Compilerconstructie

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http://www.liacs.nl/home/rvvliet/coco/

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Static Type Checking

6.1 Variants of Syntax Trees

Directed Acyclic Graphs for Expressions

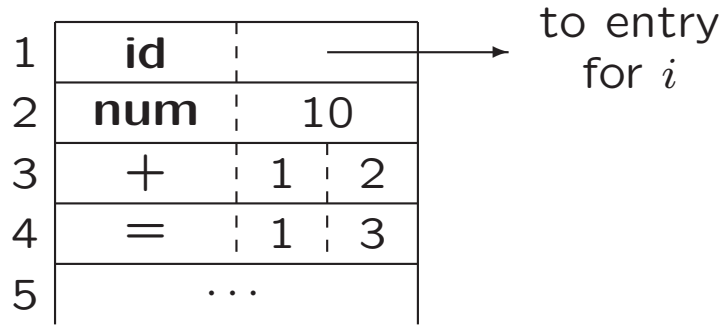
$a + a * (b - c) + (b - c) * d$

Syntax tree vs DAG

Producing Syntax Trees or DAG's

Production	Semantic Rules
1) $E \to E_1 + T$	$E.node =$ **new** $Node('+', E_1.node, T.node)$
2) $E \to E_1 - T$	$E.node =$ **new** $Node('-', E_1.node, T.node)$
3) $E \to T$	$E.node = T.node$
4) $T \to (\ E\ )$	$T.node = E.node$
5) $T \to$ **id**	$T.node =$ **new** $Leaf($**id**, **id**.$entry)$
6) $T \to$ **num**	$T.node =$ **new** $Leaf($**num**, **num**.$val)$

Value-Number Method



Static Checking

- Type checks:
  Verify that type of a construct matches the expected one

- Flow-of-control checks:
  Example: break-statement must be enclosed in while-, for- or switch-statement

- ...

6.3 Types and Declarations

Types can be used for

- Type checking

- Translation
  Type information useful
  - to determine storage needed
  - to calculate address of array element
  - to insert explicit type conversions
  - to choose right version of operator
  - ...

Type Expressions

Types have structure

Example: array type `int[2][3]`

- Basic types: boolean, char, integer, float, void
- Type names: typedefs in C, class names in C++
- Type constructors:
  - array
  - record: data structure with named fields
  - $\rightarrow$ for function types: $s \rightarrow t$
  - Cartesian product $\times$: $s \times t$
  - ...

6.5 Type Checking

- Type system contains information about
  - Syntactic constructs of language
  - Notion of types
  - Logical rules to assign types to language constructs
    - if both operands of $+$ are integers, then result is integer
    - if f has type $s \to t$ and x has type s,
      then expression $f(s)$ has type t

- Sound type system

- Strongly typed implementation of language

A Simple Type Checker

A language example (Pascal-like)

- $P \rightarrow D; S$
- $D \rightarrow D; D \mid \textbf{id} : T$
- $T \rightarrow \textbf{boolean} \mid \textbf{char} \mid \textbf{integer} \mid \textbf{array}\ [\textbf{num}\ ]\ \textbf{of}\ T \mid \hat{}T$
- $S \rightarrow \textbf{id} := E \mid \textbf{if}\ E\ \textbf{then}\ S \mid \textbf{while}\ E\ \textbf{do}\ S \mid S; S$
- $E \rightarrow \textbf{true} \mid \textbf{false} \mid \textbf{literal} \mid \textbf{num} \mid \textbf{id} \mid E\ \textbf{and}\ E$
  $\mid E\ \textbf{mod}\ E \mid E[E] \mid E\hat{}$

A Simple Type Checker

Translation scheme for saving type of identifier

$$
\begin{array}{lcll}
P & \rightarrow & D; S & \\
D & \rightarrow & D; D & \\
D & \rightarrow & \textbf{id} : T & \{\mathit{addType}(\textbf{id}.\mathit{entry}, T.\mathit{type});\} \\
T & \rightarrow & \textbf{boolean} & \{T.\mathit{type} = \mathit{boolean};\} \\
T & \rightarrow & \textbf{char} & \{T.\mathit{type} = \mathit{char};\} \\
T & \rightarrow & \textbf{integer} & \{T.\mathit{type} = \mathit{integer};\} \\
T & \rightarrow & \hat{}\,T_1 & \{T.\mathit{type} = \mathit{pointer}(T_1.\mathit{type});\} \\
T & \rightarrow & \textbf{array}\ [\textbf{num}\ ]\ \textbf{of}\ T_1 & \{T.\mathit{type} = \mathit{array}(1 \ldots \textbf{num}.\mathit{val}, T_1.\mathit{type});\}
\end{array}
$$

