Bison

The Yacc-compatible Parser Generator
28 July 2020, Bison Version 3.7.1

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Cover art by Etienne Suvasa.

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Introduction

Bison is a general-purpose parser generator that converts an annotated context-free grammar into a deterministic LR or generalized LR (GLR) parser employing LALR(1), IELR(1) or canonical LR(1) parser tables. Once you are proficient with Bison, you can use it to develop a wide range of language parsers, from those used in simple desk calculators to complex programming languages.

Bison is upward compatible with Yacc: all properly-written Yacc grammars ought to work with Bison with no change. Anyone familiar with Yacc should be able to use Bison with little trouble. You need to be fluent in C, C++ or Java programming in order to use Bison or to understand this manual.

We begin with tutorial chapters that explain the basic concepts of using Bison and show three explained examples, each building on the last. If you don't know Bison or Yacc, start by reading these chapters. Reference chapters follow, which describe specific aspects of Bison in detail.

Bison was written originally by Robert Corbett. Richard Stallman made it Yacc-compatible. Wilfred Hansen of Carnegie Mellon University added multi-character string literals and other features. Since then, Bison has grown more robust and evolved many other new features thanks to the hard work of a long list of volunteers. For details, see the `THANKS` and `ChangeLog` files included in the Bison distribution.

This edition corresponds to version 3.7.1 of Bison.

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1 The Concepts of Bison

This chapter introduces many of the basic concepts without which the details of Bison will not make sense. If you do not already know how to use Bison or Yacc, we suggest you start by reading this chapter carefully.

1.1 Languages and Context-Free Grammars

In order for Bison to parse a language, it must be described by a *context-free grammar*. This means that you specify one or more *syntactic groupings* and give rules for constructing them from their parts. For example, in the C language, one kind of grouping is called an 'expression'. One rule for making an expression might be, "An expression can be made of a minus sign and another expression". Another would be, "An expression can be an integer". As you can see, rules are often recursive, but there must be at least one rule which leads out of the recursion.

The most common formal system for presenting such rules for humans to read is *Backus-Naur Form* or "BNF", which was developed in order to specify the language Algol 60. Any grammar expressed in BNF is a context-free grammar. The input to Bison is essentially machine-readable BNF.

There are various important subclasses of context-free grammars. Although it can handle almost all context-free grammars, Bison is optimized for what are called LR(1) grammars. In brief, in these grammars, it must be possible to tell how to parse any portion of an input string with just a single token of lookahead. For historical reasons, Bison by default is limited by the additional restrictions of LALR(1), which is hard to explain simply. See Section 5.7 [Mysterious Conflicts], page 120, for more information on this. You can escape these additional restrictions by requesting IELR(1) or canonical LR(1) parser tables. See Section 5.8.1 [LR Table Construction], page 122, to learn how.

Parsers for LR(1) grammars are *deterministic*, meaning roughly that the next grammar rule to apply at any point in the input is uniquely determined by the preceding input and a fixed, finite portion (called a *lookahead*) of the remaining input. A context-free grammar can be *ambiguous*, meaning that there are multiple ways to apply the grammar rules to get the same inputs. Even unambiguous grammars can be *nondeterministic*, meaning that no fixed lookahead always suffices to determine the next grammar rule to apply. With the proper declarations, Bison is also able to parse these more general context-free grammars, using a technique known as GLR parsing (for Generalized LR). Bison's GLR parsers are able to handle any context-free grammar for which the number of possible parses of any given string is finite.

In the formal grammatical rules for a language, each kind of syntactic unit or grouping is named by a *symbol*. Those which are built by grouping smaller constructs according to grammatical rules are called *nonterminal symbols*; those which can't be subdivided are called *terminal symbols* or *token kinds*. We call a piece of input corresponding to a single terminal symbol a *token*, and a piece corresponding to a single nonterminal symbol a *grouping*.

We can use the C language as an example of what symbols, terminal and nonterminal, mean. The tokens of C are identifiers, constants (numeric and string), and the various keywords, arithmetic operators and punctuation marks. So the terminal symbols of a grammar

for C include 'identifier', 'number', 'string', plus one symbol for each keyword, operator or punctuation mark: 'if', 'return', 'const', 'static', 'int', 'char', 'plus-sign', 'open-brace', 'close-brace', 'comma' and many more. (These tokens can be subdivided into characters, but that is a matter of lexicography, not grammar.)

Here is a simple C function subdivided into tokens:

```
int               /* keyword 'int' */
square (int x)    /* identifier, open-paren, keyword 'int',
                     identifier, close-paren */
{                 /* open-brace */
  return x * x;   /* keyword 'return', identifier, asterisk,
                     identifier, semicolon */
}                 /* close-brace */
```

The syntactic groupings of C include the expression, the statement, the declaration, and the function definition. These are represented in the grammar of C by nonterminal symbols 'expression', 'statement', 'declaration' and 'function definition'. The full grammar uses dozens of additional language constructs, each with its own nonterminal symbol, in order to express the meanings of these four. The example above is a function definition; it contains one declaration, and one statement. In the statement, each 'x' is an expression and so is 'x * x'.

Each nonterminal symbol must have grammatical rules showing how it is made out of simpler constructs. For example, one kind of C statement is the `return` statement; this would be described with a grammar rule which reads informally as follows:

A 'statement' can be made of a 'return' keyword, an 'expression' and a 'semicolon'.

There would be many other rules for 'statement', one for each kind of statement in C.

One nonterminal symbol must be distinguished as the special one which defines a complete utterance in the language. It is called the *start symbol*. In a compiler, this means a complete input program. In the C language, the nonterminal symbol 'sequence of definitions and declarations' plays this role.

For example, '1 + 2' is a valid C expression—a valid part of a C program—but it is not valid as an *entire* C program. In the context-free grammar of C, this follows from the fact that 'expression' is not the start symbol.

The Bison parser reads a sequence of tokens as its input, and groups the tokens using the grammar rules. If the input is valid, the end result is that the entire token sequence reduces to a single grouping whose symbol is the grammar's start symbol. If we use a grammar for C, the entire input must be a 'sequence of definitions and declarations'. If not, the parser reports a syntax error.

1.2 From Formal Rules to Bison Input

A formal grammar is a mathematical construct. To define the language for Bison, you must write a file expressing the grammar in Bison syntax: a *Bison grammar* file. See Chapter 3 [Bison Grammar Files], page 46.

A nonterminal symbol in the formal grammar is represented in Bison input as an identifier, like an identifier in C. By convention, it should be in lower case, such as `expr`, `stmt` or `declaration`.

The Bison representation for a terminal symbol is also called a *token kind*. Token kinds as well can be represented as C-like identifiers. By convention, these identifiers should be upper case to distinguish them from nonterminals: for example, `INTEGER`, `IDENTIFIER`, `IF` or `RETURN`. A terminal symbol that stands for a particular keyword in the language should be named after that keyword converted to upper case. The terminal symbol `error` is reserved for error recovery. See Section 3.2 [Symbols, Terminal and Nonterminal], page 52.

A terminal symbol can also be represented as a character literal, just like a C character constant. You should do this whenever a token is just a single character (parenthesis, plus-sign, etc.): use that same character in a literal as the terminal symbol for that token.

A third way to represent a terminal symbol is with a C string constant containing several characters. See Section 3.2 [Symbols, Terminal and Nonterminal], page 52, for more information.

The grammar rules also have an expression in Bison syntax. For example, here is the Bison rule for a C `return` statement. The semicolon in quotes is a literal character token, representing part of the C syntax for the statement; the naked semicolon, and the colon, are Bison punctuation used in every rule.

```
stmt: RETURN expr ';' ;
```

See Section 3.3 [Grammar Rules], page 54.

1.3 Semantic Values

A formal grammar selects tokens only by their classifications: for example, if a rule mentions the terminal symbol 'integer constant', it means that *any* integer constant is grammatically valid in that position. The precise value of the constant is irrelevant to how to parse the input: if 'x+4' is grammatical then 'x+1' or 'x+3989' is equally grammatical.

But the precise value is very important for what the input means once it is parsed. A compiler is useless if it fails to distinguish between 4, 1 and 3989 as constants in the program! Therefore, each token in a Bison grammar has both a token kind and a *semantic value*. See Section 3.4 [Defining Language Semantics], page 56, for details.

The token kind is a terminal symbol defined in the grammar, such as `INTEGER`, `IDENTIFIER` or `','`. It tells everything you need to know to decide where the token may validly appear and how to group it with other tokens. The grammar rules know nothing about tokens except their kinds.

The semantic value has all the rest of the information about the meaning of the token, such as the value of an integer, or the name of an identifier. (A token such as `','` which is just punctuation doesn't need to have any semantic value.)

For example, an input token might be classified as token kind `INTEGER` and have the semantic value 4. Another input token might have the same token kind `INTEGER` but value 3989. When a grammar rule says that `INTEGER` is allowed, either of these tokens is acceptable because each is an `INTEGER`. When the parser accepts the token, it keeps track of the token's semantic value.

Each grouping can also have a semantic value as well as its nonterminal symbol. For example, in a calculator, an expression typically has a semantic value that is a number. In a compiler for a programming language, an expression typically has a semantic value that is a tree structure describing the meaning of the expression.

