TD1: Recursive Descent

Top-down Parsing

CMPT 379: Compilers

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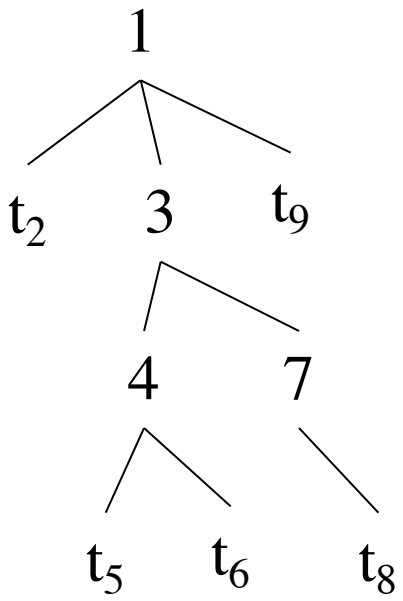
anoopsarkar.github.io/compilers-class

Top-Down Parsing

- The parse tree is constructed
  - From the top
  - From the left to right



- Terminals are seen in the order of appearance in the token stream

  $t_2\ t_5\ t_6\ t_8\ t_9$

Recursive Descent Parsing

- Consider the grammar
  - $E \rightarrow T + E \mid T$
  - $T \rightarrow int \mid int * T \mid (E)$

- Token stream is $int_5 * int_2$
- Start from top-level non-terminal E
  - Try the rules for E in order

Recursive Descent Parsing

$E \rightarrow T + E$

$E \rightarrow T$

$T \rightarrow \text{int}$

$T \rightarrow \text{int} * T$

$T \rightarrow (E)$

Input:

$\text{int}_5 * \text{int}_2$

Try $E_0 \rightarrow T_1 + E_2$

Try $T_1 \rightarrow \text{int}$

Token int matches!

but + does not match to input — Failure

Try $T_1 \rightarrow \text{int} * T_2$

Tokens int and * match

Try $T_3 \rightarrow \text{int}$

Token int matches

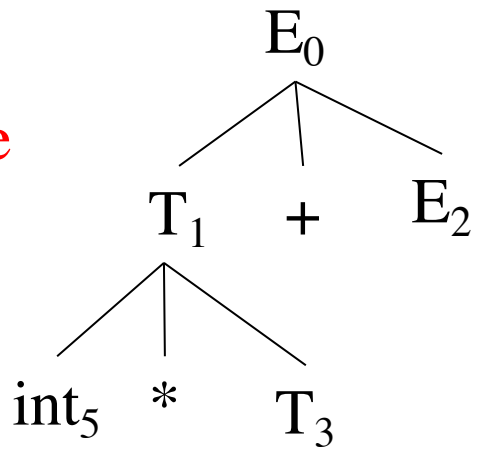
input is matched but tree should match $+ E_2$ — Failure

Try $T_1 \rightarrow (E_3)$

Token (does not match — Failure

has exhausted the choices for T_1

backtrack to choices for E_0



Recursive Descent Parsing

$E \rightarrow T + E$

$E \rightarrow T$

$T \rightarrow int$

$T \rightarrow int * T$

$T \rightarrow (E)$

Input:

$int_5 * int_2$

Try: $E_0 \rightarrow T_1$

Try $T_1 \rightarrow int$

Token int matches!

but no non-terminals left and

the input is not matched completely

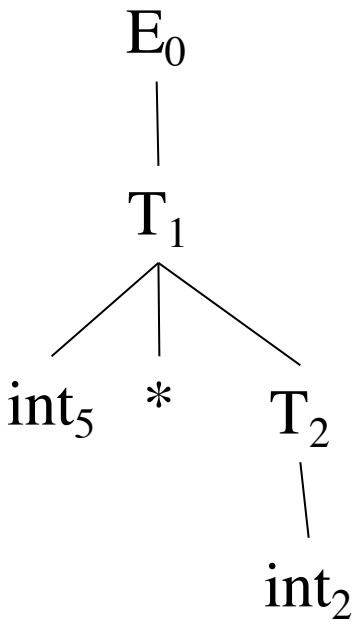
Failure

Try $T_1 \rightarrow int * T_2$

Tokens int , * match

Try $T_2 \rightarrow int$

Token int matches!



Succeed! No non-terminal left in the tree, input is totally matched

Preliminaries

- TOKEN: the type of all tokens
  - Special tokens INT, OPEN, CLOSE, PLUS, TIMES
- The global next points to the next token in the input

Implementing Productions

- Define boolean functions that check the token string for match of
  - A given token terminal

    bool term(TOKEN tok) { return *next++ == tok; }
  - A given production of S (the n-th)

    bool S_n() {…}
  - Any production of S

    bool S() {…}
- These functions advance next

Implementing Productions

$E \rightarrow T$

$E \rightarrow T + E$

- For production $E \rightarrow T$

  bool E_1() { return T(); }

- For production $E \rightarrow T + E$

  bool E_2() { return T() && term(PLUS) && E(); }

- For all productions of E (with backtracking)

```
bool E() {
    TOKEN *save = next;
     return  (next= save, E1()) || (next= save, E2()); }
```

Implementing Productions

- For non-terminal T

```
bool T1() { return terms(OPEN) && E() && term(CLOSE); }
bool T2() { return terms(INT) && term(TIMES) && T(); }
bool T3() { return terms(INT); }

bool T() {
    TOKEN *save = next;
    return   (next= save, T1())
          || (next= save, T2())
          || (next= save, T3()); }
```

