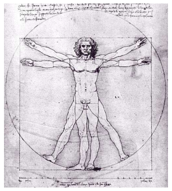
Anatomy of a Small Compiler

COMS W4115



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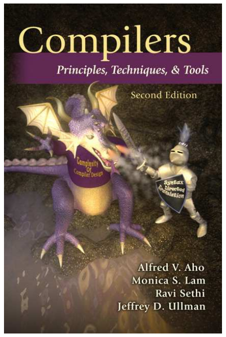
Appendix A of the Dragon Book



A simple C-like language

```
{
  int i; int j;
  float[10][10] a;
  i = 0;
  while ( i < 10 ) {
    j = 0;
    while ( j < 10 ) {
      a[i][j] = 0;
      j = j+1;
    }
    i = i+1;
  }
  i = 0;
  while ( i < 10 ) {
    a[i][i] = 1;
    i = i+1;
  }
}
```

```
L1:  i = 0
L3:  iffalse i < 10 goto L4
L5:  j = 0
L6:  iffalse j < 10 goto L7
L8:  t1 = i * 80
     t2 = j * 8
     t3 = t1 + t2
     a [ t3 ] = 0
L9:  j = j + 1
     goto L6
L7:  i = i + 1
     goto L3
L4:  i = 0
L10: iffalse i < 10 goto L2
L11: t4 = i * 80
     t5 = i * 8
     t6 = t4 + t5
     a [ t6 ] = 1
L12: i = i + 1
     goto L10
L2:
```

The Scanner

```
class MyLexer extends Lexer;
options { k = 2; }

WHITESPACE : (' ' | '\t' | '\n' { newline(); } )+
             { $setType(Token.SKIP); } ;

protected DIGITS : ('0'..'9')+ ;

NUM : DIGITS ('.' DIGITS { $setType(REAL); } )? ;

AND :     "&&" ;   LE :     "<=" ;   SEMI :   ';'  ;
OR  :     "||" ;   GT :     '>'  ;   LPAREN : '('  ;
ASSIGN : '='   ;   GE :     ">=" ;   RPAREN : ')'  ;
EQ :      "==" ;   LBRACE : '{'  ;   PLUS :   '+'  ;
NOT :     '!'  ;   RBRACE : '}'  ;   MINUS :  '-'  ;
NE :      "!=" ;   LBRACK : '['  ;   MUL :    '*'  ;
LT :      '<'  ;   RBRACK : ']'  ;   DIV :    '/'  ;

ID : ('_' | 'a'..'z' | 'A'..'Z')
     ('_' | 'a'..'z' | 'A'..'Z' | '0'..'9')* ;
```

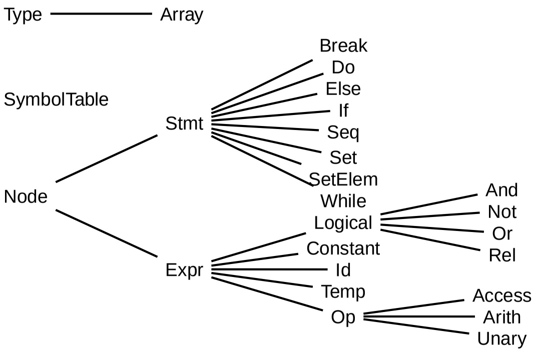
The Parser: Statements

```
class MyParser extends Parser;
options { buildAST = true; }
tokens  { NEGATE; DECLS; }

program : LBRACE^ decls (stmt)* RBRACE! ;

decls : (decl)* { #decls = #([DECLS, "DECLS"], #decls); } ;

decl : ("int" | "char" | "bool" | "float")
       (LBRACK! NUM RBRACK!)* ID SEMI! ;

stmt : loc ASSIGN^ bool SEMI!
     | "if"^ LPAREN! bool RPAREN! stmt
       (options {greedy=true;}: "else"! stmt)?
     | "while"^ LPAREN! bool RPAREN! stmt
     | "do"^ stmt "while"! LPAREN! bool RPAREN! SEMI!
     | "break" SEMI!
     | program
     | SEMI
     ;
```