1.4 Semantic Actions

In order to be useful, a program must do more than parse input; it must also produce some output based on the input. In a Bison grammar, a grammar rule can have an *action* made up of C statements. Each time the parser recognizes a match for that rule, the action is executed. See Section 3.4.6 [Actions], page 59.

Most of the time, the purpose of an action is to compute the semantic value of the whole construct from the semantic values of its parts. For example, suppose we have a rule which says an expression can be the sum of two expressions. When the parser recognizes such a sum, each of the subexpressions has a semantic value which describes how it was built up. The action for this rule should create a similar sort of value for the newly recognized larger expression.

For example, here is a rule that says an expression can be the sum of two subexpressions:

```
expr: expr '+' expr   { $$ = $1 + $3; } ;
```

The action says how to produce the semantic value of the sum expression from the values of the two subexpressions.

1.5 Writing GLR Parsers

In some grammars, Bison's deterministic LR(1) parsing algorithm cannot decide whether to apply a certain grammar rule at a given point. That is, it may not be able to decide (on the basis of the input read so far) which of two possible reductions (applications of a grammar rule) applies, or whether to apply a reduction or read more of the input and apply a reduction later in the input. These are known respectively as *reduce/reduce* conflicts (see Section 5.6 [Reduce/Reduce Conflicts], page 117), and *shift/reduce* conflicts (see Section 5.2 [Shift/Reduce Conflicts], page 112).

To use a grammar that is not easily modified to be LR(1), a more general parsing algorithm is sometimes necessary. If you include `%glr-parser` among the Bison declarations in your file (see Section 3.1 [Outline of a Bison Grammar], page 46), the result is a Generalized LR (GLR) parser. These parsers handle Bison grammars that contain no unresolved conflicts (i.e., after applying precedence declarations) identically to deterministic parsers. However, when faced with unresolved shift/reduce and reduce/reduce conflicts, GLR parsers use the simple expedient of doing both, effectively cloning the parser to follow both possibilities. Each of the resulting parsers can again split, so that at any given time, there can be any number of possible parses being explored. The parsers proceed in lockstep; that is, all of them consume (shift) a given input symbol before any of them proceed to the next. Each of the cloned parsers eventually meets one of two possible fates: either it runs into a parsing error, in which case it simply vanishes, or it merges with another parser, because the two of them have reduced the input to an identical set of symbols.

During the time that there are multiple parsers, semantic actions are recorded, but not performed. When a parser disappears, its recorded semantic actions disappear as well, and

are never performed. When a reduction makes two parsers identical, causing them to merge, Bison records both sets of semantic actions. Whenever the last two parsers merge, reverting to the single-parser case, Bison resolves all the outstanding actions either by precedences given to the grammar rules involved, or by performing both actions, and then calling a designated user-defined function on the resulting values to produce an arbitrary merged result.

1.5.1 Using GLR on Unambiguous Grammars

In the simplest cases, you can use the GLR algorithm to parse grammars that are unambiguous but fail to be LR(1). Such grammars typically require more than one symbol of lookahead.

Consider a problem that arises in the declaration of enumerated and subrange types in the programming language Pascal. Here are some examples:

```
type subrange = lo .. hi;
type enum = (a, b, c);
```

The original language standard allows only numeric literals and constant identifiers for the subrange bounds ('`lo`' and '`hi`'), but Extended Pascal (ISO/IEC 10206) and many other Pascal implementations allow arbitrary expressions there. This gives rise to the following situation, containing a superfluous pair of parentheses:

```
type subrange = (a) .. b;
```

Compare this to the following declaration of an enumerated type with only one value:

```
type enum = (a);
```

(These declarations are contrived, but they are syntactically valid, and more-complicated cases can come up in practical programs.)

These two declarations look identical until the '`..`' token. With normal LR(1) one-token lookahead it is not possible to decide between the two forms when the identifier '`a`' is parsed. It is, however, desirable for a parser to decide this, since in the latter case '`a`' must become a new identifier to represent the enumeration value, while in the former case '`a`' must be evaluated with its current meaning, which may be a constant or even a function call.

You could parse '`(a)`' as an "unspecified identifier in parentheses", to be resolved later, but this typically requires substantial contortions in both semantic actions and large parts of the grammar, where the parentheses are nested in the recursive rules for expressions.

You might think of using the lexer to distinguish between the two forms by returning different tokens for currently defined and undefined identifiers. But if these declarations occur in a local scope, and '`a`' is defined in an outer scope, then both forms are possible— either locally redefining '`a`', or using the value of '`a`' from the outer scope. So this approach cannot work.

A simple solution to this problem is to declare the parser to use the GLR algorithm. When the GLR parser reaches the critical state, it merely splits into two branches and pursues both syntax rules simultaneously. Sooner or later, one of them runs into a parsing error. If there is a '`..`' token before the next '`;`', the rule for enumerated types fails since it cannot accept '`..`' anywhere; otherwise, the subrange type rule fails since it requires a '`..`' token. So one of the branches fails silently, and the other one continues normally, performing all the intermediate actions that were postponed during the split.

If the input is syntactically incorrect, both branches fail and the parser reports a syntax error as usual.

The effect of all this is that the parser seems to "guess" the correct branch to take, or in other words, it seems to use more lookahead than the underlying LR(1) algorithm actually allows for. In this example, LR(2) would suffice, but also some cases that are not LR(k) for any k can be handled this way.

In general, a GLR parser can take quadratic or cubic worst-case time, and the current Bison parser even takes exponential time and space for some grammars. In practice, this rarely happens, and for many grammars it is possible to prove that it cannot happen. The present example contains only one conflict between two rules, and the type-declaration context containing the conflict cannot be nested. So the number of branches that can exist at any time is limited by the constant 2, and the parsing time is still linear.

Here is a Bison grammar corresponding to the example above. It parses a vastly simplified form of Pascal type declarations.

```
%token TYPE DOTDOT ID

%left '+' '-'
%left '*' '/'

%%
type_decl: TYPE ID '=' type ';' ;

type:
  '(' id_list ')'
| expr DOTDOT expr
;

id_list:
  ID
| id_list ',' ID
;

expr:
  '(' expr ')'
| expr '+' expr
| expr '-' expr
| expr '*' expr
| expr '/' expr
| ID
;
```

When used as a normal LR(1) grammar, Bison correctly complains about one reduce/reduce conflict. In the conflicting situation the parser chooses one of the alternatives, arbitrarily the one declared first. Therefore the following correct input is not recognized:

```
type t = (a) .. b;
```

The parser can be turned into a GLR parser, while also telling Bison to be silent about the one known reduce/reduce conflict, by adding these two declarations to the Bison grammar file (before the first '%%'):

```
%glr-parser
%expect-rr 1
```

No change in the grammar itself is required. Now the parser recognizes all valid declarations, according to the limited syntax above, transparently. In fact, the user does not even notice when the parser splits.

So here we have a case where we can use the benefits of GLR, almost without disadvantages. Even in simple cases like this, however, there are at least two potential problems to beware. First, always analyze the conflicts reported by Bison to make sure that GLR splitting is only done where it is intended. A GLR parser splitting inadvertently may cause problems less obvious than an LR parser statically choosing the wrong alternative in a conflict. Second, consider interactions with the lexer (see Section 7.1 [Semantic Info in Token Kinds], page 132) with great care. Since a split parser consumes tokens without performing any actions during the split, the lexer cannot obtain information via parser actions. Some cases of lexer interactions can be eliminated by using GLR to shift the complications from the lexer to the parser. You must check the remaining cases for correctness.

In our example, it would be safe for the lexer to return tokens based on their current meanings in some symbol table, because no new symbols are defined in the middle of a type declaration. Though it is possible for a parser to define the enumeration constants as they are parsed, before the type declaration is completed, it actually makes no difference since they cannot be used within the same enumerated type declaration.

1.5.2 Using GLR to Resolve Ambiguities

Let's consider an example, vastly simplified from a C++ grammar.

```
%{
  #include <stdio.h>
  #define YYSTYPE char const *
  int yylex (void);
  void yyerror (char const *);
%}

%token TYPENAME ID

%right '='
%left '+'

%glr-parser

%%

prog:
  %empty
| prog stmt    { printf ("\n"); }
;
```

```
stmt:
  expr ';'  %dprec 1
| decl      %dprec 2
;

expr:
  ID                  { printf ("%s ", $$); }
| TYPENAME '(' expr ')'
                      { printf ("%s <cast> ", $1); }
| expr '+' expr   { printf ("+ "); }
| expr '=' expr   { printf ("= "); }
;

decl:
  TYPENAME declarator ';'
                      { printf ("%s <declare> ", $1); }
| TYPENAME declarator '=' expr ';'
                      { printf ("%s <init-declare> ", $1); }
;

declarator:
  ID                  { printf ("\"%s\" ", $1); }
| '(' declarator ')'
;
```

This models a problematic part of the C++ grammar—the ambiguity between certain declarations and statements. For example,

```
T (x) = y+z;
```

parses as either an `expr` or a `stmt` (assuming that 'T' is recognized as a `TYPENAME` and 'x' as an `ID`). Bison detects this as a reduce/reduce conflict between the rules `expr : ID` and `declarator : ID`, which it cannot resolve at the time it encounters `x` in the example above. Since this is a GLR parser, it therefore splits the problem into two parses, one for each choice of resolving the reduce/reduce conflict. Unlike the example from the previous section (see Section 1.5.1 [Using GLR on Unambiguous Grammars], page 18), however, neither of these parses "dies," because the grammar as it stands is ambiguous. One of the parsers eventually reduces `stmt : expr ';'` and the other reduces `stmt : decl`, after which both parsers are in an identical state: they've seen 'prog stmt' and have the same unprocessed input remaining. We say that these parses have *merged*.

