Compiler Design

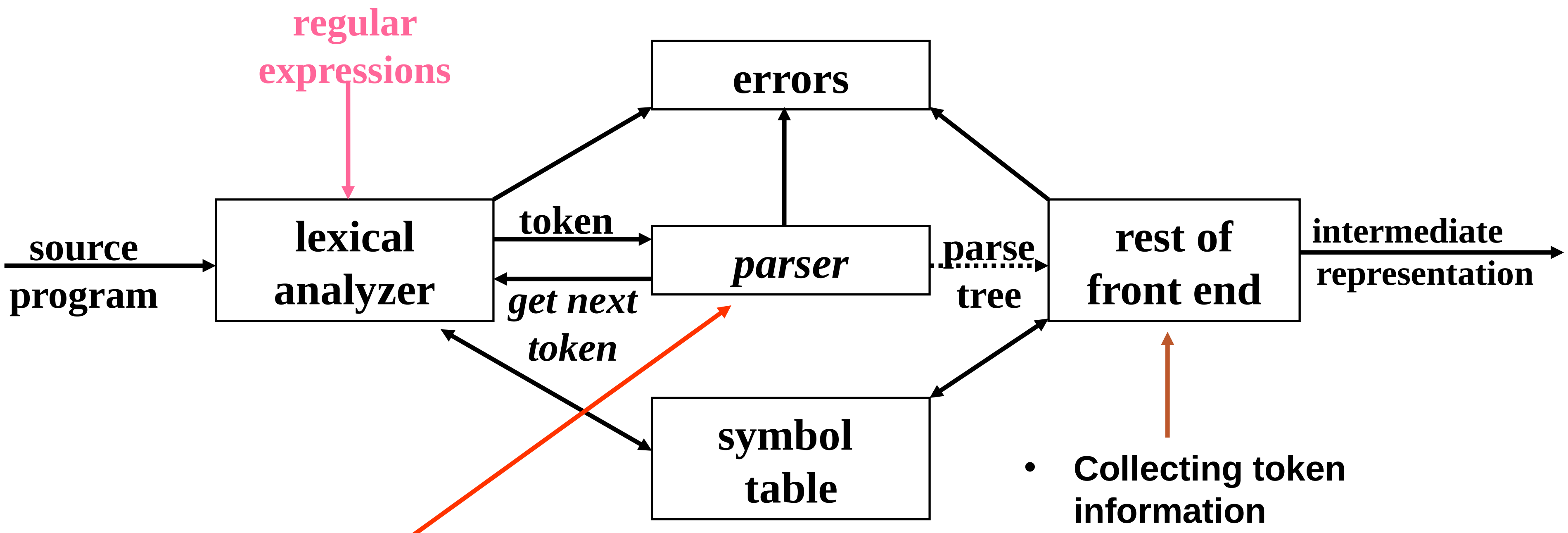
Language and Grammars

- Every (programming) language has precise rules
  - In English:
    - Subject Verb Object
  - In C
    - programs are made of functions
      - » Functions are made of statements etc.

Parsing

- A.K.A. Syntax Analysis
  - Recognize sentences in a language.
  - Discover the structure of a document/program.
  - Construct (implicitly or explicitly) a tree (called as a parse tree) to represent the structure.
  - The above tree is used later to guide translation.

Parsing During Compilation



- Collecting token information
- Perform type checking
- Intermediate code generation

- uses a grammar to check structure of tokens
- produces a parse tree
- syntactic errors and recovery
- recognize correct syntax
- report errors

Errors in Programs

- **Lexical**

  if x<1 thenn y = 5;
  "Typos"
- **Syntactic**

  if ((x<1) & (y>5))) ...
  { ... { ... _ ... }
- **Semantic**

  if (x+5) then ...
  Type Errors
  Undefined IDs, etc.
- **Logical Errors**

  if (i<9) then ...
  Should be <= not <
  Bugs
  Compiler cannot detect Logical Errors

Error Detection

- Much responsibility on Parser
  - Many errors are syntactic in nature
  - Precision/ efficiency of modern parsing method
  - Detect the error as soon as possible
- Challenges for error handler in Parser
  - Report error clearly and accurately
  - Recover from error and continue..
  - Should be efficient in processing
- Good news is
  - Simple mechanism can catch most common errors
- Errors don't occur that frequently!!
  - 60% programs are syntactically and semantically correct
  - 80% erroneous statements have only 1 error, 13% have 2
  - Most error are trivial : 90% single token error
  - 60% punctuation, 20% operator, 15% keyword, 5% other error

Adequate Error Reporting is Not a Trivial Task

- Difficult to generate clear and accurate error messages.

