Recursive Descent Parsing

Introduction to Recursive Descent Parsing

1. Finished the first part of the course on automaton and languages
2. Next is recursive descent parsers
   - Parsers that expand start symbol into program which is being parsed

Parser Classification

1. LR: Bottom Up Parser
   - L: Scan left to right
   - R: Traces rightmost derivation of input string
2. LL: Top Down Parser
   - L: Scan left to right
   - L: Traces leftmost derivation of input string
3. Parser must be deterministic
   - Looking at leftmost token allows parser to uniquely choose a rule
   - Also must look at end of sentence to choose the correct, unique rule
   - This is why LR parsers are popular
4. Maximum amount of lookup needed for a parser
   - LL(0), LL(1), LR(1), LR(k)
     - 0: No lookahead required
     - 1: 1 token lookahead is required
     - Lower is better!
   - Number (k) refers to maximum look ahead
   - Most parsers don't require more than 2 tokens of lookahead
   - Deterministic parsing is known as non-backtracking parsing
   - Non-deterministic parsing means it can't uniquely choose a rule and will have to backtrack and try another path
     - Not time efficient for very large programs

Recursive Descent Parsing

1. Writing a function to parse each of the non-terminal variables
   - Non-terminal variable -> convert -> select rule for expansion
   - Select correct rule for expansion
     - matchToken(token)
     - Matching: Consumes token
     - Non-matching: Error
   - How do we seelct the correct rule?
     - peekToken
   - Output is an abstract syntax tree
2. Familiar example:
   - expr ::= expr addop term | term
   - term ::= term '*' factor | factor
   - factor ::= '(' expr ')' | num | id
   - addop ::= '+' | '-'

Backus Naur Form (BNF)

1. Backus Naur Form
   - expr ::= expr addop term | term
   - term ::= term '*' factor | factor
   - factor ::= '(' expr ')' | num | id

- addop ::= ‘+’ | ‘-’
- expr and term have left recursion
  - How do we handle this?

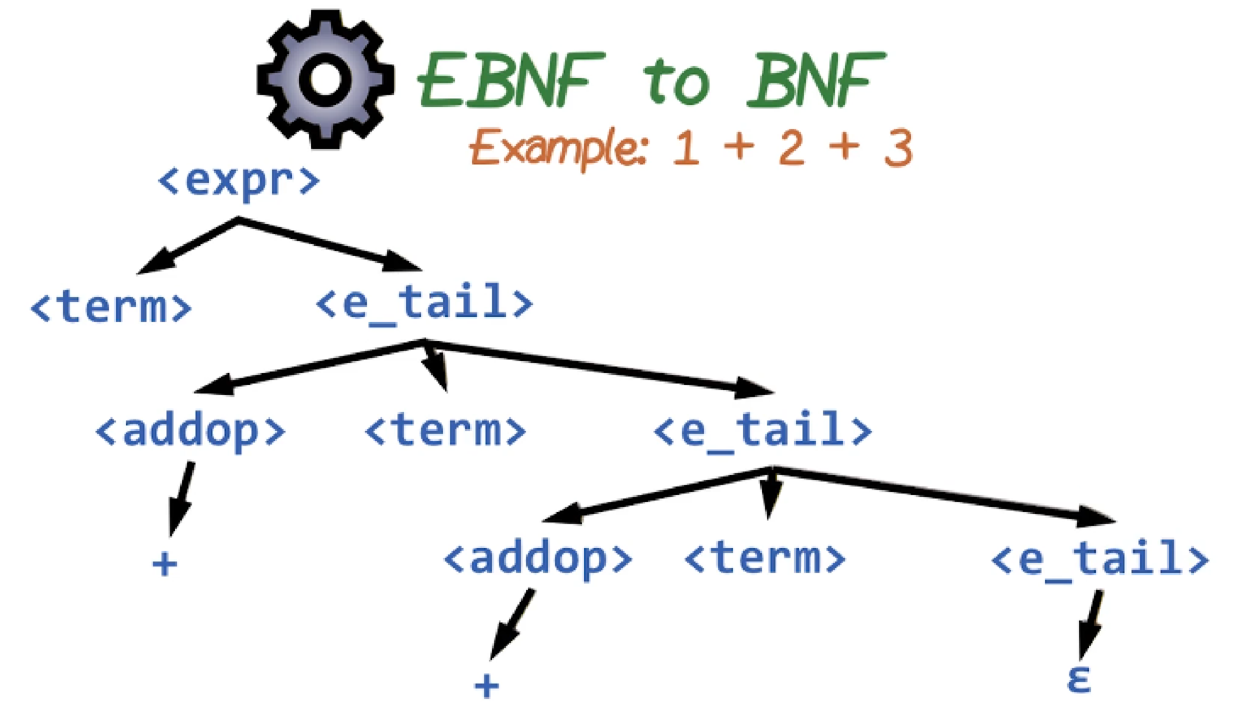
2. Extended Backus Naur Form (EBNF)
   - Uses {} notation ot indicate 0 or more
     - Concept is similar to ‘*’ operator of regexp
     - Num ::= [0-9][0-9]*
   - expr ::= term addop term
     - Head: term
     - Tail: addop term
   - This can be rewritten as:
     - expr ::= term {addop term}