The Parser: Expressions

```
bool     : join (OR^ join)* ;

join     : equality (AND^ equality)* ;

equality : rel ((EQ^ | NE^) rel)* ;

rel      : expr ((LT^ | LE^ | GT^ | GE^) expr)* ;

expr     : term ((PLUS^ | MINUS^) term)* ;

term     : unary ((MUL^ | DIV^) unary)* ;

unary    : MINUS^ unary { #unary.setType(NEGATE); }
         | NOT^ unary | factor ;

factor   : LPAREN! bool RPAREN! | loc
         | NUM | REAL | "true" | "false" ;

loc      : ID^ (LBRACK! bool RBRACK!)* ;
```

The IR Classes



SymbolTable.java

```
public class SymbolTable {
    private Hashtable table;
    protected SymbolTable outer;
    public SymbolTable(SymbolTable st) {
        table = new Hashtable();
        outer = st;
    }
    public void put(String token, Type t, int b) {
        table.put(token, new Id(token, t, b));
    }
    public Id get(String token) {
        for (SymbolTable tab = this ; tab != null ;
             tab = tab.outer) {
            Id id = (Id)(tab.table.get(token));
            if ( id != null ) return id;
        }
        return null;
    }
}
```

Type.java (Basic types)

```
public class Type {
    public int width = 0;
    public String name = "";
    public Type(String s, int w) { name = s; width = w; }
    public static final Type
      Int = new Type("int", 4), Float = new Type("float", 8),
      Char = new Type("char", 1), Bool = new Type("bool", 1);
    public static boolean numeric(Type p) {
        return p == Type.Char || p == Type.Int ||
               p == Type.Float; }
    public static Type max(Type p1, Type p2) {
        if (!numeric(p1) || !numeric(p2)) return null;
        else if (p1 == Type.Float || p2 == Type.Float)
            return Type.Float;
        else if (p1 == Type.Int || p2 == Type.Int)
            return Type.Int;
        else return Type.Char;
    }
}
```

Node.java (Stmts and Exprs)

```
public class Node {
    void error(String s) { throw new Error(s); }
    static int labels = 0;
    public static int newlabel() { return ++labels; }
    public static void emitlabel(int i) {
       System.out.print("L" + i + ":");
    }
    public static void emit(String s) {
       System.out.println("\t" + s);
    }
}
```

Expr.java (has a type)

```
public class Expr extends Node {
  public String s;
  public Type type;
  Expr(String tok, Type p) { s = tok; type = p; }
  public Expr gen() { return this; }
  public Expr reduce() { return this; }
  public void jumping(int t, int f) {
    emitjumps(toString(), t, f); }
  public void emitjumps(String test, int t, int f) {
    if (t != 0 && f != 0) {
      emit("if " + test + " goto L" + t);
      emit("goto L" + f);
    } else if (t != 0) emit("if " + test + " goto L" + t);
    else if (f != 0) emit("iffalse " + test + " goto L" + f);
  }
  public String toString() { return s; }
}
```

Op.java (operator)

```
public class Op extends Expr {
    public Op(String tok, Type p) { super(tok,p); }
    public Expr reduce() {
        Expr x = gen();
        Temp t = new Temp(type);
        emit(t.toString() + " = " + x.toString());
        return t;
    }
}
```

Arith.java (binary arithmetic)

```
public class Arith extends Op {
    public Expr expr1, expr2;
    public Arith(String op, Expr x1, Expr x2) {
        super(op, null); expr1 = x1;  expr2 = x2;
        type = Type.max(expr1.type, expr2.type);
        if (type == null) error("type error");
    }
    public Expr gen() { return new Arith(s, expr1.reduce(),
                                         expr2.reduce()); }
    public String toString() {
        return expr1.toString() + " " + s + " " +
               expr2.toString();
    }
}
```

Logical.java (logical operator)

```
public class Logical extends Expr {
  public Expr expr1, expr2;
  Logical(String tok, Expr x1, Expr x2) {
    super(tok, null); expr1 = x1; expr2 = x2;
    type = check(expr1.type, expr2.type);
    if (type == null) error("type error");
  }
  public Type check(Type p1, Type p2) {
    if (p1 == Type.Bool && p2 == Type.Bool) return Type.Bool;
    else return null;
  }
  public Expr gen() {
    int f = newlabel(); int a = newlabel();
    Temp temp = new Temp(type);
    this.jumping(0, f);
    emit(temp.toString() + " = true");
    emit("goto L" + a); emitlabel(f);
    emit(temp.toString() + " = false");
    emitlabel(a);
    return temp;
  }
  public String toString(){
    return expr1.toString() + " "+ s + " "+ expr2.toString();
  }
}
```