Example

```
function foo () {
...
if (...) {
...
} else {
  ...
```

Missing } here

```
...
}
<eof>
```

Not detected until here

Example

```
int myVarr;
...
x = myVar;
...
```

Misspelled ID here

Not detected until here

ERROR RECOVERY

- After first error recovered
  - Compiler must go on!
    - Restore to some state and process the rest of the input

- **Error-Correcting Compilers**
  - Issue an error message
  - Fix the problem
  - Produce an executable

Example

```
Error on line 23: "myVarr" undefined.
"myVar" was used.
```

May not be a good Idea!!

- Guessing the programmers intention is not easy!

ERROR RECOVERY MAY TRIGGER MORE ERRORS!

- Inadequate recovery may introduce more errors
  - Those were not programmers errors

- Example:

```
int myVar flag ;
...
x := flag;
...
...
while  (flag==0)
...
```

Declaration of flag is discarded

Variable flag is undefined

Variable falg is undefined

Too many Error message may be obscuring

- May bury the real message
- Remedy:
  - allow 1 message per token or per statement
  - Quit after a maximum (e.g. 100) number of errors

ERROR RECOVERY APPROACHES: PANIC MODE

- Discard tokens until we see a "synchronizing" token.

> **Example**
>
> Skip to next occurrence of
> `}` **`end`** `;`
> Resume by parsing the next statement

- The key…
  - Good set of synchronizing tokens
  - Knowing what to do then
- Advantage
  - Simple to implement
  - Does not go into infinite loop
  - Commonly used
- Disadvantage
  - May skip over large sections of source with some errors

ERROR RECOVERY APPROACHES: PHRASE-LEVEL RECOVERY

- Compiler corrects the program
  - by deleting or inserting tokens
    - ...so it can proceed to parse from where it was.

Example

while (x==4) y:= a + b

Insert do to fix the statement

- The key...
  - Don't get into an infinite loop
    - ...constantly inserting tokens and never scanning the actual source
- Generally used for error-repairing compilers
  - Difficulty: Point of error detection might be much later the point of error occurrence

ERROR RECOVERY APPROACHES: ERROR PRODUCTIONS

- Augment the CFG with “Error Productions”
- Now the CFG accepts anything!
- If “error productions” are used...

  Their actions:

  { print (“Error...”) }

- Used with...
  - LR (Bottom-up) parsing
  - Parser Generators

ERROR RECOVERY APPROACHES: GLOBAL CORRECTION

- Theoretical Approach
- Find the minimum change to the source to yield a valid program
  - Insert tokens, delete tokens, swap adjacent tokens
- Global Correction Algorithm

  Input: grammatically incorrect input string x; grammar G

  Output: grammatically correct string y

  Algorithm: converts x → y using minimum number changes (insertion, deletion etc.)
- Impractical algorithms - too time consuming

Parsers

- We categorize the parsers into two groups:

1. **Top-Down Parser**
   - the parse tree is created top to bottom, starting from the root.
2. **Bottom-Up Parser**
   - the parse is created bottom to top; starting from the leaves

- Both top-down and bottom-up parsers scan the input from left to right (one symbol at a time).
- Efficient top-down and bottom-up parsers can be implemented only for sub-classes of context-free grammars.
  - LL for top-down parsing
  - LR for bottom-up parsing

CONTEXT FREE GRAMMARS (CFG)

A context-free grammar has four components: G = (V, Σ, P, S)

- ✓A set of **non-terminals** (V). Non-terminals are syntactic variables that denote sets of strings. The non-terminals define sets of strings that help define the language generated by the grammar.
- ✓A set of tokens, known as **terminal symbols** (Σ). Terminals are the basic symbols from which strings are formed.
- ✓A set of **productions** (P). The productions of a grammar specify the manner in which the terminals and non-terminals can be combined to form strings. Each production consists of a **non-terminal** called the left side of the production, an arrow, and a sequence of tokens and/or **on- terminals**, called the right side of the production.
- ✓One of the non-terminals is designated as the **start symbol** (S); from where the production begins.

