Compiling Techniques

Lecture 6: Dealing with Ambiguity + Bottom-Up Parsing

Ambiguity Definition

- If a grammar has more than one leftmost (or rightmost) derivation for a single sentential form, the grammar is ***ambiguous***
- This is a problem when interpreting an input program or when building an internal representation

Ambiguous Grammar: Example Associativity

Ambiguous Grammar: example 1

```
Expr ::= Expr Op Expr | num | id
Op   ::= + | *
```

This grammar has multiple leftmost derivations for x + 2 * y.

One possible derivation

```
Expr
Expr Op Expr
id(x) Op Expr
id(x) + Expr
id(x) + Expr Op Expr
id(x) + num(2) Op Expr
id(x) + num(2) * Expr
id(x) + num(2) * id (y)
```

x + (2 * y)

Another possible derivation

```
Expr
Expr Op Expr
Expr Op Expr Op Expr
id(x) Op Expr Op Expr
id(x) + Expr Op Expr
id(x) + num(2) Op Expr
id(x) + num(2) * Expr
id(x) + num(2) * id (y)
```

(x + 2) * y

Ambiguous Grammar: Example If-Then-Else

Ambiguous Grammar: example 2

```
Stmt ::= if Expr then Stmt
       | if Expr then Stmt else Stmt
       | OtherStmt
```

Input

if E1 then if E2 then S1 else S2

One possible interpretation

```
if E1 then
  if E2 then
    S1
else
  S2
```

Another possible interpretation

```
if E1 then
  if E2 then
    S1
  else
    S2
```

Removing Ambiguity

- Must rewrite the grammar to avoid generating the problem
- Match each else to innermost unmatched if (common sense)

Unambiguous grammar

```
Stmt ::= if Expr then Stmt
       | if Expr then WithElse else Stmt
       | OtherStmt

WithElse ::= if Expr then WithElse else WithElse
       | OtherStmt
```

- Intuition: the `WithElse` restricts what can appear in the then part
- With this grammar, the example has only one derivation

Derivation with Unambiguous Grammar

```
Stmt ::= if Expr then Stmt
       | if Expr then WithElse else Stmt
       | OtherStmt

WithElse ::= if Expr then WithElse else WithElse
       | OtherStmt
```

Derivation for: if E1 then if E2 then S1 else S2

```
Stmt
if Expr then Stmt
if E1   then Stmt
if E1   then if Expr then WithElse else Stmt
if E1   then if E2   then WithElse else Stmt
if E1   then if E2   then S1       else Stmt
if E1   then if E2   then S1       else S2
```

Deeper Ambiguity

- Ambiguity usually refers to confusion in the CFG (Context Free Grammar)
- Consider the following case: a = f(17)

  In Algol-like languages, f could be either a function or an array
- In such case, context is required
  - Need to track declarations
  - Really a type issue, not context-free syntax
  - Requires en extra-grammatical solution
  - Must handle these with a different mechanism

```
Step outside the grammar rather than making it more complex. This will be treated
during semantic analysis.
```

Ambiguity Final Words

Ambiguity arises from two distinct sources:

- Confusion in the context-free syntax (e.g. *if then else*)
- Confusion that requires context to be resolved (e.g. *array vs function*)

Resolving ambiguity:

- To remove context-free ambiguity, rewrite the grammar
- To handle context-sensitive ambiguity delay the detection of such problem (semantic analysis phase):
  For instance, it is legal during syntactic analysis to have: `void i ; i=4;`

Bottom-Up vs. Top-Down Parsers

Top-Down Parser

A top-down parser builds a derivation by working from the start symbol to the input sentence.

Bottom-Up Parser

A bottom-up parser builds a derivation by working from the input sentence back to the start symbol.