And.java (logical AND)

```
public class And extends Logical{
    public And(Expr x1, Expr x2) { super("&&", x1, x2); }
    public void jumping(int t, int f) {
        int label = f != 0 ? f : newlabel();
        expr1.jumping(0, label);
        expr2.jumping(t, f);
        if (f == 0) emitlabel(label);
    }
}
```

Stmt.java (statements)

```
public class Stmt extends Node {
    public Stmt() {}
    public static Stmt Null = new Stmt();
    public void gen(int b, int a) {}
    int after = 0;
    public static Stmt Enclosing = Stmt.Null;
}
```

While.java (while loop)

```
public class While extends Stmt{
    Expr expr;
    Stmt stmt;
    public While() { expr = null; stmt = null; }
    public void init(Expr x,Stmt s){
        expr = x;
        stmt = s;
        if (expr.type != Type.Bool)
          expr.error("boolean required in while");
    }
    public void gen(int b, int a){
        after = a;
        expr.jumping(0, a);
        int label = newlabel();
        emitlabel(label);
        stmt.gen(label, b);
        emit("goto L" + b);
    }
}
```

Tree Walker (Program)

```
class MyWalker extends TreeParser;
{
  SymbolTable top = null;
  int used = 0; // Number of bytes in local declarations
}

program returns [Stmt s]
{ s = null; Stmt s1;}
  : #(LBRACE
      { SymbolTable saved_environment = top;
        top = new SymbolTable(top); }
      decls
      s=stmts
      { top = saved_environment; }
    )
  ;
```

Tree Walker (Declarations)

```
decls
{ Type t = null; }
  : #(DECLS
      (t=type ID { top.put(#ID.getText(), t, used);
                   used += t.width; } )* )
  ;
type returns [Type t]
{ t = null; }
  : ( "bool"  { t = Type.Bool;  }
    | "char"  { t = Type.Char;  }
    | "int"   { t = Type.Int;   }
    | "float" { t = Type.Float; } )
    (t=dims[t])?
  ;
dims[Type t1] returns [Type t]
{ t = t1; }
  : NUM (t=dims[t])?
    { t = new Array(Integer.parseInt(#NUM.getText()), t); }
  ;
```

Tree Walker (Statements)

```
stmts returns [Stmt s]
{ s = null; Stmt s1; }
  : s=stmt (s1=stmts { s = new Seq(s, s1); } )?
  ;

stmt returns [Stmt s]
{ Expr e1, e2;
  s = null;
  Stmt s1, s2;
}
  : #(ASSIGN e1=expr e2=expr
      { if (e1 instanceof Id) s = new Set((Id) e1, e2);
        else s = new SetElem((Access) e1, e2);
      }
    )
  | #("if" e1=expr s1=stmt
       ( s2=stmt { s = new Else(e1, s1, s2); }
       | /* nothing */ { s = new If(e1, s1); } ))
```

```
| #("while"
     { While whilenode = new While();
       s2 = Stmt.Enclosing;
       Stmt.Enclosing = whilenode; }
     e1=expr
     s1=stmt
     { whilenode.init(e1, s1);
       Stmt.Enclosing = s2;
       s = whilenode; } )
| #("do"
     { Do donode = new Do();
       s2 = Stmt.Enclosing;
       Stmt.Enclosing = donode; }
     s1=stmt
     e1=expr
     { donode.init(s1, e1);
       Stmt.Enclosing = s2;
       s = donode; } )
| "break" { s = new Break(); }
| s=program
| SEMI { s = Stmt.Null; }
;
```

Tree Walker (Expressions)