Example of CFG:

G = (V, Σ, P, S)Where:

V = { Q, Z, N }

Σ = { 0, 1 }

P = { Q → Z | Q → N | Q → Ɛ | Z → 0Q0 |

N → 1Q1 }

S = { Q }

- This grammar describes palindrome language, such as: 1001, 11100111, 00100, 1010101, 11111, etc.

RULE ALTERNATIVE NOTATIONS

E → E + E
E → (E)
E → - E
E → ID

E → E + E
→ (E)
→ - E
→ ID

E → E + E
| (E)
| - E
| ID

E → E + E | (E) | - E | ID

All Notations are Equivalent

NOTATIONAL CONVENTIONS

Terminals

a b c ...

Nonterminals

A B C ...
S
Expr

Grammar Symbols (Terminals or Nonterminals)

X Y Z U V W ...

Strings of Symbols

A sequence of zero
Or more terminals
And nonterminals

α β γ ...

Strings of Terminals

x y z u v w ...

Including ε

Examples

$A \rightarrow \alpha B$

A rule whose righthand side ends with a nonterminal

$A \rightarrow x \alpha$

A rule whose righthand side begins with a string of terminals (call it "x")

DERIVATIONS

- A derivation is basically a sequence of production rules, in order to get the input string. During parsing, we take two decisions for some sentential form of input:
- Deciding the non-terminal which is to be replaced.
- Deciding the production rule, by which, the non-terminal will be replaced.

To decide which non-terminal to be replaced with production rule, we can have two options.

DERIVATIONS

1. E → E + E
2. → E * E
3. → (E)
4. → - E
5. → ID

A "Derivation" of "(id*id)"

E ⇒ (E) ⇒ (E*E) ⇒ (id*E) ⇒ (id*id)

"Sentential Forms"

A sequence of terminals and nonterminals in a derivation

(id*E)

DERIVATIONS

If $A \rightarrow \beta$ is a rule, then we can write

$$\underbrace{\alpha A \gamma}_{} \Rightarrow \alpha\beta\gamma$$

Any sentential form containing a nonterminal (call it A)

… such that A matches the nonterminal in some rule.

Derives in zero-or-more steps $\Rightarrow^*$

$$E \Rightarrow^* \texttt{(\underline{id}*\underline{id})}$$

If $\alpha \Rightarrow^* \beta$ and $\beta \Rightarrow \gamma$, then $\alpha \Rightarrow^* \gamma$

Derives in one-or-more steps $\Rightarrow+$

CFG Terminology

Given

G A grammar

S The Start Symbol

Define

L(G) The language generated

$L(G) = \{ w \mid S \Rightarrow^{+} w \}$

"Equivalence" of CFG's

If two CFG's generate the same language, we say they are "equivalent."

$G_1 \approx G_2$ whenever $L(G_1) = L(G_2)$

In making a derivation...

Choose which nonterminal to expand

Choose which rule to apply

LEFTMOST DERIVATION

In a derivation... always expand the *leftmost* nonterminal.

$$
\begin{aligned}
& \mathrm{E} \\
\Rightarrow\ & \mathrm{E+E} \\
\Rightarrow\ & \mathtt{(E)+E} \\
\Rightarrow\ & \mathtt{(E*E)+E} \\
\Rightarrow\ & \mathtt{(\underline{id}*E)+E} \\
\Rightarrow\ & \mathtt{(\underline{id}*\underline{id})+E} \\
\Rightarrow\ & \mathtt{(\underline{id}*\underline{id})+\underline{id}}
\end{aligned}
$$

1.	E	$\rightarrow$	E + E
2.		$\rightarrow$	E * E
3.		$\rightarrow$	(E)
4.		$\rightarrow$	- E
5.		$\rightarrow$	ID

Let $\Rightarrow_{LM}$ denote a step in a leftmost derivation ($\Rightarrow_{LM}{}^{*}$ means zero-or-more steps)

At each step in a leftmost derivation, we have

$$w A \gamma \Rightarrow_{LM} w \beta \gamma \qquad \text{where } A \rightarrow \beta \text{ is a rule}$$

(Recall that w is a string of terminals.)

Each sentential form in a leftmost derivation is called a "left-sentential form."

If $S \Rightarrow_{LM}{}^{*} \alpha$ then we say α is a "left-sentential form."

