$[\textbf{Unary1}]\ \frac{O \ \triangleright_{Expr}\ e : \texttt{int}}{O \ \triangleright_{Expr}\ \text{Unary}(\text{"+"}/\text{"-"}, e) : \texttt{int}}$$

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$$[\textbf{Unary1}]\ \frac{O \rhd_{Expr} e : \texttt{int}}{O \rhd_{Expr} \text{Unary}(\text{"+"}/\text{"-"}, e) : \texttt{int}}$$

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$$[\textbf{Binary1}]\ \frac{O \rhd_{Expr} e1 : \texttt{int}, O \rhd_{Expr} e2 : \texttt{int}}{O \rhd_{Expr} \text{Binary}(\text{"+"}/\text{"-"}/\text{"*"}/\text{"\%"}, e1, e2) : \texttt{int}}$$

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$$[\textbf{Binary2}]\ \frac{O \rhd_{Expr} e1 : \texttt{boolean}, O \rhd_{Expr} e2 : \texttt{boolean}}{O \rhd_{Expr} \text{Binary}(\text{"\&\&"}/\text{"||"}, e1, e2) : \texttt{boolean}}$$

Expression–Regel: Variablen

$$[\textbf{LocalOrFieldVar}]\ \frac{O \ \rhd_{Id} \ v : \theta}{O \ \rhd_{Expr} \ \text{LocalOrFieldVar}(\ v\ ) : \theta}$$

Expression–Regel: Variablen

$$[\textbf{LocalOrFieldVar}] \quad \frac{O \rhd_{Id} v : \theta}{O \rhd_{Expr} \text{LocalOrFieldVar}(v) : \theta}$$

$$[\textbf{InstVar}] \quad \frac{O \rhd_{Expr} re : \overline{\tau}, \qquad O_{\overline{\tau}} \rhd_{Id} v : \theta}{O \rhd_{Expr} \text{InstVar}(re, v) : \theta}$$

Beispiel InstVar

```
class A {
    int attr;
    A meth(Boolean x) { ... }
}
```

$O_{\mathtt{A}} = \{\, \mathtt{attr} : \mathtt{int},\ \mathtt{meth} : \mathtt{Boolean} \to \mathtt{A} \,\}$

```
...
A a = new A()
a.attr = 5;
```

übersetzt in abstrakte syntax: **InstVar**(**LocalOrFieldVar**(*a*), *attr*).

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Expression–Regel: Statement–Expressions

[**New**] $O \rhd_{Expr} \mathsf{New}(\theta) : \theta$

[1] $\leq^*$ ist die Subtypen–Relation

Expression–Regel: Statement–Expressions

$$[\textbf{New}] \qquad O \rhd_{Expr} \text{New}(\theta) : \theta$$

$$[\textbf{Assign}] \qquad \frac{O \rhd_{Expr} ve : \theta', O \rhd_{Expr} e : \theta}{O \rhd_{Expr} \text{Assign}(ve, e) : \theta'} \; \theta \leq^* \theta'^{1}$$

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$$[\textbf{Method-Call}] \qquad \frac{\begin{array}{c} O \ \rhd_{Expr} \ re : \overline{\tau} \\ O_{\overline{\tau}} \ \rhd_{Id} \ m : \theta'_1 \times \ldots \times \theta'_n \rightarrow \theta \\ \forall 1 \leqslant i \leqslant n : \ O \ \rhd_{Expr} \ e_i : \theta_i \end{array}}{O \ \rhd_{Expr} \ \mathsf{MethodCall}(\,re, m, (e_1, \ldots, e_n)\,) : \theta} \ \theta_i \leq^* \theta'_i$$

[1] $\leq^*$ ist die Subtypen–Relation

Beispiel MethodCall

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$O_{\mathtt{A}} = \{\, \mathtt{attr} : \mathtt{int},\ \mathtt{meth} : \mathtt{Boolean} \to \mathtt{A} \,\}$

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übers. in abstrakte Syntax:

MethodCall(**LocalOrFieldVar**(*a*), *meth*, Bool(`true`)).

