COP 3402 Systems Software

Intermediate Code Generation

Outline

1. From a syntax graph to a recursive decent parser
2. Syntax of tiny-PL/0 (subset of PL/0)
3. Generation of PM/0 code for programming constructs of tiny-PL/0
4. Symbol table

Building a Parser from a Syntax Graph

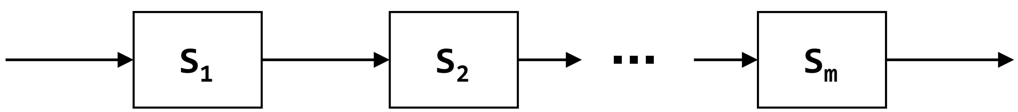
Transforming a grammar expressed in EBNF to syntax graph is helps visualize the parsing process of a sentence because the syntax graph reflects the flow of control of the parser.

Rules to construct a parser from a syntax graph (N. Wirth):

B1.- Reduce the system of graphs to as few individual graphs as possible by appropriate substitution.

B2.- Translate each graph into a procedure declaration according to the subsequent rules B3 through B7.

B3.- A sequence of elements



is translated into the compound statement

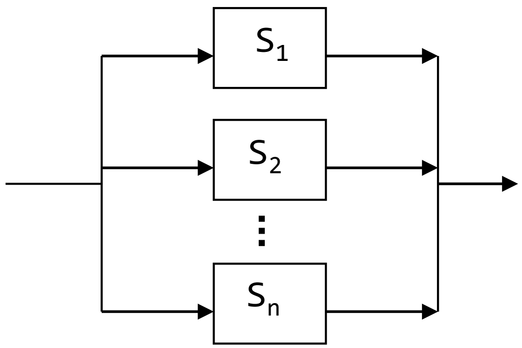
$$\{\ T(S_1);\ T(S_2);\ \ldots\ ;\ T(S_n)\ \}$$

$T(S_i)$ **denotes the translation of graph** S_i

Building a Parser from a Syntax Graph

<u>**Rules to construct a parser from a syntax graph:**</u>

B4.- A choice of elements




```
switch (tok)
{
  case tok in L1 : T(S1);    if tok in L1 T(S1) else
  case tok in L2 : T(S2);    if tok in L2 T(S2) else
  ...                        ...
  case tok in Ln : T(Sn);    if tok in Ln T(Sn)}
  default: error             else   error
}
```

is translated into **a selective statement or** **a conditional statement**

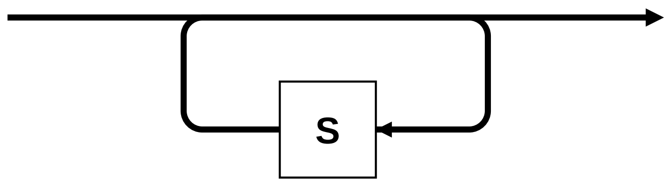
L_i denotes the set of tokens that can occur at the beginning of S_i.

L_i contains a single token, say `t`, then `tok in` L_i should be expressed as `tok == t`

Building a Parser from a Syntax Graph

Rules to construct a parser from a syntax graph:

B5.- A loop of the form



is translated into the statement

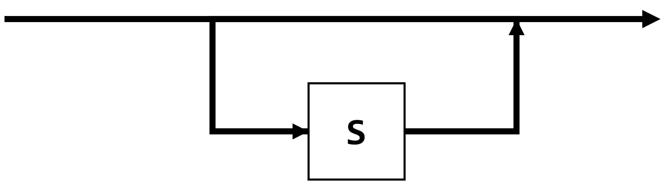
```
while tok in L do T(S)
```

where `T(S)` is the translation of `S` according to rules B3 through B7

Building a Parser from a Syntax Graph

Rules to construct a parser from a syntax graph:

B6.- A loop of the form



is translated into the statement

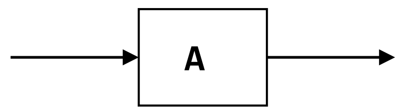
```
if ch in L { T(S) }
```

where `T(S)` is the translation of `S` according to rules B3 through B8

Building a Parser from a Syntax Graph

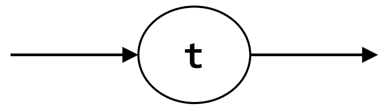
Rules to construct a parser from a syntax graph:

B7.- An element of the graph denoting another graph A



is translated into the procedure call statement `A`.