RIGHTMOST DERIVATION

In a derivation… always expand the *rightmost* nonterminal.

$$
\begin{aligned}
& E \\
\Rightarrow\ & E+E \\
\Rightarrow\ & E+\underline{id} \\
\Rightarrow\ & (E)+\underline{id} \\
\Rightarrow\ & (E*E)+\underline{id} \\
\Rightarrow\ & (E*\underline{id})+\underline{id} \\
\Rightarrow\ & (\underline{id}*\underline{id})+\underline{id}
\end{aligned}
$$

1.	E	$\rightarrow$	E + E
2.		$\rightarrow$	E * E
3.		$\rightarrow$	(E)
4.		$\rightarrow$	- E
5.		$\rightarrow$	ID

Let $\Rightarrow_{RM}$ denote a step in a rightmost derivation ($\Rightarrow_{RM}{}^{*}$ means zero-or-more steps)

At each step in a rightmost derivation, we have

$$\alpha A w \Rightarrow_{RM} \alpha\beta w \qquad \text{where } A \rightarrow \beta \text{ is a rule}$$

(Recall that w is a string of terminals.)

Each sentential form in a rightmost derivation is called a "right-sentential form."

If $S \Rightarrow_{RM}{}^{*} \alpha$ then we say α is a "right-sentential form."

PARSE TREE

- A parse tree is a graphical representation of a derivation sequence of a sentential form.
- Tree nodes represent symbols of the grammar (nonterminals or terminals) and tree edges represent derivation steps.
- Inner nodes of a parse tree are non-terminal symbols.
- The leaves of a parse tree are terminal symbols.

PARSE TREE

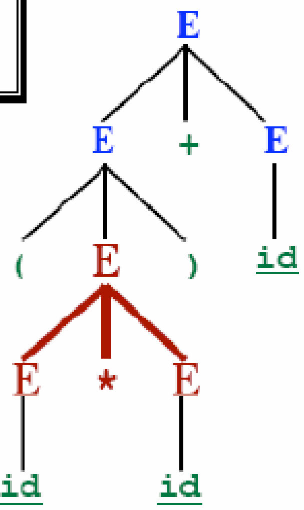
Two choices at each step in a derivation...

- Which non-terminal to expand
- Which rule to use in replacing it

The parse tree remembers only this

Leftmost Derivation:

$$
\begin{aligned}
& E \\
\Rightarrow\ & E+E \\
\Rightarrow\ & (E)+E \\
\Rightarrow\ & (E*E)+E \\
\Rightarrow\ & (\underline{id}*E)+E \\
\Rightarrow\ & (\underline{id}*\underline{id})+E \\
\Rightarrow\ & (\underline{id}*\underline{id})+\underline{id}
\end{aligned}
$$



1. E → E + E
2. → E * E
3. → (E)
4. → - E
5. → ID

PARSE TREE

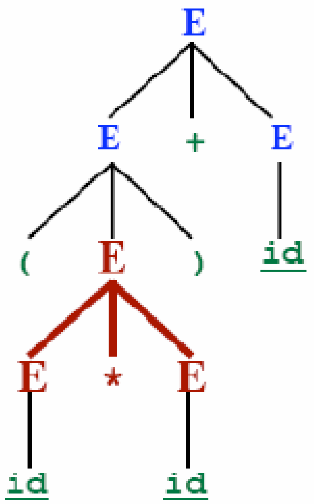
Two choices at each step in a derivation...

- Which non-terminal to expand
- Which rule to use in replacing it

The parse tree remembers only this

Rightmost Derivation:

$$
\begin{aligned}
& E \\
\Rightarrow\ & E+E \\
\Rightarrow\ & E+\underline{id} \\
\Rightarrow\ & (E)+\underline{id} \\
\Rightarrow\ & (E*E)+\underline{id} \\
\Rightarrow\ & (E*\underline{id})+\underline{id} \\
\Rightarrow\ & (\underline{id}*\underline{id})+\underline{id}
\end{aligned}
$$



1. E → E + E
2. → E * E
3. → (E)
4. → - E
5. → ID

PARSE TREE

Two choices at each step in a derivation...