Beispiel MethodCall

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$$[\textbf{Ident}]\ \frac{O_{\texttt{A}}}{O_{\texttt{A}} \rhd_{Id} \texttt{meth} : \texttt{Boolean} \to \texttt{A}}$$

$$[\textbf{BoolLiteral}]\ \text{Bool}(\, \texttt{true} \,) : \texttt{boolean}$$

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Statement–Regeln

$$[\textbf{Return}]\ \frac{O \rhd_{Expr} e : \theta}{O \rhd_{Stmt} \text{Return}(\, e \,) : \theta}$$

[2] upper bound

Statement–Regeln

$$[\textbf{Return}]\ \frac{O \rhd_{Expr} e : \theta}{O \rhd_{Stmt} \text{Return}(\, e \,) : \theta}$$

$$[\textbf{If}]\ \frac{O \rhd_{Stmt} s_1 : \theta_1, O \rhd_{Stmt} s_2 : \theta_2 \quad O \rhd_{Expr} e : \texttt{boolean}}{O \rhd_{Stmt} \text{If}(\, e, s_1, s_2 \,) : \overline{\theta}, \textit{wobei}\ \overline{\theta} \in \textbf{UB}^2(\, \theta_1, \theta_2 \,)}$$

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$$[\textbf{While}]\ \frac{O \rhd_{Expr} e : \texttt{boolean},\ O \rhd_{Stmt} \text{Block}(\, B \,) : \theta}{O \rhd_{Stmt} \text{While}(\, e, \text{Block}(\, B \,) \,) : \theta}$$

[2] upper bound

Statement–Regeln: Statement–Expressions

[**New**] $O \rhd_{Stmt} \mathsf{New}(\theta) : \texttt{void}$

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Statement–Regeln: Statement–Expressions

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Block–Statement Regeln

$$[\textbf{BlockInit}] \quad \frac{O \ \rhd_{Stmt} \ stmt : \theta}{O \ \rhd_{Stmt} \ \text{Block}(\ stmt\ ) : \theta}$$

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$$[\textbf{Block}]\quad \frac{O \rhd_{Stmt} \ s_1 : \theta,\ O \rhd_{Stmt} \ \text{Block}(\ s_2; \ldots; s_n;\ ) : \theta'}{O \rhd_{Stmt} \ \text{Block}(\ s_1; s_2; \ldots; s_n;\ ) : \overline{\theta},\ \textit{wobei}\ \overline{\theta} \in \textbf{UB}(\ \theta, \theta'\ )}$$

Block–Statement Regeln

$$[\textbf{BlockInit}]\ \frac{O \rhd_{Stmt} \ stmt : \theta}{O \rhd_{Stmt} \ \text{Block}(\ stmt\ ) : \theta}$$

$$[\textbf{Block}]\ \frac{O \rhd_{Stmt} \ s_1 : \theta,\ O \rhd_{Stmt} \ \text{Block}(\ s_2; \ldots; s_n;\ ) : \theta'}{O \rhd_{Stmt} \ \text{Block}(\ s_1; s_2; \ldots; s_n;\ ) : \overline{\theta},\ wobei\ \overline{\theta} \in \textbf{UB}(\ \theta, \theta'\ )}$$

$$[\textbf{Blockvoid}]\ \frac{\begin{array}{c} O \rhd_{Stmt} \ s_1 : \texttt{void}, \\ O \rhd_{Stmt} \ \text{Block}(\ s_2; \ldots; s_n;\ ) : \theta \end{array}}{O \rhd_{Stmt} \ \text{Block}(\ s_1; s_2; \ldots; s_n;\ ) : \theta}$$

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$$[\textbf{Block-Local-VarDecl}]\ \frac{O \backslash \{\ v : \theta'\ \} \cup \{\ v : \overline{\theta}\ \} \rhd_{Stmt} \ \text{Block}(\ s_2; \ldots; s_n;\ ) : \theta}{O \rhd_{Stmt} \ \text{Block}(\ \text{LocalVarDecl}(\ v, \overline{\theta}\ ); s_2; \ldots; s_n;\ ) : \theta}$$

