Readings

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- ✓ Why did Wilkes' final code example use self-modifying code?
- ✓ Any final observations (not necessarily in 42 words)?

(Top-Down) Parsing

CS 132: Compiler Design

January 26, 2011

Context Free Grammars

Grammars are used to describe concrete syntax. And several different concrete syntaxes are used for grammars!

$$
\begin{array}{rl}
S \rightarrow & \textbf{if}\ E\ \textbf{then}\ S\ \textbf{else}\ S \\
\mid & \textbf{begin}\ S\ L \\
\mid & \textbf{print}\ E
\end{array}
$$

```
<digit> ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
<expr>  ::= <digit>
          | <expr> - <expr>
          | ( <expr> - <expr> )
```

pointer:

    * *type-qualifier-list*$_{opt}$

    * *type-qualifier-list*$_{opt}$ *pointer*

Production Sequences vs. Parse Trees

```
E ::= E + E | 0 | 1 | 2 | 3 | ... | 9
```

Production Sequences vs. Parse Trees

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E ::= E + E | 0 | 1 | 2 | 3 | ... | 9
```

E $\Rightarrow$ E + E $\Rightarrow$ 3 + E $\Rightarrow$ 3 + E + E $\Rightarrow$ 3 + 2 + E $\Rightarrow$ 3 + 2 + 1

Production Sequences vs. Parse Trees

```
E ::= E + E | 0 | 1 | 2 | 3 | ... | 9
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$E \Rightarrow E + E \Rightarrow 3 + E \Rightarrow 3 + E + E \Rightarrow 3 + 2 + E \Rightarrow 3 + 2 + 1$

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Production Sequences vs. Parse Trees

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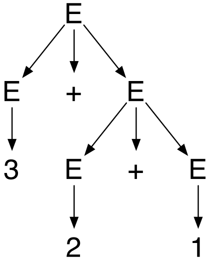

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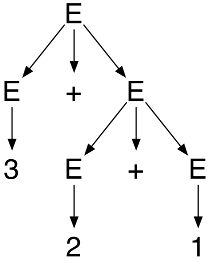

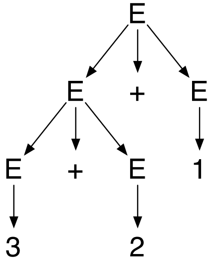

Ambiguity

What is an *ambiguous* grammar? Which of the following grammars are ambiguous? Why do we care?

```
<exp> ::= <digit>
        | <exp> - <exp>

<exp> ::= <digit>
        | ( <exp> - <exp> )

<exp> ::= <digit>
        | <exp> - <digit>

<exp> ::= <digit>
        | <digit> - <exp>

<exp> ::= <digit>
        | <exp> <exp> -
```

Encoding Precedence

```
<exp> ::= <term>
        | <exp> + <term>
        | <exp> - <term>

<term> ::= <factor>
         | <factor> * <term>
         | <factor> / <term>

<factor> ::= <digit>
           | ( <expr> )
```

Practical Issues

- ✓ What might we return from the parser?
  - Parse Tree
  - Abstract Syntax Tree (AST)
  - Value (of a parsed expression)
  - Code (for a parsed program)
  - ...
- ✓ Typical Performance Constraints:
  - $O(n)$ time for n tokens. (Compare with $O(n^3)$.)
  - Single (left-to-right) pass through the tokens.

Most Popular Approaches

Without loss of generality, assume we are building the parse tree.

We can build this tree:

- ✓ Top-Down: Start at the root, and work down (depth-first)
- ✓ Bottom-Up: Start with the leaves, and repeatedly join small trees together to make bigger trees.

Naïve Top-Down: Backtracking search

Try all possible ways of parsing.

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Try all possible ways of parsing.

This could often be made to work. But

1. it's often inefficient
2. it's trickier to implement than one might think

Bogus Backtracking

```
S -> Aa | Ba
A -> a | c | ac
B -> Bb | b
```

```
Consume_S():
    try Consume_A(), then consume a
    if fails, try Consume_B(), then consume a
```

Bogus Backtracking

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Consume_A():
    try consume a
    if fails, try consume c
    if fails, try consume a then consume c
```

[What's wrong?]

Bogus Backtracking

```
S -> Aa | Ba
A -> a | c | ac
B -> Bb | b
```

```
Consume_S():
    try Consume_A(), then consume a
    if fails, try Consume_B(), then consume a

Consume_A():
    try consume a
    if fails, try consume c
    if fails, try consume a then consume c
```

[What's wrong?]