- Which non-terminal to expand
- Which rule to use in replacing it

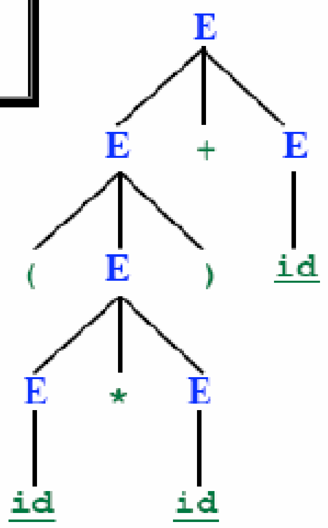
The parse tree remembers only this

Leftmost Derivation:

```
   E
⇒  E+E
⇒  (E)+E
⇒  (E*E)+E
⇒  (id*E)+E
⇒  (id*id)+E
⇒  (id*id)+id
```

Rightmost Derivation:

```
   E
⇒  E+E
⇒  E+id
⇒  (E)+id
⇒  (E*E)+id
⇒  (E*id)+id
⇒  (id*id)+id
```



1. E → E + E
2. → E * E
3. → (E)
4. → - E
5. → ID

PARSE TREE

Given a leftmost derivation, we can build a parse tree.

Given a rightmost derivation, we can build a parse tree.

Lefttmost Derivation of `(id*id)+id`

Rightmost Derivation of `(id*id)+id`

Same Parse Tree

Every parse tree corresponds to...

- A single, unique leftmost derivation
- A single, unique rightmost derivation

AMBIGUOUS GRAMMAR

Ambiguity:

However, one input string may have several parse trees!!!

Therefore:

- Several leftmost derivations
- Several rightmost derivations

A grammar that produces more than one parse tree for any input sentence is said to be an ambiguous grammar.

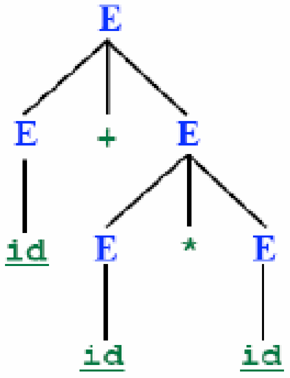
AMBIGUOUS GRAMMAR

1. E → E + E
2. → E * E
3. → (E)
4. → - E
5. → ID

Input: id+id*id

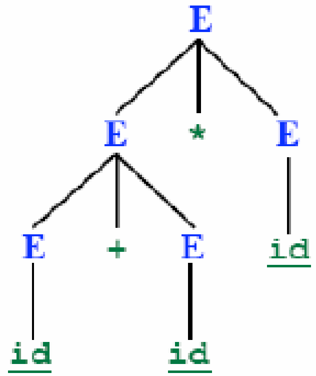
Leftmost Derivation #1

E
$\Rightarrow$ E+E
$\Rightarrow$ id+E
$\Rightarrow$ id+E*E
$\Rightarrow$ id+id*E
$\Rightarrow$ id+id*id



Leftmost Derivation #2

E
$\Rightarrow$ E*E
$\Rightarrow$ E+E*E
$\Rightarrow$ id+E*E
$\Rightarrow$ id+id*E
$\Rightarrow$ id+id*id



AMBIGUOUS GRAMMAR

E::= E + E	E::= (E)
E::= E - E	E::= num
E::= E * E	E::= id
E::= E / E	

- ***Is this an ambiguous grammar?***
- **Example:**
  - Find a derivation for the expression: **4 / 2 + 2**

AMBIGUOUS GRAMMAR

- Why are ambiguous grammars problematic?

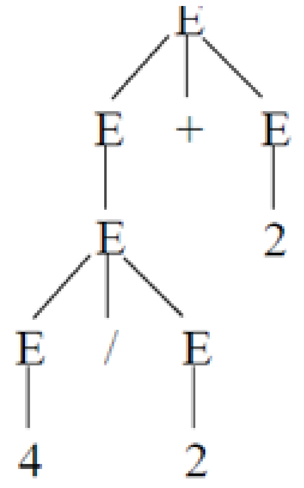
  (4 / 2) + 2 = 4   or   4 / (2 + 2) = 1

- It is often possible to transform an ambiguous grammar into an equivalent unambiguous grammar.
- In our grammar,
  - * has higher precedence than +
  - each operator associates to the left

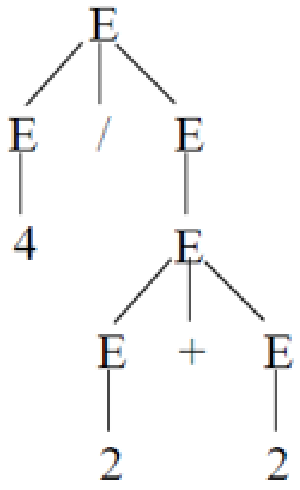
AMBIGUOUS GRAMMAR

E::= E + E
E::= E - E
E::= E * E
E::= E / E

E::= (E)
E::= num
E::= id



4 / 2 + 2



AMBIGUOUS GRAMMAR

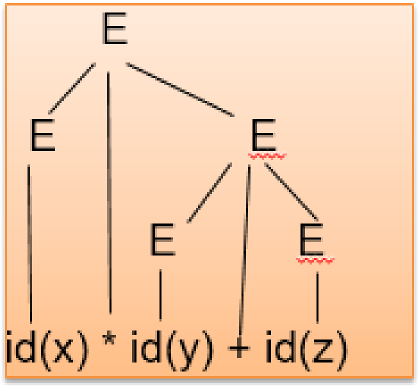
- For the most parsers, the grammar must be unambiguous.
- unambiguous grammar