EBNF Quiz

1. Match the operator with its symbol. Put the corresponding letter in the text box.
   - [bnf] {1,3}: Between one and three repetitions
   - [bnf]+: One or more repetitions
   - [bnf]*: Zero or more repetitions

EBNF to BNF

1. term ::= term ‘*’ factor | factor
   - EBNF
     - term ::= factor {‘*’ factor}
   - BNF
     - term ::= factor t_tail
     - t_tail ::= ‘*’ factor t_tail | ’ ’
2. Expressions
   - expr ::= term e_tail
   - e_tail ::= addop term e_tail | ’ ’



EBNF to BNF

Revised Grammar Rules

1. EBNF to BNF
   - expr ::= term e_tail
   - e_tail ::= addop term e_tail | ' '
   - term ::= factor t_tail
   - t_tail ::= '*' factor t_tail | ' '
   - factor ::= '(' expr ')' | num | id
   - addop ::= '+' | '-'

Revised Grammar Rules Quiz

1. Consider the following revised grammar which has removed left recursion and converted it to right. State whether the following statement is true or false.
   - Conversion of left recursion to right recursion makes the grammar ambiguous.
     - False

Solutions Parts 1 and 2

1. EBNF Nonrecursive version

```
// expr ::= term {addop term}
// addop ::= '+' | '-'
void expr()
{
    term();
    int token;
    while ((token = peekToken()) == PLUS || token == MINUS) {
```

```
        matchToken(token);
        term();
    }
}
```

