Smacc: a Compiler-Compiler

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CHAPTER 1

About this booklet

This booklet describes SmaCC, the Smalltalk Compiler-Compiler originally developed by John Brant.

1.1 Contents

It contains:

- A tutorial originally written by John Brant and Don Roberts (SmaCC[1]) and adapted to Pharo.
- Syntax to declare Syntax trees.
- Details about the directives.
- Scanner and Parser details.
- Support for transformations.
- Idioms: Often we have recurring patterns and it is nice to document them.

SmaCC was ported to Pharo by Thierry Goubier, who actively maintains the SmaCC Pharo port. SmaCC is used in production systems; for example, it supports the automatic conversion from Delphi to C#.

1.2 Obtaining SmaCC

If you haven't already done so, you will need to load Smacc. Execute this code in a Pharo playground:

```
Metacello new
  baseline: 'SmaCC';
  repository: 'github://ThierryGoubier/SmaCC';
  load
```

Note that there is another version of SmaCC that is now part of Moose http://moosetechnology.com. The difference between them is that the Moose version uses different tools to load the parser and scanner, and incorporates a special debugger. In addition, the Moose version does not support the parser shortcuts described in the Section "Shortcuts". In the future, we hope that these versions will be unified.

[1] http://www.refactory.com/Software/SmaCC

1.3 Basics

The compilation process comprises two phases: scanning (sometimes called lexing) and parsing. Scanning converts an input stream of characters into a stream of *tokens*. These tokens form the input to the parsing phase. Parsing converts the stream of tokens into some object: exactly *what* object is determined by you, the user of SmaCC.

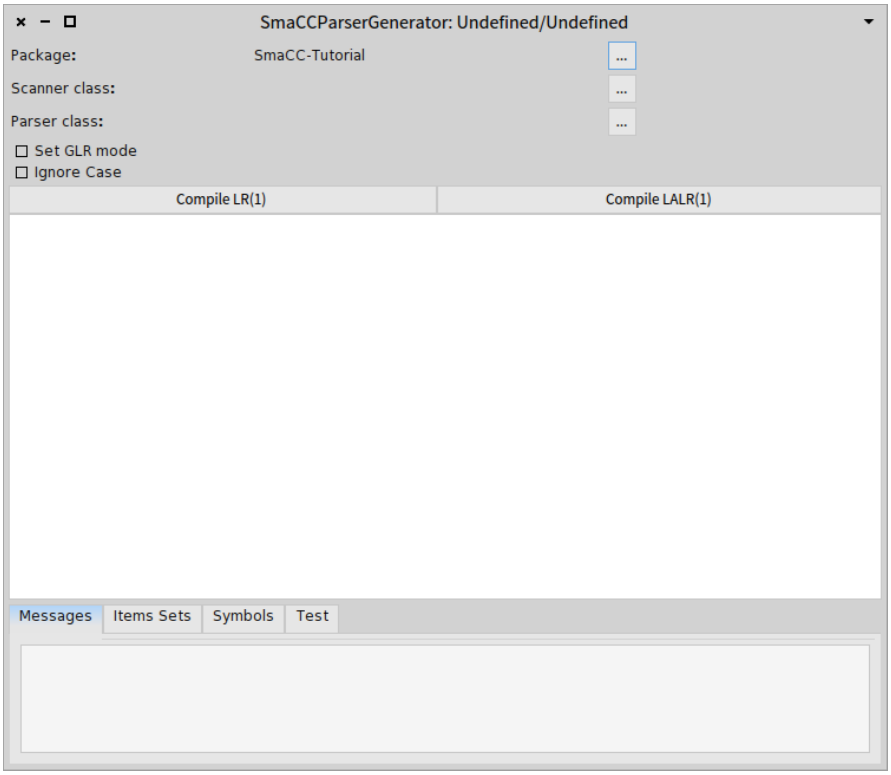
CHAPTER 2

A first SmaCC tutorial

This tutorial demonstrates the basic features of SmaCC, the Smalltalk Compiler Compiler. We will use SmaCC to develop a simple calculator. This tutorial was originally developed by Don Roberts and John Brant, and later modified by T. Goubier, S. Ducasse and J. Lecerf.

2.1 Opening the tools

Once you have loaded the code of SmaCC, you should open the SmaCC Parser Generator tool (Figure 2-1). In Pharo, you can do this using the *Tools* submenu of the *World* menu.



SmaCCParserGenerator: Undefined/Undefined

Package: SmaCC-Tutorial

Scanner class:

Parser class:

□ Set GLR mode

□ Ignore Case

Figure 2-1 SmaCC GUI Tool: The place to define the scanner and parser.

Our first calculator is going to be relatively simple. It is going to take two numbers and add them together. To get started

- Edit the definition the pane below the compile LR(1) buttons.
- Once you are done:
  - Click on the Scanner class and type ExpressionScanner.
  - Click on the Parser class and type ExpressionParser.
- press either Compiler LR(1) or Compiled LALR(1) buttons.

You are now ready to edit first your scanner and parser. Note that you edit everything in one file (using the SmaCC tool). Once compiled, the tools will generate two classes and fill them with sufficient information to create the scanner and parser, as shown as Figure 2-2.

2.2 First, the Scanner

To start things off, we have to tell the scanner how to recognize a number. A number starts with one or more digits, possibly followed by a decimal point with zero or more digits after it. The scanner definition for this token (called a token specification) is:

```
<number>        :       [0-9]+ (\. [0-9]*) ? ;
```

Let's go over each part:

`<number>` Names the token identified by the token specification. The name inside the <> must be a legal Pharo variable name.

`:` Separates the name of the token from the token's definition.

`[0-9]` Matches any single character in the range `'0'` to `'9'` (a digit). We could also use `\d` or `<isDigit>` as these also match digits.

`+` Matches the previous expression one or more times. In this case, we are matching one or more digits.

`( ... )` Groups subexpressions. In this case we are grouping the decimal point and the numbers following the decimal point.

`\.` Matches the '.' character (`.` has a special meaning in regular expressions; \ quotes it).

`*` Matches the previous expression zero or more times.

`?` Matches the previous expression zero or one time (i.e., it is optional).

`;` Terminates a token specification.

Ignoring Whitespace

We don't want to have to worry about whitespace in our language, so we need to define what whitespace is, and tell SmaCC to ignore it. To do this, enter the following token specification on the next line:

```
<whitespace>    :       \s+;
```

`\s` matches any whitespace character (space, tab, linefeed, etc.). So how do we tell the scanner to ignore it? If you look in the `SmaCCScanner` class (the superclass of all the scanners created by SmaCC), you will find a method named `whitespace`. If a scanner understands a method that has the same name as a token name, that method will be executed whenever the scanner matches that kind of token. As you can see, the `SmaCCScanner>>whitespace` method eats whitespace.

```
SmaCCScanner >> whitespace
  "By default, eat the whitespace"
  self resetScanner.
  ^ self scanForToken
```

SmaCCScanner also defines a comment method that behaves similarly. However, the SmaCCScanner>>comment method also stores the interval in the source where the comment occurred in the comments instance variable.

```
SmaCCScanner >> comment
  comments add: (Array with: start + 1 with: matchEnd).
  ^ self whitespace
```

The only other token that will appear in our system is the + token for addition. However, since this token is a constant, there is no need to define it as a token in the scanner. Instead, we can enter it directly (as a quoted string) in the grammar rules that define the parser.

2.3 Second, the Calculator Grammar

Speaking of the grammar, let's go ahead and define it. Enter the following specification below your two previous rules in the editor pane, as shown in Figure 2-2.

```
Expression
  : Expression "+" Number
  | Number
  ;
Number
  : <number>
  ;
```

This basically says that an expression is either a number, or an expression added to a number. You should now have something that looks like Figure 2-2.