B8.- An element of the graph denoting a terminal symbol *x*



is translated into the statement

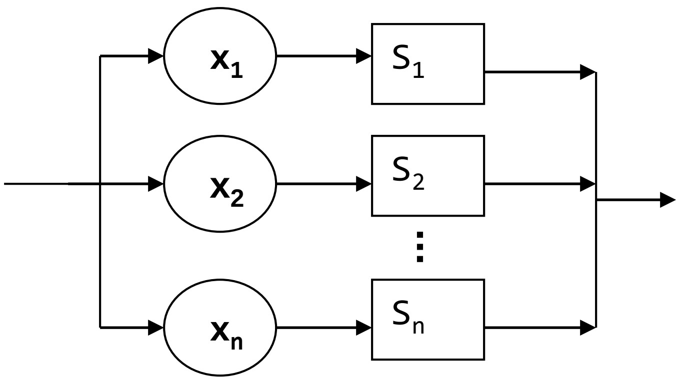
```
if (tok == t) { read(tok) } else { error }
```

where error is a routine called when an ill-formed construct is encountered.

Building a Parser from a Syntax Graph

Useful variants of rules B4 and B5:

B4a.- A choice of elements



Conditional

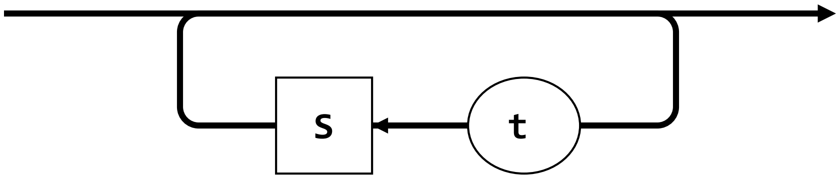
if tok == t_1 { read(ch); T(S_1); } else
if tok == t_2 { read(ch); T(S_2); } else
. . .

if tok == t_n { read(ch); T(S_n); } else
error

Building a Parser from a Syntax Graph

Useful variants of rules B4 and B5:

B5a.- A loop of the form



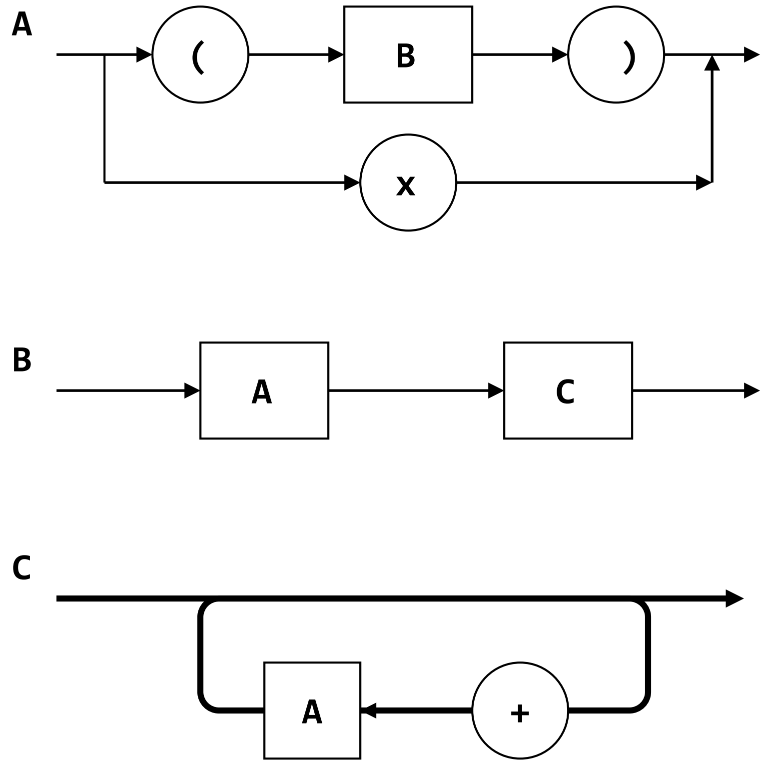
is translated into the statement

```
while (tok == t ) {
      read(tok); T(S);
}
```

