Week 4
Code Generation

Paul Chew
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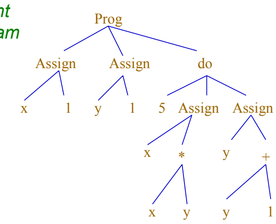
Recall

- We use *recursive descent parsing* to go from *program* to *AST* (Abstract Syntax Tree)




```
x = 1; y = 1;
do 5:
  x = x * y;
  y = y + 1;
  end;
end.
```

Prog(Assign(x,1),Assign(y,1),do(5,Assign(x,*(x,y)),Assign(y,+(y,1))))

Recall the Example Grammar

program → { statement } **end .**

statement → name **=** expression **;**

statement → **do** expression **:**
{ statement } **end ;**

expression → part [(**+** | **-** | ***** | **/**) part]

part → (name | number | **(** expression **)**)

name → (**x** | **y** | **z**)

- Notation:
  - { } indicates zero or more occurrences
  - [ ] indicates zero or one occurrence
  - (| |) indicates choice

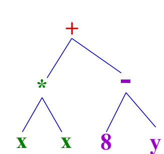
Recursion

- The grammar drives the design of the parser
  - We write a parsing method for each nonterminal
  - Within the method, each terminal token is checked; the nonterminals can take care of themselves (via recursive calls)
- The AST drives the design of the code generator
  - We write a code-generation method for each AST node-type
  - Within the method, we generate code for the node; the subtrees can take care of themselves (via recursive calls)

Code for Expressions

- Goal is to leave expression's value on top of the SaM stack
- For our example, there are 3 kinds of expression nodes:
  - Numbers (e.g., 42)
  - Variables (e.g., x)
    - We assume x is at mem 0, y at mem 1, and z at mem 2
  - Operators (e.g., +)
- Desired code
  - Number
    PUSHIMM 42
  - Variable
    PUSHOFF 0
  - Operator
    <code for left subtree>
    <code for right subtree>
    ADD

Example Expression Code



PUSHOFF 0
PUSHOFF 0
TIMES
PUSHIMM 8
PUSHOFF 1
SUB
ADD

Code For Assignment Statements

- Goal is to store the value of the <expression> into the <variable> (e.g., y)
  - We already have the code to place the expression's value on top of the stack
- Desired code

  <code for expression>
  STOREOFF 1

- Example: y = x + 5;

  PUSHOFF 0
  PUSHIMM 5
  ADD
  STOREOFF 1

Code For Do Statements

- This is harder because we have to maintain a counter
- Goal is to
  - Place do <expression> on top of stack to act as counter
  - If counter has reached zero we remove counter from stack and leave the loop
  - Generate code for all <statements> within the do-statement
  - Decrement the counter

<code for expression>
loop: DUP
NOT
JUMPC endloop
<code for statements>
PUSHIMM 1
SUB
JUMP loop
endloop: ADDSP -1

- Mistake: Code is wrong if <expression> is negative

Code for a Program

- Goal is to
  - Reserve space for the three variables (x, y, and z)
  - Print the values of the 3 variable at the end of the program
- Note that no one type of AST node produces much code
  - The do-statement was the most complicated
  - It produced 7 instructions of its own

ADDSP 3
<code for statements>
WRITE
WRITE
WRITE
STOP

Example Program and Resulting Code

```
x = 1; y = 1;
do 5:
  x = x * y;
  y = y + 1;
  end;
end.
```

ADDSP 3
PUSHIMM 1
STOREOFF 0
PUSHIMM 1
STOREOFF 1
PUSHIMM 5

do1: DUP
NOT
JUMPC end1
PUSHOFF 0
PUSHOFF 1
TIMES
STOREOFF 0
PUSHOFF 1
PUSHIMM 1
ADD
STOREOFF 1
PUSHIMM 1
SUB
JUMP do1
end1: ADDSP –1
WRITE
WRITE
WRITE
STOP

EBNF

- BNF = Backus-Naur Form
  - A way of representing a grammar for a programming language
  - Originally Backus *Normal* Form
    - Switched at suggestion of Knuth (partly because not really a *normal* form)
    - Naur was editor of Algol-60 document which used BNF
- EBNF = Extended BNF
  - Basically, BNF with some extra simplifying notation
  - There is an official standard, but common to modify it
- Typical constructs
  - Way to distinguish between terminals and nonterminals
  - { } for repetition
  - [ ] for optional
  - (| |) for choice

Example Grammar Notation: Java

Statement:
Block
if *ParExpression Statement* [else *Statement]*
for (*ForInit*$_{Opt}$; *[Expression]* ; *ForUpdate*$_{Opt}$) *Statement*
while *ParExpression Statement*
do *Statement* while *ParExpression* ;
try *Block (Catches* | *[Catches]* finally *Block)*
switch *ParExpression* { *SwitchBlockStatementGroups* }
synchronized *ParExpression Block*
return *[Expression]* ;
throw *Expression* ;
break *[Identifier]*
continue *[Identifier]*
;
ExpressionStatement
Identifier : *Statement*

Example Grammar Notation: Python

```
if_stmt ::=
        "if" expression ":" suite
          ( "elif" expression ":" suite )*
          ["else" ":" suite]

while_stmt ::=
        "while" expression ":" suite
          ["else" ":" suite]

for_stmt ::=
        "for" target_list "in" expression_list
         ":" suite
          ["else" ":" suite]
```


Grammar for Bali (Version for Part 2)

program -> mainFunction
mainFunction ->
  int main ( ) functionBody
functionBody ->
  { variableDeclaration* **}**
  { statement* **}**
type ->**int** | **boolean**
variableDeclaration ->
  type ***name*** (**,** ***name***)* **;**

- Nonterminals are shown as plain, specific terminals are shown as **bold-blue**, and nonspecific terminals are shown as ***bold italic***
- An arrow -> indicates a production rule.
- Parentheses ( ) are used for grouping.
- Asterisk * indicates repetition (0 or more times).
- Brackets [ ] indicate an optional occurrence.
- A vertical bar | indicates choice.

Rest of the Grammar for Bali (Part 2)

statement ->***name*** **=** expression **;**
statement -> **return** [expression] **;**
statement -> **{** statement* **}**
statement -> **if** expression
  then statement
  [**else** statement]
statement ->
  while expression **do** statement
statement ->
  do statement **while** expression **;**
statement -> expression **;**
statement -> **print** expression **;**
statement -> **;**

expression ->
  expPart [binaryOp expPart]
expPart -> ***integer*** | **true** | **false**
expPart -> **readInt ( )**
expPart ->***name***
expPart -> **(** expression **)**
expPart -> unaryOp expPart
binaryOp ->arithmeticOp |
  comparisionOp | booleanOp
arithmeticOp -> **+** | **-** | ***** | **/** | **%**
comparisonOp ->
  < | **>** | **<=** | **>=** | **==** | **!=**
booleanOp -> **&&** | **||** | **^**
unaryOp -> **-** | **!**