At this point, the GLR parser requires a specification in the grammar of how to choose between the competing parses. In the example above, the two `%dprec` declarations specify that Bison is to give precedence to the parse that interprets the example as a `decl`, which implies that `x` is a declarator. The parser therefore prints

```
"x" y z + T <init-declare>
```

The `%dprec` declarations only come into play when more than one parse survives. Consider a different input string for this parser:

```
T (x) + y;
```

This is another example of using GLR to parse an unambiguous construct, as shown in the previous section (see Section 1.5.1 [Using GLR on Unambiguous Grammars], page 18). Here, there is no ambiguity (this cannot be parsed as a declaration). However, at the time the Bison parser encounters x, it does not have enough information to resolve the reduce/reduce conflict (again, between x as an `expr` or a `declarator`). In this case, no precedence declaration is used. Again, the parser splits into two, one assuming that x is an `expr`, and the other assuming x is a `declarator`. The second of these parsers then vanishes when it sees +, and the parser prints

```
x T <cast> y +
```

Suppose that instead of resolving the ambiguity, you wanted to see all the possibilities. For this purpose, you must merge the semantic actions of the two possible parsers, rather than choosing one over the other. To do so, you could change the declaration of `stmt` as follows:

```
stmt:
  expr ';'  %merge <stmtMerge>
| decl      %merge <stmtMerge>
;
```

and define the `stmtMerge` function as:

```
static YYSTYPE
stmtMerge (YYSTYPE x0, YYSTYPE x1)
{
  printf ("<OR> ");
  return "";
}
```

with an accompanying forward declaration in the C declarations at the beginning of the file:

```
%{
  #define YYSTYPE char const *
  static YYSTYPE stmtMerge (YYSTYPE x0, YYSTYPE x1);
%}
```

With these declarations, the resulting parser parses the first example as both an `expr` and a `decl`, and prints

```
"x" y z + T <init-declare> x T <cast> y z + = <OR>
```

Bison requires that all of the productions that participate in any particular merge have identical '`%merge`' clauses. Otherwise, the ambiguity would be unresolvable, and the parser will report an error during any parse that results in the offending merge.

1.5.3 GLR Semantic Actions

The nature of GLR parsing and the structure of the generated parsers give rise to certain restrictions on semantic values and actions.

1.5.3.1 Deferred semantic actions

By definition, a deferred semantic action is not performed at the same time as the associated reduction. This raises caveats for several Bison features you might use in a semantic action in a GLR parser.

In any semantic action, you can examine `yychar` to determine the kind of the lookahead token present at the time of the associated reduction. After checking that `yychar` is not set to `YYEMPTY` or `YYEOF`, you can then examine `yylval` and `yylloc` to determine the lookahead token's semantic value and location, if any. In a nondeferred semantic action, you can also modify any of these variables to influence syntax analysis. See Section 5.1 [Lookahead Tokens], page 111.

In a deferred semantic action, it's too late to influence syntax analysis. In this case, `yychar`, `yylval`, and `yylloc` are set to shallow copies of the values they had at the time of the associated reduction. For this reason alone, modifying them is dangerous. Moreover, the result of modifying them is undefined and subject to change with future versions of Bison. For example, if a semantic action might be deferred, you should never write it to invoke `yyclearin` (see Section 4.5 [Special Features for Use in Actions], page 107) or to attempt to free memory referenced by `yylval`.

1.5.3.2 YYERROR

Another Bison feature requiring special consideration is `YYERROR` (see Section 4.5 [Special Features for Use in Actions], page 107), which you can invoke in a semantic action to initiate error recovery. During deterministic GLR operation, the effect of `YYERROR` is the same as its effect in a deterministic parser. The effect in a deferred action is similar, but the precise point of the error is undefined; instead, the parser reverts to deterministic operation, selecting an unspecified stack on which to continue with a syntax error. In a semantic predicate (see Section 1.5.4 [Controlling a Parse with Arbitrary Predicates], page 23) during nondeterministic parsing, `YYERROR` silently prunes the parse that invoked the test.

1.5.3.3 Restrictions on semantic values and locations

GLR parsers require that you use POD (Plain Old Data) types for semantic values and location types when using the generated parsers as C++ code.

1.5.4 Controlling a Parse with Arbitrary Predicates

In addition to the `%dprec` and `%merge` directives, GLR parsers allow you to reject parses on the basis of arbitrary computations executed in user code, without having Bison treat this rejection as an error if there are alternative parses. For example,

```
widget:
  %?{  new_syntax } "widget" id new_args  { $$ = f($3, $4); }
| %?{ !new_syntax } "widget" id old_args  { $$ = f($3, $4); }
;
```

is one way to allow the same parser to handle two different syntaxes for widgets. The clause preceded by `%?` is treated like an ordinary midrule action, except that its text is handled as an expression and is always evaluated immediately (even when in nondeterministic mode). If the expression yields 0 (false), the clause is treated as a syntax error, which, in a nonde-

terministic parser, causes the stack in which it is reduced to die. In a deterministic parser, it acts like `YYERROR`.

As the example shows, predicates otherwise look like semantic actions, and therefore you must take them into account when determining the numbers to use for denoting the semantic values of right-hand side symbols. Predicate actions, however, have no defined value, and may not be given labels.

There is a subtle difference between semantic predicates and ordinary actions in nondeterministic mode, since the latter are deferred. For example, we could try to rewrite the previous example as

```
widget:
  { if (!new_syntax) YYERROR; }
    "widget" id new_args  { $$ = f($3, $4); }
|  { if (new_syntax) YYERROR; }
    "widget" id old_args  { $$ = f($3, $4); }
;
```

(reversing the sense of the predicate tests to cause an error when they are false). However, this does *not* have the same effect if `new_args` and `old_args` have overlapping syntax. Since the midrule actions testing `new_syntax` are deferred, a GLR parser first encounters the unresolved ambiguous reduction for cases where `new_args` and `old_args` recognize the same string *before* performing the tests of `new_syntax`. It therefore reports an error.

Finally, be careful in writing predicates: deferred actions have not been evaluated, so that using them in a predicate will have undefined effects.

1.6 Locations

Many applications, like interpreters or compilers, have to produce verbose and useful error messages. To achieve this, one must be able to keep track of the *textual location*, or *location*, of each syntactic construct. Bison provides a mechanism for handling these locations.

Each token has a semantic value. In a similar fashion, each token has an associated location, but the type of locations is the same for all tokens and groupings. Moreover, the output parser is equipped with a default data structure for storing locations (see Section 3.5 [Tracking Locations], page 66, for more details).

Like semantic values, locations can be reached in actions using a dedicated set of constructs. In the example above, the location of the whole grouping is `@$`, while the locations of the subexpressions are `@1` and `@3`.

When a rule is matched, a default action is used to compute the semantic value of its left hand side (see Section 3.4.6 [Actions], page 59). In the same way, another default action is used for locations. However, the action for locations is general enough for most cases, meaning there is usually no need to describe for each rule how `@$` should be formed. When building a new location for a given grouping, the default behavior of the output parser is to take the beginning of the first symbol, and the end of the last symbol.

1.7 Bison Output: the Parser Implementation File

When you run Bison, you give it a Bison grammar file as input. The most important output is a C source file that implements a parser for the language described by the grammar. This

parser is called a *Bison parser*, and this file is called a *Bison parser implementation file*. Keep in mind that the Bison utility and the Bison parser are two distinct programs: the Bison utility is a program whose output is the Bison parser implementation file that becomes part of your program.

The job of the Bison parser is to group tokens into groupings according to the grammar rules—for example, to build identifiers and operators into expressions. As it does this, it runs the actions for the grammar rules it uses.

The tokens come from a function called the *lexical analyzer* that you must supply in some fashion (such as by writing it in C). The Bison parser calls the lexical analyzer each time it wants a new token. It doesn't know what is "inside" the tokens (though their semantic values may reflect this). Typically the lexical analyzer makes the tokens by parsing characters of text, but Bison does not depend on this. See Section 4.3 [The Lexical Analyzer Function `yylex`], page 100.

The Bison parser implementation file is C code which defines a function named `yyparse` which implements that grammar. This function does not make a complete C program: you must supply some additional functions. One is the lexical analyzer. Another is an error-reporting function which the parser calls to report an error. In addition, a complete C program must start with a function called `main`; you have to provide this, and arrange for it to call `yyparse` or the parser will never run. See Chapter 4 [Parser C-Language Interface], page 98.

Aside from the token kind names and the symbols in the actions you write, all symbols defined in the Bison parser implementation file itself begin with '`yy`' or '`YY`'. This includes interface functions such as the lexical analyzer function `yylex`, the error reporting function `yyerror` and the parser function `yyparse` itself. This also includes numerous identifiers used for internal purposes. Therefore, you should avoid using C identifiers starting with '`yy`' or '`YY`' in the Bison grammar file except for the ones defined in this manual. Also, you should avoid using the C identifiers '`malloc`' and '`free`' for anything other than their usual meanings.