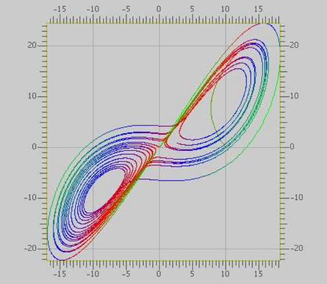
```
expr returns [Expr e]
{
  Expr a, b;
  e = null;
}
  : #(OR     a=expr b=expr { e = new Or(a, b); } )
  | #(AND    a=expr b=expr { e = new And(a, b); } )
  | #(EQ     a=expr b=expr { e = new Rel("==", a, b); } )
  | #(NE     a=expr b=expr { e = new Rel("!=", a, b); } )
  | #(LT     a=expr b=expr { e = new Rel("<", a, b); } )
  | #(LE     a=expr b=expr { e = new Rel("<=", a, b); } )
  | #(GT     a=expr b=expr { e = new Rel(">", a, b); } )
  | #(GE     a=expr b=expr { e = new Rel(">=", a, b); } )
  | #(PLUS   a=expr b=expr { e = new Arith("+", a, b); } )
  | #(MINUS  a=expr b=expr { e = new Arith("-", a, b); } )
  | #(MUL    a=expr b=expr { e = new Arith("*", a, b); } )
  | #(DIV    a=expr b=expr { e = new Arith("/", a, b); } )
  | #(NOT    a=expr        { e = new Not(a); } )
  | #(NEGATE a=expr        { e = new Unary("-", a); } )
  | NUM  { e = new Constant(#NUM.getText(), Type.Int); }
```

```
| REAL { e = new Constant(#REAL.getText(), Type.Float); }
| "true"                  { e = Constant.True; }
| "false"                 { e = Constant.False; }
| #(ID
    { Id i = top.get(#ID.getText());
      if (i == null)
        System.out.println(#ID.getText() + " undeclared");
      e = i;
    }
    ( a=expr
      { Type type = e.type;
        type = ((Array)type).of;
        Expr w = new Constant(type.width);
        Expr loc = new Arith("*", a, w);
      }
      ( a=expr
        { type = ((Array)type).of;
          w = new Constant(type.width);
          loc = new Arith("+", loc, new Arith("*", a, w));
        }
      )*
      { e = new Access(i, loc, type); }
    )?
  )
;
```

Statistics

File	Role	# lines
grammar.g	Scanner/Parser/Walker	190
Main.java	main() procedure	27
SymbolTable.java	Symbol table	20
Type.java	Basic types	19
Array.java	Array type	10
Node.java	Statements and Expressions	7
Stmt.java	A node	7
Break.java	break statement	10
Do.java	do-while statement	17
Else.java	if-else statement	17
If.java	if statement	14
Seq.java	statement sequences	15
SetElem.java	assign to array	22
Set.java	assign to scalar	19
While.java	while statement	18
Expr.java	A node	16
Constant.java	constant expression	11
Id.java	variable identifier	4
Temp.java	temporary variable	6
Op.java	operator (expression)	9
Access.java	array index	10
Arith.java	arithmetic expression	12
Unary.java	unary negation	10
Logical.java	logical operator (expression)	27
And.java	logical AND	9
Not.java	logical NOT	5
Or.java	logical OR	9
Rel.java	$<$, =, etc.	14
total		550

Mx



Mx

A Programming Langauge for Scientific Computation

Resembles Matlab, Octave, Mathematica, etc.

Project from Spring 2003

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Example

Plotting the Lorenz equations

$$\begin{aligned}\frac{dy_0}{dt} &= \alpha(y_1 - y_0)\\ \frac{dy_1}{dt} &= y_0(r - y_2) - y_1\\ \frac{dy_2}{dt} &= y_0 y_1 - b y_2\end{aligned}$$

Mx source part 1

```
/* Lorenz equation parameters*/

a = 10;
b = 8/3.0;
r = 28;

/* Two-argument function returning a vector*/
 func Lorenz ( y, t ) = [ a*(y[1]-y[0]);
                        -y[0]*y[2] + r*y[0] - y[1];
                        y[0]*y[1] - b*y[2] ];

/* Runge-Kutta numerical integration procedure*/
func RungeKutta( f, y, t, h ) {
    k1 = h * f( y, t );
    k2 = h * f( y+0.5*k1, t+0.5*h );
    k3 = h * f( y+0.5*k2, t+0.5*h );
    k4 = h * f( y+k3, t+h );
    return y + (k1+k4)/6.0 + (k2+k3)/3.0;
}
```