Beispiel I

```
while (true) {
    return 1;
}
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$O = \emptyset$

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$$[\textbf{Int-Literal}] \qquad O \rhd_{Expr} \text{Integer}(1) : \texttt{int}$$

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$$\frac{[\textbf{Int-Literal}]}{[\textbf{Return}]}\ \frac{O \rhd_{Expr} \text{Integer}(1) : \texttt{int}}{O \rhd_{Stmt} \text{Return}(\text{Integer}(1)) : \texttt{int}}$$

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$$\dfrac{\dfrac{[\textbf{Int-Literal}]\quad O \rhd_{Expr} \text{Integer}(1) : \texttt{int}}{[\textbf{Return}]\quad O \rhd_{Stmt} \text{Return}(\text{Integer}(1)) : \texttt{int}}}{[\textbf{Block-Init}]\quad O \rhd_{Stmt} \text{Block}(\text{Return}(\text{Integer}(1))) : \texttt{int}}$$

Beispiel I

```
while (true) {
    return 1;
}
```

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$$[\textbf{Bool-Literal}]\ O \rhd_{Expr} \text{Bool}(\ \mathit{True}\ ) : \texttt{boolean}$$

$$\dfrac{[\textbf{Int-Literal}]\ O \rhd_{Expr} \text{Integer}(\ 1\ ) : \texttt{int}}{[\textbf{Return}]\ O \rhd_{Stmt} \text{Return}(\ \text{Integer}(\ 1\ )\ ) : \texttt{int}}$$

$$\dfrac{[\textbf{Block-Init}]\ O \rhd_{Stmt} \text{Return}(\ \text{Integer}(\ 1\ )\ )\ ) : \texttt{int}}{O \rhd_{Stmt} \text{Block}(\ \text{Return}(\ \text{Integer}(\ 1\ )\ )\ ) : \texttt{int}}$$

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Beispiel II

```
class A { }
```

```
class B { }
```

```
{ return new A();
  new A();
  return new B(); }
```

[3] analog zu $O \rhd_{Expr}$ **Return**(New(B)) : B hergeleitet

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$$\text{[New]}\ O \rhd_{Expr} \text{New}(B) : \texttt{B}$$

$$\text{[Return]}\ \frac{O \rhd_{Expr} \text{New}(B) : \texttt{B}}{O \rhd_{Stmt} \text{Return}(\text{New}(B)) : \texttt{B}}$$

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$$\dfrac{\dfrac{\dfrac{O \rhd_{Expr} \text{ New}(B) : \texttt{B}}{O \rhd_{Stmt} \text{ Return}(\text{New}(B)) : \texttt{B}}\,[\textbf{Return}]}{O \rhd_{Stmt} \text{ Block}(\text{Return}(\text{New}(B))) : \texttt{B}}\,[\textbf{Block-Init}]}\,[\textbf{New}]$$

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class A { }

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[**New**] $O \rhd_{Expr} \text{New}(A) : \texttt{void}$

$$\dfrac{\dfrac{O \rhd_{Expr} \text{New}(B) : \texttt{B}}{O \rhd_{Stmt} \text{Return}(\text{New}(B)) : \texttt{B}}\ [\textbf{Return}]}{O \rhd_{Stmt} \text{Block}(\text{Return}(\text{New}(B))) : \texttt{B}}\ [\textbf{Block - Init}]\ [\textbf{New}]$$

[3] analog zu $O \rhd_{Expr}$ **Return**(New(B)) : B hergeleitet

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```
class A { }

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  new A();
  return new B(); }
```

```
class B { }
```

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$$\dfrac{[\textbf{Block-void}]\ \dfrac{[\textbf{New}]\ O \rhd_{Expr} \text{New}(A) : \texttt{void} \qquad [\textbf{Block-Init}]\ \dfrac{[\textbf{Return}]\ \dfrac{[\textbf{New}]\ O \rhd_{Expr} \text{New}(B) : \texttt{B}}{O \rhd_{Stmt} \text{Return}(\text{New}(B)) : \texttt{B}}}{O \rhd_{Stmt} \text{Block}(\text{Return}(\text{New}(B))) : \texttt{B}}}{O \rhd_{Stmt} \text{Block}(\text{New}(A); \text{Return}(\text{New}(B))) : \texttt{B}}$$