2. BNF Recursive Version

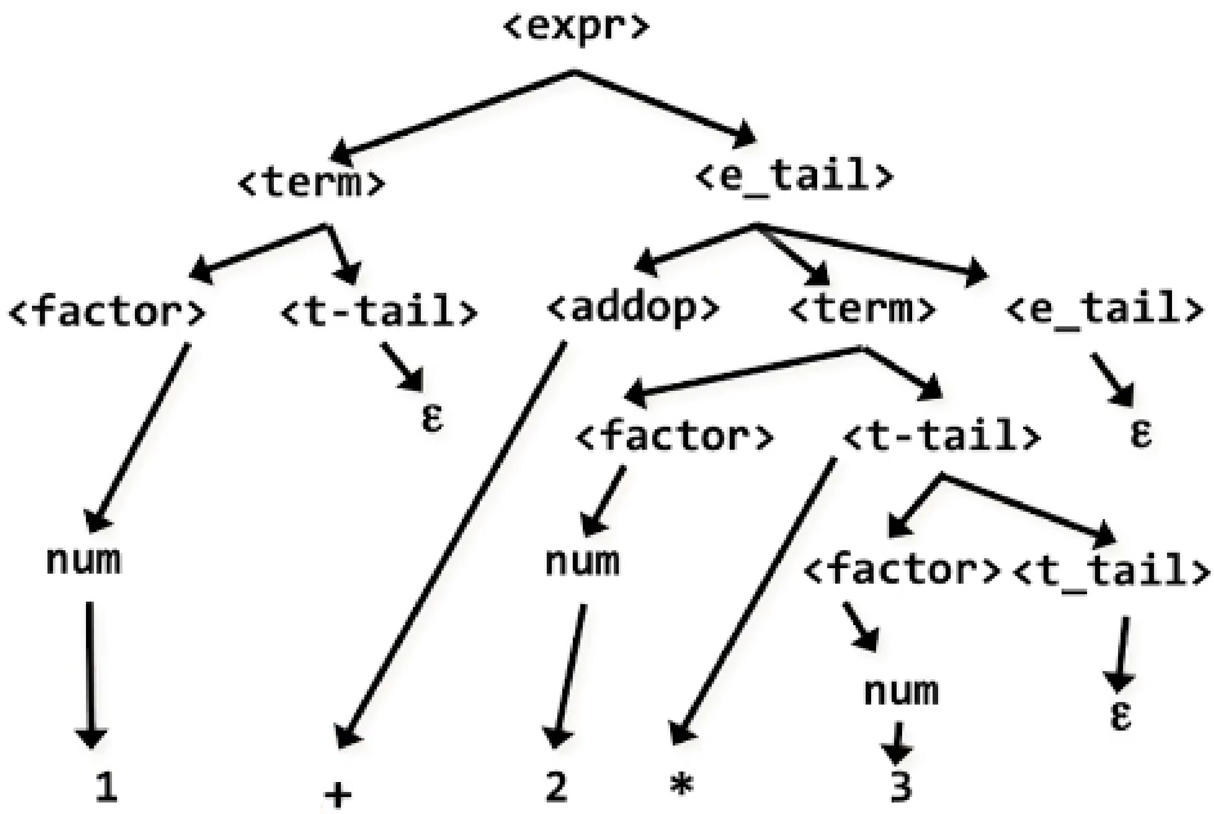
```
// expr ::= term e_tail
// e_tail ::= addop term e_tail | ''
// addop ::= '+' | '-;

enum {PLUS, MINUS, MULT, LPAREN, RPAREN, NUM, ID};
void expr()
{
    term();
    e_tail();
}

void e_tail()
{
    int token;
    if ((token = peekToken()) == PLUS || token == MINUS) {
        matchToken(token);
        term();
        e_tail();
    } else {
        return;
    }
}

void term()
{
    factor();
    t_tail();
}

// term ::= factor t_tail
// t_tail ::= '*' factor t_tail | ''
void t_tail()
{
    if (peekToken() == MULTI) {
        matchToken(MULTI);
        factor();
        t_tail();
    } else {
        return;
    }
}

// factor ::= '(' expr ')' | num | id
void factor()
{
    if (peekToken() == LPAREN) {
        matchToken(LPAREN);
        expr();
```

```
        matchToken(RPAREN);
    } else if (peekToken() == NUM) {
        matchToken(NUM);
    } else if (peekToken() == ID) {
        matchToken(ID);
    }
}
```

Regex Grammar Quiz

1. Write a grammar in BNF to generate regular expression:
   - a* b | c+
   - Use e for epsilon and appropriate non-terminals and S as start symbol
   - a, b, and c are tokens
   - Use ':' for the arrows
2. Solution:
   - S -> A B | C
   - A -> e
   - A -> a A
   - B -> b
   - C -> c D
   - D -> c D
   - D -> e

Solutions Example Part 1 and 2



Recursive Descent Parsing

More of Left Recursion

1. Remove left conversion by converting from BNF to EBNF
2. If a grammar is left recursive we must first rewrite it to make it right recursive
    - Simple immediate left recursion
    - A-> A u | v where v does not start with A
        - Change to A -> v A'
            - A' -> u A' | ''
    - Change exp -> exp addop term
        - exp -> term exp'
        - exp' => addop term exp' | ''
3. General Immediate Left Recursion
    - A -> Au1 | Au2 | ... | Aun | v1 | v2 | ... | vm
        - Where vi does not start with A
    - Solution:
        - A -> v1A' | v2A' | ... | vmA'
        - A' -> u1A' | u2A' | ... | unA' | ''
    - exp -> exp + term | exp - term | term
        - exp -> term exp'
        - exp' -> +term exp' | -term exp' | ''

