Top down Parsing

- Following grammar generates types of Pascal

  type → simple
  | ↑ id
  | array [simple] of type

  simple → integer
  | char
  | num dotdot num

Example …

- Construction of a parse tree is done by starting the root labeled by a start symbol

- repeat following two steps

  - at a node labeled with non terminal A select one of the productions of A and construct children nodes

    (Which production?)

  - find the next node at which subtree is Constructed

    (Which node?)

- Parse
  array [num dotdot num] of integer

Start symbol

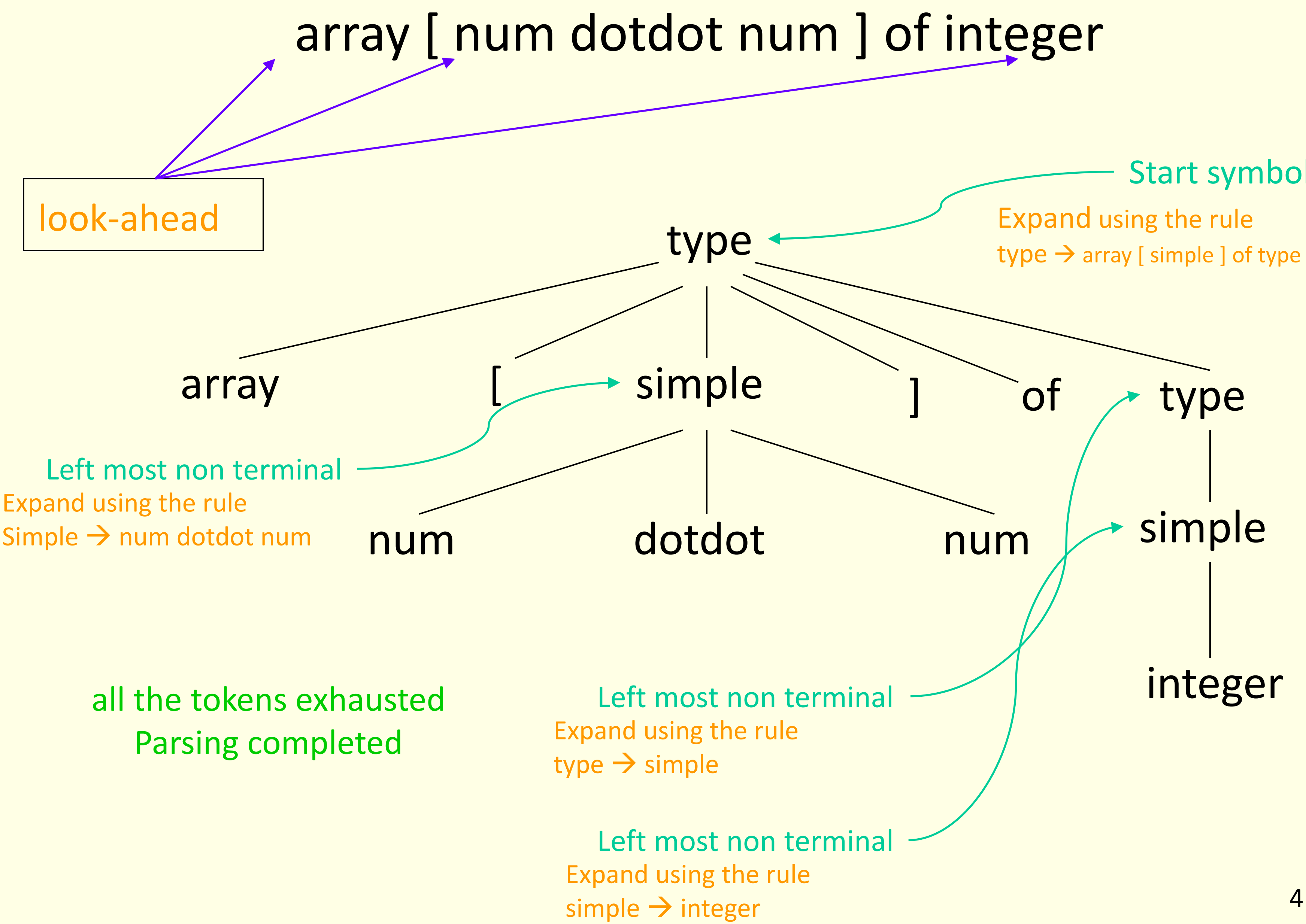
type

simple

Expanded using the rule type → simple

- Cannot proceed as non terminal “simple” never generates a string beginning with token “array”. Therefore, requires back-tracking.

- Back-tracking is not desirable, therefore, take help of a “look-ahead” token. The current token is treated as look-ahead token. (restricts the class of grammars)



array [num dotdot num] of integer
look-ahead
Start symbol
Expand using the rule
type → array [simple] of type
type
array
[
simple
]
of
type
Left most non terminal
Expand using the rule
Simple → num dotdot num
num
dotdot
num
simple
integer
all the tokens exhausted
Parsing completed
Left most non terminal
Expand using the rule
type → simple
Left most non terminal
Expand using the rule
simple → integer

Recursive descent parsing

First set:

Let there be a production

$$A \to \alpha$$

then First(α) is the set of tokens that appear as the first token in the strings generated from α

For example :
First(simple) = {integer, char, num}
First(num dotdot num) = {num}

Define a procedure for each non terminal

```
procedure type;
  if lookahead in {integer, char, num}
    then simple
    else if lookahead = ↑
          then begin match( ↑ );
                     match(id)
               end
          else if lookahead = array
               then begin match(array);
                          match([);
                          simple;
                          match(]);
                          match(of);
                          type
                    end
               else error;
```

```
procedure simple;
  if lookahead = integer
    then match(integer)
    else if lookahead = char
            then match(char)
            else if lookahead = num
                    then begin match(num);
                                match(dotdot);
                                match(num)
                          end
                    else
                         error;

procedure match(t:token);
    if lookahead = t
       then lookahead = next token
       else error;
```