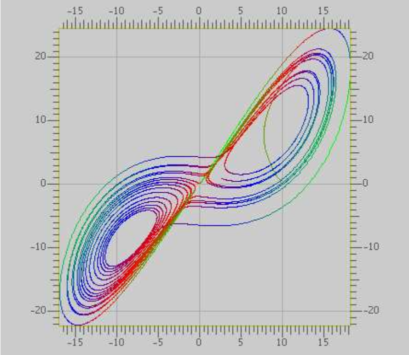
Mx source part 2

```
/* Parameters for the procedure*/
N = 20000;
p = zeros(N+1,3);
t = 0.0;
h = 0.001;
x = [ 10; 0; 10 ];
p[0,:] = x’; /* matrix transpose */

for ( i = 1:N ) {
    x = RungeKutta( Lorenz, x, t, h );
    p[i,:] = x’;
    t += h;
}

colormap(3);
plot(p);
return 0;
```

Result



file	lines	role
Scanner and Parser: Builds the tree		
grammar.g	314	Lexer/Parser (ANTLR source)
Interpreter: Walks the tree, invokes objects’ methods		
walker.g	170	Tree Walker (ANTLR source)
MxInterpreter.java	359	Function invocation, etc.
MxSymbolTable.java	109	Name-to-object mapping
Top-level: Invokes the interpreter		
MxMain.java	153	Command-line interface
MxException.java	13	Error reporting
Runtime system: Represents data, performs operations		
MxDataType.java	169	Base class
MxBool.java	63	Booleans
MxInt.java	152	Integers
MxDouble.java	142	Floating-point
MxString.java	47	String
MxVariable.java	26	Undefined variable
MxFunction.java	81	User-defined functions
MxInternalFunction.m4	410	sin, cos, etc. (macro processed)
jamaica/Matrix.java	1387	Matrices
MxMatrix.java	354	Wrapper
jamaica/Range.java	163	e.g., 1:10
MxRange.java	67	Wrapper
jamaica/BitArray.java	226	Matrix masks
MxBitArray.java	47	Wrapper
jamaica/Painter.java	339	Bitmaps
jamaica/Plotter.java	580	2-D plotting
total	5371	

The Scanner

```
class MxAntlrLexer extends Lexer;

options {
    k = 2;
    charVocabulary = ’\3’..’\377’;
    testLiterals = false;
    exportVocab = MxAntlr;
}

protected ALPHA : ’a’..’z’ | ’A’..’Z’ | ’_’;

protected DIGIT : ’0’..’9’;

WS : (’ ’ | ’\t’)+ { $setType(Token.SKIP); } ;

NL : (’\n’ | (’\r’ ’\n’) => ’\r’ ’\n’ | ’\r’)
     { $setType(Token.SKIP); newline(); } ;
```

The Scanner

```
COMMENT : ( "/*" ( options {greedy=false;} :
                   NL
                   | ~( ’\n’ | ’\r’ )
                 )* "*/"
             | "//" (~( ’\n’ | ’\r’ ))* NL
           ) { $setType(Token.SKIP); } ;

LDV_LDVEQ : "/’" (
                   (’=’) => ’=’ { $setType(LDVEQ); }
                   | { $setType(LDV); }
                 );
```

The Scanner

```
LPAREN  : ’(’;
RPAREN  : ’)’;
/* ... */
TRSP    : ’\’’;
COLON   : ’:’;
DCOLON  : "::";

ID options { testLiterals = true; }
  : ALPHA (ALPHA|DIGIT)* ;

NUMBER : (DIGIT)+ (’.’ (DIGIT)*)?
         ((’E’|’e’) (’+’|’-’)? (DIGIT)+)? ;

STRING : ’"’!
         ( ~(’"’ | ’\n’) | (’"’! ’"’) )*
         ’"’! ;
```

The Parser: Top-level

```
class MxAntlrParser extends Parser;

options {
    k = 2;
    buildAST = true;
    exportVocab = MxAntlr;
}

tokens {
   STATEMENT;
   FOR_CON;
   /* ... */
}

program : ( statement | func_def )* EOF!
          { #program = #([STATEMENT,"PROG"], program); }
        ;
```

