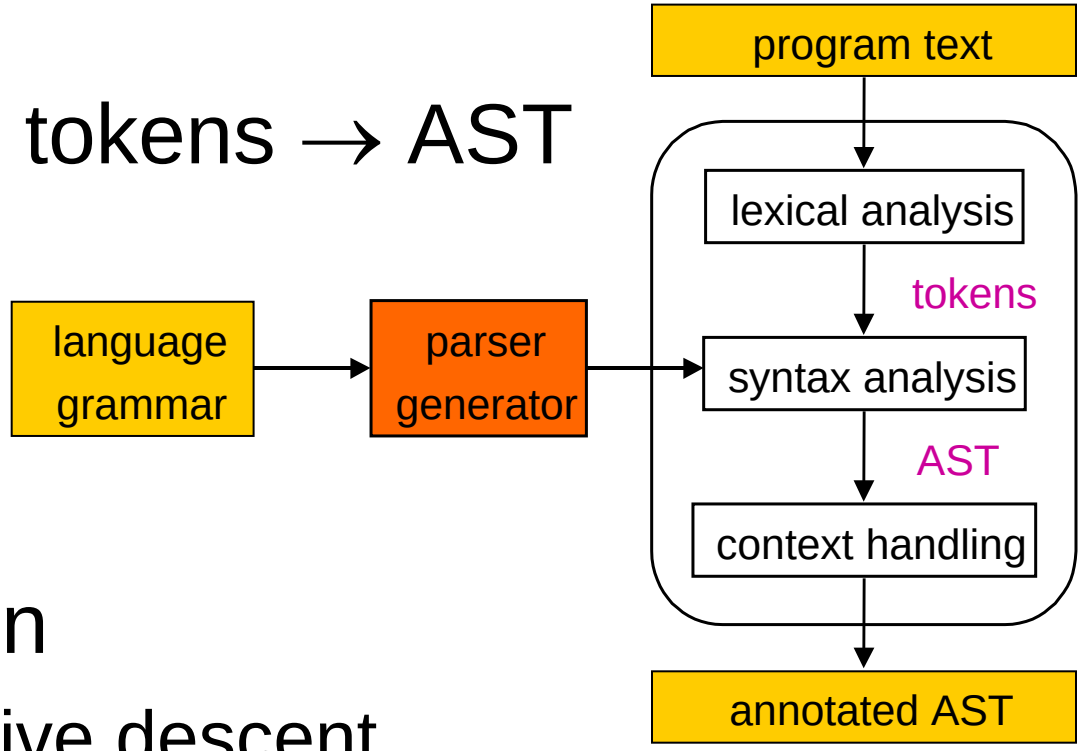
Compiler construction in4303 – lecture 3