In some cases the Bison parser implementation file includes system headers, and in those cases your code should respect the identifiers reserved by those headers. On some non-GNU hosts, `<limits.h>`, `<stddef.h>`, `<stdint.h>` (if available), and `<stdlib.h>` are included to declare memory allocators and integer types and constants. `<libintl.h>` is included if message translation is in use (see Section 4.6 [Parser Internationalization], page 109). Other system headers may be included if you define `YYDEBUG` (see Section 8.5 [Tracing Your Parser], page 148) or `YYSTACK_USE_ALLOCA` (see Appendix A [Bison Symbols], page 208) to a nonzero value.

1.8 Stages in Using Bison

The actual language-design process using Bison, from grammar specification to a working compiler or interpreter, has these parts:

1. Formally specify the grammar in a form recognized by Bison (see Chapter 3 [Bison Grammar Files], page 46). For each grammatical rule in the language, describe the action that is to be taken when an instance of that rule is recognized. The action is described by a sequence of C statements.

2. Write a lexical analyzer to process input and pass tokens to the parser. The lexical analyzer may be written by hand in C (see Section 4.3 [The Lexical Analyzer Function `yylex`], page 100). It could also be produced using Lex, but the use of Lex is not discussed in this manual.

3. Write a controlling function that calls the Bison-produced parser.

4. Write error-reporting routines.

To turn this source code as written into a runnable program, you must follow these steps:

1. Run Bison on the grammar to produce the parser.

2. Compile the code output by Bison, as well as any other source files.

3. Link the object files to produce the finished product.

1.9 The Overall Layout of a Bison Grammar

The input file for the Bison utility is a *Bison grammar file*. The general form of a Bison grammar file is as follows:

```
%{
Prologue
%}

Bison declarations

%%
Grammar rules
%%
Epilogue
```

The '`%%`', '`%{`' and '`%}`' are punctuation that appears in every Bison grammar file to separate the sections.

The prologue may define types and variables used in the actions. You can also use preprocessor commands to define macros used there, and use `#include` to include header files that do any of these things. You need to declare the lexical analyzer `yylex` and the error printer `yyerror` here, along with any other global identifiers used by the actions in the grammar rules.

The Bison declarations declare the names of the terminal and nonterminal symbols, and may also describe operator precedence and the data types of semantic values of various symbols.

The grammar rules define how to construct each nonterminal symbol from its parts.

The epilogue can contain any code you want to use. Often the definitions of functions declared in the prologue go here. In a simple program, all the rest of the program can go here.

2 Examples

Now we show and explain several sample programs written using Bison: a Reverse Polish Notation calculator, an algebraic (infix) notation calculator — later extended to track "locations" — and a multi-function calculator. All produce usable, though limited, interactive desk-top calculators.

These examples are simple, but Bison grammars for real programming languages are written the same way. You can copy these examples into a source file to try them.

2.1 Reverse Polish Notation Calculator

The first example is that of a simple double-precision *Reverse Polish Notation* calculator (a calculator using postfix operators). This example provides a good starting point, since operator precedence is not an issue. The second example will illustrate how operator precedence is handled.

The source code for this calculator is named `rpcalc.y`. The '`.y`' extension is a convention used for Bison grammar files.

2.1.1 Declarations for `rpcalc`

Here are the C and Bison declarations for the Reverse Polish Notation calculator. As in C, comments are placed between '`/*...*/`' or after '`//`'.

```
/* Reverse Polish Notation calculator. */

%{
  #include <stdio.h>
  #include <math.h>
  int yylex (void);
  void yyerror (char const *);
%}

%define api.value.type {double}
%token NUM

%% /* Grammar rules and actions follow. */
```

The declarations section (see Section 3.1.1 [The prologue], page 46) contains two preprocessor directives and two forward declarations.

The `#include` directive is used to declare the exponentiation function `pow`.

The forward declarations for `yylex` and `yyerror` are needed because the C language requires that functions be declared before they are used. These functions will be defined in the epilogue, but the parser calls them so they must be declared in the prologue.

The second section, Bison declarations, provides information to Bison about the tokens and their types (see Section 3.1.3 [The Bison Declarations Section], page 51).

The `%define` directive defines the variable `api.value.type`, thus specifying the C data type for semantic values of both tokens and groupings (see Section 3.4.1 [Data Types of Semantic Values], page 56). The Bison parser will use whatever type `api.value.type` is

defined as; if you don't define it, `int` is the default. Because we specify '`{double}`', each token and each expression has an associated value, which is a floating point number. C code can use `YYSTYPE` to refer to the value `api.value.type`.

Each terminal symbol that is not a single-character literal must be declared. (Single-character literals normally don't need to be declared.) In this example, all the arithmetic operators are designated by single-character literals, so the only terminal symbol that needs to be declared is `NUM`, the token kind for numeric constants.

2.1.2 Grammar Rules for `rpcalc`

Here are the grammar rules for the Reverse Polish Notation calculator.

```
input:
  %empty
| input line
;

line:
  '\n'
| exp '\n'      { printf ("%.10g\n", $1); }
;

exp:
  NUM
| exp exp '+'   { $$ = $1 + $2;      }
| exp exp '-'   { $$ = $1 - $2;      }
| exp exp '*'   { $$ = $1 * $2;      }
| exp exp '/'   { $$ = $1 / $2;      }
| exp exp '^'   { $$ = pow ($1, $2); }  /* Exponentiation */
| exp 'n'       { $$ = -$1;          }  /* Unary minus   */
;
%%
```

The groupings of the rpcalc "language" defined here are the expression (given the name `exp`), the line of input (`line`), and the complete input transcript (`input`). Each of these nonterminal symbols has several alternate rules, joined by the vertical bar '`|`' which is read as "or". The following sections explain what these rules mean.

The semantics of the language is determined by the actions taken when a grouping is recognized. The actions are the C code that appears inside braces. See Section 3.4.6 [Actions], page 59.

You must specify these actions in C, but Bison provides the means for passing semantic values between the rules. In each action, the pseudo-variable `$$` stands for the semantic value for the grouping that the rule is going to construct. Assigning a value to `$$` is the main job of most actions. The semantic values of the components of the rule are referred to as `$1`, `$2`, and so on.

2.1.2.1 Explanation of `input`

Consider the definition of `input`:

```
input:
```

```
    %empty
| input line
;
```

This definition reads as follows: "A complete input is either an empty string, or a complete input followed by an input line". Notice that "complete input" is defined in terms of itself. This definition is said to be *left recursive* since `input` appears always as the leftmost symbol in the sequence. See Section 3.3.3 [Recursive Rules], page 55.

The first alternative is empty because there are no symbols between the colon and the first '|'; this means that `input` can match an empty string of input (no tokens). We write the rules this way because it is legitimate to type `Ctrl-d` right after you start the calculator. It's conventional to put an empty alternative first and to use the (optional) `%empty` directive, or to write the comment '`/* empty */`' in it (see Section 3.3.2 [Empty Rules], page 55).

The second alternate rule (`input line`) handles all nontrivial input. It means, "After reading any number of lines, read one more line if possible." The left recursion makes this rule into a loop. Since the first alternative matches empty input, the loop can be executed zero or more times.

The parser function `yyparse` continues to process input until a grammatical error is seen or the lexical analyzer says there are no more input tokens; we will arrange for the latter to happen at end-of-input.

2.1.2.2 Explanation of `line`

Now consider the definition of `line`:

```
line:
  '\n'
| exp '\n'  { printf ("%.10g\n", $1); }
;
```

The first alternative is a token which is a newline character; this means that rpcalc accepts a blank line (and ignores it, since there is no action). The second alternative is an expression followed by a newline. This is the alternative that makes rpcalc useful. The semantic value of the `exp` grouping is the value of `$1` because the `exp` in question is the first symbol in the alternative. The action prints this value, which is the result of the computation the user asked for.

This action is unusual because it does not assign a value to `$$`. As a consequence, the semantic value associated with the `line` is uninitialized (its value will be unpredictable). This would be a bug if that value were ever used, but we don't use it: once rpcalc has printed the value of the user's input line, that value is no longer needed.

2.1.2.3 Explanation of `expr`

The `exp` grouping has several rules, one for each kind of expression. The first rule handles the simplest expressions: those that are just numbers. The second handles an addition-expression, which looks like two expressions followed by a plus-sign. The third handles subtraction, and so on.

```
exp:
  NUM
| exp exp '+'    { $$ = $1 + $2;    }
```

```
| exp exp '-'     { $$ = $1 - $2;     }
...
;
```

We have used '|' to join all the rules for `exp`, but we could equally well have written them separately:

```
exp: NUM;
exp: exp exp '+'  { $$ = $1 + $2; };
exp: exp exp '-'  { $$ = $1 - $2; };
...
```

Most of the rules have actions that compute the value of the expression in terms of the value of its parts. For example, in the rule for addition, `$1` refers to the first component `exp` and `$2` refers to the second one. The third component, `'+'`, has no meaningful associated semantic value, but if it had one you could refer to it as `$3`. The first rule relies on the implicit default action: '`{ $$ = $1; }`'.

When `yyparse` recognizes a sum expression using this rule, the sum of the two subexpressions' values is produced as the value of the entire expression. See Section 3.4.6 [Actions], page 59.

You don't have to give an action for every rule. When a rule has no action, Bison by default copies the value of `$1` into `$$`. This is what happens in the first rule (the one that uses `NUM`).