Left recursion

- A top down parser with production $A \rightarrow A\ \alpha$ may loop forever

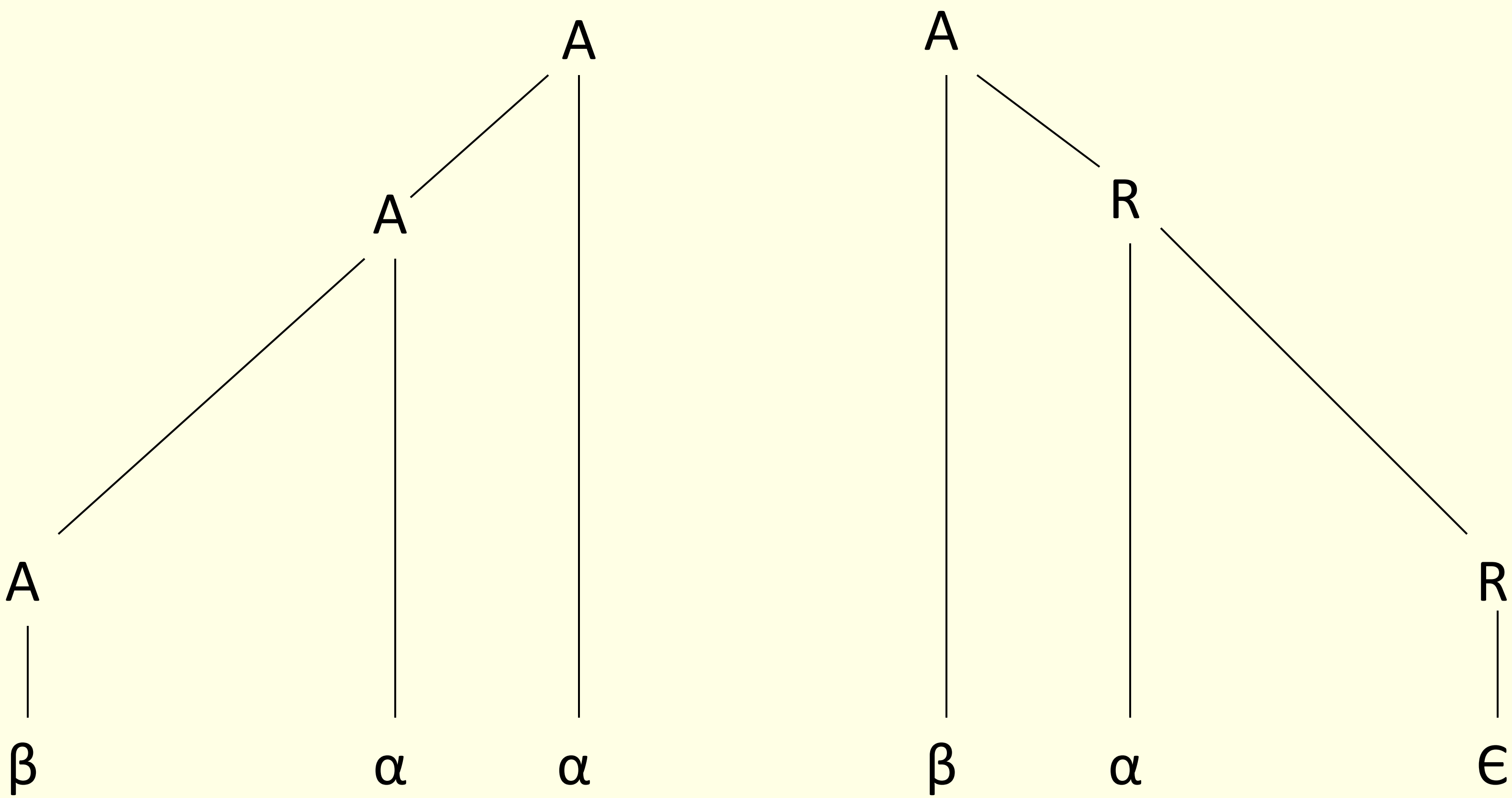
- From the grammar $A \rightarrow A\ \alpha \mid \beta$ left recursion may be eliminated by transforming the grammar to

$A \rightarrow \beta\ \ R$

$R \rightarrow \alpha\ R \mid \varepsilon$

Parse tree corresponding
to a left recursive grammar

Parse tree corresponding
to the modified grammar



Both the trees generate string βα*

Example

- Consider grammar for arithmetic expressions

  $E \rightarrow E + T \mid T$
  $T \rightarrow T * F \mid F$
  $F \rightarrow (E) \mid id$

- After removal of left recursion the grammar becomes

  $E \rightarrow T E'$
  $E' \rightarrow + T E' \mid \epsilon$
  $T \rightarrow F T'$
  $T' \rightarrow * F T' \mid \epsilon$
  $F \rightarrow (E) \mid id$

Removal of left recursion

In general

$A \rightarrow A\alpha_1 \mid A\alpha_2 \mid \ldots\ldots \mid A\alpha_m$
$\mid \beta_1 \mid \beta_2 \mid \ldots\ldots \mid \beta_n$

transforms to

$A \rightarrow \beta_1 A' \mid \beta_2 A' \mid \ldots\ldots \mid \beta_n A'$
$A' \rightarrow \alpha_1 A' \mid \alpha_2 A' \mid \ldots\ldots \mid \alpha_m A' \mid \epsilon$

Left recursion hidden due to many productions

- Left recursion may also be introduced by two or more grammar rules. For example:

  S → Aa | b
  A → Ac | Sd | Є

  there is a left recursion because

  $S \rightarrow Aa \rightarrow Sda$

- In such cases, left recursion is removed systematically
  - Starting from the first rule and replacing all the occurrences of the first non terminal symbol
  - Removing left recursion from the modified grammar