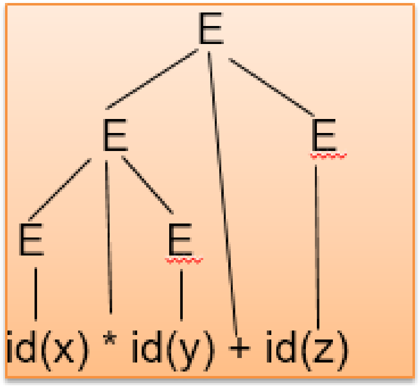
  → unique selection of the parse tree for a sentence
- *We should eliminate the ambiguity in the grammar during the design phase of the compiler.*
- An **unambiguous** grammar should be written to eliminate the ambiguity.
- We have to prefer one of the parse trees of a sentence (generated by an ambiguous grammar) to disambiguate that grammar to restrict to this choice.

AMBIGUOUS GRAMMAR

- What about this grammar?

```
E ::= E + E
    | E - E
    | E * E
    | E / E
    | num
    | id
```





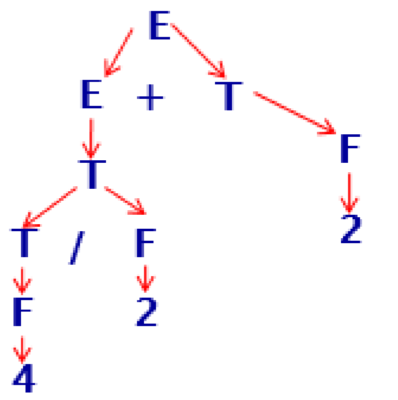
- Operators **+ - * /** have the same precedence!
- It is *ambiguous*: has more than one parse tree for the same input sequence (depending which derivations are applied each time)

UNAMBIGUOUS GRAMMAR

E::= E + E
E::= E - E
E::= E * E
E::= E / E
E::= (E)
E::= num
E::= id

Ambiguous to unambiguous grammar

E ::= E + T
E ::= E - T
E ::= T
T::= T * F
T::= T / F
T::= F
F ::= id
F ::= num
F ::= (E)



PREDICTIVE PARSING

- The goal is to construct a top-down parser that never backtracks
- Always leftmost derivations
- We must transform a grammar in two ways:
  - eliminate left recursion
  - perform left factoring
- These rules eliminate most common causes for backtracking although they do not guarantee a completely backtrack-free parsing

LEFT RECURSION: INFINITE LOOPING PROBLEM

A grammar is left-recursive if it has a non-terminal A, such that there is a derivation :

$A \;^{+} A$, for some .

Top-Down parsing can't reconcile this type of grammar, since it could consistently make choice which wouldn't allow termination.

A A A A … etc. A A |

So we have to convert our left-recursive grammar into an equivalent grammar which is not left-recursive.

The left-recursion may appear in a single step of the derivation (*immediate left-recursion*), or may appear in more than one step of the derivation.

IMMEDIATE LEFT RECURSION

- $A \rightarrow A\,\alpha \mid \beta$ where β does not start with A

$\Downarrow$ eliminate immediate left recursion

$A \rightarrow \beta\, A'$ where A' is a new nonterminal

$A' \rightarrow \alpha\, A' \mid \varepsilon$ an equivalent grammar

More General (but still immediate):

$$A \rightarrow A\alpha_1 \mid A\alpha_2 \mid A\alpha_3 \mid \ldots \mid \beta_1 \mid \beta_2 \mid \beta_3 \mid \ldots$$

Transform into:

$$A \rightarrow \beta_1 A' \mid \beta_2 A' \mid \beta_3 A' \mid \ldots$$

$$A' \rightarrow \alpha_1 A' \mid \alpha_2 A' \mid \alpha_3 A' \mid \ldots \mid \varepsilon$$

IMMEDIATE LEFT RECURSION ELIMINATION: EXAMPLE

Our Example :

E   E + T | T

T   T * F | F

F   (E) | id

E   TE’

E’   + TE’ |

T   FT’

T’   * FT’ |

F   (E) | id

LEFT RECURSION IN MORE THAN ONE STEP

- A grammar cannot be immediately left-recursive, but it still can be left-recursive.
- By just eliminating the immediate left-recursion, we may not get a grammar which is not left-recursive.