Left Recursion Quiz 1

1. Given the following grammar, determine if it is left recursive.
   - E -> E + T | T
   - T -> T * F | F
   - F -> (E) | id

Left Recursion Quiz 2

1. Apply the transformation to E and rewrite the grammar.
   - Use 'e' for epsilon.
   - E -> E+T|T
   - Solution:
     - E -> TE'
     - E' -> +TE'|e

Left Recursion Quiz 3

1. Apply the transformation to T and rewrite the grammar.
   - Use 'e' for epsilon.
   - T -> T*F|F
   - Solution:
     - T -> FT'
     - T' -> *FT'|e

Left Recursion Quiz 4

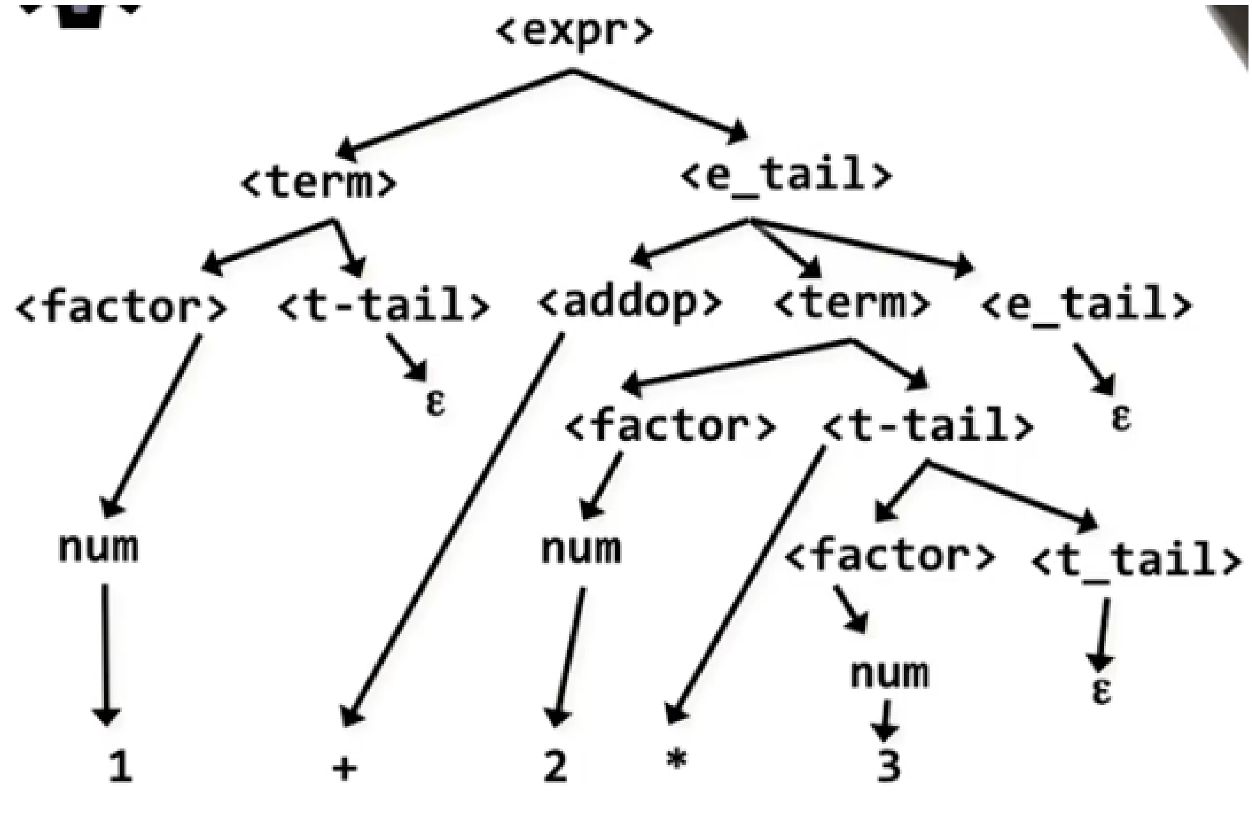
1. Rewrite the grammar in 5 lines.
   - E -> TE'
   - E' -> +TE'|e
   - T -> FT'
   - T' -> *FT'|e
   - F -> (E)|id