Removal of left recursion due to many productions …

- After the first step (substitute S by its rhs in the rules) the grammar becomes

  $S \rightarrow Aa \mid b$

  $A \rightarrow Ac \mid Aad \mid bd \mid \epsilon$

- After the second step (removal of left recursion) the grammar becomes

  $S \rightarrow Aa \mid b$

  $A \rightarrow bdA' \mid A'$

  $A' \rightarrow cA' \mid adA' \mid \epsilon$

Left factoring

- In top-down parsing when it is not clear which production to choose for expansion of a symbol

  defer the decision till we have seen enough input.

  In general if $A \rightarrow \alpha\beta_1 \mid \alpha\beta_2$

  defer decision by expanding A to $\alpha A'$

  we can then expand A' to β_1 or β_2

- Therefore $A \rightarrow \alpha\ \beta_1 \mid \alpha\ \beta_2$

  transforms to

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

Dangling else problem again

Dangling else problem can be handled by left factoring

stmt → if expr then stmt else stmt
| if expr then stmt

can be transformed to

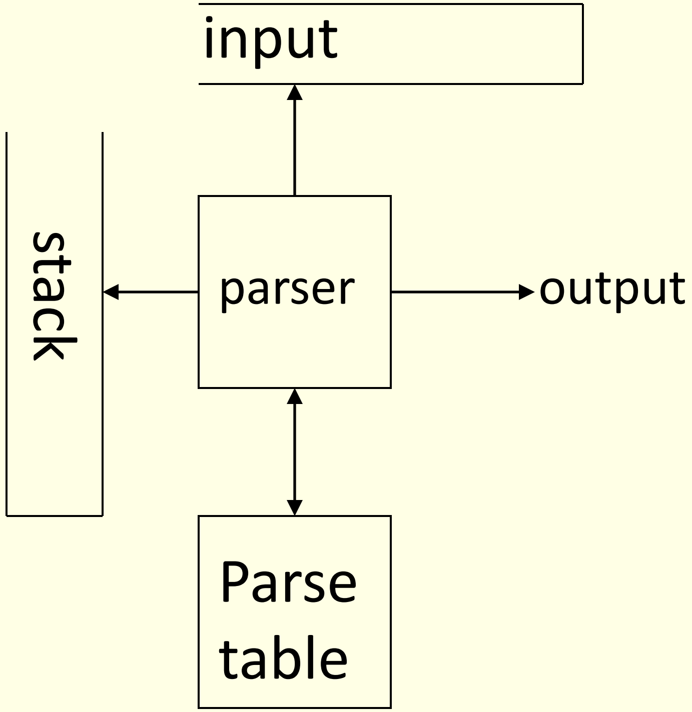
stmt → if expr then stmt S'
S' → else stmt | ∈

Predictive parsers

- A non recursive top down parsing method
- Parser “predicts” which production to use
- It removes backtracking by fixing one production for every non-terminal and input token(s)
- Predictive parsers accept LL(k) languages
  – First L stands for left to right scan of input
  – Second L stands for leftmost derivation
  – k stands for number of lookahead token
- In practice LL(1) is used

Predictive parsing

- Predictive parser can be implemented by maintaining an external stack



Parse table is a two dimensional array M[X,a] where "X" is a non terminal and "a" is a terminal of the grammar

Example

- Consider the grammar

E → T E’

E' → +T E' | ϵ

T → F T'

T' → * F T' | ϵ

F → (E) | id

Parse table for the grammar

	id	+	*	(	)	$
E	E→TE’			E→TE’		
E’		E’→+TE’			E’→ϵ	E’→ϵ
T	T→FT’			T→FT’		
T’		T’→ϵ	T’→*FT’		T’→ϵ	T’→ϵ
F	F→id			F→(E)		