$E \rightarrow T + E$

$E \rightarrow T$

$T \rightarrow (E)$

$T \rightarrow int * T$

$T \rightarrow int$

Recursive Descent Parsing

- To start the parser
  - Initialize next to point to the first token
  - Invoke E()
- Note how this simulates our previous example
- Easy to implement
- But this does not always work …

Left-Recursion in Recursive Descent Parsing

- Consider a production $S \rightarrow S\ a$
  - bool $S_1()$ { return S() && term(a); }
  - bool S() { return $S_1()$; }
- S() will get into an infinite loop
- Left-recursive grammar has a nonterminal S
  - $S \rightarrow^+ \ldots S \ldots$
- Recursive descent parsing does not work for left-recursive grammars

Elimination of Left Recursion

- Consider the left recursive grammar
  - $S \rightarrow S\ a \mid b$
- S generates all strings starting with 'b' and followed by a number of 'a'
- Can rewrite using right-recursion
  - $S \rightarrow b\ S'$
  - $S' \rightarrow a\ S' \mid \varepsilon$

No Immediate Left Recursion

- In general for immediate left recursion
  - $S \rightarrow S\ \alpha_1 \mid \ldots \mid S\ \alpha_n \mid \beta_1 \mid \ldots \mid \beta_m$
- All strings derived from S start with one of $\beta_1, \ldots, \beta_m$ and continue with several instances of $\alpha_1, \ldots, \alpha_n$
- Rewrite as
  - $S \rightarrow \beta_1\ S' \mid \ldots \mid \beta_m\ S'$
  - $S' \rightarrow \alpha_1\ S' \mid \ldots \mid \alpha_n\ S' \mid \varepsilon$

No Immediate Left Recursion

$T \Rightarrow T*F \Rightarrow T*F*F \Rightarrow F*F*F$

$$
\begin{aligned}
T &: T * F \\
&\mid F \\
F &: a \\
&\mid b \\
&\mid c
\end{aligned}
$$

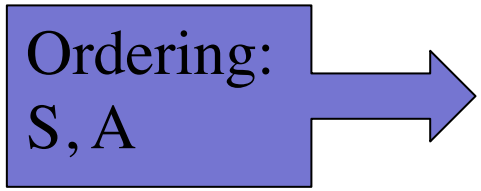
No left recursion

$$
\begin{aligned}
T &: F\ T' \\
T' &: *\ F\ T' \\
&\mid \varepsilon \\
F &: a \\
&\mid b \\
&\mid c
\end{aligned}
$$

$T \Rightarrow FT' \Rightarrow F*FT' \Rightarrow F*F*FT' \Rightarrow F*F*F$

Remove General Left Recursion

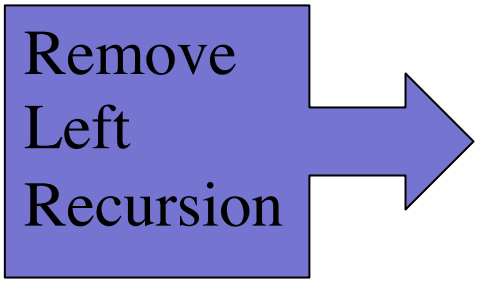
S : A a
  | b
A : A c
  | S d
  | ε



S : A a
  | b
A : A c
  | A a d
  | b d
  | ε

Immediate Left Recursion

S : A a
  | b
A : A c
  | A a d
  | b d
  | ε



S : A a
  | b
A : b d A'
  | A'
A' : c A'
  | a d A'
  | ε

General Left Recursion

Input: grammar G with no cycles A -> A or empty rules A -> ε

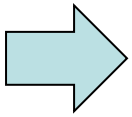
Output: grammar with no left recursion

Arrange nonterminals in order $A_1, A_2, A_3, \ldots, A_n$

```
for i = 1 to n {
   for j = 1 to i-1 {
      replace each rule A_i -> A_j α where A_j -> β_1 | … | β_m with
      the rules A_i -> β_1 α | … | β_m α
   }
   remove immediate left recursion among A_i rules
}
```

Remove General Left Recursion

S : A a
  | b
A : A c
  | S d
  | B
B : B e
  | A f
  | S g
  | h



S : A a
  | b
A : b d A'
  | B A'
A’ : a d A'
  | c A'
  | ε

B : b d A' a g B'
  | b d A' f B'
  | b g B'
  | h B'
B’ : A' a g B'
  | A' f B'
  | e B'
  | ε

Summary of Recursive Descent

- Simple and general parsing strategy
  - Left-recursion must be eliminated first
    - Most of the time manually (but it can be done automatically)
  - Backtracking is inefficient
  - In practice, backtracking is eliminated by restricting the grammar
  - Used in production compilers (e.g. gcc front-end)

How to compute: Does $X \Rightarrow^* \varepsilon$?

- The question `Does $X \Rightarrow^* \varepsilon$?' can be written as the predicate: nullable(X)

Nullable = {} (set containing nullable non-terminals)
Changed = True
While (changed):
  changed = False
  if X is not in Nullable:
    if
      1. $X \rightarrow \varepsilon$ is in the grammar, or
      2. $X \rightarrow Y_1 \ldots Y_n$ is in the grammar and Y_i is in Nullable for all i then add X to Nullable; changed = True