[3] analog zu $O \rhd_{Expr} \textbf{Return}(\text{New}(B)) : \texttt{B}$ hergeleitet

Beispiel II

```
class A { }

{ return new A();
  new A();
  return new B(); }
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class B { }
```

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$$\dfrac{\dfrac{\dfrac{}{O \rhd_{Expr} \texttt{New}(\,A\,) : \texttt{void}}\,[\textbf{New}] \quad \dfrac{\dfrac{}{O \rhd_{Expr} \texttt{New}(\,B\,) : \texttt{B}}\,[\textbf{New}]}{O \rhd_{Stmt} \texttt{Return}(\,\texttt{New}(\,B\,)\,) : \texttt{B}}\,[\textbf{Return}]}{O \rhd_{Stmt} \texttt{Block}(\,\texttt{Return}(\,\texttt{New}(\,B\,)\,)\,) : \texttt{B}}\,[\textbf{Block-Init}]}{O \rhd_{Stmt} \texttt{Return}(\,\texttt{New}(\,A\,)\,) : \texttt{A}^3 \quad O \rhd_{Stmt} \texttt{Block}(\,\texttt{New}(\,A\,); \texttt{Return}(\,\texttt{New}(\,B\,)\,)\,) : \texttt{B}}\,[\textbf{Block-void}]$$

$$O \rhd_{Stmt} \texttt{Block}(\,\texttt{Return}(\,\texttt{New}(\,A\,)\,); \texttt{New}(\,A\,); \texttt{Return}(\,\texttt{New}(\,B\,)\,)\,) : \texttt{Object}\,[\textbf{Block}],$$

wobei $\textbf{UB}(\,\texttt{A}, \texttt{B}\,) = \texttt{Object}$

[3] analog zu $O \rhd_{Expr} \textbf{Return}(\,\texttt{New}(\,B\,)\,) : \texttt{B}$ hergeleitet

Datenstruktur typisierter Expressions

```
type Type = String

-- data Type = TVar(String)              -- Typvariable
--           | TC(String, [Type])        -- Typkonstruktor
--           | WC                        -- Wildscard
--           | WC_Super(Type)            -- Super-Wildscard
--           | WC_Extends(Type)          -- Extends-Wildcard
```

Datenstruktur typisierter Expressions

```
type Type = String

-- data Type = TVar(String)              -- Typvariable
--           | TC(String, [Type])        -- Typkonstruktor
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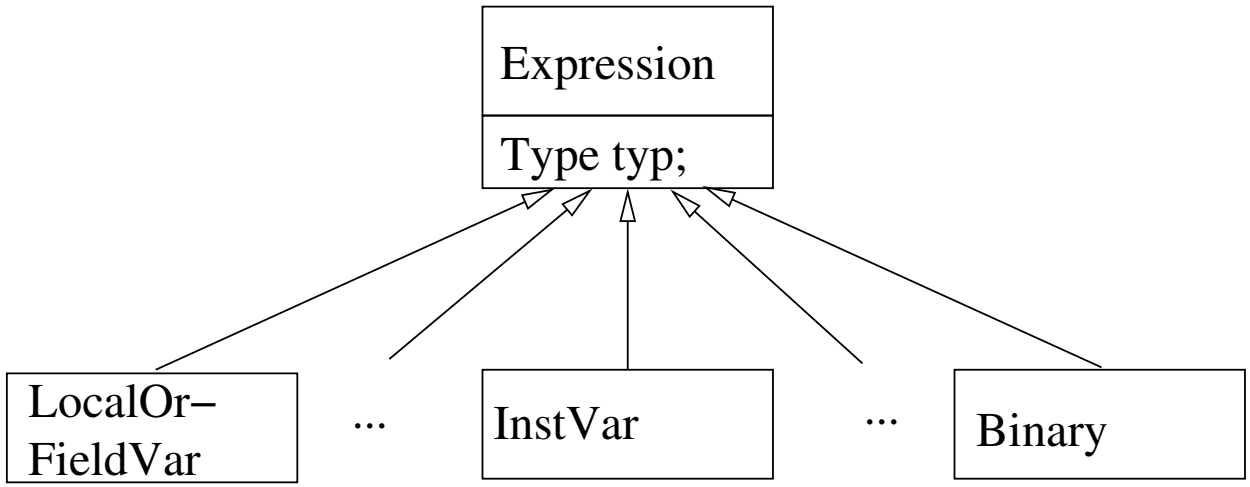
--           | WC_Super(Type)            -- Super-Wildscard
--           | WC_Extends(Type)          -- Extends-Wildcard
data Expr = This
          | Super
          | LocalOrFieldVar(String)
          | InstVar(Expr, String)
          | Unary(String, Expr)
          | Binary(String, Expr, Expr)
          | Integer(Integer)
          | Bool(Bool)
          | Char(Char)
          | String(String)
          | Jnull
          | StmtExprExpr(StmtExpr)
          | TypedExpr(Expr, Type)
```

