Compiler Construction

Lecture 20: Code Generation III (Translation to Intermediate Code)

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Outline

Syntax of EPL

Definition (Syntax of EPL)

The syntax of EPL is defined as follows:

$$
\begin{array}{lrll}
\mathbb{Z}: & & z & \text{(* } z \text{ is an integer *)} \\
\mathit{Ide}: & & I & \text{(* } I \text{ is an identifier *)} \\
\mathit{AExp}: & A & ::= z \mid I \mid A_1 \texttt{ + } A_2 \mid \ldots & \\
\mathit{BExp}: & B & ::= A_1 \texttt{ < } A_2 \mid \texttt{not } B \mid B_1 \texttt{ and } B_2 \mid B_1 \texttt{ or } B_2 & \\
\mathit{Cmd}: & C & ::= I \texttt{ := } A \mid C_1 \texttt{;} C_2 \mid \texttt{if } B \texttt{ then } C_1 \texttt{ else } C_2 \mid & \\
 & & \quad \texttt{while } B \texttt{ do } C \mid I\texttt{()} & \\
\mathit{Dcl}: & D & ::= D_C\ D_V\ D_P & \\
 & D_C & ::= \varepsilon \mid \texttt{const } I_1 \texttt{ := } z_1\texttt{,}\ldots\texttt{,}I_n \texttt{ := } z_n\texttt{;} & \\
 & D_V & ::= \varepsilon \mid \texttt{var } I_1\texttt{,}\ldots\texttt{,}I_n\texttt{;} & \\
 & D_P & ::= \varepsilon \mid \texttt{proc } I_1\texttt{;}K_1\texttt{;}\ldots\texttt{;}I_n\texttt{;}K_n\texttt{;} & \\
\mathit{Blk}: & K & ::= D\ C & \\
\mathit{Pgm}: & P & ::= \texttt{in/out } I_1\texttt{,}\ldots\texttt{,}I_n\texttt{;}K\texttt{.} &
\end{array}
$$

The Abstract Machine AM

Definition (Abstract machine for EPL)

The abstract machine for EPL (AM) is defined by the state space

$$S := PC \times DS \times PS$$

with

- the program counter $PC := \mathbb{N}$,
- the data stack $DS := \mathbb{Z}^*$ (top of stack to the right), and
- the procedure stack (or: runtime stack) $PS := \mathbb{Z}^*$ (top of stack to the left).

Thus a state $s = (l, d, p) \in S$ is given by

- a program label $l \in PC$,
- a data stack $d = d.r : \ldots : d.1 \in DS$, and
- a procedure stack $p = p.1 : \ldots : p.t \in PS$.

AM Instructions

Definition (AM instructions)

The set of AM instructions is divided into

arithmetic instructions: `ADD`, `MULT`, ...

Boolean instructions: `NOT`, `AND`, `OR`, `LT`, ...

jumping instructions: `JMP(`ca`)`, `JFALSE(`ca`)` ($ca \in PC$)

procedure instructions: `CALL(`ca`,`dif`,`loc`)` ($ca \in PC$, $dif, loc \in \mathbb{N}$), `RET`

transfer instructions: `LOAD(`dif`,`off`)`, `STORE(`dif`,`off`)` ($dif, off \in \mathbb{N}$),
`LIT(`z`)` ($z \in \mathbb{Z}$)

Structure of Procedure Stack I

The semantics of procedure and transfer instructions requires a particular structure of the procedure stack $p \in PS$: is must be composed of frames (or: activation records) of the form

$$sl : dl : ra : v_1 : \ldots : v_k$$

where

static link sl: points to frame of surrounding declaration environment
$\Longrightarrow$ used to access non-local variables

dynamic link dl: points to previous frame (i.e., of calling procedure)
$\Longrightarrow$ used to remove topmost frame after termination of procedure call

return address ra: program label after termination of procedure call
$\Longrightarrow$ used to continue program execution after termination of procedure call

local variables v_i: values of locally declared variables

Structure of Procedure Stack II

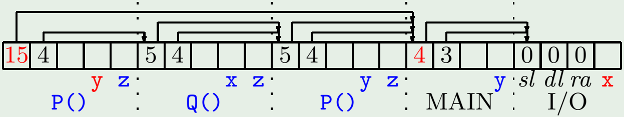
Observation:

- The usage of a variable in a procedure body refers to its innermost declaration.
- If the level difference between the usage and the declaration is *dif*, then a chain of *dif* static links has to be followed to access the corresponding frame.

