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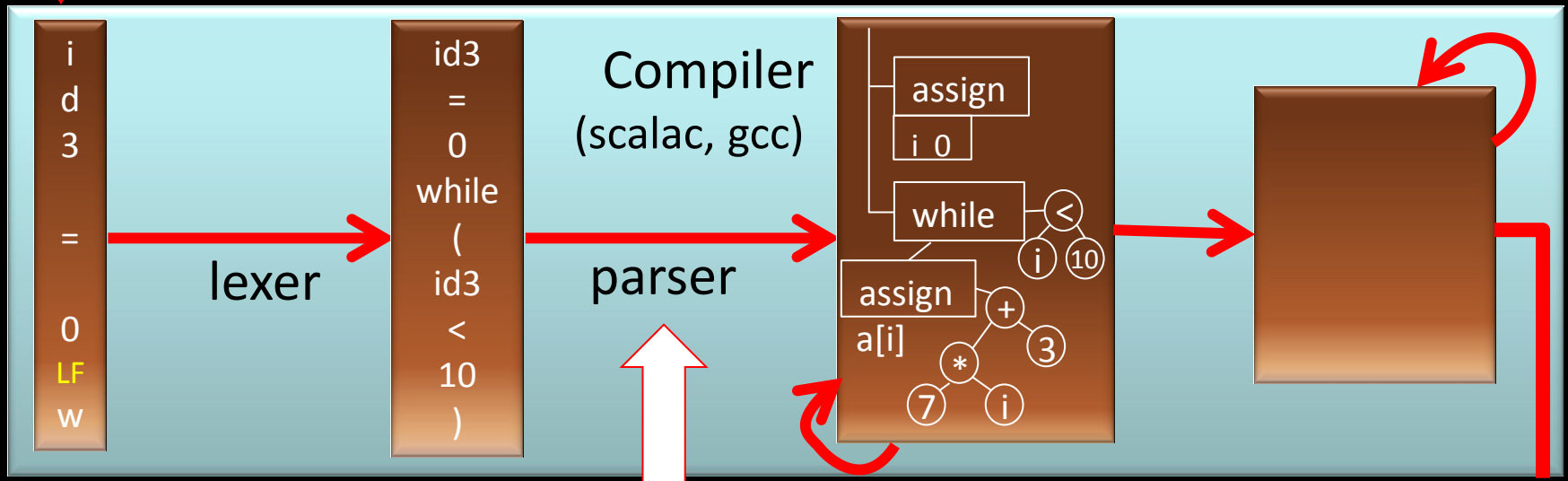
Compiler Construction 2010, Lecture 3

Top-Down Parsing

Compiler Construction

```
Id3 = 0
while (id3 < 10) {
  println(“”,id3);
  id3 = id3 + 1 }
```

source code



characters

words (tokens)

trees

context-free grammar

Today

- Manual recursive descent parser
  - parser for the while language
- Constructing syntax trees
- Refactoring grammars
- Computing first, follow, nullable
  - LL(1) grammar
- Table-driven top-down parser
  - How to use one, how to build one

Recursive Descent Parsing

Recursive Descent is Decent

descent = a movement downward

decent = adequate, good enough

Recursive descent is a decent parsing technique

- can be easily implemented manually based on the grammar (which may require transformation)
- efficient (linear) in the size of the token sequence

Correspondence between grammar and code

- concatenation → ;
- alternative (|) → if
- repetition (*) → while
- nonterminal → recursive procedure

A Rule of While Language Syntax

statmt ::=

println (stringConst , ident)

| *ident = expr*

| *if (expr) statmt (else statmt)*$^{?}$

| *while (expr) statmt*

| *{ statmt* }*

Parser for the statmt Rule

```
def skip(t : Token) = if (lexer.token == t) lexer.next
   else error("Expected"+ t)
// statmt ::=
def statmt = {
   // println ( stringConst , ident )
   if (lexer.token == Println) { lexer.next;
      skip(openParen); skip(stringConst); skip(comma);
      skip(identifier); skip(closedParen)
   // | ident = expr
   } else if (lexer.token == Ident) { lexer.next;
      skip(equality); expr
   // | if ( expr ) statmt (else statmt)?
   } else if (lexer.token == ifKeyword) { lexer.next;
      skip(openParen); expr; skip(closedParen); statmt;
      if (lexer.token == elseKeyword) { lexer.next; statmt }
   // | while ( expr ) statmt
```

Continuing Parser for the Rule

```
// | while ( expr ) statmt
 } else if (lexer.token == whileKeyword) { lexer.next;
   skip(openParen); expr; skip(closedParen); statmt

// | { statmt* }

 } else if (lexer.token == openBrace) { lexer.next;
   while (isFirstOfStatmt) { statmt }
   skip(closedBrace)

 } else { error("Unknown statement, found token " +
                lexer.token)  }
```