Example

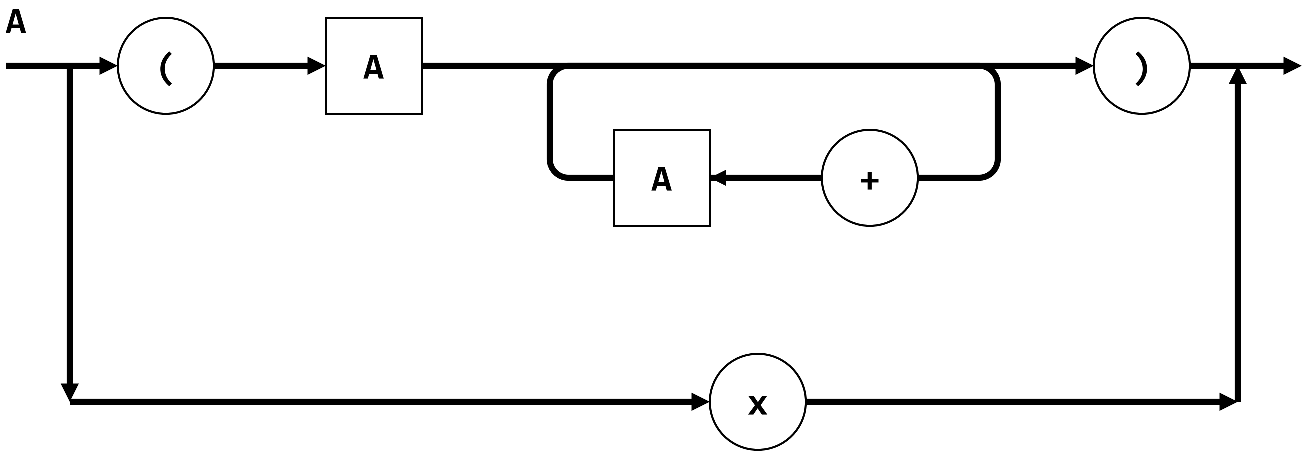
We now apply these rules to write the parser based on the syntax graph

```
A ::= “x” | “(“ B “)”
B ::= A C
C ::= { “+” A }
```



Syntax Graph

We will obtain this graph:



We can generate a parser program by transforming this graph following the appropriate rules from B1 to B8.

The parser is written in PL/0-based pseudocode.

Parser Program for the Graph A

```
var ch : char;

procedure A;
  begin
    if ch = ‘x’ then get(tok)
    else if ch = ‘(‘ then
    begin
      get(tok);
      A;
      while tok = ‘+’ do
      begin
        get(tok);
        A;
      end;
      if tok = ‘)’ then get(tok) else error(err_number)
    end
    else error(err_number)
  end;

begin
  get(tok);
  A;
end.
```