Example (cf. Example 19.5)

```
in/out x;
  const c = 10;
  var y;
  proc P;
    var y, z;
    proc Q;
      var x, z;
      [... P() ...]
    [... x ... y ... Q() ...]
  proc R;
    [... P() ...]
  [... P() ...].
```

Procedure stack after second call of P:



P uses x $\Longrightarrow$ $dif = 2$ P uses y $\Longrightarrow$ $dif = 0$

AM Programs and Their Semantics

Definition (Semantics of AM programs)

An AM program is a sequence of $k \geq 1$ labeled AM instructions:

$$P = 1 : O_1; \ldots ; k : O_k$$

The set of all AM programs is denoted by AM.

The semantics of AM programs is determined by

$$[\![.]\!] : AM \times S \dashrightarrow S$$

with

$$[\![P]\!](l, d, p) := \begin{cases} [\![P]\!]([\![O_l]\!](l, d, p)) & \text{if } l \in [k] \\ (l, d, p) & \text{otherwise} \end{cases}$$

Outline

Translation of EPL into AM Programs

Goal: define translation mapping

$$\text{trans} : Pgm \dashrightarrow AM$$

The translation employs a symbol table:

$$\begin{aligned} Tab := \{\text{st} \mid \text{st} : Ide \dashrightarrow {} & (\{\texttt{const}\} \times \mathbb{Z}) \\ \cup {} & (\{\texttt{var}\} \times Lev \times Off) \\ \cup {} & (\{\texttt{proc}\} \times PC \times Lev \times Size)\} \end{aligned}$$

whose entries are created by declarations:

- constant declarations: $(\texttt{const}, z)$
  - value $z \in \mathbb{Z}$
- variable declarations: $(\texttt{var}, lev, off)$
  - declaration level $lev \in Lev := \mathbb{N}$ $(0 \cong \text{I/O}, 1 \cong \text{MAIN}, \ldots)$
  - offset $off \in Off := \mathbb{N}$
  - offset and difference between usage and declaration level determine procedure stack entry
- procedure declarations: $(\texttt{proc}, ca, lev, loc)$
  - code address $ca \in PC$
  - declaration level $lev \in Lev$
  - number of local variables $loc \in Size := \mathbb{N}$

Maintaining the Symbol Table

The symbol table is maintained by the function $\mathrm{update}(D, \mathrm{st}, l)$ which specifies the update of symbol table st according to declaration D (with respect to current level l):

Definition 20.1 (update function)

$$\mathrm{update} : \mathit{Dcl} \times \mathit{Tab} \times \mathit{Lev} \dashrightarrow \mathit{Tab}$$

is defined by

$$\begin{array}{ll}
\multicolumn{2}{l}{\mathrm{update}(D_C\ D_V\ D_P, \mathrm{st}, l)} \\
:= & \mathrm{update}(D_P, \mathrm{update}(D_V, \mathrm{update}(D_C, \mathrm{st}, l), l), l) \\
 & \text{if all identifiers in } D_C\ D_V\ D_P \text{ different} \\
\multicolumn{2}{l}{\mathrm{update}(\varepsilon, \mathrm{st}, l)} \\
:= & \mathrm{st} \\
\multicolumn{2}{l}{\mathrm{update}(\texttt{const}\ I_1\ \texttt{:=}\ z_1\texttt{,}\ \ldots\texttt{,}I_n\ \texttt{:=}\ z_n\texttt{;}, \mathrm{st}, l)} \\
:= & \mathrm{st}[I_1 \mapsto (\texttt{const}, z_1), \ldots, I_n \mapsto (\texttt{const}, z_n)] \\
\multicolumn{2}{l}{\mathrm{update}(\texttt{var}\ I_1\texttt{,}\ \ldots\texttt{,}I_n\texttt{;}, \mathrm{st}, l)} \\
:= & \mathrm{st}[I_1 \mapsto (\texttt{var}, l, 1), \ldots, I_n \mapsto (\texttt{var}, l, n)] \\
\multicolumn{2}{l}{\mathrm{update}(\texttt{proc}\ I_1\texttt{;}K_1\texttt{;}\ \ldots\texttt{;}I_n\texttt{;}K_n\texttt{;}, \mathrm{st}, l)} \\
:= & \mathrm{st}[I_1 \mapsto (\texttt{proc}, a_1, l, \mathrm{size}(K_1)), \ldots, I_n \mapsto (\texttt{proc}, a_n, l, \mathrm{size}(K_n))] \\
 & \text{with ``fresh'' addresses } a_1, \ldots, a_n \\
 & \text{where } \mathrm{size}(D_C\ \texttt{var}\ I_1\texttt{,}\ \ldots\texttt{,}I_n\texttt{;}\ D_P C) := n
\end{array}$$