Top-down parsing

Chapter 2.2 - 2.2.4

Overview

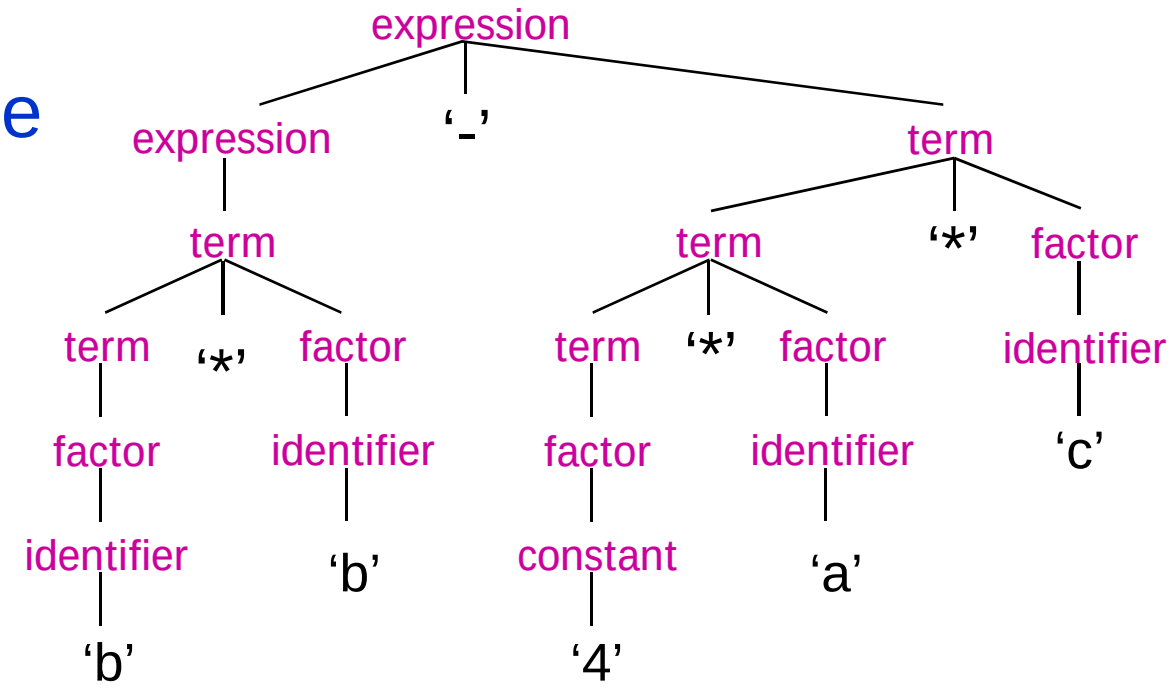
- syntax analysis: tokens → AST



- AST construction
  - by hand: recursive descent
  - automatic: top-down (LLgen), bottom-up (yacc)

Syntax analysis

- parsing: given a context-free grammar and a stream of tokens, find the derivation that ties them together.
- result: parse tree



Context free grammar

- $G = (V_N, V_T, S, P)$
  - V_N : set of Non-terminal symbols
  - V_T : set of Terminal symbols
  - S : Start symbol ($S \in V_N$)
  - P : set of Production rules $\{N \rightarrow \alpha\}$

- $V_N \cap V_T = \varnothing$
- $P = \{N \rightarrow \alpha \mid N \in V_N \wedge \alpha \in (V_N \cup V_T)^*\}$

Top-down parsing

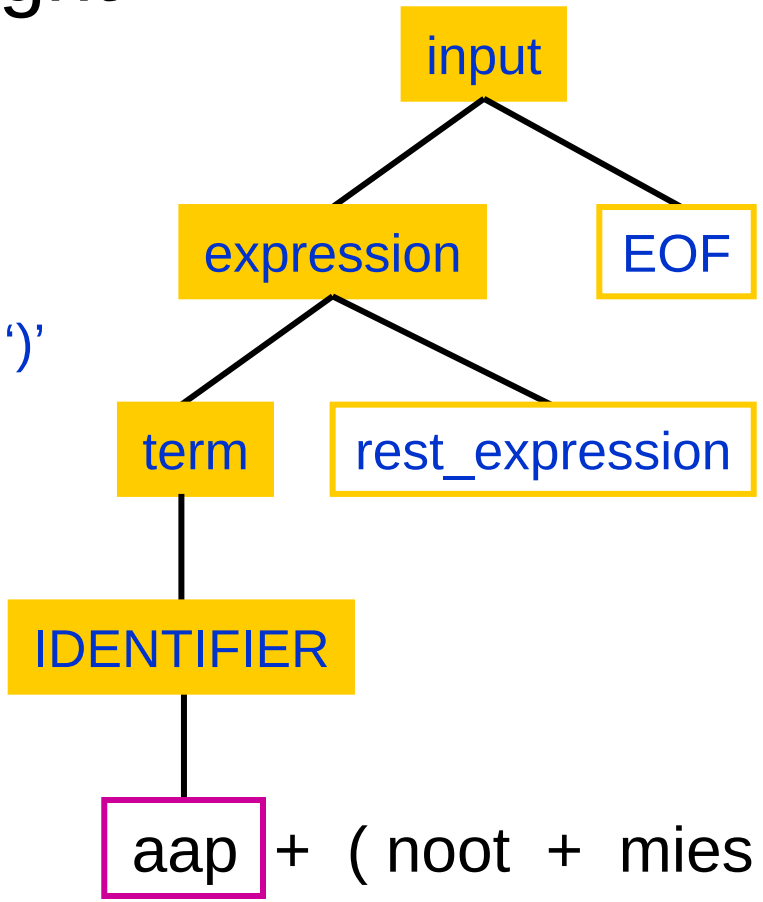
- process tokens left to right
- expression grammar

