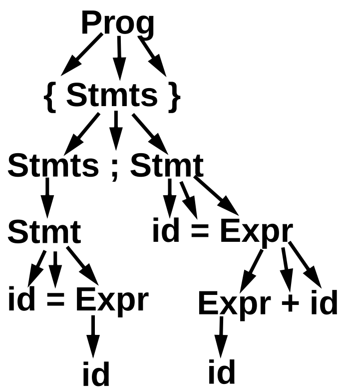
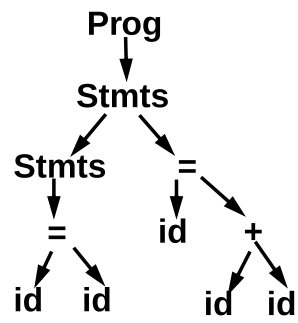
## Parse Trees

To illustrate a derivation, we can draw a *derivation tree* (also called a *parse tree*):






An *abstract syntax tree* (AST) shows essential structure but eliminates unnecessary delimiters and intermediate symbols:






If $A \rightarrow \gamma$ is a production then
$\alpha A \beta \Rightarrow \alpha \gamma \beta$
where $\Rightarrow$ denotes a one step derivation (using production $A \rightarrow \gamma$).

We extend $\Rightarrow$ to $\Rightarrow^+$ (derives in one or more steps), and $\Rightarrow^*$ (derives in zero or more steps).

We can show our earlier derivation as

**Prog** $\Rightarrow$
**{ Stmts }** $\Rightarrow$
**{ Stmts ; Stmt }** $\Rightarrow$
**{ Stmt ; Stmt }** $\Rightarrow$
**{ id = Expr ; Stmt }** $\Rightarrow$
**{ id = id ; Stmt }** $\Rightarrow$
**{ id = id ; id = Expr }** $\Rightarrow$
**{ id = id ; id = Expr + id}** $\Rightarrow$
**{ id = id ; id = id + id}**

**Prog** $\Rightarrow^+$ **{ id = id ; id = id + id}**



When deriving a token sequence, if more than one non-terminal is present, we have a choice of which to expand next.

We must specify, at each step, which non-terminal is expanded, and what production is applied.

For simplicity we adopt a convention on what non-terminal is expanded at each step.

We can choose the leftmost possible non-terminal at each step.

A derivation that follows this rule is a *leftmost derivation*.

If we know a derivation is leftmost, we need only specify what productions are used; the choice of non-terminal is always fixed.

To denote derivations that are leftmost,

we use $\Rightarrow_L$, $\Rightarrow^+_L$ , and $\Rightarrow^*_L$

The production sequence discovered by a large class of parsers (the top-down parsers) is a leftmost derivation, hence these parsers produce a *leftmost parse*.

**Prog** $\Rightarrow_L$

**{ Stmts }** $\Rightarrow_L$

**{ Stmts ; Stmt }** $\Rightarrow_L$

**{ Stmt ; Stmt }** $\Rightarrow_L$

**{ id = Expr ; Stmt }** $\Rightarrow_L$

**{ id = id ; Stmt }** $\Rightarrow_L$

**{ id = id ; id = Expr }** $\Rightarrow_L$

**{ id = id ; id = Expr + id}** $\Rightarrow_L$

**{ id = id ; id = id + id}**

**Prog** $\Rightarrow^+_L$ **{ id = id ; id = id + id}**



# Rightmost Derivations

A rightmost derivation is an alternative to a leftmost derivation. Now the rightmost non-terminal is always expanded.

This derivation sequence may seem less intuitive given our normal left-to-right bias, but it corresponds to an important class of parsers (the bottom-up parsers, including CUP).

As a bottom-up parser discovers the productions used to derive a token sequence, it discovers a rightmost derivation, but in *reverse order*.

The last production applied in a rightmost derivation is the first that is discovered. The first production used, involving the start symbol, is discovered last.



The sequence of productions recognized by a bottom-up parser is a rightmost parse.

It is the exact reverse of the production sequence that represents a rightmost derivation.

For rightmost derivations, we use the notation $\Rightarrow_R$, $\Rightarrow^+_R$ , and $\Rightarrow^*_R$

**Prog** $\Rightarrow_R$

**{ Stmts }** $\Rightarrow_R$

**{ Stmts ; Stmt }** $\Rightarrow_R$

**{ Stmts ; id = Expr }** $\Rightarrow_R$

**{ Stmts ; id = Expr + id }** $\Rightarrow_R$

**{ Stmts ; id = id + id }** $\Rightarrow_R$

**{ Stmt ; id = id + id }** $\Rightarrow_R$

**{ id = Expr ; id = id + id }** $\Rightarrow_R$

**{ id = id ; id = id + id}**

**Prog** $\Rightarrow^+$ **{ id = id ; id = id + id}**



You can derive the same set of tokens using leftmost and rightmost derivations; the only difference is the order in which productions are used.

## Ambiguous Grammars

Some grammars allow more than one parse tree for the same token sequence. Such grammars are *ambiguous*. Because compilers use syntactic structure to drive translation, ambiguity is undesirable—it may lead to an unexpected translation.