Blank entries are error states. For example
E cannot derive a string starting with ‘+’

Parsing algorithm

- The parser considers 'X' the symbol on top of stack, and 'a' the current input symbol
- These two symbols determine the action to be taken by the parser
- Assume that '$' is a special token that is at the bottom of the stack and terminates the input string

if X = a = $ then halt

if X = a ≠ $ then pop(x) and ip++

if X is a non terminal
then if M[X,a] = {X → UVW}
then begin pop(X); push(W,V,U)
end
else error

Example

Stack	input	action
$E	id + id * id $	expand by E→TE’
$E’T	id + id * id $	expand by T→FT’
$E’T’F	id + id * id $	expand by F→id
$E’T’id	id + id * id $	pop id and ip++
$E’T’	+ id * id $	expand by T’→Є
$E’	+ id * id $	expand by E’→+TE’
$E’T+	+ id * id $	pop + and ip++
$E’T	id * id $	expand by T→FT’

Example …

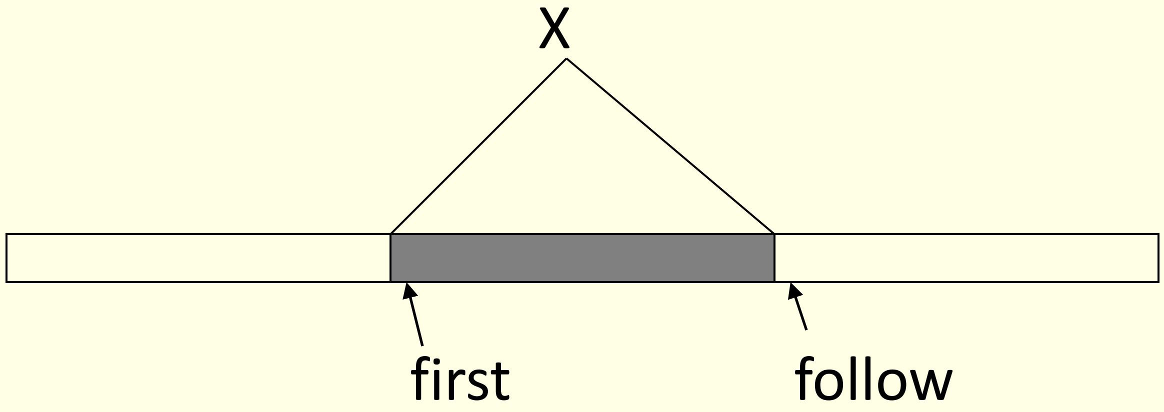
Stack	input	action
$E'T'F	id * id $	expand by F→id
$E'T'id	id * id $	pop id and ip++
$E'T'	* id $	expand by T'→*FT'
$E'T'F*	* id $	pop * and ip++
$E'T'F	id $	expand by F→id
$E'T'id	id $	pop id and ip++
$E'T'	$	expand by T'→Є
$E'	$	expand by E'→Є
$	$	halt

Constructing parse table

- Table can be constructed if for every non terminal, every lookahead symbol can be handled by at most one production

- First(α) for a string of terminals and non terminals α is
  - Set of symbols that might begin the fully expanded (made of only tokens) version of α

- Follow(X) for a non terminal X is
  - set of symbols that might follow the derivation of X in the input stream



Compute first sets

- If X is a terminal symbol then First(X) = {X}
- If X → Є is a production then Є is in First(X)
- If X is a non terminal

  and X → $Y_l Y_2$ … Y_k is a production

  then

  if for some i, a is in First(Y_i)

  and Є is in all of First(Y_j) (such that j<i)

  then a is in First(X)
- If Є is in First (Y_1) … First(Y_k) then Є is in First(X)