The Initial Symbol Table

An EPL program $P = \texttt{in/out}\ I_1\texttt{,}\ \ldots\ \texttt{,}I_n\texttt{;}K\texttt{.} \in Pgm$ has a semantics of type $\mathbb{Z}^n \dashrightarrow \mathbb{Z}^n$.

Given $(z_1, \ldots, z_n) \in \mathbb{Z}^n$, we choose the initial state

$$s := (1, \varepsilon, \underbrace{0 : 0 : 0 : z_1 : \ldots : z_n}_{\text{I/O frame}}) \in S = PC \times DS \times PS$$

Thus the corresponding initial symbol table has n entries:

$$\mathrm{st}_{I/O}(I_j) := (\texttt{var}, 0, j) \qquad \text{for every } j \in [n]$$

Outline

Translation of Programs

Translation of $\texttt{in/out}\ I_1\texttt{,}\ldots\texttt{,}I_n\texttt{;}D\ C\texttt{.}$:

1. Create MAIN frame for executing C
2. Stop program execution after return

Definition 20.2 (Translation of programs)

The mapping

$$\text{trans} : Pgm \dashrightarrow AM$$

is defined by

$$\begin{aligned}\text{trans}(\texttt{in/out}\ I_1\texttt{,}\ldots\texttt{,}I_n\texttt{;}K\texttt{.}) := \ & 1 : \texttt{CALL(}a\texttt{,0,}\text{size}(K)\texttt{);}\\ & 2 : \texttt{JMP(0);}\\ & \text{kt}(K, \text{st}_{I/O}, a, 1)\end{aligned}$$

Outline

Translation of Blocks

Translation of $D\ C$:

1. Update symbol table according to D
2. Create code for procedures declared in D
   (using the updated symbol table – recursion!)
3. Create code for C (using the updated symbol table)

Definition 20.3 (Translation of blocks)

The mapping

$$\mathrm{kt} : \mathit{Blk} \times \mathit{Tab} \times \mathit{PC} \times \mathit{Lev} \dashrightarrow \mathit{AM}$$

("block translation") is defined by

$$\begin{aligned}\mathrm{kt}(D\ C, \mathrm{st}, a, l) := {} & \mathrm{dt}(D, \mathrm{update}(D, \mathrm{st}, l), l) \\ & \mathrm{ct}(C, \mathrm{update}(D, \mathrm{st}, l), a, l) \\ & a' : \texttt{RET;}\end{aligned}$$

Outline

Translation of Declarations

Translation of D:

- Generate code for the procedures declared in D

Definition 20.4 (Translation of declarations)

The mapping

$$\mathrm{dt} : \mathit{Dcl} \times \mathit{Tab} \times \mathit{Lev} \dashrightarrow \mathit{AM}$$

("declaration translation") is defined by

$$\begin{aligned}
&\mathrm{dt}(D_C\ D_V\ D_P, \mathrm{st}, l)\\
&\quad := \quad \mathrm{dt}(D_P, \mathrm{st}, l)\\
&\mathrm{dt}(\varepsilon, \mathrm{st}, l)\\
&\quad := \quad \varepsilon\\
&\mathrm{dt}(\texttt{proc}\ I_1\,\texttt{;}\,K_1\,\texttt{;}\ \ldots\ \texttt{;}\,I_n\,\texttt{;}\,K_n\,\texttt{;}, \mathrm{st}, l)\\
&\quad := \quad \mathrm{kt}(K_1, \mathrm{st}, a_1, l+1)\\
&\qquad\qquad\quad \vdots\\
&\qquad\qquad\ \ \mathrm{kt}(K_n, \mathrm{st}, a_n, l+1)\\
&\qquad\qquad\ \ \text{where } \mathrm{st}(I_j) = (\texttt{proc}, a_j, \ldots, \ldots) \text{ for every } j \in [n]
\end{aligned}$$