2.4 Compile the Scanner and the Parser

We are almost ready to compile a parser now, but first we need to specify the names of the scanner and parser classes that SmaCC will create. These names are entered using the ... buttons for scanner class and parser class. Enter CalculatorScanner and CalculatorParser respectively. Once the class names are entered, press Compile LR(1) or Compile LALR(1). This will create new Pharo classes for the CalculatorScanner and CalculatorParser, and compile several methods in those classes. All the methods that SmaCC compiles will go into a "generated" method protocol. You should not change those methods or add new methods to the "generated" method protocols, because these methods are replaced or deleted each time you compile.

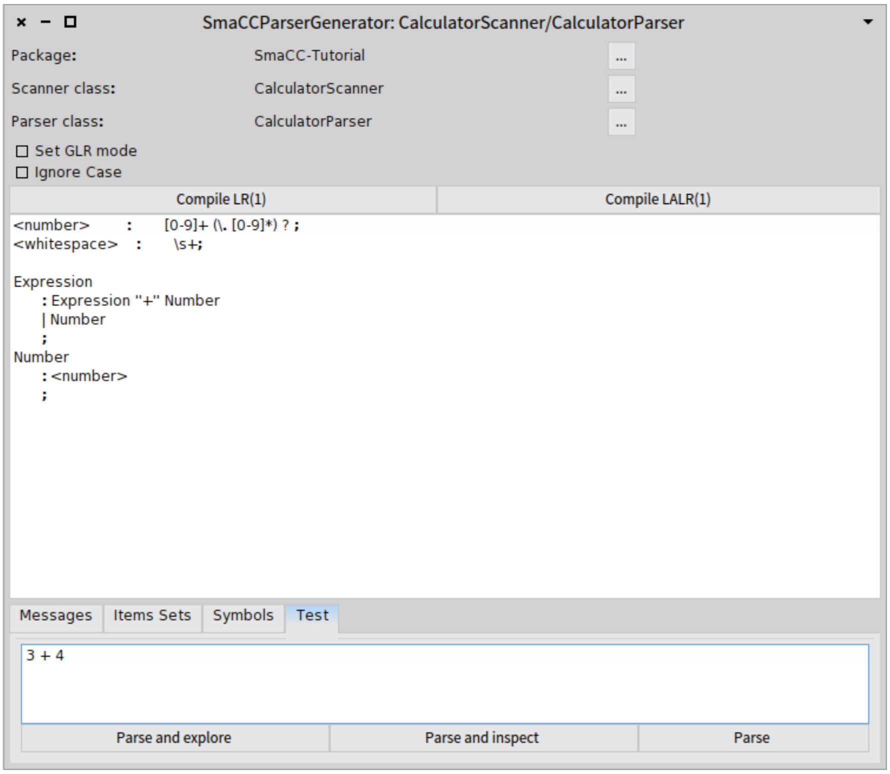
Whenever SmaCC creates new classes, they are placed in the package (or package tag) named in the Package entry box. You may wish to select a different package by pressing '...'.

2.5 Testing Our Parser

Now we are ready to test our parser. Go to the "test" pane, enter 3 + 4, and press "Parse"; you will see that the parser correctly parses it. If you press "Parse and inspect" you will see an inspector on an OrderedCollection that contains the parsed tokens, as shown in Figure 2-3. This is because we haven't specified what the parser is supposed to do when it parses.

You can also enter incorrect items as test input. For example, try to parse 3 + + 4 or 3 + a. An error message should appear in the text.

If you are interested in the generated parser, you may wish to look at the output from compiling the parser in the Symbols or Item Sets tab.



Package: SmaCC-Tutorial

Scanner class: CalculatorScanner

Parser class: CalculatorParser

□ Set GLR mode

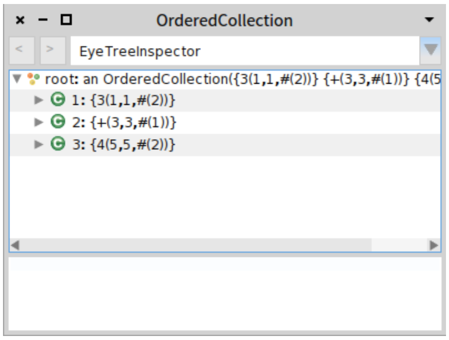
□ Ignore Case

```
<number>       :     [0-9]+ (\. [0-9]*) ? ;
<whitespace>   :      \s+;

Expression
     : Expression "+" Number
     | Number
     ;
Number
     : <number>
     ;
```

```
3 + 4
```

Figure 2-2 First grammar: the Scanner part followed by the Parser part.



```
▼ root: an OrderedCollection({3(1,1,#(2))} {+(3,3,#(1))} {4(5
   ▶ 1: {3(1,1,#(2))}
   ▶ 2: {+(3,3,#(1))}
   ▶ 3: {4(5,5,#(2))}
```

Figure 2-3 Inspector on 3 + 4

- The Symbols tab lists all of the terminal and non-terminal symbols that were used in the parser. The number besides each is the internal id used by the parser.
- The Item Sets tab lists the LR item sets that were used in the parser. These are printed in a format that is similar to the format used by many text books.
- The Messages tab is used to display any warnings generated while the parser was compiled. The most common warning is for ambiguous actions.

2.6 Defining actions

Now we need to define the actions that need to happen when we parse our expressions. Currently, our parser is just validating that the expression is a bunch of numbers added together. Generally, you want to create some structure that represents what you've parsed (e.g., a parse tree). However, in this case, we are not concerned about the structure, but we are concerned about the result: the *value* of the expression. For our example, we can calculate the value by modifying the grammar to be:

```
Expression
  : Expression "+" Number {'1' + '3'}
  | Number {'1'}
  ;
Number
  : <number> {'1' value asNumber}
  ;
```

The text between the braces is Pharo code that is evaluated when the grammar rule is applied. Strings that contain a number are replaced with the corresponding expression in the production. For example, in the first rule for Expression, the `'1'` will be replaced by the object that matches Expression, and the `'3'` will be replaced by the object that matches `Number`. The second item in the rule is the `"+"` token. Since we already know what it is, there is no need to refer to it by number.

Compile the new parser. Now, when you do a 'Parse and inspect' from the test pane containing `3 + 4`, you should see the result: `7`.

2.7 Named Expressions

One problem with the quoted numbers in the previous example is that if you change a rule, you may also need to change the code for that rule. For example, if you inserted a new token at the beginning of the rule for Expression, then you would also need to increment all of the numeric references in the Pharo code.

We can avoid this problem by using named expressions. After each part of a rule, we can specify its name. Names are enclosed in single quotes, and must be legal Pharo variable names. Doing this for our grammar we get:

```
Expression
  : Expression 'expression' "+" Number 'number' {expression + number}
  | Number 'number' {number}
  ;
Number
  : <number> 'numberToken' {numberToken value asNumber}
  ;
```

This will result in the same language being parsed as in the previous example, with the same actions. Using named expressions makes it much easier to maintain your parsers.

2.8 Extending the language

Let’s extend our language to add subtraction. Here is the new grammar:

```
Expression
  : Expression 'expression' "+" Number 'number' {expression + number}
  | Expression 'expression' "-" Number 'number' {expression - number}
  | Number 'number' {number}
  ;
Number
  : <number> 'numberToken' {numberToken value asNumber}
  ;
```

After you’ve compiled this, `'3 + 4 - 2'` should return `'5'`. Next, let’s add multiplication and division:

```
Expression
  : Expression 'expression' "+" Number 'number' {expression + number}
  | Expression 'expression' "-" Number 'number' {expression - number}
  | Expression 'expression' "*" Number 'number' {expression * number}
  | Expression 'expression' "/" Number 'number' {expression / number}
  | Number 'number' {number}
  ;
Number
  : <number> 'numberToken' {numberToken value asNumber}
  ;
```

2.9 Handling priority

Here we run into a problem. If you evaluate `'2 + 3 * 4'` you end up with 20. The problem is that in standard arithmetic, multiplication has a higher precedence than addition. Our grammar evaluates strictly left-to-right. The standard solution for this problem is to define additional non-terminals to force the sequence of evaluation. Using that solution, our grammar would look like this.

```
Expression
  : Term 'term' {term}
  | Expression 'expression' "+" Term 'term' {expression + term}
  | Expression 'expression' "-" Term 'term' {expression - term}
  ;
Term
  : Number 'number' {number}
  | Term 'term' "*" Number 'number' {term * number}
  | Term 'term' "/" Number 'number' {term / number}
  ;
Number
  : <number> 'numberToken' {numberToken value asNumber}
  ;
```

If you compile this grammar, you will see that `'2 + 3 * 4'` evaluates to `'14'`, as you would expect.