First Symbols for Non-terminals

statmt ::= println (stringConst , ident)
| ident = expr
| if (expr) statmt (else statmt)?
| while (expr) statmt
| { statmt* }

- Consider a grammar G and non-terminal N

$L_G(N)$ = { set of strings that N can derive }

L(statmt) – all statements of while language

first(N) = { a | aw in $L_G(N)$, a – terminal,
w – string of terminals}

first(statmt) = { println, ident, if, while, { }

(we will see how to compute first in general)

Compiler Construction

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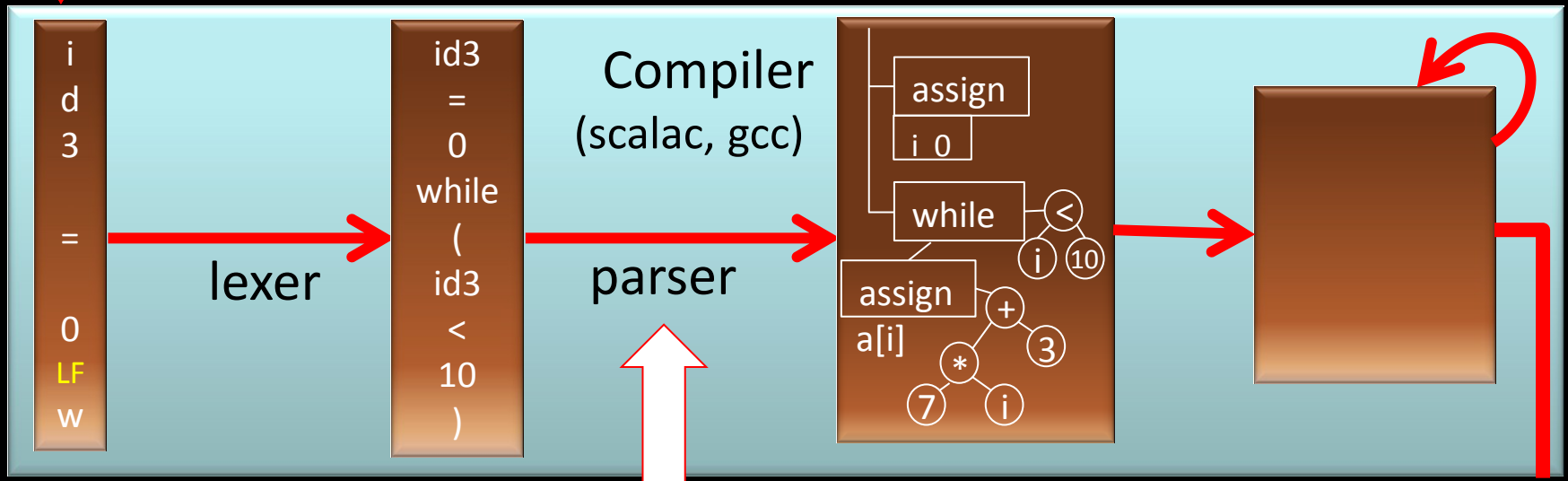

characters

words (tokens)

context-free grammar

trees

Trees for Statements

statmt ::= println (stringConst , ident)
| ident = expr
| if (expr) statmt (else statmt)?
| while (expr) statmt
| { statmt* }

```
abstract class Statmt
case class PrintlnS(msg : String, var : Identifier) extends Statmt
case class Assignment(left : Identifier, right : Expr) extends Statmt
case class If(cond : Expr, trueBr : Statmt,
                           falseBr : Option[Statmt]) extends Statmt
case class While(cond : Expr, body : Expr) extends Statmt
case class Block(sts : List[Statmt]) extends Statmt
```

Our Parser Produced Nothing

```
def skip(t : Token) : unit = if (lexer.token == t) lexer.next
  else error("Expected"+ t)
// statmt ::=
def statmt : unit = {
  // println ( stringConst , ident )
  if (lexer.token == Println) { lexer.next;
    skip(openParen); skip(stringConst); skip(comma);
    skip(identifier); skip(closedParen)
  // | ident = expr
  } else if (lexer.token == Ident) { lexer.next;
    skip(equality); expr
```

Parser Returning a Tree

```
def expect(t : Token) : Token = if (lexer.token == t) { lexer.next;t}
  else error("Expected"+ t)
// statmt ::=
def statmt : Statmt = {
  // println ( stringConst , ident )
  if (lexer.token == Println) { lexer.next;
    skip(openParen); val s = getString(skip(stringConst));
    skip(comma);
    val id = getIdent(skip(identifier)); skip(closedParen)
    PrintlnS(s, id)
 // | ident = expr
  } else if (lexer.token.class == Ident) { val lhs = getIdent(lexer.token)
    lexer.next;
    skip(equality); val e = expr
    Assignment(lhs, e)
```