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Definition 20.5 (Translation of commands)

The mapping

$$\mathrm{ct} : \mathit{Cmd} \times \mathit{Tab} \times \mathit{PC} \times \mathit{Lev} \dashrightarrow \mathit{AM}$$

("command translation") is defined by

$$
\begin{aligned}
\mathrm{ct}(I \;\texttt{:=}\; A, \mathrm{st}, a, l) &:= \mathrm{at}(A, \mathrm{st}, a, l) \\
&\; a' : \texttt{STORE(}l - \mathit{lev}\texttt{,}\mathit{off}\texttt{);} \\
&\; \text{if } \mathrm{st}(I) = (\texttt{var}, \mathit{lev}, \mathit{off}) \\
\mathrm{ct}(I\texttt{()}, \mathrm{st}, a, l) &:= a : \texttt{CALL(}\mathit{ca}\texttt{,}l - \mathit{lev}\texttt{,}\mathit{loc}\texttt{);} \\
&\; \text{if } \mathrm{st}(I) = (\texttt{proc}, \mathit{ca}, \mathit{lev}, \mathit{loc}) \\
\mathrm{ct}(C_1\texttt{;}C_2, \mathrm{st}, a, l) &:= \mathrm{ct}(C_1, \mathrm{st}, a, l) \\
&\; \mathrm{ct}(C_2, \mathrm{st}, a', l) \\
\mathrm{ct}(\texttt{if } B \texttt{ then } C_1 \texttt{ else } C_2, \mathrm{st}, a, l) &:= \mathrm{bt}(B, \mathrm{st}, a, l) \\
&\; a' : \texttt{JFALSE(}a''\texttt{);} \\
&\; \mathrm{ct}(C_1, \mathrm{st}, a'+1, l) \\
&\; a'' - 1 : \texttt{JMP(}a'''\texttt{);} \\
&\; \mathrm{ct}(C_2, \mathrm{st}, a'', l) \\
&\; a''' : \\
\mathrm{ct}(\texttt{while } B \texttt{ do } C, \mathrm{st}, a, l) &:= \mathrm{bt}(B, \mathrm{st}, a, l) \\
&\; a' : \texttt{JFALSE(}a''+1\texttt{);} \\
&\; \mathrm{ct}(C, \mathrm{st}, a'+1, l) \\
&\; a'' : \texttt{JMP(}a\texttt{);}
\end{aligned}
$$

Outline

1. Repetition: Intermediate Code
2. The Symbol Table
3. Translation of Programs
4. Translation of Blocks
5. Translation of Declarations
6. Translation of Commands
7. **Translation of Expressions**
8. A Translation Example
9. Correctness of the Translation
10. Outlook

Definition 20.6 (Translation of Boolean expressions)

The mapping

$$\mathrm{bt} : \mathit{BExp} \times \mathit{Tab} \times \mathit{PC} \times \mathit{Lev} \dashrightarrow \mathit{AM}$$

("Boolean expression translation") is defined by

$$\begin{aligned}
\mathrm{bt}(A_1 \texttt{<} A_2, \mathrm{st}, a, l) &:= \mathrm{at}(A_1, \mathrm{st}, a, l) \\
& \mathrm{at}(A_2, \mathrm{st}, a', l) \\
& a'' : \texttt{LT;} \\
\mathrm{bt}(\texttt{not}\ B, \mathrm{st}, a, l) &:= \mathrm{bt}(B, \mathrm{st}, a, l) \\
& a' : \texttt{NOT;} \\
\mathrm{bt}(B_1\ \texttt{and}\ B_2, \mathrm{st}, a, l) &:= \mathrm{bt}(B_1, \mathrm{st}, a, l) \\
& \mathrm{bt}(B_2, \mathrm{st}, a', l) \\
& a'' : \texttt{AND;} \\
\mathrm{bt}(B_1\ \texttt{or}\ B_2, \mathrm{st}, a, l) &:= \mathrm{bt}(B_1, \mathrm{st}, a, l) \\
& \mathrm{bt}(B_2, \mathrm{st}, a', l) \\
& a'' : \texttt{OR;}
\end{aligned}$$

Translation of Arithmetic Expressions

Definition 20.7 (Translation of arithmetic expressions)