2.10 Handling priority with directives

As you can imagine, defining additional non-terminals gets pretty complicated as the number of levels of precedence increases. We can use ambiguous grammars and precedence rules to simplify this situation. Here is the same grammar using precedence to enforce our desired evaluation order:

```
%left "+" "-";
%left "*" "/";

Expression
  : Expression 'exp1' "+" Expression 'exp2' {exp1 + exp2}
  | Expression 'exp1' "-" Expression 'exp2' {exp1 - exp2}
  | Expression 'exp1' "*" Expression 'exp2' {exp1 * exp2}
  | Expression 'exp1' "/" Expression 'exp2' {exp1 / exp2}
  | Number 'number' {number}
  ;
Number
  : <number> 'numberToken' {numberToken value asNumber}
  ;
```

Notice that we changed the grammar so that there are Expressions on both sides of the operator. This makes the grammar ambiguous: an expression like `'2 + 3 * 4'` can be parsed in two ways. This ambiguity is resolved using SmaCC's precedence rules.

The two lines that we added to the top of the grammar mean that `+` and `-` are evaluated left-to-right and have the same precedence. Likewise, the second line means that `*` and `/` are evaluated left-to-right and have equal precedence. Because the rule for `+` and `-` comes first, `+` and `-` have lower precedence than `*` and `/`. Grammars using precedence rules are usually much more intuitive, especially in cases with many precedence levels. Just as an example, let's add exponentiation and parentheses. Here is our final grammar:

```
<number> : [0-9]+ (\. [0-9]*) ? ;
<whitespace> : \s+;
%left "+" "-";
%left "*" "/";
%right "^";

Expression
  : Expression 'exp1' "+" Expression 'exp2' {exp1 + exp2}
  | Expression 'exp1' "-" Expression 'exp2' {exp1 - exp2}
  | Expression 'exp1' "*" Expression 'exp2' {exp1 * exp2}
  | Expression 'exp1' "/" Expression 'exp2' {exp1 / exp2}
  | Expression 'exp1' "^" Expression 'exp2' {exp1 raisedTo: exp2}
  | "(" Expression 'expression' ")" {expression}
  | Number 'number' {number}
  ;
Number
  : <number> 'numberToken' {numberToken value asNumber}
  ;
```

Once you have compiled the grammar, you will be able to evaluate `3 + 4 * 5 ^ 2 ^ 2` to get 2503. Since the exponent operator `^` is defined to be right associative, this expression is evaluated as `3 + (4 * (5 ^ (2 ^ 2)))`. We can also evaluate expressions with parentheses. For example, evaluating `(3 + 4) * (5 - 2) ^ 3` results in 189.

The sections that follow provide more information on SmaCC's scanner and parser, and on the directives that control SmaCC.

Subsequent sections explain how SmaCC can automatically produce an AST for you, and even how one parse tree can be transformed into another.

CHAPTER 3

SmaCC Scanner

Scanning takes an input stream of characters and converts that into a stream of tokens. The tokens are then passed on to the parsing phase.

The scanner is specified by a collection of token specifications. Each token is specified by:

```
TokenName    :    RegularExpression ;
```

TokenName is a valid variable name that is surrounded by <>. For example, `<token>` is a valid `TokenName`, but `<token name>` is not since `token name` isn't a valid variable name. The `RegularExpression` is a regular expression that matches a token. It should match one or more characters in the input stream. The colon character, `:`, is used to separate the TokenName and the `RegularExpression`, and the semicolon character, `;`, is used to terminate the token specification.

3.1 Regular Expression Syntax

While the rules are specified as regular expressions, there are many different syntaxes for regular expressions. SmaCC uses a relatively simple syntax, which is specified below. If you wish to have a richer syntax, you can modify the scanner's parser: `SmaCCDefinitionScanner` and `SmaCCDefinitionParser`. These classes were created using SmaCC.

\character Matches a special character. The character immediately following the backslash is matched exactly, unless it is a letter. Backslash-letter combinations have other meanings and are specified below.

\cLetter Matches a control character. Control characters are the first 26 characters (e.g., \cA equals `Character value: 0`). The letter that follows the `\c` must be an uppercase letter.

\d Matches a digit, 0-9.

\D Matches anything that is not a digit.

\f Matches a form-feed character, `Character value: 12`.

\n Matches a newline character, `Character value: 10`.

\r Matches a carriage return character, `Character value: 13`.

\s Matches any whitespace character, [\f\n\r\t\v].

\S Matches any non-whitespace character.

\t Matches a tab, `Character value: 9`.

\v Matches a vertical tab, `Character value: 11`.

\w Matches any letter, number or underscore, [A-Za-z0-9_].

\W Matches anything that is not a letter, number or underscore.

\xHexNumber Matches a character specified by the hex number following the \x. The hex number must be at least one character long and no more than four characters for Unicode characters and two characters for non-Unicode characters. For example, \x20 matches the space character (Character value: 16r20), and \x1FFF matches Character value: 16r1FFF.

<token> Copies the definition of <token> into the current regular expression. For example, if we have <hexdigit> : \d | [A-F] ;, we can use <hexdigit> in a later rule: <hexnumber> : <hexdigit> + ;. Note that you must define a token *before* you use it in another rule.

<isMethod> Copies the characters where Character>>isMethod returns true into the current regular expression. For example, instead of using \d, we could use <isDigit> since Character>>isDigit returns true for digits.

[characters] Matches one of the characters inside the []. This is a shortcut for the | operator. In addition to single characters, you can also specify character ranges with the - character. For example, [a-z] matches any lower case letter.

[^characters] Matches any character not listed in the characters block. [^a] matches anything except for a.

# comment Creates a comment that is ignored by SmaCC. Everything from the # to the end of the line is ignored.

exp1 | exp2 Matches either exp1 or exp2.

exp1 exp2 Matches exp1 followed by exp2. \d \d matches two digits.

exp* Matches exp zero or more times. 0* matches '' and 000.

exp? Matches exp zero or one time. 0? matches only '' or 0.

exp+ Matches exp one or more times. 0+ matches 0 and 000, but not ''.

exp{min,max} Matches exp at least min times but no more than max times. 0{1,2} matches only 0 or 00. It does not match '' or 000.

(exp) Groups exp for precedence. For example, (a b)* matches ababab. Without the parentheses, a b * would match abbbb but not ababab.

Since there are multiple ways to combine expressions, we need precedence rules for their combination. The or operator, |, has the lowest precedence and the *, ?, +, and {,} operators have the highest precedence. For example, a | b c * matches a or bcccc, but not accc or bcbcbc. If you wish to match a or b followed by any number of c's, you need to use (a | b) c *.

Whitespace is ignored in SmaCC regular expressions everywhere *except* within square brackets. This means that you can add spaces between terms to make your REs more readable. However, inside square brackets, spaces are significant, so don't add spaces there unless you mean to include space (or, with ^, to *exclude* space) from the set of allowable characters.

3.2 Overlapping Tokens

SmaCC can handle overlapping tokens without any problems. For example, the following is a legal SmaCC scanner definition:

```
<variable>  : [a-zA-Z] \w* ;
<any_character> : . ;
```

This definition will match a variable or a single character. A variable can also be a single character [a-zA-Z], so the two tokens overlap. SmaCC handles overlapping tokens by preferring the longest matching token. If multiple token definitions match sequences of the same maximum length, first token specified by the grammar is chosen. For example, an a could be a <variable> or an <any_character> token, but since <variable> is specified first, SmaCC will prefer it.