EBNF grammar for Tiny-PL/0

```
<program> ::= block "."
<block>   ::= <const-declaration> <var-declaration> <statement>

<const-declaration> ::= [ "const" <ident> "=" <number> { "," <ident> "=" <number> } ";" ]
<var-declaration>   ::= [ "var" <ident> { "," <ident>} ";" ]
<statement >        ::= [   <ident> ":=" <expression>
                          | "begin" <statement> { ";" <statement> } "end"
                          | "if" <condition> "then" <statement>
                          | "while" <condition> "do" <statement>
                          | "read" <ident>
                          | "write" <ident>
                        ]

<condition>   ::= "odd" <expression>
               | <expression> <rel-op> <expression>

<rel-op>     ::= "=" | "<>" | "<" | "<=" | ">" | ">="
<expression> ::= [ "+" | "-" ] <term> { ( "+" | "-" ) <term>}
<term>       ::= <factor> { ( "*" | "/" ) <factor>}
<factor>     ::= <ident> | <number> | "(" <expression> ")"

<number> and <ident> are tokens with semantic values
```

Symbol Table

The symbol table or name table records information about each symbol name in the program.

Each piece of information associated with a name is called an attribute.

For instance, the type of a variable, the parameters of a procedure, the number of dimensions for an array etc.

The symbol table can be organized as a linear list, a tree, or as a hash table.

Symbol Table

Symbol table operations **Enter** (insert) **Lookup** (retrieval)

Enter
When a declaration is processed the name is inserted into the symbol table

If the programming language does not require declarations (such as JavaScript or Python), then the name is inserted when the first occurrence of the name is found.

In tiny **PL/0**, we only enter **constants** and **variables** while parsing **`<const-declaration>`** and **`<var-declaration>`**.

Lookup
Each subsequent use of the name causes a lookup operation.

In tiny **PL/0**, we only lookup **constants** and **variables** while parsing **`<ident>`**.

For tiny **PL/0** the symbol table is **flat** because we do not have procedures (nothing is nested).

Symbol Table

We put symbols into the symbol table while parsing the `<ident>`'s inside `<const-declaration>` and `<var-declaration>`

```
<const-declaration> ::= [ “const” <ident> “=” <number> { “,” <ident> “=” <number> } “;” ]

<var-declaration>   ::= [ “var” <ident> { “,” <ident>} “;” ]
```

We get symbols from the symbol table while parsing the `<ident>` inside `<factor>` and inside `<statement>`

```
<factor>              ::= <ident> | ...

<statement >          ::= [ ...
                            | “read” <ident>
                            | “write” <ident>
                          ]
```

Lexer type definitions

We assume that we have the following definitions available.

```
// token type

typedef enum {
  nulsym = 1, identsym, numbersym, plussym, minussym,
  multsym, slashsym, oddsym, eqsym, neqsym, lessym, leqsym,
  gtrsym, geqsym, lparentsym, rparentsym, commasym, semicolonsym,
  periodsym, becomessym, beginsym, endsym, ifsym, thensym,
  whilesym, dosym, callsym, constsym, varsym, procsym, writesym,
  readsym , elsesym
} token_type;

// semantic value
//   either string (char *) for the name of a constant/an identifier
//   or     int for the value of the number

typedef union {
  string id;
  int num;
} LVAL;
```

Lexer variables and functions

We assume that we have the following definitions available.

```
// global variable holding the token type of the current token

token_type token;


// global variable holding the semantic value of the current token

LLVAL lval;


// function advance that move to the next token and
// updates the above two global variables

void advance();
```

Symbol table type definitions and functions

We assume that we have the following definitions available.

```
typedef struct symbol {
  int kind;         // constant = 1, variable = 2
  string name;      // name of constant or variable
  int num;          // number      number is only set for constant
  int level;        // L level     level and modifier are only set for variable,
  int modifier;     // M modifier  but level is always 0 for tiny PL/0
} symbol_type;


// function get_symbol that looks up a symbol in symbol table by name and
// returns pointer symbol if found and NULL if not found

symbol_type *get_symbol(string name)


// function put_symbol that puts a symbol into symbol table provided that
// a symbol with this name does not exist (calls error function if name already exists)

void put_symbol(int kind, string name, int num, int level, int modifier);
```