Example

- For the expression grammar

  $E \rightarrow T\ E'$

  $E' \rightarrow +T\ E' \mid \epsilon$

  $T \rightarrow F\ T'$

  $T' \rightarrow *\ F\ T' \mid \epsilon$

  $F \rightarrow (\ E\ ) \mid id$

  First(E) = First(T) = First(F) = { (, id }

  First(E') = {+, ϵ}

  First(T') = { *, ϵ}

Compute follow sets

1. Place $ in follow(S)

2. If there is a production $A \rightarrow \alpha B \beta$
   then everything in first(β) (except ε) is in follow(B)

3. If there is a production $A \rightarrow \alpha B$
   then everything in follow(A) is in follow(B)

4. If there is a production $A \rightarrow \alpha B \beta$
   and First(β) contains ε
   then everything in follow(A) is in follow(B)

Since follow sets are defined in terms of follow sets last two steps have to be repeated until follow sets converge

Example

- For the expression grammar

  E → T E’

  E' → + T E' | Є

  T → F T'

  T' → * F T' | Є

  F → (E) | id

  follow(E) = follow(E’) = { $,) }
  follow(T) = follow(T’) = { $,), + }
  follow(F) = { $,), +, *}

Construction of parse table

- for each production A → α do
  - for each terminal 'a' in first(α)

    M[A,a] = A → α

  - If Є is in First(α)

    M[A,b] = A → α

    for each terminal b in follow(A)

  - If ε is in First(α) and $ is in follow(A)

    M[A,$] = A → α

- A grammar whose parse table has no multiple entries is called LL(1)

Practice Assignment

- Construct LL(1) parse table for the expression grammar
  bexpr → bexpr or bterm | bterm
  bterm → bterm and bfactor | bfactor
  bfactor → not bfactor | (bexpr) | true | false

- Steps to be followed
  - Remove left recursion
  - Compute first sets
  - Compute follow sets
  - Construct the parse table

Error handling

- Stop at the first error and print a message
  - Compiler writer friendly
  - But not user friendly

- Every reasonable compiler must recover from errors and identify as many errors as possible

- However, multiple error messages due to a single fault must be avoided

- Error recovery methods
  - Panic mode
  - Phrase level recovery
  - Error productions
  - Global correction

Panic mode

- Simplest and the most popular method
- Most tools provide for specifying panic mode recovery in the grammar
- When an error is detected
  - Discard tokens one at a time until a set of tokens is found whose role is clear
  - Skip to the next token that can be placed reliably in the parse tree

Panic mode …

- Consider following code

```
begin
        a = b + c;
        x = p r ;
        h = x < 0;
end;
```

- The second expression has syntax error

- Panic mode recovery for begin-end block
  skip ahead to next ';' and try to parse the next expression

- It discards one expression and tries to continue parsing

- May fail if no further ';' is found

Phrase level recovery

- Make local correction to the input
- Works only in limited situations
  - A common programming error which is easily detected
  - For example insert a “;” after closing “}” of a class definition
- Does not work very well!

Error productions

- Add erroneous constructs as productions in the grammar
- Works only for most common mistakes which can be easily identified
- Essentially makes common errors as part of the grammar
- Complicates the grammar and does not work very well

Global corrections

- Considering the program as a whole find a correct “nearby” program
- Nearness may be measured using certain metric
- PL/C compiler implemented this scheme: anything could be compiled!
- It is complicated and not a very good idea!

Error Recovery in LL(1) parser

- Error occurs when a parse table entry M[A,a] is empty

- Skip symbols in the input until a token in a selected set (synch) appears

- Place symbols in follow(A) in synch set. Skip tokens until an element in follow(A) is seen.

  Pop(A) and continue parsing

- Add symbol in first(A) in synch set. Then it may be possible to resume parsing according to A if a symbol in first(A) appears in input.

Practice Assignment

- Reading assignment: Read about error recovery in LL(1) parsers
- Assignment to be submitted:
  - introduce synch symbols (using both follow and first sets) in the parse table created for the boolean expression grammar in the previous assignment
  - Parse “not (true and or false)” and show how error recovery works