The mapping

$$\mathrm{at} : \mathit{AExp} \times \mathit{Tab} \times \mathit{PC} \times \mathit{Lev} \dashrightarrow \mathit{AM}$$

("arithmetic expression translation") is defined by

$$\begin{aligned}
\mathrm{at}(z, \mathrm{st}, a, l) &:= a : \texttt{LIT(}z\texttt{);} \\
\mathrm{at}(I, \mathrm{st}, a, l) &:= \begin{cases} a : \texttt{LIT(}z\texttt{);} & \text{if } \mathrm{st}(I) = (\texttt{const}, z) \\ a : \texttt{LOAD(}l - \mathit{lev}\texttt{,}\mathit{off}\texttt{);} & \text{if } \mathrm{st}(I) = (\texttt{var}, \mathit{lev}, \mathit{off}) \end{cases} \\
\mathrm{at}(A_1 \texttt{ + } A_2, \mathrm{st}, a, l) &:= \mathrm{at}(A_1, \mathrm{st}, a, l) \\
& \mathrm{at}(A_2, \mathrm{st}, a', l) \\
& a'' : \texttt{ADD;}
\end{aligned}$$

Outline

Example: Factorial Function I

Example 20.8 (Factorial function (cf. Ex. 19.1))

Source code:

```
in/out x;
  var y;
  proc F;
    if x > 1 then
      y := y * x;
      x := x - 1;
      F()
  y := 1;
  F();
  x := y.
```

trans(in/out $I_1, \ldots, I_n$; K.) :=
1 : CALL(a,0,size(K));
2 : JMP(0);
kt(K, st$_{I/O}$, a, 1)
dt(D, update(D, st, l), l)
ct(C, update(D, st, l), a, l)
a' : RET;

kt(K_1, st, a_1, $l+1$)
⋮

kt($D\ C$, st, a, l) :=

update(var $I_1, \ldots, I_n$;, st, l) :=
st[$I_1 \mapsto$ (var, l, 1), …, $I_n \mapsto$ (var, l, n)]

update(proc I_1; K_1; … ; I_n; K_n;, st, l) :=
st[$I_1 \mapsto$ (proc, a_1, l, size(K_1)), …, $I_n \mapsto$ (proc, a_n, l, size(

ct(if B then C_1 else C_2, st, a, l) :=

Intermediate code:

trans(in/out x; K.) 1 : CALL(a_0,0,1);
2 : JMP(0);
kt(K, st$_{I/O}$, a_0, 1)
1 : CALL(a_0,0,1);
2 : JMP(0);
dt(D, update(D, st$_{I}$
ct(C, update(D, st$_{I/}$
a_2 : RET;
1 : CALL(a_0,0,1);
2 : JMP(0);
dt(D, st$'$, 1)
ct(C, st$'$, a_0, 1)
a_2 : RET;
1 : CALL(a_0,0,1);
2 : JMP(0);
kt(K_F, st$'$, a_1, 2)
ct(C, st$'$, a_0, 1)
a_2 : RET;
1 : CALL(a_0,0,1);
2 : JMP(0);
ct(C_F, st$'$, a_1, 2)
a_3 : RET;

Example: Factorial Function II

Example 20.8 (Factorial function; continued)

Code with symbolic addresses:

1 : `CALL(`a_0`,0,1);`
2 : `JMP(0);`
a_1 : `LOAD(2,1);`
`LIT(1);`
`GT;`
a_4 : `JFALSE(`a_3`);`
`LOAD(1,1);`
`LOAD(2,1);`
`MULT;`
`STORE(1,1);`
`LOAD(2,1);`
`LIT(1);`
`SUB;`
`STORE(2,1);`
`CALL(`a_1`,1,0);`
a_3 : `RET;`
a_0 : `LIT(1);`
`STORE(0,1);`
`CALL(`a_1`,0,0);`
`LOAD(0,1);`
`STORE(1,1);`
a_2 : `RET;`

Linearized
($a_0 = 17, a_1 = 3, a_2 = 22, a_3 = 16, a_4 = 6$):

```
 1 : CALL(17,0,1);
 2 : JMP(0);
 3 : LOAD(2,1);
 4 : LIT(1);
 5 : GT;
 6 : JFALSE(16);
 7 : LOAD(1,1);
 8 : LOAD(2,1);
 9 : MULT;
10 : STORE(1,1);
11 : LOAD(2,1);
12 : LIT(1);
13 : SUB;
14 : STORE(2,1);
15 : CALL(3,1,0);
16 : RET;
17 : LIT(1);
18 : STORE(0,1);
19 : CALL(3,0,0);
20 : LOAD(0,1);
21 : STORE(1,1);
22 : RET;
```