The formatting shown here is the recommended convention, but Bison does not require it. You can add or change white space as much as you wish. For example, this:

```
exp: NUM | exp exp '+' {$$ = $1 + $2; } | ... ;
```

means the same thing as this:

```
exp:
  NUM
| exp exp '+'    { $$ = $1 + $2; }
| ...
;
```

The latter, however, is much more readable.

2.1.3 The `rpcalc` Lexical Analyzer

The lexical analyzer's job is low-level parsing: converting characters or sequences of characters into tokens. The Bison parser gets its tokens by calling the lexical analyzer. See Section 4.3 [The Lexical Analyzer Function `yylex`], page 100.

Only a simple lexical analyzer is needed for the RPN calculator. This lexical analyzer skips blanks and tabs, then reads in numbers as `double` and returns them as `NUM` tokens. Any other character that isn't part of a number is a separate token. Note that the token-code for such a single-character token is the character itself.

The return value of the lexical analyzer function is a numeric code which represents a token kind. The same text used in Bison rules to stand for this token kind is also a C expression for the numeric code of the kind. This works in two ways. If the token kind is a character literal, then its numeric code is that of the character; you can use the same character literal in the lexical analyzer to express the number. If the token kind is an

identifier, that identifier is defined by Bison as a C enum whose definition is the appropriate code. In this example, therefore, `NUM` becomes an enum for `yylex` to use.

The semantic value of the token (if it has one) is stored into the global variable `yylval`, which is where the Bison parser will look for it. (The C data type of `yylval` is `YYSTYPE`, whose value was defined at the beginning of the grammar via '`%define api.value.type {double}`'; see Section 2.1.1 [Declarations for `rpcalc`], page 27.)

A token kind code of zero is returned if the end-of-input is encountered. (Bison recognizes any nonpositive value as indicating end-of-input.)

Here is the code for the lexical analyzer:

```
/* The lexical analyzer returns a double floating point
   number on the stack and the token NUM, or the numeric code
   of the character read if not a number.  It skips all blanks
   and tabs, and returns 0 for end-of-input. */

#include <ctype.h>
#include <stdlib.h>

int
yylex (void)
{
  int c = getchar ();
  /* Skip white space. */
  while (c == ' ' || c == '\t')
    c = getchar ();
  /* Process numbers. */
  if (c == '.' || isdigit (c))
    {
      ungetc (c, stdin);
      if (scanf ("%lf", &yylval) != 1)
        abort ();
      return NUM;
    }
  /* Return end-of-input. */
  else if (c == EOF)
    return YYEOF;
  /* Return a single char. */
  else
    return c;
}
```

2.1.4 The Controlling Function

In keeping with the spirit of this example, the controlling function is kept to the bare minimum. The only requirement is that it call `yyparse` to start the process of parsing.

```
int
main (void)
{
  return yyparse ();
}
```

2.1.5 The Error Reporting Routine

When `yyparse` detects a syntax error, it calls the error reporting function `yyerror` to print an error message (usually but not always `"syntax error"`). It is up to the programmer to supply `yyerror` (see Chapter 4 [Parser C-Language Interface], page 98), so here is the definition we will use:

```
#include <stdio.h>

/* Called by yyparse on error. */
void
yyerror (char const *s)
{
  fprintf (stderr, "%s\n", s);
}
```

After `yyerror` returns, the Bison parser may recover from the error and continue parsing if the grammar contains a suitable error rule (see Chapter 6 [Error Recovery], page 130). Otherwise, `yyparse` returns nonzero. We have not written any error rules in this example, so any invalid input will cause the calculator program to exit. This is not clean behavior for a real calculator, but it is adequate for the first example.

2.1.6 Running Bison to Make the Parser

Before running Bison to produce a parser, we need to decide how to arrange all the source code in one or more source files. For such a simple example, the easiest thing is to put everything in one file, the grammar file. The definitions of `yylex`, `yyerror` and `main` go at the end, in the epilogue of the grammar file (see Section 1.9 [The Overall Layout of a Bison Grammar], page 26).

For a large project, you would probably have several source files, and use `make` to arrange to recompile them.

With all the source in the grammar file, you use the following command to convert it into a parser implementation file:

```
$ bison file.y
```

In this example, the grammar file is called `rpcalc.y` (for "Reverse Polish CALCulator"). Bison produces a parser implementation file named `file.tab.c`, removing the '`.y`' from the grammar file name. The parser implementation file contains the source code for `yyparse`. The additional functions in the grammar file (`yylex`, `yyerror` and `main`) are copied verbatim to the parser implementation file.

2.1.7 Compiling the Parser Implementation File

Here is how to compile and run the parser implementation file:

```
# List files in current directory.
$ ls
rpcalc.tab.c  rpcalc.y

# Compile the Bison parser.
# -lm tells compiler to search math library for pow.
$ cc -lm -o rpcalc rpcalc.tab.c

# List files again.
$ ls
rpcalc  rpcalc.tab.c  rpcalc.y
```

The file `rpcalc` now contains the executable code. Here is an example session using `rpcalc`.

```
$ rpcalc
4 9 +
⇒ 13
3 7 + 3 4 5 *+-
⇒ -13
3 7 + 3 4 5 * + - n          Note the unary minus, 'n'
⇒ 13
5 6 / 4 n +
⇒ -3.166666667
3 4 ^                        Exponentiation
⇒ 81
^D                           End-of-file indicator
$
```

2.2 Infix Notation Calculator: `calc`

We now modify rpcalc to handle infix operators instead of postfix. Infix notation involves the concept of operator precedence and the need for parentheses nested to arbitrary depth. Here is the Bison code for `calc.y`, an infix desk-top calculator.

```
/* Infix notation calculator. */

%{
  #include <math.h>
  #include <stdio.h>
  int yylex (void);
  void yyerror (char const *);
%}
```

```
/* Bison declarations. */
%define api.value.type {double}
%token NUM
%left '-' '+'
%left '*' '/'
%precedence NEG   /* negation--unary minus */
%right '^'        /* exponentiation */

%% /* The grammar follows. */
input:
  %empty
| input line
;

line:
  '\n'
| exp '\n'  { printf ("\t%.10g\n", $1); }
;

exp:
  NUM
| exp '+' exp        { $$ = $1 + $3;      }
| exp '-' exp        { $$ = $1 - $3;      }
| exp '*' exp        { $$ = $1 * $3;      }
| exp '/' exp        { $$ = $1 / $3;      }
| '-' exp  %prec NEG { $$ = -$2;          }
| exp '^' exp        { $$ = pow ($1, $3); }
| '(' exp ')'        { $$ = $2;           }
;
%%
```

The functions `yylex`, `yyerror` and `main` can be the same as before.

There are two important new features shown in this code.

In the second section (Bison declarations), `%left` declares token kinds and says they are left-associative operators. The declarations `%left` and `%right` (right associativity) take the place of `%token` which is used to declare a token kind name without associativity/precedence. (These tokens are single-character literals, which ordinarily don't need to be declared. We declare them here to specify the associativity/precedence.)

Operator precedence is determined by the line ordering of the declarations; the higher the line number of the declaration (lower on the page or screen), the higher the precedence. Hence, exponentiation has the highest precedence, unary minus (`NEG`) is next, followed by '`*`' and '`/`', and so on. Unary minus is not associative, only precedence matters (`%precedence`. See Section 5.3 [Operator Precedence], page 114.

The other important new feature is the `%prec` in the grammar section for the unary minus operator. The `%prec` simply instructs Bison that the rule '`| '-' exp`' has the same precedence as `NEG`—in this case the next-to-highest. See Section 5.4 [Context-Dependent Precedence], page 116.

Here is a sample run of `calc.y`:

```
$ calc
4 + 4.5 - (34/(8*3+-3))
6.880952381
-56 + 2
-54
3 ^ 2
9
```

2.3 Simple Error Recovery

Up to this point, this manual has not addressed the issue of *error recovery*—how to continue parsing after the parser detects a syntax error. All we have handled is error reporting with `yyerror`. Recall that by default `yyparse` returns after calling `yyerror`. This means that an erroneous input line causes the calculator program to exit. Now we show how to rectify this deficiency.

The Bison language itself includes the reserved word `error`, which may be included in the grammar rules. In the example below it has been added to one of the alternatives for `line`:

```
line:
  '\n'
| exp '\n'  { printf ("\t%.10g\n", $1); }
| error '\n' { yyerrok;                  }
;
```

This addition to the grammar allows for simple error recovery in the event of a syntax error. If an expression that cannot be evaluated is read, the error will be recognized by the third rule for `line`, and parsing will continue. (The `yyerror` function is still called upon to print its message as well.) The action executes the statement `yyerrok`, a macro defined automatically by Bison; its meaning is that error recovery is complete (see Chapter 6 [Error Recovery], page 130). Note the difference between `yyerrok` and `yyerror`; neither one is a misprint.

This form of error recovery deals with syntax errors. There are other kinds of errors; for example, division by zero, which raises an exception signal that is normally fatal. A real calculator program must handle this signal and use `longjmp` to return to `main` and resume parsing input lines; it would also have to discard the rest of the current line of input. We won't discuss this issue further because it is not specific to Bison programs.

2.4 Location Tracking Calculator: `ltcalc`

This example extends the infix notation calculator with location tracking. This feature will be used to improve the error messages. For the sake of clarity, this example is a simple integer calculator, since most of the work needed to use locations will be done in the lexical analyzer.