Left Factoring

1. Left factoring is required if two or more grammar rule choices share a common prefix string
   - A -> uv | uw
2. Would cause difficulties if we look ahead only one token
   - Solution:
     - A -> uA'
     - A' -> v | w

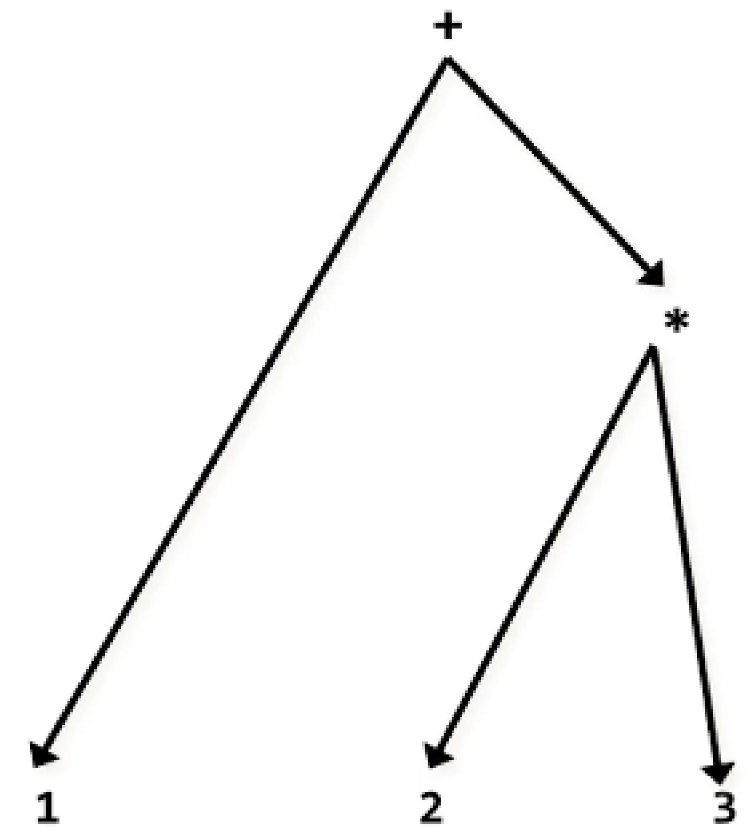
Construct Syntax Tree Part 1

1. What is the desired output? How do we convert a parse tree to an abstract syntax tree?
   - Goal: Remove intermediate non-terminal nodes to connect the token to the sub-tree root node for derivation
   - Epsilon expansions are meant to terminate recursion
     - Remove all e edges
     - Recursively remove their predecessors with outdegree 1
   - Remove intermediate non-terminal nodes to connect the token to the sub-tree root node for derivation
     - Recursively apply this process
   - Replace expr with operator



Parse Tree

Construct Syntax Tree Part 2



Abstract Syntax Tree

1. Syntax-driven Directed Construction

```
SyntaxTree* expr()
{
    SyntaxTree* temp = term();
    int token;
    while ((token = peekToken()) == PLUS || token == MINUS) {
        matchToken(token);

        SyntaxTree* tree = makeOpNode(token);
        tree->leftChild = temp;
        tree->rightChild = term();
        temp = tree;
    }
    return temp;
}
```

2. Can either construct a parse tree and convert it to an AST or generate the AST directly using the above approach