  input → expression EOF

  expression → term rest_expression

  term → IDENTIFIER | ‘(’ expression ‘)’

  rest_expression → ‘+’ expression | ε



- example expression

Bottom-up parsing

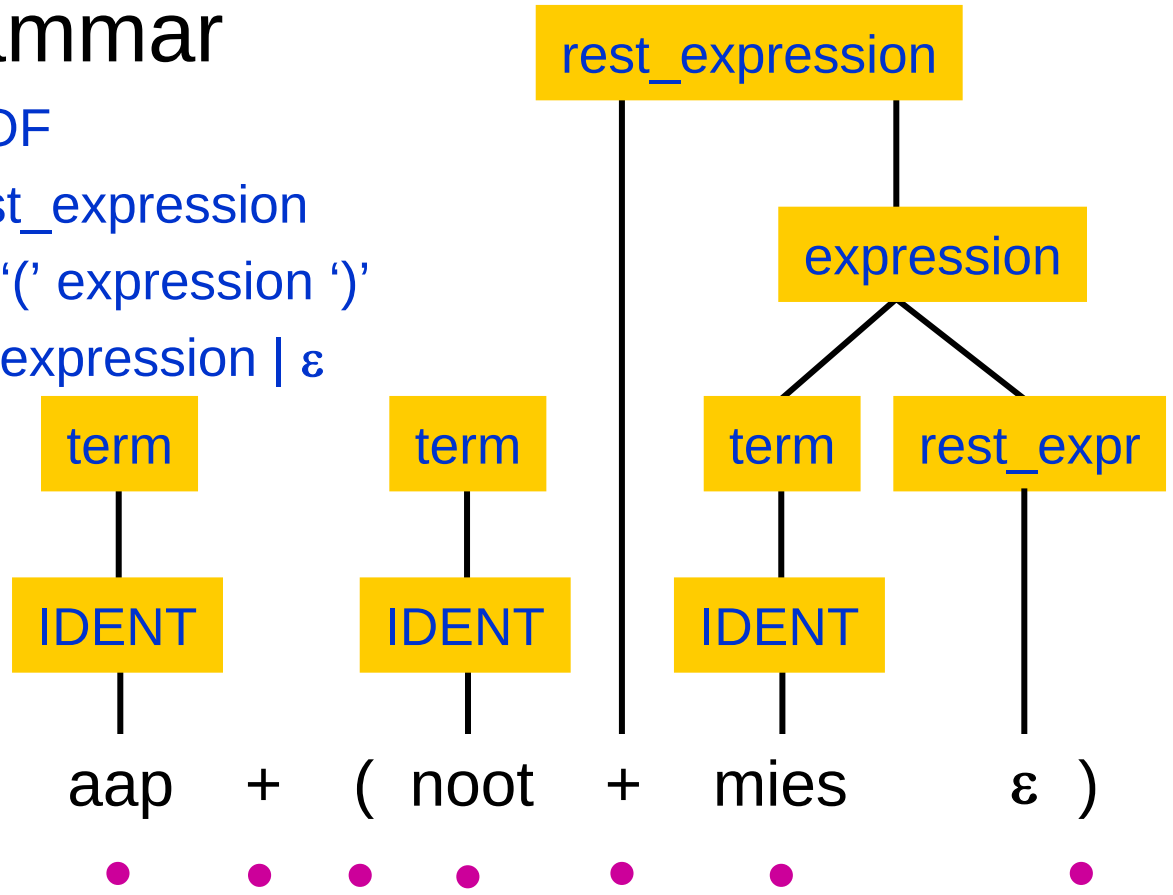
- process tokens left to right
- expression grammar