2.4.1 Declarations for `ltcalc`

The C and Bison declarations for the location tracking calculator are the same as the declarations for the infix notation calculator.

```
/* Location tracking calculator. */

%{
  #include <math.h>
  int yylex (void);
  void yyerror (char const *);
%}

/* Bison declarations. */
%define api.value.type {int}
%token NUM

%left '-' '+'
%left '*' '/'
%precedence NEG
%right '^'

%% /* The grammar follows. */
```

Note there are no declarations specific to locations. Defining a data type for storing locations is not needed: we will use the type provided by default (see Section 3.5.1 [Data Type of Locations], page 66), which is a four member structure with the following integer fields: `first_line`, `first_column`, `last_line` and `last_column`. By conventions, and in accordance with the GNU Coding Standards and common practice, the line and column count both start at 1.

2.4.2 Grammar Rules for `ltcalc`

Whether handling locations or not has no effect on the syntax of your language. Therefore, grammar rules for this example will be very close to those of the previous example: we will only modify them to benefit from the new information.

Here, we will use locations to report divisions by zero, and locate the wrong expressions or subexpressions.

```
input:
  %empty
| input line
;

line:
  '\n'
| exp '\n' { printf ("%d\n", $1); }
;

exp:
  NUM
| exp '+' exp   { $$ = $1 + $3; }
| exp '-' exp   { $$ = $1 - $3; }
| exp '*' exp   { $$ = $1 * $3; }
```

```
| exp '/' exp
    {
      if ($3)
        $$ = $1 / $3;
      else
        {
          $$ = 1;
          fprintf (stderr, "%d.%d-%d.%d: division by zero",
                   @3.first_line, @3.first_column,
                   @3.last_line, @3.last_column);
        }
    }
| '-' exp %prec NEG     { $$ = -$2; }
| exp '^' exp           { $$ = pow ($1, $3); }
| '(' exp ')'           { $$ = $2; }
```

This code shows how to reach locations inside of semantic actions, by using the pseudo-variables `@n` for rule components, and the pseudo-variable `@$` for groupings.

We don't need to assign a value to `@$`: the output parser does it automatically. By default, before executing the C code of each action, `@$` is set to range from the beginning of `@1` to the end of `@n`, for a rule with *n* components. This behavior can be redefined (see Section 3.5.3 [Default Action for Locations], page 68), and for very specific rules, `@$` can be computed by hand.

2.4.3 The `ltcalc` Lexical Analyzer.

Until now, we relied on Bison's defaults to enable location tracking. The next step is to rewrite the lexical analyzer, and make it able to feed the parser with the token locations, as it already does for semantic values.

To this end, we must take into account every single character of the input text, to avoid the computed locations of being fuzzy or wrong:

```
int
yylex (void)
{
  int c;

  /* Skip white space. */
  while ((c = getchar ()) == ' ' || c == '\t')
    ++yylloc.last_column;

  /* Step. */
  yylloc.first_line = yylloc.last_line;
  yylloc.first_column = yylloc.last_column;
```

```
    /* Process numbers. */
    if (isdigit (c))
      {
        yylval = c - '0';
        ++yylloc.last_column;
        while (isdigit (c = getchar ()))
          {
            ++yylloc.last_column;
            yylval = yylval * 10 + c - '0';
          }
        ungetc (c, stdin);
        return NUM;
      }

    /* Return end-of-input. */
    if (c == EOF)
      return YYEOF;

    /* Return a single char, and update location. */
    if (c == '\n')
      {
        ++yylloc.last_line;
        yylloc.last_column = 0;
      }
    else
      ++yylloc.last_column;
    return c;
  }
```

Basically, the lexical analyzer performs the same processing as before: it skips blanks and tabs, and reads numbers or single-character tokens. In addition, it updates `yylloc`, the global variable (of type `YYLTYPE`) containing the token's location.

Now, each time this function returns a token, the parser has its kind as well as its semantic value, and its location in the text. The last needed change is to initialize `yylloc`, for example in the controlling function:

```
int
main (void)
{
  yylloc.first_line = yylloc.last_line = 1;
  yylloc.first_column = yylloc.last_column = 0;
  return yyparse ();
}
```

Remember that computing locations is not a matter of syntax. Every character must be associated to a location update, whether it is in valid input, in comments, in literal strings, and so on.

2.5 Multi-Function Calculator: `mfcalc`

Now that the basics of Bison have been discussed, it is time to move on to a more advanced problem. The above calculators provided only five functions, '+', '−', '*', '/' and '^'. It would be nice to have a calculator that provides other mathematical functions such as `sin`, `cos`, etc.

It is easy to add new operators to the infix calculator as long as they are only single-character literals. The lexical analyzer `yylex` passes back all nonnumeric characters as tokens, so new grammar rules suffice for adding a new operator. But we want something more flexible: built-in functions whose syntax has this form:

    function_name (*argument*)

At the same time, we will add memory to the calculator, by allowing you to create named variables, store values in them, and use them later. Here is a sample session with the multi-function calculator:

```
$ mfcalc
pi = 3.141592653589
⇒ 3.1415926536
sin(pi)
⇒ 0.0000000000
alpha = beta1 = 2.3
⇒ 2.3000000000
alpha
⇒ 2.3000000000
ln(alpha)
⇒ 0.8329091229
exp(ln(beta1))
⇒ 2.3000000000
$
```

Note that multiple assignment and nested function calls are permitted.

2.5.1 Declarations for `mfcalc`

Here are the C and Bison declarations for the multi-function calculator.

```
%{
  #include <stdio.h>  /* For printf, etc. */
  #include <math.h>   /* For pow, used in the grammar. */
  #include "calc.h"   /* Contains definition of 'symrec'. */
  int yylex (void);
  void yyerror (char const *);
%}

%define api.value.type union /* Generate YYSTYPE from these types: */
%token <double>  NUM     /* Double precision number. */
%token <symrec*> VAR FUN /* Symbol table pointer: variable/function. */
%nterm <double>  exp
```

```
%precedence '='
%left '-' '+'
%left '*' '/'
%precedence NEG /* negation--unary minus */
%right '^'       /* exponentiation */
```

The above grammar introduces only two new features of the Bison language. These features allow semantic values to have various data types (see Section 3.4.2 [More Than One Value Type], page 57).

The special `union` value assigned to the `%define` variable `api.value.type` specifies that the symbols are defined with their data types. Bison will generate an appropriate definition of `YYSTYPE` to store these values.

Since values can now have various types, it is necessary to associate a type with each grammar symbol whose semantic value is used. These symbols are `NUM`, `VAR`, `FUN`, and `exp`. Their declarations are augmented with their data type (placed between angle brackets). For instance, values of `NUM` are stored in `double`.

The Bison construct `%nterm` is used for declaring nonterminal symbols, just as `%token` is used for declaring token kinds. Previously we did not use `%nterm` before because nonterminal symbols are normally declared implicitly by the rules that define them. But `exp` must be declared explicitly so we can specify its value type. See Section 3.7.4 [Nonterminal Symbols], page 72.

2.5.2 Grammar Rules for `mfcalc`

Here are the grammar rules for the multi-function calculator. Most of them are copied directly from `calc`; three rules, those which mention `VAR` or `FUN`, are new.

```
%% /* The grammar follows. */
input:
  %empty
| input line
;

line:
  '\n'
| exp '\n'   { printf ("%.10g\n", $1); }
| error '\n' { yyerrok;                }
;
```

```
exp:
  NUM
| VAR                { $$ = $1->value.var;           }
| VAR '=' exp        { $$ = $3; $1->value.var = $3;  }
| FUN '(' exp ')'    { $$ = $1->value.fun ($3);      }
| exp '+' exp        { $$ = $1 + $3;                 }
| exp '-' exp        { $$ = $1 - $3;                 }
| exp '*' exp        { $$ = $1 * $3;                 }
| exp '/' exp        { $$ = $1 / $3;                 }
| '-' exp  %prec NEG { $$ = -$2;                     }
| exp '^' exp        { $$ = pow ($1, $3);            }
| '(' exp ')'        { $$ = $2;                      }
;
/* End of grammar. */
%%
```

2.5.3 The `mfcalc` Symbol Table

The multi-function calculator requires a symbol table to keep track of the names and meanings of variables and functions. This doesn't affect the grammar rules (except for the actions) or the Bison declarations, but it requires some additional C functions for support.

The symbol table itself consists of a linked list of records. Its definition, which is kept in the header `calc.h`, is as follows. It provides for either functions or variables to be placed in the table.

```
/* Function type. */
typedef double (func_t) (double);

/* Data type for links in the chain of symbols. */
struct symrec
{
  char *name;  /* name of symbol */
  int type;    /* type of symbol: either VAR or FUN */
  union
  {
    double var;    /* value of a VAR */
    func_t *fun;   /* value of a FUN */
  } value;
  struct symrec *next;  /* link field */
};

typedef struct symrec symrec;

/* The symbol table: a chain of 'struct symrec'. */
extern symrec *sym_table;

symrec *putsym (char const *name, int sym_type);
symrec *getsym (char const *name);
```

The new version of `main` will call `init_table` to initialize the symbol table:

```
struct init
{
  char const *name;
  func_t *fun;
};

struct init const funs[] =
{
  { "atan", atan },
  { "cos",  cos  },
  { "exp",  exp  },
  { "ln",   log  },
  { "sin",  sin  },
  { "sqrt", sqrt },
  { 0, 0 },
};

/* The symbol table: a chain of 'struct symrec'. */
symrec *sym_table;

/* Put functions in table. */
static void
init_table (void)
{
  for (int i = 0; funs[i].name; i++)
    {
      symrec *ptr = putsym (funs[i].name, FUN);
      ptr->value.fun = funs[i].fun;
    }
}
```

By simply editing the initialization list and adding the necessary include files, you can add additional functions to the calculator.