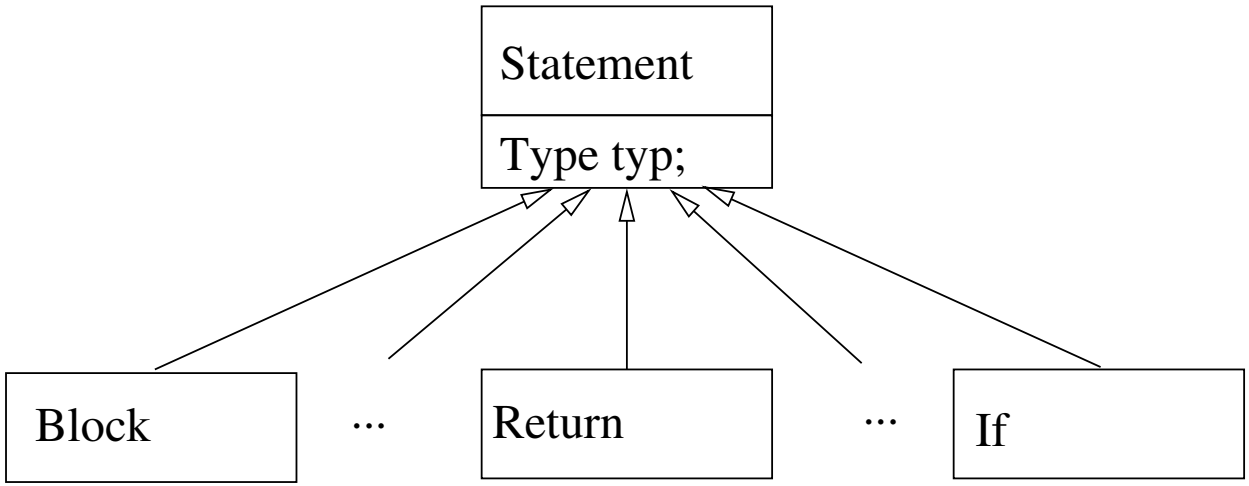
Datenstruktur typisierter Statements

```
data Stmt = Block([Stmt])
          | Return( Expr )
          | While( Expr , Stmt )
          | LocalVarDecl(String)
          | If(Expr, Stmt , Maybe Stmt)
          | StmtExprStmt(StmtExpr)
          | TypedStmt(Stmt, Type)

data StmtExpr = Assign(String, Expr)
          | New(Type, [Expr])
          | MethodCall(Expr, String, [Expr])
          | TypedStmtExpr(StmtExpr, Type)
```