If you want the parser to attempt to parse will all the possible kinds of token, override the method SmaCCParser>>tryAllTokens to answer true instead of false.

3.3 Token Action Methods

A *Token Action Method* is a hand-written method in your scanner whose name is the same as the name of a token, (for example, the method whitespace). For this reason, token action methods are sometimes also called ”matching methods”.

A token action method will be executed whenever a token with the corresponding name is recognized. Notice that the SmaCCScanner superclass has default implementations of methods whitespace and comment; these methods are executed whenever the tokens <whitespace> and <comment> are scanned, and ignore those tokens. If you want to store comments, then you should override the SmaCCScanner>>comment method.

When implementing a Token Action Method, you can find the characters that comprise the token in the outputStream, an instance variable inherited from SmaCCScanner. Your method *must* answer a SmaCCToken. Here are two examples.

```
whitespace
  "By default, eat the whitespace"

  self resetScanner.
  ^ self scanForToken
```

This is the default action when spaces are scanned: the scanner is reset, and then used to scan for the token *following* the spaces. This following token is returned; as a consequence, the spaces are ignored.

```
leftBrace
  braceDepth := braceDepth + 1.
  ^ self createTokenFor: '{'
```

This is the token action from a scanner that needs to keep track of the number of <leftBrace> tokens. After incrementing a counter, it returns the same token that would have been created if the there had been no token action.

Token Action Methods can also be used to handle overlapping token classes. For example, in the C grammar, a type definition is lexically identical to an identifier. The only way that they can be disambiguated is by looking up the name in the type table. In our example C scanner, we have an IDENTIFIER method that is used to determine whether the token is really an IDENTIFIER or whether it is a TYPE_NAME:

```
IDENTIFIER
  | name |
  name := outputStream contents.
  matchActions := (typeNames includes: name)
    ifTrue: [ Array with: self TypeNameId ]
    ifFalse: [ Array with: self IDENTIFIERId ].
  outputStream reset.
  ^ SmaCCToken value: name start: start ids: matchActions
```

3.4 Unreferenced Tokens

If a token is not referenced from a grammar specification, it will not be included in the generated scanner, unless the token’s name is also a name of a method (see previous section). This, coupled with the ability to do substitutions, allows you to have the equivalent of macros within your scanner specification. However, be aware that if you are simply trying to generate a scanner, you will have to make sure that you create a dummy parser specification that references all of the tokens that you want in the final scanner.

3.5 Unicode Characters

SmaCC compiles the scanner into a bunch of conditional tests on characters. Normally, it assumes that characters have values between 0 and 255, and it can make some optimizations based on this fact. With the directive ==%unicode;= in the input, SmaCC will assume that characters have values between 0 and 65535. Unicode characters outside that range are not at present handled.

CHAPTER 4

SmaCC Parser

Parsing converts the stream of tokens provided by the scanner into some object. Normally, this object will be a parse tree, but it does not have to be a parse tree. For example, the SmaCC tutorial shows a calculator. This calculator does not produce a parse tree; it produces the result, a number.

4.1 Production Rules

The production rules contains the grammar for the parser. The first production rule is considered to be the starting rule for the parser. Each production rule consists of a non-terminal symbol name followed by a ”:” separator which is followed by a list of possible productions separated by vertical bar, ”|”, and finally terminated by a semicolon, ”;”.

```
Expression
  : Expression 'left' "+" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "-" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "*" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "/" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "^" 'operator' Expression 'right' {{Binary}}
  | "(" Expression ")" {{}}
  | Number
  ;
Number
  : <number> {{Number}}
  ;
```

Each production consists of a sequence of non-terminal symbols, tokens, or keywords followed by some optional Smalltalk code enclosed in curly brackets, {} or a AST node definition enclosed in two curly brackets, {{}}. Non-terminal symbols are valid Smalltalk variable names and must be defined somewhere in the parser definition. Forward references are valid. Tokens are enclosed in angle brackets as they are defined in the scanner (e.g., <token>) and keywords are enclosed in double-quotes (e.g., ”then”). Keywords that contain double-quotes need to have two double-quotes per each double-quote in the keyword. For example, if you need a keyword for one double-quote character, you would need to enter ”””” (four double-quote characters).

The Smalltalk code is evaluated whenever that production is matched. If the code is a zero or a one argument symbol, then that method is performed. For a one argument symbol, the argument is an OrderedCollection that contains one element for each item in the production. If the code isn’t a zero or one argument symbol, then the code is executed and whatever is returned by the code is the result of the production. If no Smalltalk code is specified, then the default action is to execute the #reduceFor: method (unless you are producing an AST parser). This method converts all items into an OrderedCollection. If one of the items is another OrderedCollection, then all of its elements are added to the new collection.

Inside the Smalltalk code you can refer to the values of each production item by using literal strings. The literal string, '1', refers the to value of the first production item. The values for tokens and keywords will be SmaCCToken objects. The value for all non-terminal symbols will be whatever the Smalltalk code evaluates to for that non-terminal symbol.

4.2 Named Symbols

When entering the Smalltalk code, you can get the value for a symbol by using the literal strings (e.g., '2'). However, this creates difficulties when modifying a grammar. If you insert some symbol at the beginning of a production, then you will need to modify your Smalltalk code changing all literal string numbers. Instead you can name each symbol in the production and then refer to the name in the Smalltalk code. To name a symbol (non-terminal, token, or keyword), you need to add a quoted variable name after the symbol in the grammar. For example, "MySymbol : Expression 'expr' "+" <number> 'num' {expr + num} ;" creates two named variables. One for the non-terminal Expression and one for the <number> token. These variables are then used in the Smalltalk code.

4.3 Error Recovery

Normally, when the parser encounters an error, it raises the SmaCCParserError exception and parsing is immediately stopped. However, there are times when you may wish to try to parse more of the input. For example, if you are highlighting code, you do not want to stop highlighting at the first syntax error. Instead you may wish to attempt to recover after the statement separator – the period ".". SmaCC uses the error symbol to specify where error recovery should be attempted. For example, we may have the following rule to specify a list of Smalltalk statements:

```
Statements : Expression | Statements "." Expression ;
```

If we wish to attempt recovery from a syntax error when we encounter a period, we can change our rule to be:

```
Statements : Expression | Statements "." Expression | error "." Expression ;
```

While the error recovery allows you to proceed parsing after a syntax error, it will not allow you to return a parse tree from the input. Once the input has been parsed with errors, it will raise a non-resumable SmaCCParserError.

4.4 Shortcuts

Extended BNF grammars extend the usual notation for grammar productions with some convenient shortcuts. SmaCC (but not the Moose version) supports the common notations of star (*) for 0 or more, question mark (?) for 0 or 1, and plus (+) for 1 or more repetitions of the preceding item. For example, rather than specifying a `ParameterList` in the conventional way, like this

```
<name> :  [a-zA-Z]  ([a-zA-Z]  | [0-9] | _ | ')*;
<whitespace>:  (\x20|\xA0|\r)* ;

ParameterList
  : Parameter
  | ParameterList Parameter
  ;

Parameter
  : <name>
  ;
```

we can be more concise and specify it like this:

```
<name> :  [a-zA-Z]  ([a-zA-Z]  | [0-9] | _ | ')*;
<whitespace>:  (\x20|\xA0|\r)* ;

ParameterList
  : Parameter  +
  ;

Parameter
  : <name>
  ;
```

If we are generating an AST, these shortcuts have the aditional advantage of producing more compact AST nodes. For more information, see the Chapter on Idioms.