Two important functions allow look-up and installation of symbols in the symbol table. The function `putsym` is passed a name and the kind (`VAR` or `FUN`) of the object to be installed. The object is linked to the front of the list, and a pointer to the object is returned. The function `getsym` is passed the name of the symbol to look up. If found, a pointer to that symbol is returned; otherwise zero is returned.

```
/* The mfcalc code assumes that malloc and realloc
   always succeed, and that integer calculations
   never overflow.  Production-quality code should
   not make these assumptions.  */
#include <assert.h>
#include <stdlib.h> /* malloc, realloc. */
#include <string.h> /* strlen. */
```

```
symrec *
putsym (char const *name, int sym_type)
{
  symrec *res = (symrec *) malloc (sizeof (symrec));
  res->name = strdup (name);
  res->type = sym_type;
  res->value.var = 0; /* Set value to 0 even if fun. */
  res->next = sym_table;
  sym_table = res;
  return res;
}

symrec *
getsym (char const *name)
{
  for (symrec *p = sym_table; p; p = p->next)
    if (strcmp (p->name, name) == 0)
      return p;
  return NULL;
}
```

2.5.4 The `mfcalc` Lexer

The function `yylex` must now recognize variables, numeric values, and the single-character arithmetic operators. Strings of alphanumeric characters with a leading letter are recognized as either variables or functions depending on what the symbol table says about them.

The string is passed to `getsym` for look up in the symbol table. If the name appears in the table, a pointer to its location and its type (`VAR` or `FUN`) is returned to `yyparse`. If it is not already in the table, then it is installed as a `VAR` using `putsym`. Again, a pointer and its type (which must be `VAR`) is returned to `yyparse`.

No change is needed in the handling of numeric values and arithmetic operators in `yylex`.

```
#include <ctype.h>
#include <stddef.h>

int
yylex (void)
{
  int c = getchar ();

  /* Ignore white space, get first nonwhite character. */
  while (c == ' ' || c == '\t')
    c = getchar ();

  if (c == EOF)
    return YYEOF;
```

```
      /* Char starts a number => parse the number. */
      if (c == '.' || isdigit (c))
        {
          ungetc (c, stdin);
          if (scanf ("%lf", &yylval.NUM) != 1)
            abort ();
          return NUM;
        }
```

Bison generated a definition of YYSTYPE with a member named NUM to store value of NUM symbols.

```
      /* Char starts an identifier => read the name. */
      if (isalpha (c))
        {
          static ptrdiff_t bufsize = 0;
          static char *symbuf = 0;
          ptrdiff_t i = 0;
          do
            {
              /* If buffer is full, make it bigger. */
              if (bufsize <= i)
                {
                  bufsize = 2 * bufsize + 40;
                  symbuf = realloc (symbuf, (size_t) bufsize);
                }
              /* Add this character to the buffer. */
              symbuf[i++] = (char) c;
              /* Get another character. */
              c = getchar ();
            }
          while (isalnum (c));

          ungetc (c, stdin);
          symbuf[i] = '\0';

          symrec *s = getsym (symbuf);
          if (!s)
            s = putsym (symbuf, VAR);
          yylval.VAR = s; /* or yylval.FUN = s. */
          return s->type;
        }

      /* Any other character is a token by itself. */
      return c;
    }
```

2.5.5 The `mfcalc` Main

The error reporting function is unchanged, and the new version of `main` includes a call to `init_table` and sets the `yydebug` on user demand (See Section 8.5 [Tracing Your Parser], page 148, for details):

```
/* Called by yyparse on error. */
void yyerror (char const *s)
{
  fprintf (stderr, "%s\n", s);
}

int main (int argc, char const* argv[])
{
  /* Enable parse traces on option -p. */
  if (argc == 2 && strcmp(argv[1], "-p") == 0)
    yydebug = 1;
  init_table ();
  return yyparse ();
}
```

This program is both powerful and flexible. You may easily add new functions, and it is a simple job to modify this code to install predefined variables such as `pi` or `e` as well.

2.6 Exercises

1. Add some new functions from `math.h` to the initialization list.

2. Add another array that contains constants and their values. Then modify `init_table` to add these constants to the symbol table. It will be easiest to give the constants type `VAR`.

3. Make the program report an error if the user refers to an uninitialized variable in any way except to store a value in it.

3 Bison Grammar Files

Bison takes as input a context-free grammar specification and produces a C-language function that recognizes correct instances of the grammar.

The Bison grammar file conventionally has a name ending in '`.y`'. See Chapter 9 [Invoking Bison], page 154.

3.1 Outline of a Bison Grammar

A Bison grammar file has four main sections, shown here with the appropriate delimiters:

```
%{
  Prologue
%}

Bison declarations

%%
Grammar rules
%%

Epilogue
```

Comments enclosed in '`/* ... */`' may appear in any of the sections. As a GNU extension, '`//`' introduces a comment that continues until end of line.

3.1.1 The prologue

The *Prologue* section contains macro definitions and declarations of functions and variables that are used in the actions in the grammar rules. These are copied to the beginning of the parser implementation file so that they precede the definition of `yyparse`. You can use '`#include`' to get the declarations from a header file. If you don't need any C declarations, you may omit the '`%{`' and '`%}`' delimiters that bracket this section.

The *Prologue* section is terminated by the first occurrence of '`%}`' that is outside a comment, a string literal, or a character constant.

You may have more than one *Prologue* section, intermixed with the *Bison declarations*. This allows you to have C and Bison declarations that refer to each other. For example, the `%union` declaration may use types defined in a header file, and you may wish to prototype functions that take arguments of type `YYSTYPE`. This can be done with two *Prologue* blocks, one before and one after the `%union` declaration.

```
%{
  #define _GNU_SOURCE
  #include <stdio.h>
  #include "ptypes.h"
%}

%union {
  long n;
  tree t;  /* tree is defined in ptypes.h. */
}
```

```
%{
  static void print_token (yytoken_kind_t token, YYSTYPE val);
%}


...
```

When in doubt, it is usually safer to put prologue code before all Bison declarations, rather than after. For example, any definitions of feature test macros like `_GNU_SOURCE` or `_POSIX_C_SOURCE` should appear before all Bison declarations, as feature test macros can affect the behavior of Bison-generated `#include` directives.

3.1.2 Prologue Alternatives

The functionality of *Prologue* sections can often be subtle and inflexible. As an alternative, Bison provides a `%code` directive with an explicit qualifier field, which identifies the purpose of the code and thus the location(s) where Bison should generate it. For C/C++, the qualifier can be omitted for the default location, or it can be one of `requires`, `provides`, `top`. See Section 3.7.15 [%code Summary], page 94.

Look again at the example of the previous section:

```
%{
  #define _GNU_SOURCE
  #include <stdio.h>
  #include "ptypes.h"
%}

%union {
  long n;
  tree t;  /* tree is defined in ptypes.h. */
}

%{
  static void print_token (yytoken_kind_t token, YYSTYPE val);
%}


...
```

Notice that there are two *Prologue* sections here, but there's a subtle distinction between their functionality. For example, if you decide to override Bison's default definition for `YYLTYPE`, in which *Prologue* section should you write your new definition? You should write it in the first since Bison will insert that code into the parser implementation file *before* the default `YYLTYPE` definition. In which *Prologue* section should you prototype an internal function, `trace_token`, that accepts `YYLTYPE` and `yytoken_kind_t` as arguments? You should prototype it in the second since Bison will insert that code *after* the `YYLTYPE` and `yytoken_kind_t` definitions.

This distinction in functionality between the two *Prologue* sections is established by the appearance of the `%union` between them. This behavior raises a few questions. First, why should the position of a `%union` affect definitions related to `YYLTYPE` and `yytoken_kind_t`?

Second, what if there is no `%union`? In that case, the second kind of *Prologue* section is not available. This behavior is not intuitive.

To avoid this subtle `%union` dependency, rewrite the example using a `%code top` and an unqualified `%code`. Let's go ahead and add the new YYLTYPE definition and the `trace_token` prototype at the same time:

```
%code top {
  #define _GNU_SOURCE
  #include <stdio.h>

  /* WARNING: The following code really belongs
   * in a '%code requires'; see below. */

  #include "ptypes.h"
  #define YYLTYPE YYLTYPE
  typedef struct YYLTYPE
  {
    int first_line;
    int first_column;
    int last_line;
    int last_column;
    char *filename;
  } YYLTYPE;
}

%union {
  long n;
  tree t;  /* tree is defined in ptypes.h. */
}

%code {
  static void print_token (yytoken_kind_t token, YYSTYPE val);
  static void trace_token (yytoken_kind_t token, YYLTYPE loc);
}

...
```

In this way, `%code top` and the unqualified `%code` achieve the same functionality as the two kinds of *Prologue* sections, but it's always explicit which kind you intend. Moreover, both kinds are always available even in the absence of `%union`.