The Parser: Statements

```
statement
  : for_stmt
  | if_stmt
  | loop_stmt
  | break_stmt
  | continue_stmt
  | return_stmt
  | load_stmt
  | assignment
  | func_call_stmt
  | LBRACE! (statement)* RBRACE!
      {#statement = #([STATEMENT,"STATEMENT"], statement); }
  ;
```

The Parser: Statements 1

```
for_stmt : "for"^ LPAREN! for_con RPAREN! statement ;

for_con : ID ASGN! range (COMMA! ID ASGN! range)*
          { #for_con = #([FOR_CON,"FOR_CON"], for_con); }
        ;

if_stmt : "if"^ LPAREN! expression RPAREN! statement
          (options {greedy = true;}: "else"! statement )?
        ;

loop_stmt! : "loop" ( LPAREN! id:ID RPAREN! )? stmt:statement
      { if ( null == #id )
           #loop_stmt = #([LOOP,"loop"], #stmt);
        else
           #loop_stmt = #([LOOP,"loop"], #stmt, #id);
      } ;
```

The Parser: Statements 2

```
break_stmt : "break"^ (ID)? SEMI! ;
continue_stmt : "continue"^ (ID)? SEMI! ;
return_stmt : "return"^ (expression)? SEMI! ;
load_stmt : "include"^ STRING SEMI! ;

assignment
  : l_value ( ASGN^ | PLUSEQ^ | MINUSEQ^ | MULTEQ^
            | LDVEQ^ | MODEQ^ | RDVEQ^
            ) expression SEMI!
  ;

func_call_stmt : func_call SEMI! ;

func_call
  : ID LPAREN! expr_list RPAREN!
    { #func_call = #([FUNC_CALL,"FUNC_CALL"], func_call); }
  ;
```

The Parser: Function Definitions

```
func_def
  : "func"^ ID LPAREN! var_list RPAREN! func_body
  ;

var_list
  : ID ( COMMA! ID )*
    { #var_list = #([VAR_LIST,"VAR_LIST"], var_list); }
  | { #var_list = #([VAR_LIST,"VAR_LIST"], var_list); }
  ;

func_body
   : ASGN! a:expression SEMI!
     { #func_body = #a; }
   | LBRACE! (statement)* RBRACE!
     { #func_body = #([STATEMENT,"FUNC_BODY"], func_body); }
   ;
```

The Parser: Expressions

```
expression : logic_term ( "or"^ logic_term )* ;
logic_term : logic_factor ( "and"^ logic_factor )* ;
logic_factor : ("not"^)? relat_expr ;
relat_expr : arith_expr ( (GE^ | LE^ | GT^
                        | LT^ | EQ^ | NEQ^) arith_expr )? ;
arith_expr : arith_term ( (PLUS^ | MINUS^) arith_term )* ;
arith_term : arith_factor
    ( (MULT^ | LDV^ | MOD^ | RDV^) arith_factor )* ;
arith_factor
 : PLUS! r_value
   { #arith_factor = #([UPLUS,"UPLUS"], arith_factor); }
 | MINUS! r_value
   { #arith_factor = #([UMINUS,"UMINUS"], arith_factor); }
 | r_value (TRSP^)* ;
r_value
  : l_value | func_call | NUMBER | STRING | "true" | "false"
  | array | LPAREN! expression RPAREN! ;
l_value : ID^ ( LBRK! index RBRK! )* ;
```

The Walker: Top-level

```
{
  import java.io.*;
  import java.util.*;
}

class MxAntlrWalker extends TreeParser;
options{
    importVocab = MxAntlr;
}

{
    static MxDataType null_data = new MxDataType( "<NULL>" );
    MxInterpreter ipt = new MxInterpreter();
}
```

The Walker: Expressions

```
expr returns [ MxDataType r ]
{
    MxDataType a, b;
    Vector v;
    MxDataType[] x;
    String s = null;
    String[] sx;
    r = null_data;
}
  : #("or" a=expr right_or:.)
      { if ( a instanceof MxBool )
            r = ( ((MxBool)a).var ? a : expr(#right_or) );
        else
            r = a.or( expr(#right_or) );
      }
  | #("and" a=expr right_and:.)
      { if ( a instanceof MxBool )
             r = ( ((MxBool)a).var ? expr(#right_and) : a );
        else
             r = a.and( expr(#right_and) );
      }
```