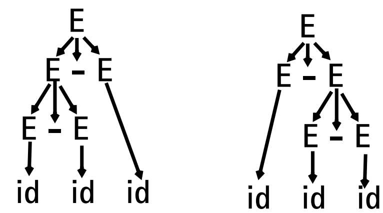
Consider

**E → E - E**

**| id**

When parsing the input a-b-c (where a, b and c are scanned as identifiers) we can build the following two parse trees:






The effect is to parse a-b-c as either (a-b)-c or a-(b-c). These two groupings are certainly not equivalent.

Ambiguous grammars are usually voided in building compilers; the tools we use, like Yacc and CUP, strongly prefer unambiguous grammars.

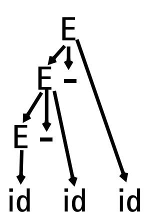
To correct this ambiguity, we use

**E → E - id**

**| id**



Now a-b-c can only be parsed as:






## Operator Precedence

Most programming languages have *operator precedence* rules that state the order in which operators are applied (in the absence of explicit parentheses). Thus in C and Java and CSX, `a+b*c` means compute `b*c`, then add in `a`.

These operators precedence rules can be incorporated directly into a CFG.

Consider

**E → E + T**

**| T**

**T → T * P**

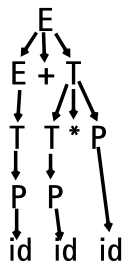
**| P**

**P → id**

**| ( E )**

Does **a+b*c** mean **(a+b)*c** or **a+(b*c)**?

The grammar tells us! Look at the derivation tree:




The other grouping can't be obtained unless explicit parentheses are used.

(Why?)



# Java CUP

Java CUP is a parser-generation tool, similar to Yacc.

CUP builds a Java parser for LALR(1) grammars from production rules and associated Java code fragments.

When a particular production is recognized, its associated code fragment is executed (typically to build an AST).

CUP generates a Java source file **parser.java**. It contains a class **parser**, with a method

```
Symbol parse()
```

The **Symbol** returned by the parser is associated with the grammar's start symbol and contains the AST for the whole source program.



The file **sym.java** is also built for use with a JLex-built scanner (so that both scanner and parser use the same token codes).

If an unrecovered syntax error occurs, **Exception()** is thrown by the parser.

CUP and Yacc accept exactly the same class of grammars—all LL(1) grammars, plus many useful non-LL(1) grammars.

CUP is called as

```
java java_cup.Main < file.cup
```



# Java CUP Specifications

Java CUP specifications are of the form:

- Package and import specifications
- User code additions
- Terminal and non-terminal declarations
- A context-free grammar, augmented with Java code fragments

## Package and Import Specifications

You define a package name as:

```
package name ;
```

You add imports to be used as:

```
import java_cup.runtime.*;
```

## User Code Additions

You may define Java code to be included within the generated parser:

`action code {: /*java code */ :}`
This code is placed within the generated action class (which holds user-specified production actions).

`parser code {: /*java code */ :}`
This code is placed within the generated parser class .

`init with{: /*java code */ :}`
This code is used to initialize the generated parser.

`scan with{: /*java code */ :}`
This code is used to tell the generated parser how to get tokens from the scanner.



## Terminal and Non-terminal Declarations

You define terminal symbols you will use as:

**terminal classname** $\textbf{name}_1$**,** $\textbf{name}_2$**, ...**

**classname** is a class used by the scanner for tokens (**CSXToken**, **CSXIdentifierToken**, etc.)

You define non-terminal symbols you will use as:

**non terminal classname** $\textbf{name}_1$**,** $\textbf{name}_2$**, ...**

**classname** is the class for the AST node associated with the non-terminal (**stmtNode**, **exprNode**, etc.)



## Production Rules

Production rules are of the form

**name ::=** $\textbf{name}_1$ $\textbf{name}_2$ **... action ;**

or

**name ::=** $\textbf{name}_1$ $\textbf{name}_2$ **...** $\textbf{action}_1$
    **|** $\textbf{name}_3$ $\textbf{name}_4$ **...** $\textbf{action}_2$
    **| ...**
    **;**

Names are the names of terminals or non-terminals, as declared earlier.

Actions are Java code fragments, of the form

`{: /*java code */ :}`

The Java object assocated with a symbol (a token or AST node) may be named by adding a **:id** suffix to a terminal or non-terminal in a rule.



**RESULT** names the left-hand side non-terminal.

The Java classes of the symbols are defined in the terminal and non-terminal declaration sections.

For example,

```
prog ::= LBRACE:l stmts:s RBRACE
   {: RESULT =
        new csxLiteNode(s,
          l.linenum,l.colnum); :}
```

This corresponds to the production

**prog → { stmts }**

The left brace is named **l**; the stmts non-terminal is called **s**.

In the action code, a new **CSXLiteNode** is created and assigned to **prog**. It is constructed from the AST node associated with **s**. Its line and column numbers are those given to the left brace, **l** (by the scanner).

To tell CUP what non-terminal to use as the start symbol (**`prog`** in our example), we use the directive:

```
start with prog;
```