  input → expression EOF

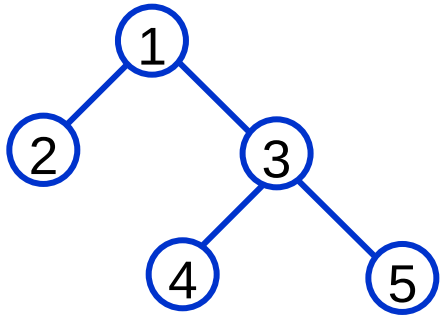
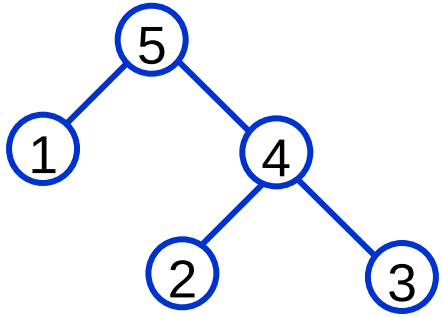
  expression → term rest_expression

  term → IDENTIFIER | ‘(’ expression ‘)’

  rest_expression → ‘+’ expression | ε



Comparison

	top-down	**bottom-up**
node creation	pre-order 	post-order 
alternative selection	first token	last token
grammar type	restricted LL(1)	relaxed LR(1)
implementation	manual + automatic	automatic

Recursive descent parsing

- each rule *N* translates to a boolean function
  - return true if a terminal production of *N* was matched
  - return false otherwise (without consuming any token)
- try alternatives of *N* in turn
- a terminal symbol must match the current token
- a non-terminal is matched by calling its routine

input → expression EOF

```
int input(void) {
  return expression() && require(token(EOF));
}
```

Recursive descent parsing

expression → term rest_expression

```
int expression(void) {
  return term() && require(rest_expression());
}
```

term → IDENTIFIER | ‘(’ expression ‘)’

```
int term(void) {
  return token(IDENTIFIER) ||
    token('(') && require(expression()) && require(token(')'));
}
```

Recursive descent parsing

rest_expression → '+' expression | ε

```
int rest_expression(void) {
  return token('+') && require(expression()) || 1;
}
```

auxiliary functions

- consume matched tokens
- report syntax errors

```
int token(int tk) {
    if (Token.class != tk) return 0;
    get_next_token(); return 1;
}

int require(int found) {
    if (!found) error();
    return 1;
}
```

Automatic top-down parsing

- follow recursive descent scheme, but avoid interpretation overhead
- for each rule and alternative determine the tokens it can start with: FIRST set
- parsing scheme for rule $N \rightarrow A_1 \mid A_2 \mid \ldots$
  - **if** token $\in$ FIRST(A_1) **then** parse A_1
  - **else if** token $\in$ FIRST(A_2) **then** parse A_2
  - *…*
  - **else** ERROR

Exercise (4 min.)

- determine the FIRST set of the non-terminals in our expression grammar

input → expression EOF
expression → term rest_expression
term → IDENTIFIER | '(' expression ')'
rest_expression → '+' expression | ε

- and, for this grammar

S → A B
A → A 'a' | ε
B → B 'b' | 'b'

Answers

Computing the FIRST set

- $N \rightarrow w \quad (w \in V_T)$
- $N \rightarrow A_1 \mid A_2 \mid \ldots$
- $N \rightarrow \varepsilon$
- $N \rightarrow A\ \beta$

closure algorithm:

- initial values
- inference rules
- iterative solution

Predictive parsing

- similar to recursive descent, but no back-tracking
- functions “know” what they are doing

input → expression EOF FIRST(expression) = {IDENT, ‘(‘}

```
void input(void) {
  switch (Token.class) {
    case IDENT: case '(':
                    expression(); token(EOF); break;
    default:        error();

  }

}

void token(int tk) {

  if (Token.class != tk) error();

  get_next_token();

}
```

Predictive parsing

expression → term rest_expression FIRST(term) = {IDENT, '('}

```
void expression(void) {
  switch (Token.class) {
    case IDENT: case '(':
                    term(); rest_expression(); break;
    default:        error();

  }

}
```

term → IDENTIFIER | '(' expression ')'

```
void term(void) {
  switch (Token.class) {
    case IDENT:     token(IDENT); break;
    case '(':       token('('); expression(); token(')'); break;
    default:        error();

  }

}
```

Predictive parsing

rest_expression → '+' expression | ε FIRST(rest_expr) = {'+', ε}

```
void rest_expression(void) {
  switch (Token.class) {
    case '+':           token('+'); expression(); break;
    case EOF: case ')': break;
    default:            error();
  }
}
```