Bottom-Up Parsing: Example

Example: CFG

```
Goal ::= a A B e
A ::= A b c | b
B ::= d
```

`Input:` `abbcde`

Bottom-Up Parsing

`abbcde`

Bottom-Up Parsing: Example

Example: CFG

```
Goal ::= a A B e
A ::= A b c | b
B ::= d
```

Input: abbcde

Bottom-Up Parsing

abbcde
aAbcde

Bottom-Up Parsing: Example

Example: CFG

```
Goal ::= a A B e
A ::= A b c | b
B ::= d
```

Input: abbcde

Bottom-Up Parsing

abbcde
a**Abc**de
aAde

Bottom-Up Parsing: Example

Example: CFG

```
Goal ::= a A B e
A ::= A b c | b
B ::= d
```

Input: abbcde

Bottom-Up Parsing

```
abbcde
aAbcde
aAde
aABe
```

Bottom-Up Parsing: Example

Example: CFG

```
Goal ::= a A B e
A ::= A b c | b
B ::= d
```

Input: `abbcde`

Bottom-Up Parsing

productions (follow **rightmost derivation**) ↑

```
abbcde
aAbcde
aAde
aABe
Goal
```

↓ reductions

Leftmost vs. Rightmost derivation

Leftmost derivation

Rewrite leftmost nonterminal next

Rightmost derivation

Rewrite rightmost nonterminal next

Example: CFG

```
Goal ::= a A B e
A ::= A b c | b
B ::= d
```

Leftmost derivation
LL Parser (Top-Down)

```
Goal
aABe
aAbcBe
abbcBe
abbcde
```

Rightmost derivation
LR Parser (Bottom-Up)

```
Goal
aABe
aAde
aAbcde
abbcde
```

Shift-reduce parser

Consists of a stack and the input

Uses four actions:

1. **shift**: next symbol is shifted onto the stack
2. **reduce**: pop the symbols Y_n, …, Y_1 from the stack that form the rhs of a production rule $X ::= Y_n, \ldots, Y_1$
3. **accept**: stop parsing and report success
4. **error**: reporting an error

How does the parser know when to shift or when to reduce?

Similarly to the top-down parser, can back-track if wrong decision made or try to look ahead.
Can build a DFA to decide when to shift or to reduce.

Shift-reduce parser: Example

Input	Operations	Stack
abbcde	shift	a
bbcde	shift	ab
bcde	reduce	aA
bcde	shift	aAb
cde	shift	aAbc
de	reduce	aA
de	shift	aAd
e	reduce	aAB
e	shift	aABe
	reduce	Goal
	accept	

Example: CFG

```
Goal ::= a A B e
A ::= A b c | b
B ::= d
```

Choice here: shift or reduce?

Can lookahead one symbol to make decision.

(Knowing what to do needs analysis of the grammar, see *Engineering a Compiler §3.5*)

Top–Down vs Bottom-Up Parsing

Top-Down Parser

\+ Easy to write by hand
\+ Easy to integrate with rest of the compiler

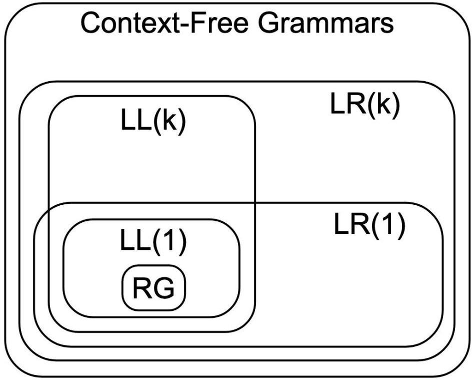
\- Recursion might lead to performance problems

Bottom-Up Parser

\+ Very efficient
\+ Supports a larger class of grammars

\- Requires generation tools
\- Rigid integration with the rest of the compiler

Last words on Parsing



Language ≠ Grammar

There is more than one grammar that can be used to define a language

These grammars might be of different “complexity” (LL(1), LL(k), LR(k))

⇒ Language complexity ≠ grammar complexity