Example 20.8 (Factorial function; continued)

Computation for `x` $= 2$:

```
1 : CALL(17,0,1);
2 : JMP(0);
3 : LOAD(2,1);
4 : LIT(1);
5 : GT;
6 : JFALSE(16);
7 : LOAD(1,1);
8 : LOAD(2,1);
9 : MULT;
10 : STORE(1,1);
11 : LOAD(2,1);
12 : LIT(1);
13 : SUB;
14 : STORE(2,1);
15 : CALL(3,1,0);
16 : RET;
17 : LIT(1);
18 : STORE(0,1);
19 : CALL(3,0,0);
20 : LOAD(0,1);
21 : STORE(1,1);
22 : RET;
```

PC	*DS*	*PS*
1	ε	$0:0:0:2$
17	ε	$4:3:2:0 : 0:0:0:2$
18	1	$4:3:2:0 : 0:0:0:2$
19	ε	$4:3:2:1 : 0:0:0:2$
3	ε	$3:2:20 : 4:3:2:1 : 0:0:0:2$
4	2	$3:2:20 : 4:3:2:1 : 0:0:0:2$
5	$2:1$	$3:2:20 : 4:3:2:1 : 0:0:0:2$
6	1	$3:2:20 : 4:3:2:1 : 0:0:0:2$
7	ε	$3:2:20 : 4:3:2:1 : 0:0:0:2$
8	1	$3:2:20 : 4:3:2:1 : 0:0:0:2$
9	$1:2$	$3:2:20 : 4:3:2:1 : 0:0:0:2$
10	2	$3:2:20 : 4:3:2:1 : 0:0:0:2$
11	ε	$3:2:20 : 4:3:2:2 : 0:0:0:2$
12	2	$3:2:20 : 4:3:2:2 : 0:0:0:2$
13	$2:1$	$3:2:20 : 4:3:2:2 : 0:0:0:2$
14	1	$3:2:20 : 4:3:2:2 : 0:0:0:2$
15	ε	$3:2:20 : 4:3:2:2 : 0:0:0:1$
3	ε	$6:2:16 : 3:2:20 : 4:3:2:2 : 0:0:0:1$
4	1	$6:2:16 : 3:2:20 : 4:3:2:2 : 0:0:0:1$
5	$1:1$	$6:2:16 : 3:2:20 : 4:3:2:2 : 0:0:0:1$
6	0	$6:2:16 : 3:2:20 : 4:3:2:2 : 0:0:0:1$
16	ε	$6:2:16 : 3:2:20 : 4:3:2:2 : 0:0:0:1$
16	ε	$3:2:20 : 4:3:2:2 : 0:0:0:1$
20	ε	$4:3:2:2 : 0:0:0:1$
21	2	$4:3:2:2 : 0:0:0:1$
22	ε	$4:3:2:2 : 0:0:0:2$
2	ε	$0:0:0:2$
0	ε	$0:0:0:2$

Outline

Theorem 20.9 (Correctness of translation)

For every $P \in Pgm$, $n \in \mathbb{N}$, and $(z_1, \ldots, z_n), (z'_1, \ldots, z'_n) \in \mathbb{Z}^n$:

$$\begin{array}{ll} & \mathfrak{M}[\![P]\!](z_1, \ldots, z_n) = (z'_1, \ldots, z'_n) \\ \Longleftrightarrow & [\![\mathrm{trans}(P)]\!](1, \varepsilon, 0:0:0:z_1:\ldots:z_n) = (0, \varepsilon, 0:0:0:z'_1:\ldots:z'_n) \end{array}$$

Proof.

see M. Mohnen: *A Compiler Correctness Proof for the Static Link Technique by means of Evolving Algebras*, Fundamenta Informaticae 29(3), 1997, pp. 257–303 □

Outline

Lectures after Chistmas Break

1. Error handling in (top-down) parsing
2. Strong noncircularity of attribute grammars
3. More about code generation
    - Static & dynamic data structures
    - Compiler backend (register allocation, ...)
4. Code analysis & optimization