FOLLOW(rest_expr) = {EOF, ')'}

- FIRST(ε) = {ε}
  - check nothing?
  - NO: token ∈ FOLLOW(rest_expr)

Limitations of LL(1) parsers

- FIRST/FIRST conflict

  term → IDENTIFIER
  | IDENTIFIER '[' expression ']'
  | '(' expression ')'

- FIRST/FOLLOW conflict

  S → A 'a' 'b'

  A → 'a' | ε

  FIRST(A) = { 'a', ε } ⊃ {'a'} = FOLLOW(A)

- left recursion

  expression → expression '-' term | term

Making grammars LL(1)

- manual labour
  - rewrite grammar
  - adjust semantic actions
- three rewrite methods
  - left factoring
  - substitution
  - left-recursion removal

Left factoring

term → IDENTIFIER
| IDENTIFIER ‘[‘ expression ‘]’

- factor out common prefix

term → IDENTIFIER after_identifier

after_identifier → ε | ‘[‘ expression ‘]’

‘[’ ∉ FOLLOW(after_identifier)

Substitution

$S \rightarrow A$ ‘a’ ‘b’

$A \rightarrow$ ‘a’ | ε

- replace non-terminal by its alternative

$S \rightarrow$ ‘a’ ‘a’ ‘b’ | ‘a’ ‘b’

Left-recursion removal

$N \rightarrow N\ \alpha \mid \beta$

- replace by

$N \rightarrow \beta\ M$

$M \rightarrow \alpha\ M \mid \varepsilon$

β
$\beta\ \alpha$
$\beta\ \alpha\ \alpha$
$\beta\ \alpha\ \alpha\ \alpha$
...

- example

N α β

expression $\rightarrow$ expression '-' term | term

expression $\rightarrow$ term tail

tail $\rightarrow$ '-' term tail | ε

Exercise (7 min.)

- make the following grammar LL(1)

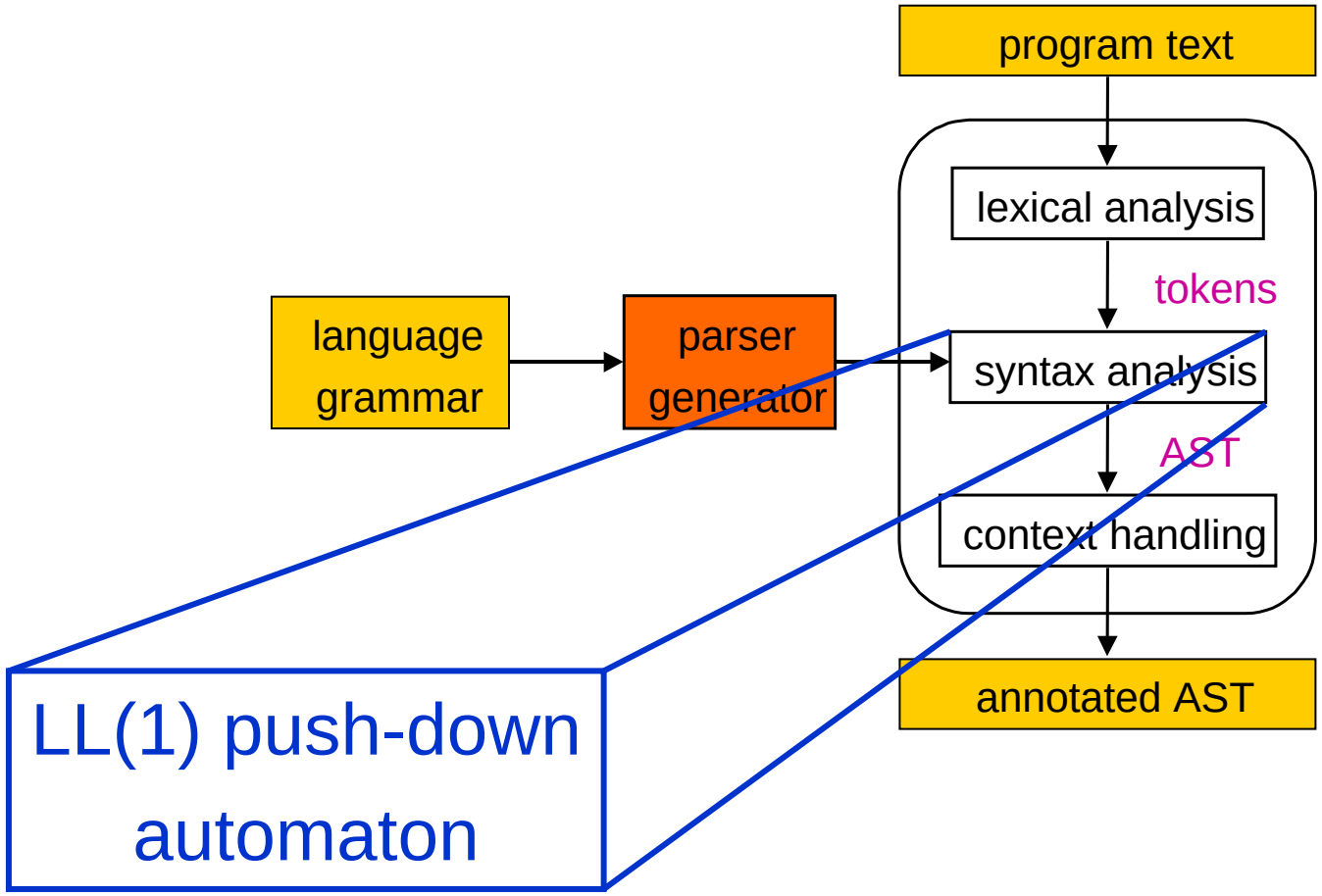
  expression → expression ‘+’ term | expression ‘-’ term | term
  term → term ‘*’ factor | term ‘/’ factor | factor
  factor → ‘(‘ expression ‘)’ | func-call | identifier | constant
  func-call → identifier ‘(‘ expr-list? ‘)’
  expr-list → expression (‘,’ expression)*