CHAPTER 5

SmaCC Directives

SmaCC has several directives that can change how the scanner and parser is generated. Each directive begins with a % character and the directive keyword. Depending on the directive, there may be a set of arguments. Finally, the directive is terminated with a semicolon character, ; as shown below:

```
%left "+" "-";
%left "*" "/";
%right "^";
%annotate_tokens;
%root Expression;
%prefix AST;
%suffix Node;
%ignore_variables leftParenToken rightParenToken;
```

5.1 Ambiguous Grammars and Precedence

SmaCC can handle ambiguous grammars. Given an ambiguous grammar, SmaCC will produce some parser. However, it may not parse correctly. For an LR parser, there are two basic types of ambiguities, reduce/reduce conflicts and shift/reduce conflicts. Reduce/reduce conflicts are bad. SmaCC has no directives to handle them and just picks one of the choices. These conflicts normally require a rewrite of your grammar or switch to GLR parsing.

On the other hand, shift/reduce conflicts can be handled by directives. When SmaCC encounters a shift/reduce conflict it will perform the shift action by default. However, you can control this action with the %left, %right, and %nonassoc directives. If a token has been declared in a %left directive, it means that the token is left-associative. Therefore, the parser will perform a reduce operation. However, if it has been declared as right-associative, it will perform a shift operation. A token defined as %nonassoc will produce an error if that is encountered during parsing. For example, you may want to specify that the equal operator, ”=”, is non-associative, so a = b = c is not parsed as a valid expression. All three directives are followed by a list of tokens.

Additionally, the %left, %right, and %nonassoc directives allow precedence to be specified. The order of the directives specifies the precedence of the tokens. The higher precedence tokens appear on the higher line numbers. For example, the following directive section gives the precedence for the simple calculator in our tutorial:

```
%left "+" "-";
%left "*" "/";
%right "^";
```

The symbols + and - appear on the first line, and hence have the lowest precedence. They are also left-associative, so `1 + 2 + 3` will be evaluated as `(1 + 2) + 3`. On the next line we see the symbols * and /; since they appear on a line with a higher line number, they have higher precedence than + and -. Finally, on line three we have the ^ symbol. It has the highest precedence, but is *right* associative. Combining all the rules allows us to parse `1 + 2 * 3 / 4 ^ 2 ^ 3` as `1 + ((2 * 3) / (4 ^ (2 ^ 3)))`.

5.2 Start Symbols

By default, the left-hand side of the first grammar rule is the start symbol. If you want to multiple start symbols, then you can specify them by using the `%start` directive followed by the nonterminals that are additional start symbols. This is useful for creating two parsers with grammars that are similar but slightly different. For example, consider a Pharo parser. You can parse methods, and you can parse expressions. These are two different operations, but have similar grammars. Instead of creating two different parsers for parsing methods and expressions, we can specify one grammar that parses methods, and also specify an alternative start symbol for parsing expressions.

The `StParser` in the SmaCC Example Parsers package has an example of this. The method `StParser class>>parseMethod:` uses the `startingStateForMethod` position to parse methods and the method `StParser class>>parseExpression:` uses the `startingStateForSequenceNode` position to parse expressions.

For example if you add the following to an hypothetical grammar

```
%start file expression statement declaration;
```

SmaCC will generate the following class methods on the parser: `startingStateForfile`, `startingStateForexpression`, `startingStateForstatement` and `startingStateFordeclaration`.

Then you can parse a subpart as follows:

```
YourParser >> parseStatement: aString
  "Parse an statement."

  ^ (self on: (ReadStream on: aString))
    setStartingState: self startingStateForstatement;
    parse
```

The ability to specify multiple start symbols is also useful when you build your grammar incrementally and want to test it at different points.

5.3 Id Methods

Internally, the various token types are represented as integers. However, there are times that you need to reference the token types. For example, in the CScanner and CParser classes, the `TYPE_NAME` token has a syntax identical to that of the IDENTIFIER token. To distinguish them, the IDENTIFIER-matching method does a lookup in the type table: if it finds a type definition with the same name as the current IDENTIFIER, it returns the TYPE_NAME token type. To determine what integer this is, the parser includes an `%id` directive for <IDENTIFIER> and <TYPE_NAME>. This generates the IDENTIFIERId and TYPE_NAMEId methods on the scanner. These methods simply return the integer representing that token type. See the `C` sample scanner and parser for an example of how the `%id` directive is used.

5.4 Case Insensitive Scanning

You can specify that the scanner should ignore case differences by using the `%ignorecase;` directive. If you have a language that is case insensitive and has several keywords, this can be a handy feature. For example, if you have THEN as a keyword in a case insensitive language, you would need to specify the token for then as `<then> : [tT] [hH] [eE] [nN] ;`. This is a pain to enter correctly. When the ignorecase directive is used, SmaCC will automatically convert THEN into `[tT][hH][eE][nN]`.

5.5 GLR Parsing

SmaCC allows you to parse ambiguous grammars using a GLR parser. The `%glr;` directive changes the type of parser that SmaCC generates. Instead of your generated parser being a subclass of `SmaCCParser`, when you use the `%glr;` directive, your parser will be a subclass of SmaCCGLRParser.

If you parse a string that has multiple representations, SmaCC will throw a `SmaCCAmbiguousResultNotification` exception, which can be handled by user code. This exception has the potential parses. The value with which it is resumed with will be selected as the definitive parse value. If the exception is not handled, then SmaCC will pick one as the definitive parse value.

5.6 AST Directives

There are several directives that are used when creating AST's.

- The `%root` directive is used to specify the root class in the AST hierarchy. The `%root` directive has a single argument that is the name that will be used to create the root class in the AST. This class will be created as a subclass of `SmaCCParseNode`.
- The `%prefix` and `%suffix` directives tell SmaCC the prefix and suffix to add to the name of the non-terminal to create the name of the AST node's class. This prefix and suffix are added to the name of every AST node, including the %root node. For example, the following will create a `RBProgramNode` class that is a subclass of `SmaCCParseNode` and is the root of all AST nodes defined by this parser.

```
%root Program;
%prefix RB;
%suffix Node;
```

By default all nodes created by SmaCC will be direct subclass of your `%root class`. However, you can specify the class hierarchy by using the `%hierarchy` directive. The syntax of the `%hierarchy` is `%hierarchy SuperclassName "(" SubclassName + ");"`. If you have multiple subclasses, you can list all of them inside the parenthesis, separated by whitespace, as follows.

```
%hierarchy Program (Expression Statement);
```

Three AST directives deal with the generated classes' instance variables.

- The `%annotate_tokens` tells SmaCC to generate instance variable names for any unnamed tokens in the grammar rules. Without this directive, an unnamed token will generate the warning

```
Unnamed symbol in production. Without a variable name the value will be dropped from the
    parsed AST."
```

With the directive, a variable name will be auto-generated, using the name of the symbol follwed by `Token`. So the symbol `<op>` would be given the name `<opToken>`.

- The `%attributes` directive allows you to add some unused instance variables to your classes. This enables you to later extend the generated classes to use those variables. The first argument to the `%attributes` directive is the class name; the second argument is a parenthesised list of variable names. For example, we could add an instance variable `cachedValue` to the `Expression` class with `%attributes Expression (cachedValue);`.

- The final instance variable directive is `%ignore_variables`. When SmaCC creates the AST node classes, it automatically generates appropriate `=` and `hash` methods. By default, these methods use all instance variables when comparing for equality and computing the hash. The `%ignore_variables` directive allows you to specify that certain variables should be ignored. For example, you may wish to ignore parentheses when you compare expressions. If you named your `(` token 'leftParen' and your `)` token 'rightParen', then you can specify this with `%ignore_variables leftParen rightParen;`.

CHAPTER 6

SmaCC Abstract Syntax Trees

SmaCC can generate abstract syntax trees from an annotated grammar. In addition to the node classes to represent the trees, SmaCC also generates a generic visitor for the tree classes. This is handy and boost your productivity especially since we can decide to change the AST form afterwards and get a new one in no time.

