

5. Semantics

Overview

- Static semantics
- Dynamic semantics
- Attribute grammars
- Abstract syntax trees
- Putting theory into practice:
 - Java recursive descent parsers

Note: Study Chapter 4 of the textbook upto and including Section 4.3.

Static and Dynamic Semantics

- Syntax concerns the *form* of a valid program, while *semantics* concerns its *meaning*
- *Static semantic* rules are enforced by a compiler at compile time
 - Implemented in semantic analysis phase of the compiler
 - Context-free grammars are not powerful enough to describe certain rules, such as checking variable declaration with variable use
 - Examples: *Type checking; Identifiers are used in appropriate context; Check subroutine call arguments; Check labels*
- *Dynamic semantic* rules are enforced by the compiler by generating code to perform the checks
 - Examples: *Array subscript values are within bounds; Arithmetic errors; Pointers are not dereferenced unless pointing to valid object; A variable is used but hasn't been initialized*
 - Some languages (Euclid, Eiffel) allow programmers to add *explicit* dynamic semantic checks in the form of *assertions*, e.g.


```
assert denominator not= 0
```
 - When a check fails at run time, an *exception* is raised

Attribute Grammars

- An *attribute grammar* links syntax with semantics
 - Every grammar production has a *semantic rule* with actions (e.g. assignments) to modify values of *attributes* of (non)terminals
 - A (non)terminal may have a number of *attributes*
 - Attributes have values that hold semantic information about the (non)terminal
 - General form:

Production	Semantic rule
$\langle A \rangle \rightarrow \langle B \rangle \langle C \rangle$	$A.a := \dots; B.a := \dots; C.a := \dots$

$A.a$ denotes attribute a of nonterminal $\langle A \rangle$

- Semantic rules are used by a compiler to enforce static semantics and/or to produce an abstract syntax tree while parsing token stream
- Can also be used to build simple language interpreters

Example Attribute Grammar

Example attribute grammar for evaluating simple expressions

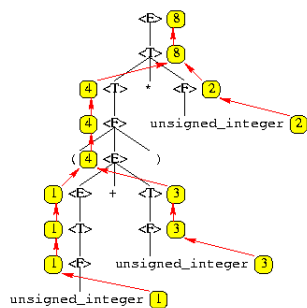
Production	Semantic rule
$\langle E_1 \rangle \rightarrow \langle E_2 \rangle + \langle T \rangle$	$E_1.val := E_2.val + T.val$
$\langle E_1 \rangle \rightarrow \langle E_2 \rangle - \langle T \rangle$	$E_1.val := E_2.val - T.val$
$\langle E \rangle \rightarrow \langle T \rangle$	$E.val := T.val$
$\langle T_1 \rangle \rightarrow \langle T_2 \rangle * \langle F \rangle$	$T_1.val := T_2.val * F.val$
$\langle T_1 \rangle \rightarrow \langle T_2 \rangle / \langle F \rangle$	$T_1.val := T_2.val / F.val$
$\langle T \rangle \rightarrow \langle F \rangle$	$T.val := F.val$
$\langle F_1 \rangle \rightarrow - \langle F_2 \rangle$	$F_1.val := -F_2.val$
$\langle F \rangle \rightarrow (\langle E \rangle)$	$F.val := E.val$
$\langle F \rangle \rightarrow \text{unsigned_int}$	$F.val := \text{unsigned_int.val}$

- The `val` attribute of a (non)terminal holds the subtotal value of the subexpression described by the (non)terminal
- Nonterminals are *indexed* in the attribute grammar (e.g. $\langle T_1 \rangle$) to distinguish multiple occurrences of the nonterminal in a production

Decorated Parse Trees

- A parser produces a parse tree that is *decorated* with the attribute values

Example decorated parse tree of $(1+3)*2$ showing `val` attribute values



- The `val` attribute of a node holds the subtotal value of the subexpression down the node

Synthesized Attributes

- Synthesized attributes* hold values used by the parent node and flow upwards

Production	Semantic rule
$\langle E_1 \rangle \rightarrow \langle E_2 \rangle + \langle T \rangle$	$E_1.val := E_2.val + T.val$

Inherited Attributes

- Inherited attributes* are defined by the parent node and flow downwards

Production	Semantic rule
$\langle E \rangle \rightarrow \langle T \rangle \langle TT \rangle$	$TT.st := T.val; E.val := TT.val$
$\langle TT_1 \rangle \rightarrow + \langle T \rangle \langle TT_2 \rangle$	$TT_2.st := TT_1.st + T.val;$ $TT_1.val := TT_2.val$
$\langle TT \rangle \rightarrow e$	$TT.val := TT.st$

Attribute Flow

- An attribute flow algorithm propagates attribute values through the parse tree by traversing the tree according to the *set and used* dependencies between attributes (an attribute must be set before it is read)

Production Action	Attribute flow

$\langle E \rangle \rightarrow \langle T \rangle \langle TT \rangle$ $TT.st := T.val$	
$\langle TT_1 \rangle \rightarrow + \langle T \rangle \langle TT_2 \rangle$ $TT_2.st := TT_1.st + T.val$	
$\langle TT \rangle \rightarrow e$ $TT.val := TT.st$	
$\langle TT_1 \rangle \rightarrow + \langle T \rangle \langle TT_2 \rangle$ $TT_1.val := TT_2.val$	
$\langle E \rangle \rightarrow \langle T \rangle \langle TT \rangle$ $E.val := TT.val$	

Recursive Descent Parser for L-Attributed Grammar

- Productions for each nonterminal are implemented as a subroutine
- Subroutine returns synthesized attributes of the nonterminal
- Subroutine takes inherited attributes of the nonterminal as subroutine arguments

<i>Production</i>	<i>Semantic rule</i>
<code><E> -> <T> <TT></code>	<code>TT.st := T.val; E.val := TT.val</code>
<code><TT₁> -> + <T> <TT₂></code>	<code>TT₂.st := TT₁.st + T.val; TT₁.val := TT₂.val</code>
<code><TT> -> e</code>	<code>TT.val := TT.st</code>

```

function E()
  Tval := T()
  TTst := Tval
  TTval := TT(TTst)
  return TTval

function TT(TT1st)
  case (input_token())
  of '+': Tval := T()
          TT2st := TT1st + Tval
          TT2val := TT(TT2st)
          TT1val := TT2val
  otherwise: TT1val := TT1st
  return TT1val
  
```

Putting theory into practice:

- Click [\[here\]](#) to view an example recursive descent parser written in Java to evaluate simple arithmetic expressions.
- Click [\[here\]](#) to view an example recursive descent parser written in Java to translate simple arithmetic expressions to LISP with a Java implementation of an AST for expressions.

Exercise 1: Find information on the C/C++ `assert()` macro defined in `<assert.h>`. What is the purpose of this macro?

Exercise 2: Augment the following grammar of nested parenthesis with semantic rules to count the number of opening parenthesis:

```

<parens> -> ( <parens> )
<parens> -> e
  
```

such that the synthesized attribute `parens.num` holds the number of opening parenthesis.

Exercise 3: Draw a decorated parse tree of the input `((()))` using the augmented grammar of Exercise 2.

Exercise 4: Write (on paper) a recursive descent parser (in Pseudo code or any other programming language) for the augmented grammar of Exercise 2.

Exercise 5: Is the augmented grammar of Exercise 2 L-attributed (yes or no)?