- and what about

  S → if E then S (else S)?

Answers

automatic generation



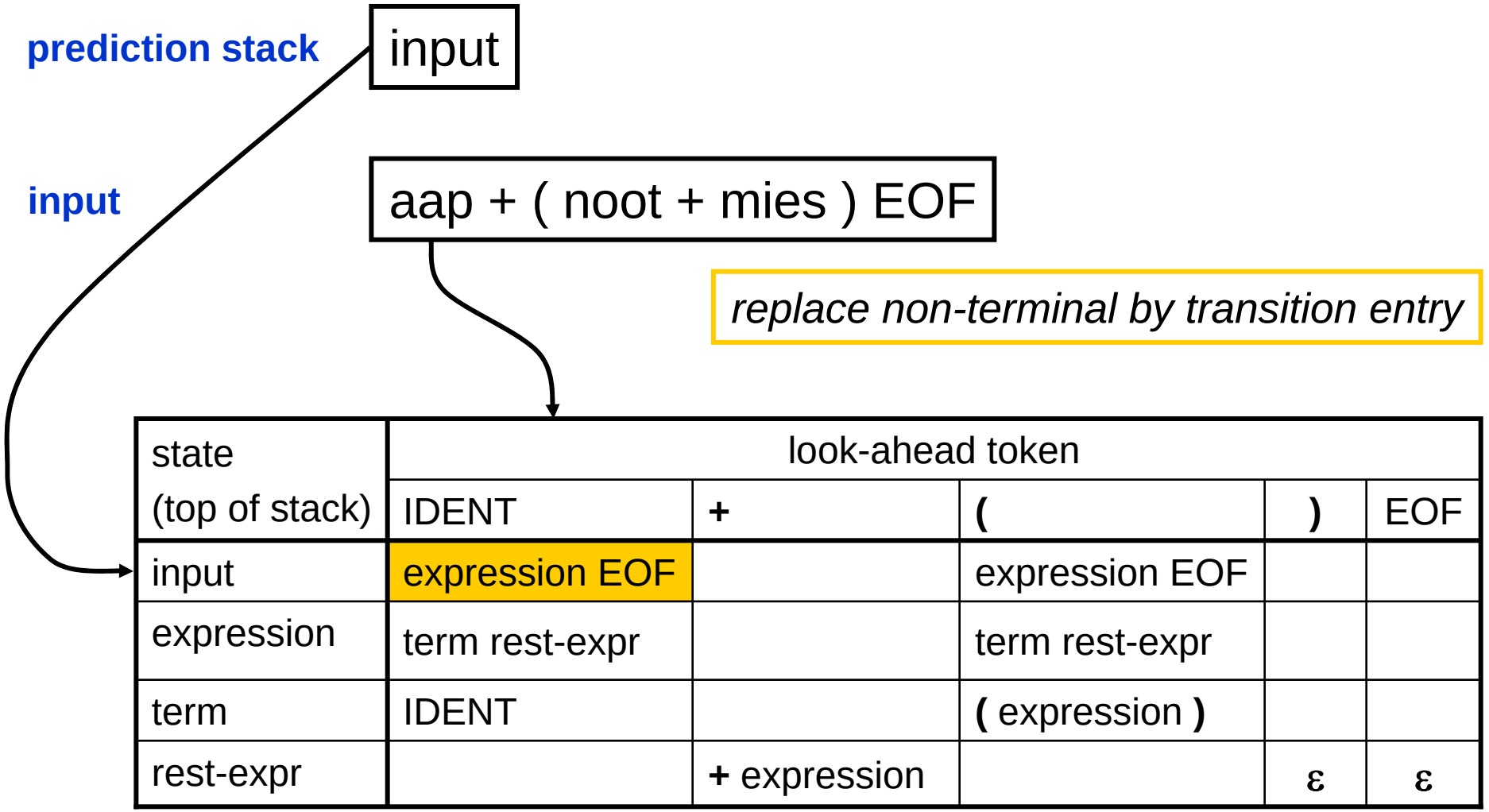
LL(1) push-down automaton

transition table

state (top of stack)	look-ahead token				
	IDENT	**+**	**(**	**)**	EOF
input	expression EOF		expression EOF		
expression	term rest-expr		term rest-expr		
term	IDENT		**(** expression **)**		
rest-expr		**+** expression		ε	ε

- stack right-hand side of production

LL(1) push-down automaton



state (top of stack)	look-ahead token				
	IDENT	+	(	)	EOF
input	expression EOF		expression EOF		
expression	term rest-expr		term rest-expr		
term	IDENT		(expression)		
rest-expr		+ expression		ε	ε

LL(1) push-down automaton

prediction stack expression EOF

input aap + (noot + mies) EOF

replace non-terminal by transition entry

state (top of stack)	look-ahead token				
	IDENT	+	(	)	EOF
input	expression EOF		expression EOF		
expression	term rest-expr		term rest-expr		
term	IDENT		(expression)		
rest-expr		+ expression		ε	ε

LL(1) push-down automaton

prediction stack term rest-expr EOF

input aap + (noot + mies) EOF

replace non-terminal by transition entry

state (top of stack)	look-ahead token				
	IDENT	**+**	**(**	**)**	EOF
