Syntax of Programming Languages *(cont'd)*

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Modified and put together by Eric Joanis 2002.

Syntactic Ambiguity

In English

Syntactically ambiguous sentences of English:

- "I saw the dog with the binoculars."
- "The friends you praise sometimes deserve it."
- "He seemed nice to her."

Other kinds of ambiguity in English:

Aside: We can often "disambiguate" ambiguous sentences. **Question:** How?

But we can be wrong.
Example: "I put the box on the table ."

In a programming language

Example grammar excerpt (based on Sebesta, p. 119):

```
<stmt>    --> <assnt-stmt> | <loop-stmt> | <if-stmt>
<if-stmt> --> if <boolean-expr> then <stmt>
           |  if <boolean-expr> then <stmt> else <stmt>
```

Example sentence:

```
if (x odd) then
if (x == 1) then
print "bleep";
else
print "boop";
```

Exercise: Draw the two parse trees.

Definition: A **grammar is ambiguous** iff it generates a sentence for which there are two or more distinct parse trees

To prove that a grammar is ambiguous, give a string and two parse trees for it.

A **sentence is ambiguous** with respect to a grammar iff that grammar generates two or more distinct parse trees for the sentence.

Note that having two distinct *derivations* does not make a sentence ambiguous. A derivation corresponds to a traversal through a parse tree, and one can traverse a single tree in many orders.

Example

Grammar: if statement two slides ago.

Sentence:

```
if (x odd) then
print "bleep";
```

One parse tree:

Two derivations:

Notation and Terminology

We say that $L(G)$ is the language generated by grammar G.

So G is ambiguous if $L(G)$ contains a sentence which has more than one parse tree, or more than one *leftmost* (or *canonical*) derivation.

Dealing with ambiguity

We have two strategies:

1. Change the *language* to include **delimiters**
2. Change the *grammar* to impose **associativity** and **precedence**

Changing the language to include delimiters

Algol 68 if-statement grammar:

```
<stmt>    --> <assnt-stmt> | <loop-stmt> | <if-stmt>
<if-stmt> --> if <boolean-expr> then <stmt> fi
           |  if <boolean-expr> then <stmt>
                                 else <stmt>
              fi
```


Example: A CFG for Arithmetic Expressions

Grammar 1:

```
<expn> --> <expn> + <expn>  |
           <expn> - <expn>  |
           <expn> * <expn>  |
           <expn> / <expn>  |
           <expn> ^ <expn>  |
           <identifier>  |
           <literal>
```

Example: parse 8 - 3 * 2

Changing the language to include delimiters

Grammar 2:

```
<expn> --> ( <expn> ) - ( <expn> )  |
           ( <expn> ) * ( <expn> )  |
           <identifier>  |
           <literal>
```

(8)-((3)*(2)) $\in L(G)$
((8)-(3))*(2) $\in L(G)$
8 - 3 * 2 $\notin L(G)$

Grammar 3:

```
<expn> --> <expn> - <expn>  |
           <expn> * <expn>  |
           <identifier>  |
           <literal>  |
           ( <expr> )
```

Accepts all expressions, but still ambiguous!

Changing the grammar to impose precedence

Grammar 4:

```
<expn> -->
```


Grouping in parse tree now reflects precedence

Example: parse 8 - 3 * 2

Precedence

- Low Precedence:
  Addition + and Subtraction -
- Medium Precedence:
  Multiplication * and Division /
- Higher Precedence:
  Exponentiation ^
- Highest Precedence:
  Parenthesized expressions (<expr>)

⇒ Ordered lowest to highest in grammar.

We still have ambiguity...

Example: `3 - 2 - 1` is still a problem.

- The grouping of operators of same precedence is not disambiguated.
- For non-commutative operators, only one parse tree is correct.
- Operators may be **left** or **right** associative.

Changing the grammar to impose associativity

Grammar 5:

```
<expn> -->
```


Associativity

- Deals with operators of same precedence
- Implicit grouping or parenthesizing
- Left associative: `*`, `/`, `+`, `-`
- Right associative: `^`

Dealing with Ambiguity

1. Can't *always* remove an ambiguity from a grammar by restructuring productions.
2. When specifying a programming language, we want the grammar to be completely unambiguous.
3. An inherently ambiguous language does not possess an unambiguous grammar.
4. There is no algorithm that can examine an arbitrary context-free grammar and tell if it is ambiguous, i.e., detecting ambiguity in context-free grammars is an *undecidable* problem.

An Inherently Ambiguous Language

Suppose we want to generate the following language:

$$\mathcal{L} = \{a^i b^j c^k \mid i, j, k \geq 1, i = j \text{ or } j = k\}$$

Grammar:

Two parse trees for $a^i b^i c^i$

Limitations of CFGs

CFGs are not powerful enough to describe some languages.

Example:

- The language consisting of strings with one or more a's followed by the same number of b's then the same number of c's.
  I.e., $\{\ a^i b^i c^i \mid i \geq 1\ \}$.
- $\{\ a^m b^n c^m d^n \mid m, n \geq 1\ \}$.

Research question: Exactly what things can and cannot be expressed with a CFG?

The Chomsky Hierarchy

There are several categories of grammar that are more and less expressive, forming a hierarchy:

Phrase-structure grammars

Context-sensitive grammars

Context-free grammars

Regular grammars

This is called the Chomsky hierarchy, after linguist Noam Chomsky, who did much of the original research.

Using CFGs for PL Syntax

Some aspects of programming language syntax can't be specified with CFGs:

- Cannot declare the same identifier twice in the same block.
- Must declare an identifier before using it.
- A[i,j] is valid only if A is two-dimensional.
- The number of actual parameters must equal the number of formal parameters.

Other things are awkward to say with CFGs:

- Identifier names must be no more than 50 characters long.

These aspects of a programming language are usually specified informally, separately from the formal grammar.

Applications of Formal Grammars

Specifying a programming language

REs for lexical syntax; BNF for syntax;
plus extra rules for things that BNF cannot say.

Identifying strings for an operating system command

Examples
(Unix commands that use extended REs):

- `ls s[y-z]*`
- `grep Se.h syntax.tex`
- Scripting languages like `awk` use regular expressions.
  `awk '/to[kg]e/ {print $1}' syntax.tex`

Voice recognition

Problem: Given recorded speech, produce a string containing the words that were spoken.

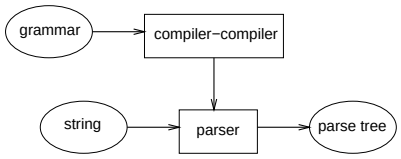
Difficulties:

How can a grammar help?

Example: ViaVoice, by IBM. See chapter 6 of the IBM Speech Programmer's Guide:

`http://wwwhome.cs.utwente.nl/~liraraki/grammar.htm`

Compiler-compilers



Examples:

- `yacc` ("yet another compiler-compiler").
  See: `man yacc`.
- `bison` (the GNU replacement for yacc)
- JavaCC.
  See: `http://www.webgain.com/products/java_cc`

So why does anyone still write compilers by hand?