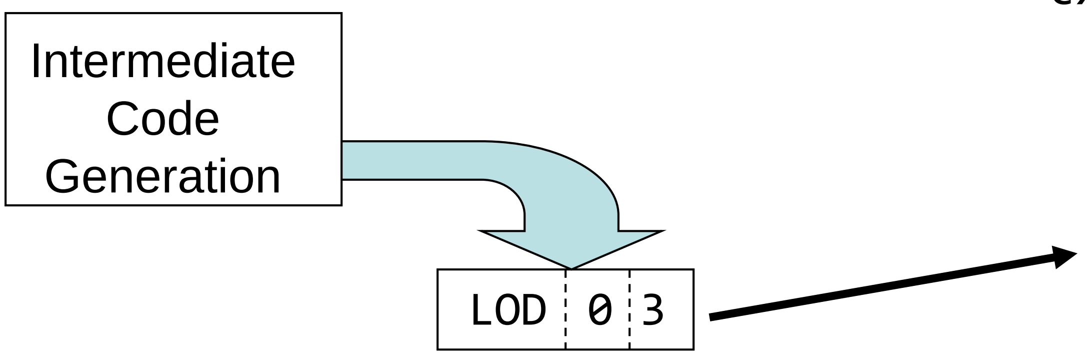
Constant declaration

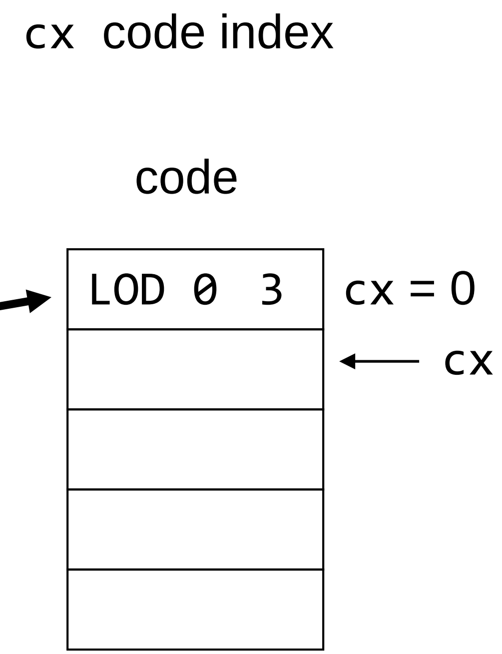
```
void const_declaration() {

  if (token != constsym) return;
  string id;

  do {
    advance();

    if (token != identsym) error("expected identifier in constant declaration");
    id = lval.id;
    advance();

    if (token != eqsym) error("expected '=' after identifier in constant declaration");
    advance();

    if (token != numbersym) error("expected number after '=' in constant declaration");
    put_symbol(1, id, lval.num, 0, 0); // constant => kind = 1
    advance();

  } while (token == commasym);

  if (token != semicolonsym) error("expected ';' at the end of constant declaration");
  advance();
}
```

Variable declaration

```
void var_declaration() {
  int num_vars = 0;

  if (token == varsym) {
    do {
      advance();

      if (token != identsym) error("expected identifier in variable declaration");
      num_vars++;
      put_symbol(2, lval.id, 0, 0, 3 + num_vars); // variable => kind = 2
      advance();
    } while (token == commasym);

    if (token != semicolonsym) error("expected ';' at the end of variable declaration");
    advance();
  }

  emit(INC, 0, 4 + num_vars); // emit is defined on the following slides
}
```

Intermediate Code Generation





Each time an instruction is generated, it is stored in the code store and the code index (cx) is incremented by one.

