Inherited Attributes

Sometimes convenient to make node’s attributes dependent on siblings or ancestors in tree.

Useful for expressing dependence on context, e.g., relating identifier uses to declarations. (This is especially important because CFG cannot capture such dependencies.)

Example: Parsing Declarations

```
D → TL  L.type := T.type  
T → int   T.type := integer  
T → real  T.type := real  
L → L₁ , id { L₁.type := L.type;  
            addsymb(id.name, L.type) }  
L → id    addsymb(id.name, L.type)
```

where addsymb adds id and its type to symbol table.

Here \( L.type \) is inherited attribute.

Parse tree for real \( a, b, c \):

![Parse Tree Example]

Dependency Graphs

Parse tree for real \( a, b, c \):

```
D
  
  T.type := real

  L.type := real

  real

  L.type := real

  L => real '

  id.name := c

  id.name := b

  id.name := a
```

Arrows show dependency relation among attributes. Taken together, arrow describe dependency graph.

Evaluate attributes in topological order of dependency graph.

If attributes are defined on parse tree, may want to evaluate attributes while (or instead of) building the tree. This is sometimes possible:

- Saw how to evaluate synthesized attributes during bottom-up parser; this method doesn’t work for inherited attributes.
- Top-down parser can easily evaluate L-attributed grammars, in which attributes don’t depend on their right ancestors. (Bottom-up parsers can sometimes handle these too, though with difficulty.)
- For some attribute grammars, must build entire tree before evaluating attributes.

Attribute Evaluation during Recursive Descent

Each non-terminal function is modified to take inherited attribute values as arguments and return (record of) synthesized attribute value(s) as result.

All inherited values are known when function is called.

All synthesized values are known when function returns.

Example revisited (with left-recursion removed):

```
class Typ :
  static Typ intTy = new Ty();
  static Typ realTy = new Ty();

void D() {
  Typ ty = T();
  L(ty);
}
void T() {
  if (tok == INT) {
    tok = lex(); return intTy;
  } else if (tok == REAL) {
    tok = lex(); return realTy;
  } else error();
}
void L(Typ ty) {
  if (tok == ID) {
    addsymb(lexeme,ty); tok = lex();
  } else error();
  if (tok == ',') {
    tok = lex();

    L(ty);
  }
} 
```
Avoiding Inherited Attributes

When using bottom-up parser (e.g., with yacc or CUP), it is desirable to avoid inherited attributes.

There are several approaches:

• Move the activity requiring the attribute to a higher node in the tree, by substituting a synthesized attribute for the inherited one, e.g.:

  D \rightarrow T L \quad \text{for each id in L.list}
  \quad \text{addsymb(id.name, T.type)}

  T \rightarrow \text{int} \quad T.type := \text{integer}

  T \rightarrow \text{real} \quad T.type := \text{real}

  L \rightarrow L_1, \ id \quad \text{L.list := mk_Ids(id,L_1.list)}

  L \rightarrow \text{id} \quad \text{L.list := mk_Ids(id,null)}

• Can sometimes rewrite grammar, e.g.:

  D \rightarrow T \ id \quad \{ D.type := T.type; \}
  \quad \text{addsymb(id.name,T.type)}

  D \rightarrow D_1, \ id \quad \{ D.type := D_1.type; \}
  \quad \text{addsymb(id.name,D.type)}

  T \rightarrow \text{int} \quad T.type := \text{integer}

  T \rightarrow \text{real} \quad T.type := \text{real}

Attributes on AST’s

Attribute grammar method extends to abstract grammars (not intended for parsing), e.g., AST grammars.

• Same concept, but evaluation always occurs after whole tree is built.

• Can use recursive descent to evaluate (rather than parse).

• Typical applications: typechecking, code generation, interpretation.

Why attribute grammars?

• Compact, convenient formalism.

• Local rules describe entire computation.

• Separate traversal from computation.

• (Purely functional rules can be evaluated in any order.)

Checking of E Language (Homework 1)

Can view checking process as evaluation of following attribute grammar, where

• exp.ok and exps.ok are synthesized boolean attributes indicating whether expression has checked successfully; and

• exp.env and exps.env are inherited environment attributes (with operators empty, extend, and lookup) containing entries for all in-scope variables.

program \rightarrow \exp \quad \exp.env := \emptyset

exp \rightarrow \text{ID} \quad \exp := \text{lookup(exp.env,ID.name)}
  \quad \exp.ok := \text{true}

\rightarrow \text{NUM} \quad \exp.ok := \text{true}

\rightarrow \exp \ ‘+’ \ exp_2 \quad \{ \exp_1.env := \exp_2.env = \exp.env; \}
  \quad \exp.ok := \exp_1.ok \text{ AND } \exp_2.ok \}

\rightarrow \exp \ ‘-’ \ exp_2 \quad \{ \exp_1.env := \exp_2.env = \exp.env; \}
  \quad \exp.ok := \exp_1.ok \text{ AND } \exp_2.ok \}

\rightarrow \text{ID} \ ‘=’ \ exp_1 \quad \{ \exp_1.env := \exp.env; \}
  \quad \exp.ok := \text{lookup(exp.env,ID.name) AND exp_1.ok} \}

\rightarrow \text{if0} exp_1 \exp_2 \exp_3 \quad \{ \exp_1.env := \exp_2.env := \exp_3.env := \exp.env; \}
  \quad \exp.ok := \exp_1.ok \text{ AND } \exp_2.ok \text{ AND } \exp_3.ok \}

\rightarrow ‘\{’ \ vars ‘;’ \ exps ‘\}’ \quad \{ \exp.env := \text{extend(exp.env,vars);} \}
  \quad \exp.ok := \exp.ok \}

exps \rightarrow \exp \quad \{ \exp.env := \exp.env; \}
  \quad \exp.ok := \exp.ok \}

\rightarrow \exp \ ‘;’ \ exps_1 \quad \{ \exp.env := \exp.env; \}
  \quad \exp.ok := \exp.ok \text{ AND } \exp.ok \}

\rightarrow \exp \ ‘;’ \ exps_1 \quad \{ \exp.env := \exp.env; \}
  \quad \exp.ok := \exp.ok \text{ AND } \exp.ok \}