Example:

$S \rightarrow Af \mid b$

$A \rightarrow Ac \mid Sd \mid e$

Is A left recursive? Yes.

Is S left recursive? Yes, but not immediate left recursion. $S \Rightarrow Af \Rightarrow Sdf$

LEFT RECURSION IN MORE THAN ONE STEP: ELIMINATION

Approach:

Look at the rules for S only (ignoring other rules)... No left recursion.

Look at the rules for A...

Do any of A's rules start with S? Yes.

$A \rightarrow Sd$

Get rid of the S. Substitute in the righthand sides of S.

$A \rightarrow Afd \mid bd$

The modified grammar:

$S \rightarrow Af \mid b$

$A \rightarrow Ac \mid Afd \mid bd \mid e$

Now eliminate immediate left recursion involving A.

$S \rightarrow Af \mid b$

$A \rightarrow bdA' \mid eA'$

$A' \rightarrow cA' \mid fdA' \mid \varepsilon$

LEFT RECURSION IN MORE THAN ONE STEP: ELIMINATION

The Original Grammar:

$S \rightarrow A\underline{f} \mid \underline{b}$

$A \rightarrow A\underline{c} \mid S\underline{d} \mid B\underline{e}$

$B \rightarrow A\underline{g} \mid S\underline{h} \mid \underline{k}$

So Far:

$S \rightarrow A\underline{f} \mid \underline{b}$

$A \rightarrow \underline{bd}A' \mid B\underline{e}A'$

$A' \rightarrow \underline{c}A' \mid \underline{fd}A' \mid \varepsilon$

LEFT RECURSION IN MORE THAN ONE STEP: ELIMINATION

The Original Grammar:

$S \rightarrow A\underline{f} \mid \underline{b}$

$A \rightarrow A\underline{c} \mid S\underline{d} \mid B\underline{e}$

$B \rightarrow A\underline{g} \mid S\underline{h} \mid \underline{k}$

So Far:

$S \rightarrow A\underline{f} \mid \underline{b}$

$A \rightarrow \underline{bd}A' \mid B\underline{e}A'$

$A' \rightarrow \underline{c}A' \mid \underline{fd}A' \mid \varepsilon$

$B \rightarrow A\underline{g} \mid S\underline{h} \mid \underline{k}$

Look at the B rules next; Does any righthand side start with "S"?

LEFT RECURSION IN MORE THAN ONE STEP: ELIMINATION

The Original Grammar:

$S \rightarrow Af \mid b$

$A \rightarrow Ac \mid Sd \mid Be$

$B \rightarrow Ag \mid Sh \mid k$

So Far:

$S \rightarrow Af \mid b$

$A \rightarrow bdA' \mid BeA'$

$A' \rightarrow cA' \mid fdA' \mid \varepsilon$

$B \rightarrow Ag \mid \underbrace{Afh \mid bh}_{} \mid k$

Substitute, using the rules for "S"

Af… | b…

LEFT RECURSION IN MORE THAN ONE STEP: ELIMINATION

The Original Grammar:

$S \rightarrow Af \mid b$
$A \rightarrow Ac \mid Sd \mid Be$
$B \rightarrow Ag \mid Sh \mid k$

So Far:

$S \rightarrow Af \mid b$
$A \rightarrow bdA' \mid BeA'$
$A' \rightarrow cA' \mid fdA' \mid \varepsilon$
$B \rightarrow Ag \mid Afh \mid bh \mid k$

Does any righthand side start with "A"?

LEFT RECURSION IN MORE THAN ONE STEP: ELIMINATION

The Original Grammar:

S → Af | b
A → Ac | Sd | Be
B → Ag | Sh | k

So Far:

S → Af | b
A → bdA' | BeA'
A' → cA' | fdA' | ε
B → bdA'g | BeA'g | Afh | bh | k

Substitute, using the rules for "A"
bdA'... | BeA'...