input	expression EOF		expression EOF		
expression	term rest-expr		term rest-expr		
term	IDENT		**(** expression **)**		
rest-expr		**+** expression		ε	ε

LL(1) push-down automaton

prediction stack IDENT rest-expr EOF

input aap + (noot + mies) EOF

pop matching token

state (top of stack)	look-ahead token				
	IDENT	**+**	**(**	**)**	EOF
input	expression EOF		expression EOF		
expression	term rest-expr		term rest-expr		
term	IDENT		**(** expression **)**		
rest-expr		**+** expression		ε	ε

LL(1) push-down automaton

prediction stack rest-expr EOF

input + (noot + mies) EOF

replace non-terminal by transition entry

state (top of stack)	look-ahead token				
	IDENT	**+**	**(**	**)**	EOF
input	expression EOF		expression EOF		
expression	term rest-expr		term rest-expr		
term	IDENT		**(** expression **)**		
rest-expr		**+** expression		ε	ε

LL(1) push-down automaton

prediction stack + expression EOF

input + (noot + mies) EOF

pop matching token

state (top of stack)	look-ahead token				
	IDENT	**+**	**(**	**)**	EOF
input	expression EOF		expression EOF		
expression	term rest-expr		term rest-expr		
term	IDENT		**(** expression **)**		
rest-expr		**+** expression		ε	ε