```
Consume_B():
    try Consume_B(), then consume b
    if fails, try consume b
```

[What's wrong?]

$LL(k)$ Grammars

```
S -> Aa | Ba
```

If each `Consume` function always "knew" which right-hand-side was correct, **we would never need to backtrack, or get tangled in infinite loops**.

$LL(k)$ Grammars

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Then

- ✓ It would be easy to write correct `Consume` functions
- ✓ Our parser would run in linear time.

$LL(k)$ Grammars

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Then

- ✓ It would be easy to write correct `Consume` functions
- ✓ Our parser would run in linear time.

We say that a grammar is $LL(k)$ if, by "peeking ahead" no more than k tokens, we can guarantee a decision that is

1. correct
2. unique

When will Top-Down Parsing Work?

Are these grammars $LL(k)$ for some k?

```
S ::= E $
E ::= n
    | plus E E
    | times E E
```

```
S ::= A
    | B
A ::= a
    | x A
B ::= b
    | y B
```

```
S ::= A
    | B
A ::= a
    | x A
B ::= b
    | x B
```

```
S ::= E $
E ::= n
    | n + E
```

```
S ::= E $
E ::= n
    | E + n
```

```
S ::= E $
E ::= E + E
    | E * E
    | n
```

Recursive Descent: Grammar as a Recursive Program

Grammar

```
S  ->  B  $
B  ->  d  |  c  B  B
```

with input `c  c  d  d  d  $`.

Making Predictions (1)

Define

$$\texttt{FIRST}(\alpha) := \{\, t \in \Sigma \mid \alpha \to^* t\beta \,\}$$

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$$\texttt{FIRST}(\alpha) := \{\, t \in \Sigma \mid \alpha \to^* t\beta \,\}$$

Consider a grammar

$$\begin{array}{lll} \texttt{A} & \texttt{::=} & \alpha_1 \\ & \texttt{|} & \alpha_2 \end{array}$$

When should our `consumeA` function predict α_1? α_2?

Making Predictions (2)

Suppose we've already predicted the next input will be an `E'`.

```
S  ::= E $
E  ::= T E'
E' ::= ϵ
     | + T E
T  ::= n
```

Which prediction should `consumeE'` do if the next token is

```
+
$
n
```

Recursive Descent Schema for $LL(1)$ Grammars

Given `A -> a1 | a2 | ... | an`*, the corresponding code is*

```
consumeA() =
   if (first_token is in FIRST(a1)) or
      (NULLABLE(a1) and (first_token is in FOLLOW(A)) then
          ...match a1 against input stream...
   else if (first_token is in FIRST(a2)) or
      (NULLABLE(a2) and (first_token is in FOLLOW(A)) then
          ...match a2 against input stream...
   ...
   else if (first token is in FIRST(a_n)) or
      (NULLABLE(an) and (first_token is in FOLLOW(A)) then
          ...match an against input stream...
   else error()
```

where

$$
\begin{array}{lcl}
\texttt{NULLABLE}(\alpha) & := & \alpha \rightarrow^* \epsilon \\
\texttt{FIRST}(\alpha) & := & \{\, t \in \Sigma \,|\, \alpha \rightarrow^* t\beta \,\} \\
\texttt{FOLLOW}(X) & := & \{\, t \in \Sigma \,|\, \texttt{S} \rightarrow^* \beta_1 X t \beta_2 \,\}
\end{array}
$$

$LL(k)$

A grammar is said to be $LL(1)$ if that generic recursive descent parser will work for all inputs.

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A language is said to be $LL(k)$ if it has an $LL(k)$ grammar

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A grammar is said to be $LL(1)$ if that generic recursive descent parser will work for all inputs.

A grammar is said to be $LL(k)$ if it works given the chance to peek at the next k tokens of the input.

A language is said to be $LL(k)$ if it has an $LL(k)$ grammar
(which generates the right strings, but not necessarily the right parse trees)

Massaging Grammars

```
S -> E $
E -> n
   | E - n
```

$\Downarrow$

Massaging Grammars

```
S -> E $
E -> n
   | E - n
```

$\Downarrow$

Eliminate "left recursion"

$\Downarrow$

Massaging Grammars

```
S -> E $
E -> n
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⇓

Eliminate "left recursion"

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```
S -> E $
E -> n
   | n - E
```

Massaging Grammars

```
S -> E $
E -> n
   | n - E
```

$\Downarrow$

Massaging Grammars

```
S -> E $
E -> n
   | n - E
```

$\Downarrow$

Left-factor

$\Downarrow$

```
S  -> E $
E  -> n E'
E' ->
    | n - E
```

Working out the Gory Details

Compute **NULLABLE**, **FIRST**, and **FOLLOW** for each nonterminal in the following grammar:

```
S -> Z $
Z -> d | X Y W Z
Y -> ϵ | c
X -> W W | a
W -> Y | w
```