Parsing and Generating PM/0-code

Emit Function

```
void emit(int op, int l, int m)
{
  if(cx > CODE_SIZE)
    error(“code too long”);
  else
  {
    code[cx].op = op;       // opcode
    code[cx].l = l;         // lexicographical level
    code[cx].m = m;         // modifier
    cx++;
  }
}
```

Parsing and Generating PM/0-code

<expression> ::= [“+” | “-”] <term> { (“+” | “-”) <term> }

```
void expression()
{
  int addop;
  if (token == plussym || token == minussym)
  {
    addop = token;
    advance();
    term();
    if(addop == minussym)
      emit(OPR, 0, OPR_NEG); // negate
  }
  else
    term ();

  while (token == plussym || token == minussym)
  {
    addop = token;
    advance( );
    term();
    if (addop == plussym)
      emit(OPR, 0, OPR_ADD); // addition
    else
      emit(OPR, 0, OPR_SUB); // subtraction
  }
}
```

Function to parse an expression

Parsing and Generating PM/0-code

<term> ::= <factor> { (“*” | “/”) <factor> }

```
void term()
{
  int mulop;
  factor();
  while(token == multsym || token == slashsym)
  {
    mulop = token;
    advance();
    factor();
    if(mulop == multsym)
      emit(OPR, 0, OPR_MUL); // multiplication
    else
      emit(OPR, 0, OPR_DIV); // division
  }
}
```

Parsing and Generating PM/0-code

“if” <condition> “then” <statement>

```
if (token == ifsym)
{
  advance();
  condition();
  if(token != thensym)
    error(“then expected”);
  else
    advance();

  ctemp = cx;
  emit(JPC, 0, 0);
  statement();
  code[ctemp].m = cx;
}
```

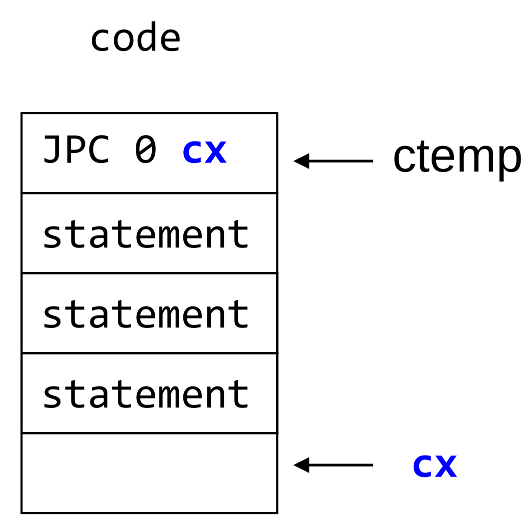
code	
JPC 0 0	← ctemp
statement	
statement	
statement	

Parsing and Generating PM/0-code

“if” <condition> “then” <statement>

```
if (token == ifsym)
{
  advance();
  condition();
  if(token != thensym)
    error(“then expected”);
  else
    advance();

  ctemp = cx;
  emit(JPC, 0, 0);
  statement();
  code[ctemp].m = cx;
}
```

changes JPC 0 0 to JPC 0 cx



Parsing and Generating PM/0-code

"while" <condition> "do" <statement>

```
if (token == whilesym)
{
  cx1 = cx;
  advance();
  condition();
  cx2 = cx;
  emit(JPC, 0, 0)
  if (token != dosym)
    error("do expected");
  else
    advance();

  statement();
  emit(JMP, 0, cx1);
  code[cx2].m = cx;
}
```

code	
condition	← cx1
JPC 0 cx	← cx2
statement	
statement	
JMP 0 cx1	
	← cx

Parsing and Generating PM/0-code

“read” <ident>, “write” <ident>, <ident> inside **<factor>**

Figure on your own how to generate code for `<ident>`.

- invoke the `get_symbol` function to determine if <ident> is a variable or constant and to obtain either
    - the modifier (indicating where the variable is stored in the activation record) or
    - the constant number
- emit `STO` and `LIT` depending on whether we have a variable or a constant.

Figure our how to generate code for <number> inside <factor> (much simpler than above because not necessary to invoke `get_symbol`).