6.1 Restarting

To create an AST, you need to annotate your grammar. Let's start with the grammar of our simple expression parser from the tutorial. Since we want to build an AST, we've removed the code that evaluates the expression.

```
<number> : [0-9]+ (\. [0-9]*) ? ;
<whitespace> : \s+;

%left "+" "-";
%left "*" "/";
%right "^";

Expression
  : Expression "+" Expression
  | Expression "-" Expression
  | Expression "*" Expression
  | Expression "/" Expression
  | Expression "^" Expression
  | "(" Expression ")"
  | Number
  ;
Number
  : <number>
  ;
```

6.2 Building nodes

Building an AST parser works similarly to the normal parser. Instead of inserting Pharo code after each production rule inside braces, {}, we insert the class name inside of double braces, {{}}. Also, instead of naming a variable for use in the Pharo code, we name a variable so that it will be included as an instance variable in the class we are defining.

Let's start with annotating the grammar for the AST node classes that we wish to parse. We need to tell SmaCC where the AST node should be created and the name of the node's class to create. In our example, we'll start by creating three node classes: Expression, Binary, and Number.

```
<number> : [0-9]+ (\. [0-9]*) ? ;
<whitespace> : \s+;

%left "+" "-";
%left "*" "/";
%right "^";

Expression
  : Expression "+" Expression {{Binary}}
  | Expression "-" Expression {{Binary}}
  | Expression "*" Expression {{Binary}}
  | Expression "/" Expression {{Binary}}
  | Expression "^" Expression {{Binary}}
  | "(" Expression ")" {{}}
  | Number
  ;
Number
  : <number> {{Number}}
  ;
```

If you compile this grammar, SmaCC will complain that we need to define a root node. Since the root hasn't been defined SmaCC compiles the grammar as if the `{{...}}` expressions where not there and generates the same parser as above.

- Notice that for the parenthesized expression, we are using `{{}}`. This is a shortcut for `{{Expression}}` (the name of our production's symbol).
- Notice that we didn't annotate the last production in the Expression definition. Since it only contains a single item, Number, SmaCC will pull up its value which in this case will be a Number AST node.

6.3 Variables and unnamed entities

Now, let's add variable names to our rules:

```
<number> : [0-9]+ (\. [0-9]*) ? ;
<whitespace> : \s+;

%left "+" "-";
%left "*" "/";
%right "^";
%annotate_tokens;

Expression
  : Expression 'left' "+" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "-" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "*" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "/" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "^" 'operator' Expression 'right' {{Binary}}
  | "(" Expression ")" {{}}
  | Number
  ;
Number
  : <number> {{Number}}
  ;
```

The first thing to notice is that we added the `%annotate_tokens;` directive. This directive tells SmaCC to automatically create an instance variable for every unnamed token and keyword in the grammar. An unamed token is a <> not followed by a variable (defined with `'aVariable'`) and an unnamed keyword is delimited by double quotes as in `"("`.

In our example above, we have

- one unnamed token, `<number>`, and
- two unnamed keywords, `(` and `)`.

When SmaCC sees an unnamed token or keyword, it adds a variable that is named based on the item and appends Token to the name. For example, in our example above, SmaCC will use

- leftParenToken for `(`,
- rightParenToken for `)`, and
- `numberToken` for `<number>`.

The method `SmaCCGrammar class>>tokenNameMap` contains the mapping to convert the keyword characters into valid Pharo variable names. You can modify this dictionary if you wish to change the default names.

6.4 Unnamed symbols

Notice that we did not name Expression in the `(` Expression `)` production rule. When you don't name a symbol in a production, SmaCC tries to figure out what you want to do. In this case, SmaCC determines that the Expression symbol produces either a Binary or Number node. Since both of these are subclasses of the Expression, SmaCC will pull up the value of Expression and add the parentheses to that node. So, if you parse `(3 + 4)`, you'll get a Binary node instead of an Expression node.

6.5 Generating the AST

Now we are ready to generate our AST. We need to add directives that tell SmaCC our root AST class node and the prefix and suffix of our classes.

```
<number> : [0-9]+ (\. [0-9]*) ? ;
<whitespace> : \s+;

%left "+" "-";
%left "*" "/";
%right "^";
%annotate_tokens;
%root Expression;
%prefix AST;
%suffix Node;

Expression
  : Expression 'left' "+" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "-" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "*" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "/" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "^" 'operator' Expression 'right' {{Binary}}
  | "(" Expression ")" {{}}
  | Number
  ;
Number
  : <number> {{Number}}
  ;
```

When you compile this grammar, in addition to the normal parser and scanner classes, SmaCC will create ASTExpressionNode, ASTBinaryNode, and ASTNumberNode node classes and an ASTExpressionNodeVisitor class that implements the visitor pattern for the tree classes.

The ASTExpressionNode class will define two instance variables, leftParenTokens and rightParenTokens, that will hold the (and) tokens. Notice that these variables hold a collection of tokens instead of a single parenthesis token. SmaCC figured out that each expression node could contain multiple parentheses and made their variables hold a collection. Also, it pluralized the leftParentToken variable name to leftParenTokens. You can customize how it pluralizes names in the SmaCCVariableDefinition class (See pluralNameBlock and pluralNames).

The ASTBinaryNode will be a subclass of ASTExpressionNode and will define three variables: left, operator, and right.

- The left and right instance variables will hold other ASTExpressionNodes and
- the operator instance variable will hold a token for the operator.

Finally, the ASTNumberNode will be a subclass of ASTExpressionNode and will define a single instance variable, number, that holds the token for the number.

Now, if we inspect the result of parsing 3 + 4, we'll get an Inspector on an ASTBinaryNode.

6.6 AST comparison

SmaCC also generates the comparison methods for each AST node. Let's add function evaluation to our expression grammar to illustrate this point.

```
<number> : [0-9]+ (\. [0-9]*) ? ;
<name> : [a-zA-Z]\w*;
<whitespace> : \s+;

%left "+" "-";
%left "*" "/";
%right "^";
%annotate_tokens;
%root Expression;
%prefix AST;
%suffix Node;

Expression
  : Expression 'left' "+" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "-" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "*" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "/" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "^" 'operator' Expression 'right' {{Binary}}
  | "(" Expression ")" {{}}
  | Number
  | Function
  ;
Number
  : <number> {{Number}}
  ;
Function
  : <name> "(" 'leftParen' _Arguments ")" 'rightParen' {{}}
  ;
_Arguments
  :
  | Arguments
  ;
Arguments
  : Expression 'argument'
  | Arguments "," Expression 'argument'
  ;
```

Now, if we inspect `Add(3, 4)`, we'll get something that looks like an `ASTFunctionNode`.

In addition to the generating the classes, SmaCC also generates the comparison methods for each AST node. For example, we can compare two parse nodes: `(CalculatorParser parse: '3 + 4') = (CalculatorParser parse: '3+4')`. This returns true as whitespace is ignored. However, if we compare `(CalculatorParser parse: '(3 + 4)') = (CalculatorParser parse: '3+4')`, we get false, since the first expression has parentheses. We can tell SmaCC to ignore these by adding the `%ignore_variables directive`:

```
<number> : [0-9]+ (\. [0-9]*) ? ;
<name> : [a-zA-Z]\w*;
<whitespace> : \s+;

%left "+" "-";
%left "*" "/";
%right "^";
%annotate_tokens;
%root Expression;
%prefix AST;
%suffix Node;
%ignore_variables leftParenToken rightParenToken;

Expression
  : Expression 'left' "+" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "-" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "*" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "/" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "^" 'operator' Expression 'right' {{Binary}}
  | "(" Expression ")" {{}}
  | Number
  | Function
  ;
Number
  : <number> {{Number}}
  ;
Function
  : <name> "(" 'leftParen' _Arguments ")" 'rightParen' {{}}
  ;
_Arguments
  :
  | Arguments
  ;
Arguments
  : Expression 'argument'
  | Arguments "," Expression 'argument'
  ;
```

Now, we get true when we compare `(CalculatorParser parse: '(3 + 4)') = (CalculatorParser parse: '3+4')`.