Datenstruktur typisierter Expressions/Statements





Typisierung von Simple–Expressions

```
return 1 + 2
```

Erg. der Parsers:

```
Binary("+", Integer(1), Integer(2))
```

Typisierung von Simple–Expressions

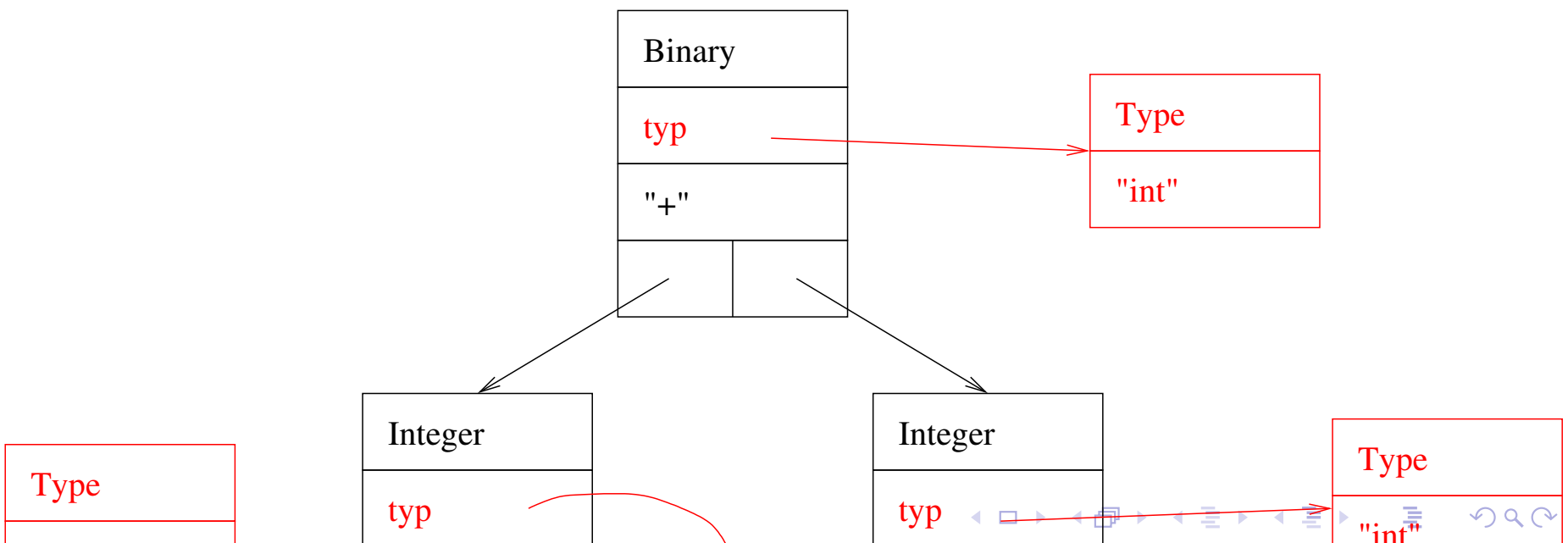
```
return 1 + 2
```

Erg. der Parsers:

```
Binary("+", Integer(1), Integer(2))
```

Typisierung:

```
TypedExpr(Binary("+",
                 TypedExpr(Integer(1), "int"),
                 TypedExpr(Integer(2), "int"))
          "int")
```



LocalOrFieldVar

```
class Klassenname {
  int v;
  int methode (int x) { return v + x; }
}
```

LocalOrFieldVar

```
class Klassenname {
  int v;
  int methode (int x) { return v + x; }
}
```

Erg. der Parsers:

```
Return(Binary("+",
                  LocalOrFieldVar("v")      ← FieldVar
                  LocalOrFieldVar("x")))    ← LocalVar
```

LocalOrFieldVar

```
class Klassenname {
  int v;
  int methode (int x) { return v + x; }
}
```

Erg. der Parsers:

```
Return(Binary("+",
                  LocalOrFieldVar("v")      ← FieldVar
                  LocalOrFieldVar("x")))    ← LocalVar
```

Typisierung:

```
Return(
  TypedExpr(
         Binary("+",
                   TypedExpr(LocalOrFieldVar("v"), "int"),
                   TypedExpr(LocalOrFieldVar("x"), "int")),
          "int"))
```

LocalOrFieldVar

```
class Klassenname {
  int v;
  int methode (int x) { return v + x; }
}
```

