TD1: Recursive Descent

Top-down Parsing

CMPT 379: Compilers
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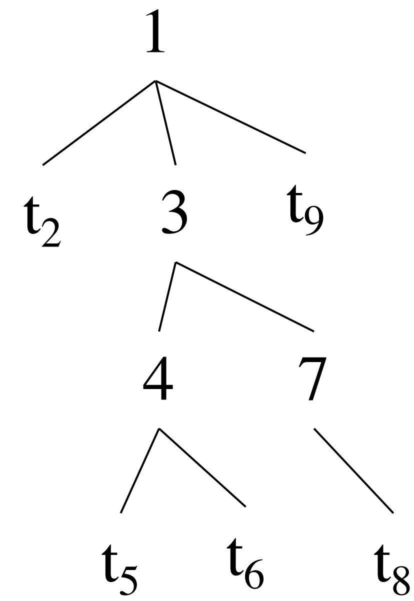
Intro t0 Top-Down Parsing

- 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
  - $E \rightarrow T + E \mid T$
  - $T \rightarrow \text{int} \mid \text{int} * T \mid (E)$

- Token stream is $\text{int}_5 * \text{int}_2$
- Start from top-level non-terminal E
  - Try the rules for E in order

Recursive Descent Parsing

$E \rightarrow T + E$

$E \rightarrow T$

$T \rightarrow int$

$T \rightarrow int * T$

$T \rightarrow (E)$

Input:

int_5 * int_2

Try $E_0 \rightarrow T_1 + E_2$

Try $T_1 \rightarrow int$

Token int matches!

but + does not match to input

Failure

Try $T_1 \rightarrow int * T_2$

Tokens int and * match

Try $T_3 \rightarrow int$

Token int matches

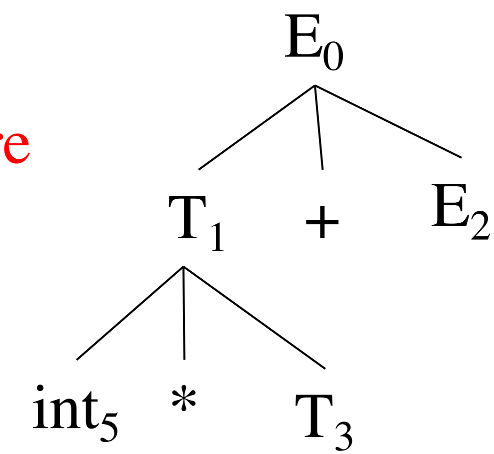
input is matched but tree should match $+ E_2$ Failure

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 $T_1 \rightarrow int * T_2$

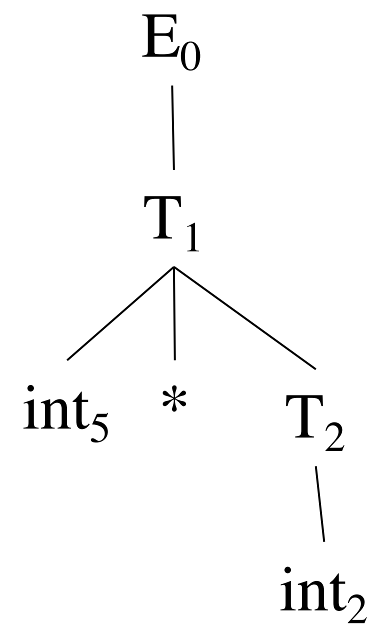
Tokens int , * match

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

$E \to T$
$E \to T + E$

- For production $E \to T$

  ```
  bool E1() { return T(); }
  ```

- For production $E \to T + E$

  ```
  bool E2() { 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()); }
```

$E \rightarrow T + E$

$E \rightarrow T$

$T \rightarrow (E)$

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

$T \rightarrow \text{int}$

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 $S \to S\ a$
  - 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
  - $S \to^{+} \ldots S \ldots$
- 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 ⇨ T*F ⇨ T*F*F ⇨ F*F*F

T : T * F
  | F
F : a
  | b
  | c

No left recursion ⇨

T : F T’
T’ : * F T’
  | ε
F : a
  | b
  | c

T ⇨ FT’ ⇨ F*FT’ ⇨ F*F*FT’ ⇨ F*F*F

Remove General Left Recursion

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

Ordering: S, A

```
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

Remove Left Recursion

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 $A_i \rightarrow A_j\ \alpha$ where $A_j \rightarrow \beta_1 \mid \ldots \mid \beta_m$ with
    the rules $A_i \rightarrow \beta_1\ \alpha \mid \ldots \mid \beta_m\ \alpha$
  }
  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 → ε is in the grammar, or
          2. X → Y_1 … Y_n is in the grammar and Y_i is in Nullable for all i then
          add X to Nullable; changed = True
```