6.7 Extending the visitor

Finally, let's subclass the generated visitor to create a visitor that evaluates the expressions. Here's the code for Pharo:

```
ASTExpressionNodeVisitor subclass: #ASTExpressionEvaluator
  instanceVariableNames: 'functions'
  classVariableNames: ''
  package: 'SmaCC-Tutorial'.
```

```
ASTExpressionEvaluator >> functions
  ^functions
    ifNil:
      [functions := (Dictionary new)
            at: ''Add'' put: [:a :b | a + b];
            yourself ]' classified: 'private'.
```

```
ASTExpressionEvaluator >> visitBinary: aBinary
  | left right operation |
  left := self acceptNode: aBinary left.
  right := self acceptNode: aBinary right.
  operation := aBinary operator value.
  operation = ''^'' ifTrue: [ ^left ** right ].
  ^left perform: operation asSymbol with: right' classified: 'visiting'.
```

```
ASTExpressionEvaluator >> visitFunction: aFunction
  | function arguments |
  function := self functions at: aFunction nameToken value
        ifAbsent:
          [self error: ''Function '' ,
            aFunction nameToken value ,
            '' is not defined'' ].
  arguments := aFunction arguments collect: [ :each | self acceptNode: each ].
  ^function valueWithArguments: arguments asArray' classified: 'visiting'.
```

```
ASTExpressionEvaluator >> visitNumber: aNumber
  ^ aNumber numberToken value asNumber' classified: 'visiting'.
```

Now we can evaluate `ASTExpressionEvaluator new accept: (CalculatorParser parse: 'Add(3,4) * 12 / 2 ^ (3 - 1) + 10')` and get 31.

CHAPTER 7

SmaCC Transformations

Once you have generated your AST using SmaCC, you may want to use SmaCC's built-in tools to transform the AST. For example, transforming the AST may make it easier to generate code.

7.1 Defining Transformations

Let's add support for transforming the simple expression ASTs generated from our calculator example. The basic idea is to define *patterns* that match subtrees of the AST, and specify how these subtrees should be re-written.

We start by extending our grammar with two additional lines.

- The first line defines how we will write a pattern in our grammar. SmaCC doesn't have a built-in pattern syntax, because whatever SmaCC were to choose might conflict with the syntax of your language. Instead, your grammar should define the `<patternToken>`: SmaCC uses this regular expression as the definition of a pattern. For our example language, we will define a pattern as anything enclosed by ` characters (e.g., `` `pattern` ``). This same choice would work for any language that does not use ` frequently in its syntax.
- The second line we need to add tells SmaCC to generate a GLR parser (`%glr;`). This allows SmaCC to parse all possible representations of a pattern expression.

Here is our grammar with those two additional lines:

```
  <number> : [0-9]+ (\. [0-9]*) ? ;
  <name> : [a-zA-Z]\w*;
  <whitespace> : \s+;

+ <patternToken> : \` [^\`]* \` ;
+ %glr;

  %left "+" "-";
  %left "*" "/";
  %right "^";
  %annotate_tokens;
  %root Expression;
  %prefix AST;
  %suffix Node;
  %ignore_variables leftParenToken rightParenToken;

  Expression
    : Expression 'left' "+" 'operator' Expression 'right' {{Binary}}
    | Expression 'left' "-" 'operator' Expression 'right' {{Binary}}
    | Expression 'left' "*" 'operator' Expression 'right' {{Binary}}
    | Expression 'left' "/" 'operator' Expression 'right' {{Binary}}
    | Expression 'left' "^" 'operator' Expression 'right' {{Binary}}
    | "(" Expression ")" {{}}
    | Number
    | Function;
  Number : <number> {{Number}};
  Function
    : <name> "(" 'leftParen' _Arguments ")" 'rightParen' {{}};
  _Arguments
    :
    | Arguments;
  Arguments
    : Expression 'argument'
    | Arguments "," Expression 'argument';
```

7.2 Pattern matching expressions

Having made these changes, we can now define *re-write rules* that specify how certain subtrees in the AST should be replaced by other subtrees. To do this, we modify our grammar by adding some pattern-matching expressions. Pattern-matching expressions look like normal expressions, but may include patterns that are surrounded by the back quote, `, character.

For example, `a` + 1 is a pattern-matching expression that matches any expression followed by + 1.

Once the pattern has matched a subtree, we transform it into a new subtree. To do this, we supply a replacement expression that uses the pattern variables from the match. Replacement expressions are strings that can contain back-quoted variables. These back-quoted variables are replaced with the appropriate subtree from the pattern.

For example, if we are searching for the pattern `a` + 1, we can supply a replacement expression like 1 + `a`. This pattern will match (3 + 4) + 1. When we perform the replacement we take the literal 1 + part of the string and append the value of the subtree that matched `a`. In this case, we would append (3 + 4) to give us 1 + (3 + 4).

7.3 Example

As an example, let’s rewrite addition expressions into reverse Polish notation. Our search pattern is `a` + `b` and our replacement expression is `a` `b` +.

```
  | rewriter compositeRewrite rewrite matcher transformation |
  compositeRewrite := SmaCCRewriteFile new.
  compositeRewrite parserClass: CalculatorParser.
  matcher := SmaCCRewriteTreeMatch new.
  matcher source: '`a` + `b`'.
  transformation := SmaCCRewriteStringTransformation new.
  transformation string: '`a` `b` +'.
  rewrite := SmaCCRewrite
    comment: 'Postfix rewriter'
    match: matcher
    transformation: transformation.
  compositeRewrite addTransformation: rewrite.
  rewriter := SmaCCRewriteEngine new.
  rewriter rewriteRule: compositeRewrite.
  rewriter rewriteTree: (CalculatorParser parse: '(3 + 4) + (4 + 3)')
```

This code rewrites (3 + 4) + (4 + 3) in RPN format and returns 3 4 + 4 3 + +. The first match that this finds is `a` = (3 + 4) and `b` = (4 + 3). Inside our replacement expression, we refer to `` `a` `` and `` `b` ``, so we first process those expression for more transformations. Since both contain other addition expressions, we rewrite both expressions to get `` `a` `` = `3 4 +` and `` `b` `` = `4 3 +`.

Here's the same example, using SmaCC's special rewrite syntax.

```
| rewriter rewriteExpression |
rewriteExpression :=
  'Parser: CalculatorParser
  >>>`a` + `b`<<<
  ->
  >>>`a` `b` +<<<'.
rewriter := SmaCCRewriteEngine new.
rewriter rewriteRule: (SmaCCRewriteRuleFileParser parse: rewriteExpression).
rewriter rewriteTree: (CalculatorParser parse: '(3 + 4) + (4 + 3)')
```

7.4 Parametrizing Transformations

Let's extend our RPN rewriter to support other expressions besides addition. We could do that by providing rewrites for all possible operators (+, -, *, /, ^), but it would be better if we could do it with a pattern. You might think that we could use `` `a` `op` `b` ``, but the pattern `` `op` `` will match only AST nodes, and not tokens like `(+)`. We can tell SmaCC to match tokens by using `` `a` `op{beToken}` `b` ``. Here's the rewrite expression that works for all expressions:

```
Parser: CalculatorParser
\>\>\>`a` `op{beToken}` `b`\<\<\<
->
\>\>\>`a` `b` `op`\<\<\<
```

If we transform `(3 + 4) * (5 - 2) ^ 3`, we'll get `3 4 + 5 2 - 3 ^ *`.

CHAPTER 8

Grammar Idioms

In this chapter, we share some coding idioms for grammars that help create more compact ASTs.

8.1 Managing Lists

Smacc automatically determines if the production rules contain a recursion that represents a list. In such case, it adds an `s` to the name of the generated instance variable and manages it as a list.

Let us take an example

```
<a> : a;
<whitespace> : \s+;

%root Line;
%prefix SmaccTutorial;

Line
  : <a> 'line' {{}}
  | Line <a> 'line' {{}}
  ;
```

Here we see that Line is recursive. Smacc will generate a class `SmaccTutorialLine` with an instance variable `lines` initialized as an ordered collection.