LEFT RECURSION IN MORE THAN ONE STEP: ELIMINATION

The Original Grammar:

S → Af | b
A → Ac | Sd | Be
B → Ag | Sh | k

So Far:

S → Af | b
A → bdA' | BeA'
A' → cA' | fdA' | ε
B → bdA'g | BeA'g | bdA'fh | BeA'fh | bh | k

Substitute, using the rules for "A"
bdA'... | BeA'...

LEFT RECURSION IN MORE THAN ONE STEP: ELIMINATION

The Original Grammar:

S → Af | b
A → Ac | Sd | Be
B → Ag | Sh | k

So Far:

S → Af | b
A → bdA' | BeA'
A' → cA' | fdA' | ε
B → bdA'g | BeA'g | bdA'fh | BeA'fh | bh | k

Finally, eliminate any immediate Left recursion involving "B"

Next Form

S → Af | b
A → bdA' | BeA'
A' → cA' | fdA' | ε
B → bdA'gB' | bdA'fhB' | bhB' | kB'
B' → eA'gB' | eA'fhB' | ε

LEFT RECURSION IN MORE THAN ONE STEP: ELIMINATION

The Original Grammar:

$S \rightarrow Af \mid b$

$A \rightarrow Ac \mid Sd \mid Be \mid C$

$B \rightarrow Ag \mid Sh \mid k$

$C \rightarrow BkmA \mid AS \mid j$

If there is another nonterminal, then do it next.

So Far:

$S \rightarrow Af \mid b$

$A \rightarrow bdA' \mid BeA' \mid CA'$

$A' \rightarrow cA' \mid fdA' \mid \varepsilon$

$B \rightarrow bdA'gB' \mid bdA'fhB' \mid bhB' \mid kB' \mid CA'gB' \mid CA'fhB'$

$B' \rightarrow eA'gB' \mid eA'fhB' \mid \varepsilon$

ALGORITHM FOR ELIMINATING LEFT RECURSION

Assume the nonterminals are ordered $A_1, A_2, A_3, \ldots$

(In the example: S, A, B)

for each nonterminal A_i (for i = 1 to N) **do**

  for each nonterminal A_j (for j = 1 to i-1) **do**

    Let $A_j \to \beta_1 \mid \beta_2 \mid \beta_3 \mid \ldots \mid \beta_N$ be all the rules for A_j

    if there is a rule of the form

      $A_i \to A_j\alpha$

    then replace it by

      $A_i \to \beta_1\alpha \mid \beta_2\alpha \mid \beta_3\alpha \mid \ldots \mid \beta_N\alpha$

    endIf

  endFor

  Eliminate immediate left recursion among the A_i rules

endFor

A_1

A_2

A_3 Inner Loop

$\ldots$

A_j

$\ldots$

A_7

$A_i \leftarrow$ Outer Loop

Left Factoring: Common Prefix Problem

Problem : Uncertain which of 2 rules to choose:

$$stmt \rightarrow \text{if } expr \text{ then } stmt \text{ else } stmt$$
$$\mid \text{if } expr \text{ then } stmt$$

When do you know which one is valid ?

What's the general form of *stmt* ?

$A \rightarrow \alpha\beta_1 \mid \alpha\beta_2$ α : if *expr* then *stmt*

β_1: else *stmt* β_2 : $\in$

Transform to:

$A \rightarrow \alpha A'$

$A' \rightarrow \beta_1 \mid \beta_2$

EXAMPLE:

$stmt \rightarrow \text{if } expr \text{ then } stmt \; rest$

$rest \rightarrow \text{else } stmt \mid \in$

Left Factoring : Example

$A \rightarrow abB \mid aB \mid cdg \mid cdeB \mid cdfB$

$\Downarrow$

$A \rightarrow aA' \mid cdg \mid cdeB \mid cdfB$

$A' \rightarrow bB \mid B$

$\Downarrow$

$A \rightarrow aA' \mid cdA''$

$A' \rightarrow bB \mid B$

$A'' \rightarrow g \mid eB \mid fB$

Left Factoring : Example

$A \rightarrow ad \mid a \mid ab \mid abc \mid b$

$\Downarrow$

$A \rightarrow aA' \mid b$

$A' \rightarrow d \mid \varepsilon \mid b \mid bc$

$\Downarrow$

$A \rightarrow aA' \mid b$

$A' \rightarrow d \mid \varepsilon \mid bA''$

$A'' \rightarrow \varepsilon \mid c$

THE END