Erg. der Parsers:

```
Return(Binary("+",
                  LocalOrFieldVar("v")      ← FieldVar
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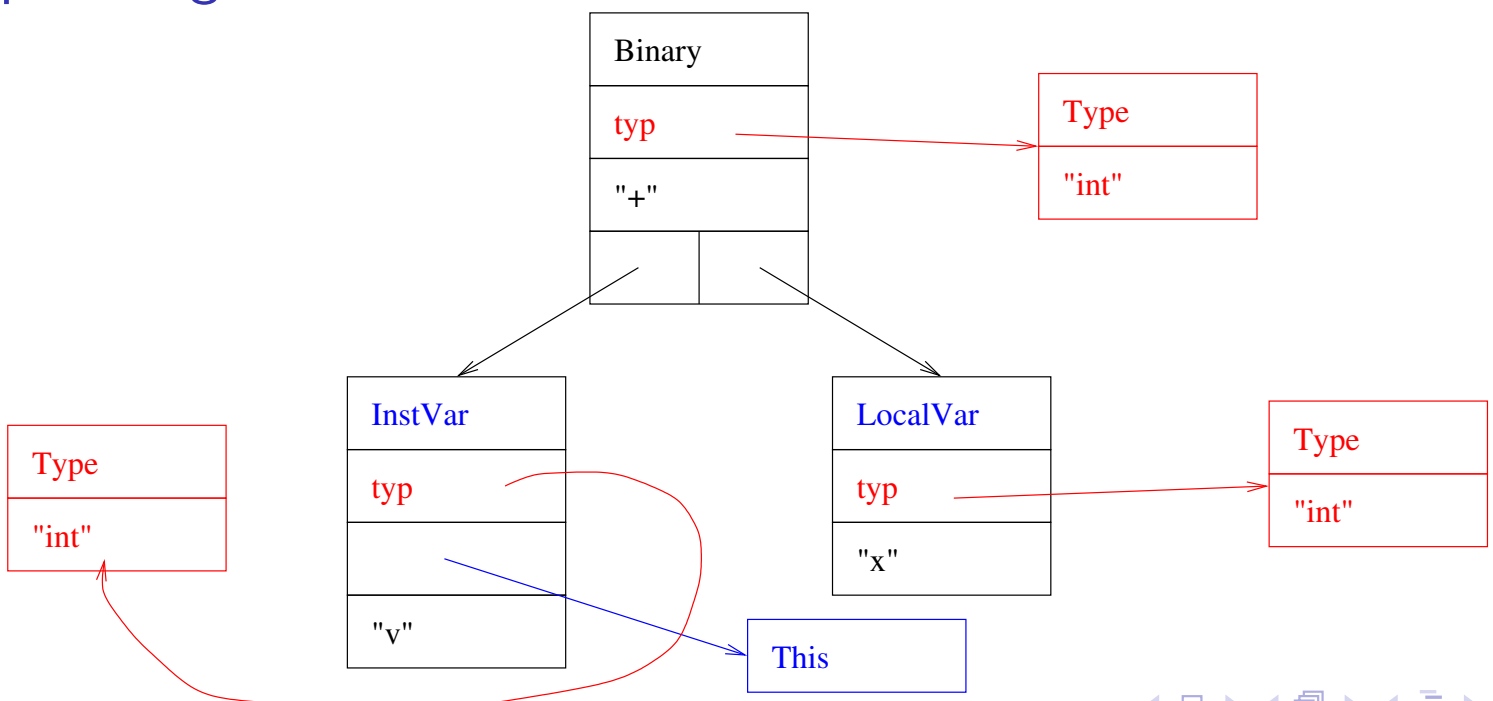
Typisierung:



InstVar, MethodCall

```
class Cl1 {
   char m1 () {
     int b;
     Cl2 x = new Cl2 ()
     return x.m2(x.v, b);
   }
}
```

```
class Cl2 {
  Cl3 v;
  char m2(Cl3 v, int w) { ...}
 }

class Cl3 { ...}
```

InstVar, MethodCall

```
class Cl1 {
   char m1 () {
     int b;
     Cl2 x = new Cl2 ()
     return x.m2(x.v, b);
   }
}
```

```
class Cl2 {
  Cl3 v;
  char m2(Cl3 v, int w) { ...}
 }

class Cl3 { ...}
```

Erg. der Parsers:

```
Return(MethodCall(LocalOrFieldVar("x"), "m2",
                  [InstVar(LocalOrFieldVar("x"), "v"),
                   LocalOrFieldVar("b")]))
```

InstVar, MethodCall

