Syntax-Directed Translation

Introduction

- Translation of languages guided by context-free grammars
- Attach attributes to the grammar symbols
  - Values of the attributes are computed by semantic rules associated with the grammar productions
  - Attribute may represent:
    - Number, type, string, memory location, label, etc.
- Syntax–directed definitions:
  - Each production has a set of semantic rules associated with it
- Conceptually we parse the input token stream, build the parse tree and then traverse the tree as needed to evaluate the semantic rules.
  - The rules may generate code, save information in the symbol table, issue error messages, etc.

Introduction

- In some cases we don't have to follow this outline literally
  - We may evaluate the rules during parsing
- Synthesized attribute:
  - The value of the attribute at a parent node can be found from the attributes of its children
    - It can be evaluated by traversing the tree bottom-up
- Inherited attribute:
  - The value of the attribute at a node can be found from the attributes at its parent node and/or its sibling nodes
    - Can be evaluated by traversing the tree top-down
- S-attributed definition:
  - A syntax-directed definition where all attributes are synthesized (the "S" stands for synthesized).

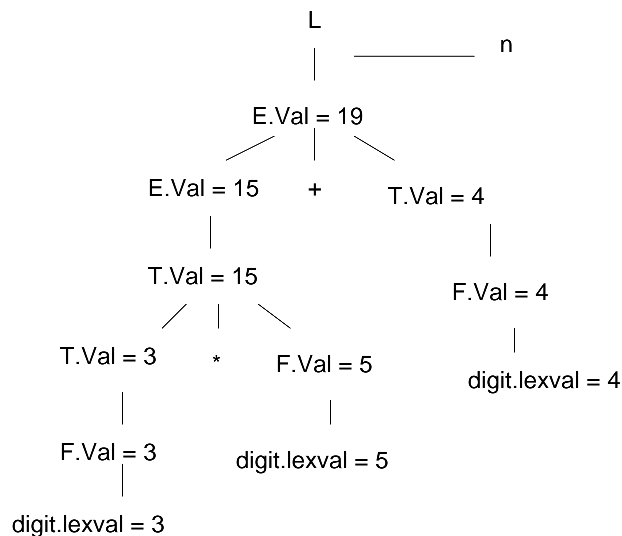
Example: Simple Desk Calculator

Production	Semantic Rules
L → E**n**	print(E.val)
E → E_1 + T	E.val := E_1.val + T.val
E → T	E.val := T.val
T → T_1 * F	T.val := T_1.val * F.val
T → F	T.val := F.val
F → (E)	F.val := E.val
F → **digit**	F.val := **digit**.lexval

Synthesized Attributes

- Synthesized attributes are very common in practice
  - Bison uses this type of attribute
- A syntax-directed definition that uses synthesized attributes exclusively is said to be an *S-attributed definition*
- A parse tree for an S-attributed definition can always be annotated by evaluating the semantic rules for the attributes at each node bottom-up

Example: Annotated parse tree for 3*5+4n



Inherited Attributes

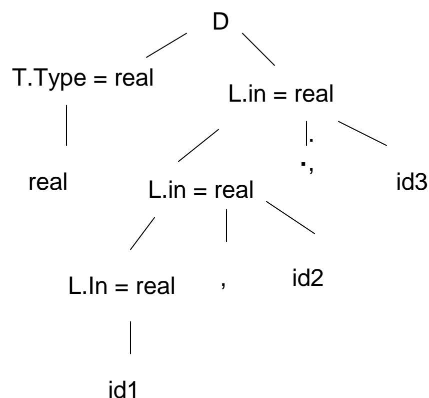
- Inherited attributes are convenient for expressing the dependence of a programming language construct on the context in which it appears.

Example

- Using inherited attributes to parse a declaration and add type information to the symbol table.

Production	Semantic Rules
D → TL	L.in := T.type
T → int	T.Type := integer
T → real	T.Type := real
L → L_1, id	L_1.in := L.in addtype (id.entry, L.in)
L → id	addtype (id.entry, L.in)

Annotated Parse Tree for real, id1, id2, id3



Bottom-up Parsing

- If all attributes are synthesized then a bottom-up parser can evaluate the attributes while it parses
- Add attribute fields to the nonterminals on the stack
- Before each production apply the semantic rule associated with the production
- E.g. Assume the semantic rule associated with the A → XYZ production is : A.a := f (X.x, Y.y, Z.z)

Bottom-up Parsing

- Before the reduction the parser stack looks like:
- After the reduction the parser stack looks like:

…	…
X	X.X
Y	Y.y
Z	Z.Z

…	…
A	A.A

Bottom-up Parsing

- This is the method that Bison uses for maintaining attributes

Bison Generated Parsers

- Bison maintains a semantic stack which, in tandem with the parser stack, helps Bison manipulate and determine the meaning of the program it compiles
- The values in the semantic stack represent the *values* or *meanings* of all the grammar symbols
- Exactly what constitutes *values* for the entries in the semantic stack depends heavily on the semantics of the language being compiled

Semantic Stack

- Manipulation of the semantic stack is triggered by the parser during *reduce* moves
- *Values* of symbols on the rhs of the production are popped off the semantic stack
- A *value* for the symbol on the lhs is determined from these values and the semantic rules of the language, and a new value is pushed back on the stack

Semantic Stack

- All symbols in the grammar have a value associated with them in the semantic stack even though some of these values may be NULL (indicating no information is needed about this symbol)
- Not all reductions require semantic actions

Semantic Rules

- Bison allows you to specify the semantic action associated with the symbol on the lhs of the production
  - These actions may return a value and may utilize the values returned by previous actions
- The lexical analyzer can return values for tokens, if desired, through the use of the global variable yylval

Semantic Rules

- An action is specified by writing arbitrary C/C++ statements enclosed in {}

```
Exp : Exp PLUS Exp
    { $$ = binaryOp( $1, A_Plus, $3); }
```

  – To return a value for the symbol Exp on the lhs, a value is assigned to $$
  – To refer to values of symbols on the rhs, the variables $1, $2, …, are used
    - These refer to the values returned by the components of the rhs of the production reading from right to left

Semantic Actions

- If no action is specified after a particular production, the default action

```
{$$ = $1;}
```

is performed

Union

- The values on the semantic stack do not have to be of a single type
  - You can define the type of the value using the %union statement in Bison
- Bison must know which type to associate with each symbol in the grammar
  - This is done using the %type statement
    - Beware, once you starting using %type, you are forced to type all symbols even though you may not be using them
  - You are required to use %type statements in your project

%union and %type

```
%union
{   int int_val;
    char *name_ptr;
    CONS *cons_ptr;
    ID *id_ptr;
    TYPE *ty_ptr;
    EXPR *exp_ptr;
}

%type <int_val> INTCONSTSY IfHead
%type <id_ptr> IdList FieldList
```