The Walker: Simple operators

```
| #("not" a=expr)           { r = a.not(); }
| #(GE a=expr b=expr)       { r = a.ge( b ); }
| #(LE a=expr b=expr)       { r = a.le( b ); }
| #(GT a=expr b=expr)       { r = a.gt( b ); }
| #(LT a=expr b=expr)       { r = a.lt( b ); }
| #(EQ a=expr b=expr)       { r = a.eq( b ); }
| #(NEQ a=expr b=expr)      { r = a.ne( b ); }
| #(PLUS a=expr b=expr)     { r = a.plus( b ); }
| #(MINUS a=expr b=expr)    { r = a.minus( b ); }
| #(MULT a=expr b=expr)     { r = a.times( b ); }
| #(LDV a=expr b=expr)      { r = a.lfracts( b ); }
| #(RDV a=expr b=expr)      { r = a.rfracts( b ); }
| #(MOD a=expr b=expr)      { r = a.modulus( b ); }
| #(COLON (c1:. (c2:.)?)?)
   {
     r = MxRange.create( (null==#c1) ? null : expr(#c1),
                         (null==#c2) ? null : expr(#c2) );
   }
| #(ASGN a=expr b=expr)      { r = ipt.assign( a, b ); }
| #(FUNC_CALL a=expr x=mexpr){ r = ipt.funcInvoke(this,a,x); }
```

The Walker: Literals, Variables, and Functions

```
| #(ARRAY                    { v = new Vector(); }
     (a=expr                 { v.add( a ); }
     )*
   ) { r = MxMatrix.joinVert( ipt.convertExprList( v ) ); }
| #(ARRAY_ROW                { v = new Vector(); }
     (a=expr                 { v.add( a ); }
     )+
   ) { r = MxMatrix.joinHori( ipt.convertExprList( v ) ); }
| num:NUMBER                 { r = ipt.getNumber( num.getText()
| str:STRING                 { r = new MxString( str.getText() )
| "true"                     { r = new MxBool( true ); }
| "false"                    { r = new MxBool( false ); }
| #(id:ID                    { r = ipt.getVariable( id.getText()
    ( x=mexpr { r = ipt.subMatrix( r, x ); } )*
   )
| #("func" fname:ID sx=vlist fbody:.)
  { ipt.funcRegister( fname.getText(), sx, #fbody ); }
```

The Walker: For and If statements

```
| #("for" x=mexpr forbody:.)
    {
        MxInt[] values = ipt.forInit( x );
        while ( ipt.forCanProceed( x, values ) ) {
          r = expr( #forbody );
          ipt.forNext( x, values );
        }
        ipt.forEnd( x );
    }
| #("if" a=expr thenp:. (elsep:.)?)
    {
        if ( !( a instanceof MxBool ) )
            return a.error( "if: expression should be bool" );
        if ( ((MxBool)a).var )
            r = expr( #thenp );
        else if ( null != elsep )
            r = expr( #elsep );
    }
```

The Walker: Multiple expressions

```
mexpr returns [ MxDataType[] rv ]
{
    MxDataType a;
    rv = null;
    Vector v;
}
  : #(EXPR_LIST         { v = new Vector(); }
          ( a=expr      { v.add( a ); }
          )*
     )                  { rv = ipt.convertExprList( v ); }
  | a=expr              { rv = new MxDataType[1]; rv[0] = a; }
  |  #(FOR_CON          { v = new Vector(); }
          ( s:ID a=expr { a.setName( s.getText() ); v.add(a); }
          )+
      )                 { rv = ipt.convertExprList( v ); }
  ;
```

The Walker: Variable list

```
vlist returns [ String[] sv ]
{
    Vector v;
    sv = null;
}
  : #(VAR_LIST     { v = new Vector(); }
        (s:ID      { v.add( s.getText() ); }
        )*
    )              { sv = ipt.convertVarList( v ); }
  ;
```