```
class Cl1 {
   char m1 () {
     int b;
     Cl2 x = new Cl2 ()
     return x.m2(x.v, b);
   }
}
```

```
class Cl2 {
  Cl3 v;
  char m2(Cl3 v, int w) { ...}
 }

class Cl3 { ...}
```

Erg. der Parsers:

```
Return(MethodCall(LocalOrFieldVar("x"), "m2",
                  [InstVar(LocalOrFieldVar("x"), "v"),
                   LocalOrFieldVar("b")]))
```

Typisierung:

```
Return(TypedExpr(
  MethodCall(TypedExpr(LocalOrFieldVar("x"), "Cl2"), "m2",
             [TypedExpr(
                InstVar(TypedExpr(LocalOrFieldVar("x"), "Cl2"),
                        "v"), "Cl3"),
              TypedExpr(LocalOrFieldVar("b"), "int")]), "char"))
```

Semantische Analyse/Algorithmus `typecheck`

```
typecheckExpr:: Expr -> [(String, Type)] -> [Class] -> Expr
typecheckStmt:: Stmt -> [(String, Type)] -> [Class] -> Stmt
```

1. Argument: Ungetypter Ausdruck/Statement
2. Argument: Tabelle mit lokalen Variablen, die durch Deklarationen LocalVarDecl verändert werden.
3. Argument: Alle sichtbaren Klassen mit Fields und Methoden

Ergebnis: getypeter Ausdruck/Statement

Semantische Analyse/Algorithmus typecheck

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typecheckExpr:: Expr -> [(String, Type)] -> [Class] -> Expr
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Ergebnis: getypeter Ausdruck/Statement

Ablauf: Lauf über alle Methoden aller Klassen:

- Check ob Variablen/Methoden deklariert
- Check, ob die Typen der Metdodenaufrufe/Zuweisung korrekt sind
- Einfügen der Typisierungen

Semantische Analyse/Algorithmus typecheck

```
Type typeCheck(Map<String, Type> localVars, Vector<Class>
classes)
```

1. Argument: Tabelle mit lokalen Variablen, die durch Deklarationen LocalVarDecl verändert werden.
2. Argument: Klassen mit Attributen (Fields) und Methoden

Ergebnis: Typ des Ausdrucks/Statements

Semantische Analyse/Algorithmus typecheck

```
Type typeCheck(Map<String, Type> localVars, Vector<Class>
classes)
```

1. Argument: Tabelle mit lokalen Variablen, die durch Deklarationen LocalVarDecl verändert werden.
2. Argument: Klassen mit Attributen (Fields) und Methoden

Ergebnis: Typ des Ausdrucks/Statements

Ablauf: Lauf über alle Methoden, alle Statements und alle Expressions der Klasse:

- Check ob Variablen/Methoden deklariert
- Check, ob die Typen der Metdodenaufrufe/Zuweisung korrekt sind
- Einfügen der Typisierungen
- Ersetzen von `LocalOrFieldVar` zu `InstVar` bzw. `LocalVar`

Beispiel: typeCheck für IF

$$[\textbf{If}]\ \frac{O \rhd_{Stmt}\ s_1 : \theta_1, O \rhd_{Stmt}\ s_2 : \theta_2 \quad O \rhd_{Expr}\ e : \texttt{boolean}}{O \rhd_{Stmt}\ \textsf{If}(\, e, s_1, s_2\,) : \overline{\theta}, \textit{wobei}\ \overline{\theta} \in \textbf{UB}(\, \theta_1, \theta_2\,)}$$

```
class Statement {
 Type typ;
 abstract Type typeCheck(Map<String, Type> localVars, Vector<Class>
      classes);
}

class If extends Statement {
  Expression cond;
  Statement ifStmt;
  Statement elseStmt;

  Type typeCheck(Map<String, Type> localVars, Class thisClass) {
    if (cond.typeCheck(localVars, thisClass).equals(new Type("boolean"))
        && ifStmt.typeCheck(localVars, classes)
                 .equals(elseStmt.typeCheck(localVars, classes))) {
        typ = ifStmt.typeCheck(localVars, classes);
        return typ;  }
    else {          //error                    }
  }
}
```