Compiling Techniques

Lecture 6: Bottom-Up Parsing

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Announcement

- New tutorial session: Friday 2pm
  check ct course webpage to find your allocated group

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Bottom-Up Parser

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

- $S \to \gamma_0 \to \gamma_1 \to \cdots \to \gamma_{n-1} \to \gamma_n$
- To reduce γ_i to γ_{i-1}, match some **rhs** β against γ_i then replace β with its corresponding **lhs**, A, assuming $A \to \beta$

Example: CFG

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

Input: abbcde

Bottom-Up Parsing

abbcde

Example: CFG

Goal ::= a A B e

A ::= A b c

A ::= b

B ::= d

Input: abbcde

Bottom-Up Parsing

abbcde

aAbcde

Example: CFG

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

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Bottom-Up Parsing

abbcde
aAbcde
aAde

Example: CFG

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

Input: abbcde

Bottom-Up Parsing

abbcde
aAbcde
aAde
aABe

Example: CFG

Goal ::= a A B e
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A ::= b
B ::= d

Input: abbcde

Bottom-Up Parsing

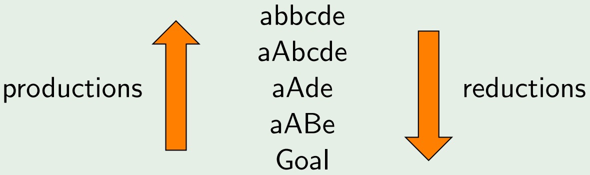
abbcde
aAbcde
aAde
aABe
Goal

Example: CFG

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

Input: abbcde

Bottom-Up Parsing



Note that the production follows a rightmost derivation.

Leftmost vs Rightmost derivation

Example: CFG

Goal ::= a A B e

A ::= A b c | b

B ::= d

Leftmost derivation

Goal
aABe
aAbcBe
abbcBe
abbcde

Rightmost derivation

Goal
aABe
aAde
aAbcde
abbcde

LL parsers

LR parsers

Shit-reduce parser

- It consists of a stack and the input
- It uses four actions:
  1. **shift**: next symbol is shifted onto the stack
  2. **reduce**: pop the symbols $Y_n, \dots, Y_1$ from the stack that form the right member of a production $X ::= Y_n, \dots, Y_1$
  3. **accept**: stop parsing and report success
  4. **error**: error reporting routine

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 we should shift or reduce.

Shit-reduce parser

Example: CFG

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

Operation:

Input

abbcde

Stack

Shit-reduce parser

Example: CFG

Goal ::= a A B e

A ::= A b c | b

B ::= d

Operation: shift

Input

bbcde

Stack

a

Shit-reduce parser

Example: CFG

Goal ::= a A B e

A ::= A b c | b

B ::= d

Operation: shift

Input	Stack
bcde	ab

Shit-reduce parser

Example: CFG

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

Operation:

Input

bcde

Stack

ab

Choice here: shift or reduce?

Can lookahead one symbol to make decision.
(Knowing what to do is not explain here, need to analyse the grammar, see EaC§3.5)

Shit-reduce parser

Example: CFG

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

Operation: reduce

Input

bcde

Stack

aA

Shit-reduce parser

Example: CFG

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

Operation: shift

Input

cde

Stack

aAb

Shit-reduce parser

Example: CFG

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

Operation:

Input

cde

Stack

aAb

Choice here: shift or reduce?

Can lookahead one symbol to make decision.
(Knowing what to do is not explain here, need to analyse the grammar, see EaC§3.5)

Shit-reduce parser

Example: CFG

Goal ::= a A B e

A ::= A b c | b

B ::= d

Operation: shift

Input

de

Stack

aAbc

Shit-reduce parser

Example: CFG

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

Operation: reduce

Input

de

Stack

aA

Shit-reduce parser

Example: CFG

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

Operation: shift

Input

e

Stack

aAd

Shit-reduce parser

Example: CFG

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

Operation: reduce

Input

e

Stack

aAB

Shit-reduce parser

Example: CFG

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

Operation: shift

Input

Stack

aABe

Shit-reduce parser

Example: CFG

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

Operation: reduce

Input

Stack

Goal

Top-Down vs Bottom-Up Parsing

Top-Down

+ Easy to write by hand
+ Easy to integrate with compiler
- Recursion might lead to performance problems

Bottom-Up

+ Very efficient
- Requires generation tools
- Rigid integration to compiler

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 1

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

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

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)
```

$x + (2 * y)$

Ambiguous Grammar: example 1

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

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

One possible derivation

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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 2

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

input

if E1 then if E2 then S1 else S2

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
```

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

- Intuition: a NoElse always has no else on its last cascaded else if statement
- With this grammar, the example has only one derivation

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

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

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

This binds the else controlling S2 to the inner if.

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 of 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;`

Next lecture

- Parse tree and abstract syntax tree