Note that, if the right-hand-side of a rule is completely empty, SmaCC does not recognise the list.

```
Line
  :
  | Line <a> 'line' {{}}
  ;
```

To avoid the empty right-hand-side, you should write this as follows:

```
Line
  : {{}}
  | Line <a> 'line' {{}}
  ;
```

8.2 Using Shortcuts

You may prefer to define your lists using the shortcuts question mark (`?`) for `0` or `1` occurrences, star (`*`) for `0` or more, and plus (`+`) for `1` or more, rather than with recursion. Let's compare the two approaches.

Let's look at a grammar that defines a parameter list recursively.

```
<name> :  [a-zA-Z]  ([a-zA-Z]  | [0-9] | _ | ')*;
<whitespace>:  (\x20|\xA0|\r)* ;

%root Root;
%prefix SmaccTutorial;
%annotate_tokens;

ParameterList
    : Parameter 'param' {{}}
    | ParameterList 'param' Parameter 'param' {{}}
    ;

Parameter
    : <name> {{}}
    ;
```

If the above grammar is used to parse a list of three names, it will generate an AST node class called `SmaccTutorialParameterList` with a `params` instance variable that holds an ordered collection. However, the contents of the ordered collection will *not* be the three parameters. Instead, the collection will have *two* elements: a parameter list (which will contain an ordered collection of two parameters), and a parameter that contains the third. Why? Because that's what the grammar specifies!

There is a trick that will instead generate a collection of three elements: remove the name `'param'` from after the recursive appearace of the non-terminal `ParameterList` in the second alternative for `ParameterList`:

```
ParameterList
    : Parameter 'param' {{}}
    | ParameterList Parameter 'param' {{}}
    ;
```

Now you will get a collection `params` containing *all* the parameters.

You can also specify the same language using `+`, like this:

```
<name> :  [a-zA-Z]  ([a-zA-Z]  | [0-9] | _ | ')*;
<whitespace>:  (\x20|\xA0|\r)* ;

%root Root;
%prefix SmaccTutorial;
%annotate_tokens;

ParameterList
    : Parameter 'params' + {{}}
    ;

Parameter
    : <name> {{}}
    ;
```

Not only is this grammar easier to read, but the generated AST will contain a single collection of parameters. If you parse three names, the result will be a `SmaccTutorialParameterList` object that contains an instance variable `params` that will be initialized to be an ordered collection of three `SmaCCTutorialParameter` nodes.

In a similar way, if you use a `*`, you will get an ordered collection containing zero or more items. However, if you use a `?`, you don't get a collection: you get either `nil` (if the item was absent), or the generated node (if it was present).

8.3 Expressing Optional Features

Often, lists contain separators, which makes specifying them a little more complex. Here is a grammar in which lists of names can be of arbitrary length, but the list items must be separated with commas. It expresses this with the ? shortcut.

```
<name> :  [a-zA-Z]  ([a-zA-Z]  | [0-9] | _ | ')*;
<whitespace>:  (\x20|\xA0|\r)* ;

%root Root;
%prefix SmaccTutorial;
%annotate_tokens;

NameList
  : ( Name 'n' ( ","  Name 'n' ) *)? {{}}
  ;

Name
  : <name>
  ;
```

SmaCC recognizes this idiom, and will generate an ordered collection of zero or more names. If you want this behaviour, it is important to use the same instance variable name (here `n`) for both the base case and the `*` repetition. If you use different names

```
NameList
  : ( Name 'n1' ( ","  Name 'n2' ) *)? {{}}
  ;
```

then the generated node will have two instance variables: `n1` will be either `nil` (if the input list is empty) or will contain the first `Name` if it is not, while `n2s` will be a collection containing the remaining Names (zero when the input list has length one).

If you prefer not to use the `*` and `?` shortcuts (or are using a verison of SmaCC that does not support them), you can get the same effect using recursion:

```
NameList
  :    {{}}
  |  NonEmptyNameList
  ;

NonEmptyNameList
  : Name 'name' {{}}
  | NonEmptyNameList  "," Name 'name' {{}}
  ;

Name
  : <name> {{ }}
  ;
```

Once again, note that no name is given to the recursive use of `NonEmptyNameList`.

In general, empty alternatives will be represented as `nil`. This avoids generating many useless objects. So

```
NameList
  :
  |  NonEmptyNameList
  ;
```

will return nil when it matches the empty input. If instead you want an empty `NameList` node, use `{{}}` for the empty alternative:

```
NameList
  :    {{}}
  |  NonEmptyNameList
  ;
```

CHAPTER 9

Conclusion

SmaCC is a really strong and stable library that is used in production since many years. It is an essential assets for dealing with languages. While PetitParser (See Deep into Pharo http://books.pharo.org) is useful for composing and reusing fragments of parsers, Smacc offers speed and more traditional parsing technology.

CHAPTER 10

Vocabulary

10.1 Reference example

Let us take the following grammar.

```
<number> : [0-9]+ (\. [0-9]*) ? ;
<whitespace> : \s+;

%left "+" "-";
%left "*" "/";
%right "^";
%annotate_tokens;
%root Expression;
%prefix AST;
%suffix Node;

Expression
    : Expression 'left' "+" 'operator' Expression 'right' {{Binary}}
    | Expression 'left' "-" 'operator' Expression 'right' {{Binary}}
    | Expression 'left' "*" 'operator' Expression 'right' {{Binary}}
    | Expression 'left' "/" 'operator' Expression 'right' {{Binary}}
    | Expression 'left' "^" 'operator' Expression 'right' {{Binary}}
    | "(" Expression ")" {{}}
    | Number
    ;
Number
    : <number> {{Number}}
    ;
```

10.2 Grammar structure

It is composed of

- Scanner part: all rules starting with <>
- Directive part: all lines starting with %
- Parser part: the rest

Elements

Production rule

The following expressions define two production rules

```
Expression
  : Expression 'left' "+" 'operator' Expression 'right' {{Binary}}
  | Expression 'left' "-" 'operator' Expression 'right' {{Binary}}
  ;

Number
  : <number> {{Number}}
  ;
```

A rule group is defined by several production rules.

- Here the first production rule has two production rules.
- While the seconde production rule has only one.

A production rule can be composed of

- non terminal often starting with uppercase
- scanner token
- keywords (delimited by `"`)
- variables (delimited by `'`)
- and action (delimited by `{}`)

Tokens

Tokens are identified by the scanner. A token specification is composed of a token name and a token regular expressions.

```
<TokenName>    :    RegularExpression ;
```

The following token specification describes a number: It starts with one or more digits, possibly followed by an decimal point with zero or more digits after it. The scanner definition for this token is:

```
<number>        :       [0-9]+ (\. [0-9]*) ? ;
```

Let's go over each part:

`<number>` Names the token identified by the expression. The name inside the <> must be a legal Pharo variable name.

`:` Separates the name of the token from the token's definition.

`[0-9]` Matches any single character in the range `'0'` to `'9'` (a digit). We could also use `\d` or `<isDigit>` as these also match digits.

`+` Matches the previous expression one or more times. In this case, we are matching one or more digits.

`( ... )` Groups subexpressions. In this case we are grouping the decimal point and the numbers following the decimal point.

`\.` Matches the '.' character (. has a special meaning in regular expressions, quotes it).

`*` Matches the previous expression zero or more times.

`?` Matches the previous expression zero or one time (i.e., it is optional).

`;` Terminates a token specification.

Keywords

Keywords are defined in the production and delimited by `"`. In the following

Non Terminal

In the production rule `Expression 'left' "+" 'operator' Expression 'right'`, Expression is a non terminal.

Variables

Variables give name to one element of a production. For example

```
Expression 'left' "^" 'operator' Expression 'right'
```

- ’left’ and ’right’ denote the expression matched by the rules
- ’operator’ denotes the caret token.