Constructing Tree for ‘if’

```
def expr : Expr = { … }
// statmt ::=
def statmt : Statmt = {
   …
// | while ( expr ) statmt
// case class If(cond : Expr, trueBr: Statmt, falseBr: Option[Statmt])
  } else if (lexer.token == ifKeyword) { lexer.next;
     skip(openParen); val c = expr; skip(closedParen);
     val trueBr = statmt
     val elseBr = if (lexer.token == elseKeyword) {
       lexer.next; Some(statmt) } else Nothing
     If(c, trueBr, elseBr)
```

Constructing Tree for ‘while’

```
def expr : Expr = { … }
// statmt ::=
def statmt : Statmt = {
  …
//  if ( expr ) statmt (else statmt)?
// case class While(cond : Expr, body : Expr) extends Statmt
```

Here each alternative started with different token

statmt ::=

println (stringConst , ident)

| ident = expr

| if (expr) statmt (else statmt)?

| while (expr) statmt

| { statmt* }

What if this is not the case?

Left Factoring Example: Function Calls

statmt ::=

println (stringConst , ident)

| ident = expr

| if (expr) statmt (else statmt)?

| while (expr) statmt

| { statmt* }

| ident (expr (, expr)*)

foo = 42 + x
foo (u , v)

code to parse the grammar:

```
 } else if (lexer.token.class == Ident) {
     ???
 }
```

Left Factoring Example: Function Calls

statmt ::=

println (stringConst , ident)

| ident assignmentOrCall

| if (expr) statmt (else statmt)?

| while (expr) statmt

| { statmt* }

assignmentOrCall ::= = expr | (expr (, expr)*)

code to parse the grammar:

```
} else if (lexer.token.class == Ident) {
    val id = getIdentifier(lexer.token); lexer.next
    assignmentOrCall(id)
}
```

Factoring pulls common parts from alternatives

Parsing Statements Worked Nicely

Let’s look at expressions

Simplified Expressions in While

statmt ::=

println (stringConst , ident)

| ident = expr

| if (expr) statmt (else statmt)?

| while (expr) statmt

| { statmt* }

expr ::= intLiteral | ident

| expr (+ | /) expr

Trees for Expressions

```
expr ::= intLiteral | ident
       | expr + expr | expr / expr
```

```
abstract class Expr
case class IntLiteral(x : Int) extends Expr
case class Variable(id : Identifier) extends Expr
case class Plus(e1 : Expr, e2 : Expr) extends Expr
case class Divide(e1 : Expr, e2 : Expr) extends Expr
```

foo + 42 / bar + arg

Parser That Follows the Grammar?

```
expr ::= intLiteral | ident
       | expr + expr | expr / expr
```

foo + 42 / bar + arg

```
def expr : Expr = {
  if (??) IntLiteral(getInt(lexer.token))
  else if (??) Variable(getIdent(lexer.token))
  else if (??) {
    val e1 = expr; val op = lexer.token; val e2 = expr
    op match Plus {
      case PlusToken => Plus(e1, e2)
      case DividesToken => Divides(e1, e2)
    } }
```

When should parser use the recursive case?!

Parse Tree vs Abstract Syntax Tree

```
expr ::= intLiteral | ident
       | expr + expr | expr / expr
```

foo + 42 / bar + arg

Node in parse tree is given by one grammar alternative.

Ambiguous grammar: if some string has multiple parse trees (then it is has multiple corresponding abstract trees)

AST is tree as Scala value

An attempt to rewrite the grammar

```
expr ::= simpleExpr (( + | / ) simpleExpr)*
simpleExpr ::= intLiteral | ident
```

```
def simpleExpr : Expr = { … }
def expr : Expr = {
  var e = simpleExpr
  while (lexer.token == PlusToken ||
         lexer.token == DividesToken)) {
    val op = lexer.token
    val eNew = simpleExpr
    op match {
      case TokenPlus => { e = Plus(e, eNew) }
      case TokenDiv => { e = Divide(e, eNew) }
    }
  }
  e }
```

foo + 42 / bar + arg

Layer the expression grammar to express priorities

```
expr ::= term (+ term)*
term ::= simpleExpr (/ simpleExpr)*
simpleExpr ::= intLiteral | ident
```

```
def expr : Expr = {
  var e = term
  while (lexer.token == PlusToken) {
    lexer.next
    e = Plus(e, term)
  }
  e
}
```

Decompose first by the least-priority operator (+)

Using recursion instead of *

expr ::= term (+ term)*

expr ::= term (+ expr)?

```
def expr : Expr = {
  val e = term
  if (lexer.token == PlusToken) {
    lexer.next
    Plus(e, expr)
  } else e
}
def term : Expr = {
  val e = simpleExpr
  if (lexer.token == DivideToken) {
    lexer.next
    Divide(e, term)
  } else e
}
```

What we have seen so far

- Manual recursive descent parser
  - parser for the while language
- Constructing syntax trees
- Refactoring grammars
- Now we can build simple parsers
  - When does it work – LL(1) grammars
  - How can we automate it?