A Simple Type Checker

Type Checking of Expressions

E	$\rightarrow$	**true**	$\{E.type = boolean;\}$
E	$\rightarrow$	**false**	$\{E.type = boolean;\}$
E	$\rightarrow$	**literal**	$\{E.type = char;\}$
E	$\rightarrow$	**num**	$\{E.type = integer;\}$
E	$\rightarrow$	**id**	$\{E.type = lookup(\textbf{id}.entry);\}$
E	$\rightarrow$	E_1 **and** E_2	$\{$**if** $(E_1.type == boolean)$ **and** $(E_2.type == boolean)$ **then** $E.type = boolean;$ **else** $E.type = type\_error;\}$
E	$\rightarrow$	E_1 **mod** E_2	$\{$**if** $(E_1.type == integer)$ **and** $(E_2.type == integer)$ **then** $E.type = integer;$ **else** $E.type = type\_error;\}$
E	$\rightarrow$	$E[E]$	$\{$**if** $(E_2.type == integer)$ **and** $(E_1.type == array(s,t))$ **then** $E.type = t;$ **else** $E.type = type\_error;\}$
E	$\rightarrow$	$E_1\hat{}$	$\{$**if** $(E_1.type == pointer(t))$ **then** $E.type = t;$ **else** $E.type = type\_error;\}$

A Simple Type Checker

Type Checking of Statements

$S \rightarrow$ **id** $:= E$ {**if** $(id.type == E.type)$ **then** $S.type = void$; **else** $S.type = type\_error$;}

$S \rightarrow$ **if** E **then** S_1 {**if** $(E.type == boolean)$ **then** $S.type = S_1.type$; **else** $S.type = type\_error$;}

$S \rightarrow$ **while** E **do** S_1 {**if** $(E.type == boolean)$ **then** $S.type = S_1.type$; **else** $S.type = type\_error$;}

$S \rightarrow S_1; S_2$ {**if** $(S_1.type == void)$ **and** $(S_2.type == void)$ **then** $S.type = void$; **else** $S.type = type\_error$;}

Type Equivalence

$S \rightarrow$ **id** $:= E$ $\{$**if** $(id.type == E.type)$
then $S.type = void$; **else** $S.type = type\_error$; $\}$

When are type expressions equivalent?

- Structural equivalence
- Name equivalence
- Use graph representation of type expressions to check equivalence
  - Leaves for basic types and type names
  - Interior nodes for type constructors
  - Cycles in case of recursively defined types. . .

Structural Equivalence

- Same basic type:
  integer is equivalent to *integer*
- Formed by applying same constructor to structurally equivalent types
  pointer($integer$) is equivalent to *pointer*($integer$)
- One is type name of other

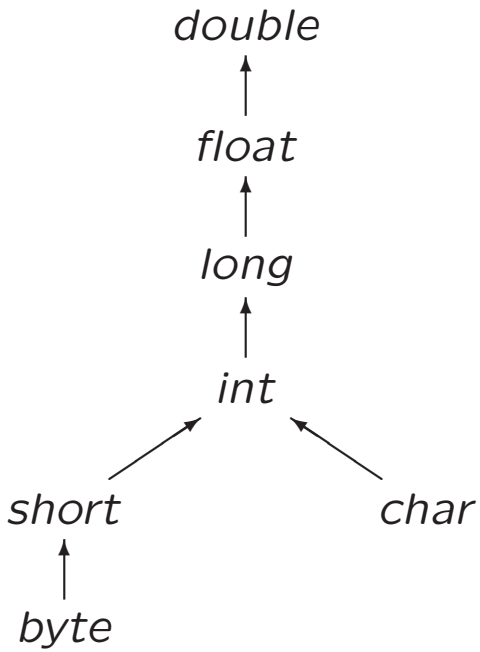
```
type  link = ^cell;
var   next : link;
      last : link;
      p    : ^cell;
      q, r : ^cell;
```

Type Conversions

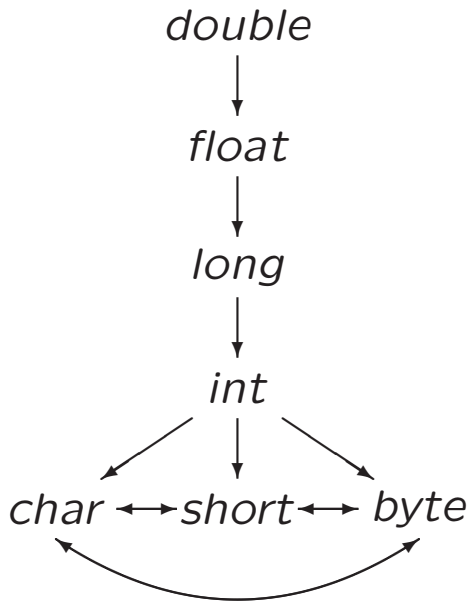
$y = x + i$ with x float and i integer

- widening conversion
- narrowing conversion
- explicit conversion (= cast)
- implicit conversion (= coercion), automatically by compiler

Conversions in Java



Widening conversions



Narrowing conversions

Coercion (Example)

Semantic action for $E \rightarrow E_1 + E_2$ uses two functions:

- *max*(t_1, t_2)
- *widen*(a, t, w)

```
Addr widen(Addr a, Type t, Type w)
{       if (t==w) return a;
        else if (t == integer and w == float)
                { temp = new Temp();
                  gen(temp '=' '(float)' a);
                  return temp;
                }
                else error;
}
```

Coercion (Example)

$$
\begin{array}{lll}
E \rightarrow E_1 + E_2 & \{ & E.type = max(E_1.type, E_2.type); \\
 & & a_1 = widen(E_1.addr, E_1.type, E.type); \\
 & & a_2 = widen(E_2.addr, E_2.type, E.type); \\
 & & E.addr \ = \textbf{new} \ Temp(); \\
 & & gen(E.addr \ ' =' \ a_1 \ ' +' \ a_2); \\
 & \} &
\end{array}
$$

Constructing Type Graphs in Yacc

```
enum Types {Tint, Tfloat, Tpointer, Tarray, ...};
typedef struct Type
{ Types type;
  struct Type *child
} Type;
```

- Type *mkint() construct int node if not already constructed
- Type *mkfloat() construct float node if not already constructed
- Type *mkarray(Type*, int) construct array-of-type node if not already constructed
- Type *mkptr(Type*)construct pointer-of-type node if not already constructed

Yacc Specification (Example)

from college 4

```
expr   : expr '+' term    { $$ = $1 + $3; }
       | term
       ;
term   : term '+' factor  { $$ = $1 * $3; }
       | factor
       ;
factor : '(' expr ')'     { $$ = $2; }
       | DIGIT
       ;

%%
/* auxiliary functions section */
yylex()
{   int c;
    c = getchar();
    if (isdigit(c))
    {   yylval = c-'0';
        return DIGIT;
    }
    return c;
}
```

Constructing Type Graphs in Yacc

Syntax-directed definitions

```
%union
{ Symbol *sym;
int num;
Type *typ;
}
%token INT
%token <sym> ID
%token <num> NUM
%type  <typ> type

%%
decl : type ID                 { addType($2, $1); }
     | type ID '[' NUM ']'     { addType($2, mkarr($1,$4)); }
     ;
type : INT                     { $$ = mkint(); }
     | type '^'                { $$ = mkptr($1); }
     | /* empty */             { $$ = mkint(); }
     ;
```

Type Checking in Yacc

Syntax-directed definitions

```
%{
enum Types {Tint, Tfloat, Tpointer, Tarray, ...};
typedef struct Type
{ Types type;
  struct Type *child
} Type;
%}
%union
{ Type *typ;
}
%type <typ> expr

%%
expr : expr '+' expr { if ($1->type != Tint || $3->type != Tint )
                         semerror("non-int operands in +");
                       else
                       { $$ = mkint();
                         gen(int-add instruction for $1 and $3);
                       }
                     }
```

Type Coercion in Yacc

Syntax-directed definitions

```
%{ ... %}
%%
expr : expr '+' expr
       { if ($1->type == Tint && $3->type == Tint)
         { $$ = mkint(); gen(int-add instruction for $1 and $3);
         }
         else if ($1->type == Tfloat && $3->type == Tfloat)
         { $$ = mkfloat(); gen(float-add instruction for $1 and $3);
         }
         else if ($1->type == Tfloat && $3->type == Tint)
         { $$ = mkfloat(); gen(int2float instruction for $3);
           gen(float-add instruction for $1 and $3);
         }
         else if ($1->type == Tint && $3->type == Tfloat)
         { $$ = mkfloat(); gen(int2float instruction for $1);
           gen(float-add instruction for $1 and $3);
         }
         else
         { semerror ("type error in +");
           $$ = mkint();
         }
       }
```

L-Values and R-Values

- $E_1 = E_2$;

- What can E_1 and E_2 be?
  $i = i + 1$;
  $i = 5$;

- L-value: left side of assignment, location
  Example: identifier i, array acces a[2]

- R-value: right side of assignment, value
  Example: identifier i, array acces a[2], constant 5, addition $i + 1$

L-Values and R-Values in Yacc

Syntax-directed definitions (C)

```
%{
typedef struct Node
{ Type *typ;
  int islval;
} Node;
%}
%union
{ Node *rec;
}
%type <rec> expr
%%
```

```
expr : expr '+' expr:
       { if ($1->typ->type != Tint ||
             $3->typ->type != Tint )
           semerror ("non-int operands in +");
         $$->typ = mkint();
         $$->islval = FALSE;
         gen(...);
       }
     | expr '=' expr
       { if ( !$1->islval || $1->typ != $3->typ )
           semerror ("invalid assignment");
         $$->typ = $1->typ;
         $$->islval = FALSE;
         gen(...);
       }
     | ID
       { $$->typ = lookup($1);
         $$->islval = TRUE;
         gen(...);
       }
```

Volgende week

- Practicum over opdracht 2
- Direct naar 302/304
- Komt spoedig online
- Inleveren 29 oktober

Compiler constructie

college 5

Static Type Checking

Chapters for reading: 6.1, 6.3.1, 6.3.2, 6.5.1, 6.5.2