The `%code top` block above logically contains two parts. The first two lines before the warning need to appear near the top of the parser implementation file. The first line after the warning is required by YYSTYPE and thus also needs to appear in the parser implementation file. However, if you've instructed Bison to generate a parser header file (see Section 3.7.13 [Bison Declaration Summary], page 79), you probably want that line to appear before the YYSTYPE definition in that header file as well. The YYLTYPE definition should also appear in the parser header file to override the default YYLTYPE definition there.

In other words, in the `%code top` block above, all but the first two lines are dependency code required by the `YYSTYPE` and `YYLTYPE` definitions. Thus, they belong in one or more `%code requires`:

```
%code top {
  #define _GNU_SOURCE
  #include <stdio.h>
}

%code requires {
  #include "ptypes.h"
}
%union {
  long n;
  tree t;   /* tree is defined in ptypes.h. */
}

%code requires {
  #define YYLTYPE YYLTYPE
  typedef struct YYLTYPE
  {
    int first_line;
    int first_column;
    int last_line;
    int last_column;
    char *filename;
  } YYLTYPE;
}

%code {
  static void print_token (yytoken_kind_t token, YYSTYPE val);
  static void trace_token (yytoken_kind_t token, YYLTYPE loc);
}

...
```

Now Bison will insert `#include "ptypes.h"` and the new `YYLTYPE` definition before the Bison-generated `YYSTYPE` and `YYLTYPE` definitions in both the parser implementation file and the parser header file. (By the same reasoning, `%code requires` would also be the appropriate place to write your own definition for `YYSTYPE`.)

When you are writing dependency code for `YYSTYPE` and `YYLTYPE`, you should prefer `%code requires` over `%code top` regardless of whether you instruct Bison to generate a parser header file. When you are writing code that you need Bison to insert only into the parser implementation file and that has no special need to appear at the top of that file, you should prefer the unqualified `%code` over `%code top`. These practices will make the purpose of each block of your code explicit to Bison and to other developers reading your grammar file. Following these practices, we expect the unqualified `%code` and `%code requires` to be the most important of the four *Prologue* alternatives.

At some point while developing your parser, you might decide to provide `trace_token` to modules that are external to your parser. Thus, you might wish for Bison to insert the prototype into both the parser header file and the parser implementation file. Since this function is not a dependency required by `YYSTYPE` or `YYLTYPE`, it doesn't make sense to move its prototype to a `%code requires`. More importantly, since it depends upon `YYLTYPE` and `yytoken_kind_t`, `%code requires` is not sufficient. Instead, move its prototype from the unqualified `%code` to a `%code provides`:

```
%code top {
  #define _GNU_SOURCE
  #include <stdio.h>
}

%code requires {
  #include "ptypes.h"
}
%union {
  long n;
  tree t;  /* tree is defined in ptypes.h. */
}

%code requires {
  #define YYLTYPE YYLTYPE
  typedef struct YYLTYPE
  {
    int first_line;
    int first_column;
    int last_line;
    int last_column;
    char *filename;
  } YYLTYPE;
}

%code provides {
  void trace_token (yytoken_kind_t token, YYLTYPE loc);
}

%code {
  static void print_token (FILE *file, int token, YYSTYPE val);
}

...
```

Bison will insert the `trace_token` prototype into both the parser header file and the parser implementation file after the definitions for `yytoken_kind_t`, `YYLTYPE`, and `YYSTYPE`.

The above examples are careful to write directives in an order that reflects the layout of the generated parser implementation and header files: `%code top`, `%code requires`, `%code provides`, and then `%code`. While your grammar files may generally be easier to read if

you also follow this order, Bison does not require it. Instead, Bison lets you choose an organization that makes sense to you.

You may declare any of these directives multiple times in the grammar file. In that case, Bison concatenates the contained code in declaration order. This is the only way in which the position of one of these directives within the grammar file affects its functionality.

The result of the previous two properties is greater flexibility in how you may organize your grammar file. For example, you may organize semantic-type-related directives by semantic type:

```
%code requires { #include "type1.h" }
%union { type1 field1; }
%destructor { type1_free ($$); } <field1>
%printer { type1_print (yyo, $$); } <field1>

%code requires { #include "type2.h" }
%union { type2 field2; }
%destructor { type2_free ($$); } <field2>
%printer { type2_print (yyo, $$); } <field2>
```

You could even place each of the above directive groups in the rules section of the grammar file next to the set of rules that uses the associated semantic type. (In the rules section, you must terminate each of those directives with a semicolon.) And you don't have to worry that some directive (like a `%union`) in the definitions section is going to adversely affect their functionality in some counter-intuitive manner just because it comes first. Such an organization is not possible using *Prologue* sections.

This section has been concerned with explaining the advantages of the four *Prologue* alternatives over the original Yacc *Prologue*. However, in most cases when using these directives, you shouldn't need to think about all the low-level ordering issues discussed here. Instead, you should simply use these directives to label each block of your code according to its purpose and let Bison handle the ordering. `%code` is the most generic label. Move code to `%code requires`, `%code provides`, or `%code top` as needed.

3.1.3 The Bison Declarations Section

The *Bison declarations* section contains declarations that define terminal and nonterminal symbols, specify precedence, and so on. In some simple grammars you may not need any declarations. See Section 3.7 [Bison Declarations], page 70.

3.1.4 The Grammar Rules Section

The *grammar rules* section contains one or more Bison grammar rules, and nothing else. See Section 3.3 [Grammar Rules], page 54.

There must always be at least one grammar rule, and the first '`%%`' (which precedes the grammar rules) may never be omitted even if it is the first thing in the file.

3.1.5 The epilogue

The *Epilogue* is copied verbatim to the end of the parser implementation file, just as the *Prologue* is copied to the beginning. This is the most convenient place to put anything that you want to have in the parser implementation file but which need not come before the

definition of `yyparse`. For example, the definitions of `yylex` and `yyerror` often go here. Because C requires functions to be declared before being used, you often need to declare functions like `yylex` and `yyerror` in the Prologue, even if you define them in the Epilogue. See Chapter 4 [Parser C-Language Interface], page 98.

If the last section is empty, you may omit the '`%%`' that separates it from the grammar rules.

The Bison parser itself contains many macros and identifiers whose names start with '`yy`' or '`YY`', so it is a good idea to avoid using any such names (except those documented in this manual) in the epilogue of the grammar file.

3.2 Symbols, Terminal and Nonterminal

Symbols in Bison grammars represent the grammatical classifications of the language.

A *terminal symbol* (also known as a *token kind*) represents a class of syntactically equivalent tokens. You use the symbol in grammar rules to mean that a token in that class is allowed. The symbol is represented in the Bison parser by a numeric code, and the `yylex` function returns a token kind code to indicate what kind of token has been read. You don't need to know what the code value is; you can use the symbol to stand for it.

A *nonterminal symbol* stands for a class of syntactically equivalent groupings. The symbol name is used in writing grammar rules. By convention, it should be all lower case.

Symbol names can contain letters, underscores, periods, and non-initial digits and dashes. Dashes in symbol names are a GNU extension, incompatible with POSIX Yacc. Periods and dashes make symbol names less convenient to use with named references, which require brackets around such names (see Section 3.6 [Named References], page 69). Terminal symbols that contain periods or dashes make little sense: since they are not valid symbols (in most programming languages) they are not exported as token names.

There are three ways of writing terminal symbols in the grammar:

- A *named token kind* is written with an identifier, like an identifier in C. By convention, it should be all upper case. Each such name must be defined with a Bison declaration such as `%token`. See Section 3.7.2 [Token Kind Names], page 70.

- A *character token kind* (or *literal character token*) is written in the grammar using the same syntax used in C for character constants; for example, `'+'` is a character token kind. A character token kind doesn't need to be declared unless you need to specify its semantic value data type (see Section 3.4.1 [Data Types of Semantic Values], page 56), associativity, or precedence (see Section 5.3 [Operator Precedence], page 114).

  By convention, a character token kind is used only to represent a token that consists of that particular character. Thus, the token kind `'+'` is used to represent the character '+' as a token. Nothing enforces this convention, but if you depart from it, your program will confuse other readers.

  All the usual escape sequences used in character literals in C can be used in Bison as well, but you must not use the null character as a character literal because its numeric code, zero, signifies end-of-input (see Section 4.3.1 [Calling Convention for `yylex`], page 100). Also, unlike standard C, trigraphs have no special meaning in Bison character literals, nor is backslash-newline allowed.

- A *literal string token* is written like a C string constant; for example, `"<="` is a literal string token. A literal string token doesn't need to be declared unless you need to specify its semantic value data type (see Section 3.4.1 [Data Types of Semantic Values], page 56), associativity, or precedence (see Section 5.3 [Operator Precedence], page 114).

  You can associate the literal string token with a symbolic name as an alias, using the `%token` declaration (see Section 3.7.2 [Token Kind Names], page 70). If you don't do that, the lexical analyzer has to retrieve the token code for the literal string token from the `yytname` table (see Section 4.3.1 [Calling Convention for `yylex`], page 100).

  Warning: literal string tokens do not work in Yacc.

  By convention, a literal string token is used only to represent a token that consists of that particular string. Thus, you should use the token kind `"<="` to represent the string '`<=`' as a token. Bison does not enforce this convention, but if you depart from it, people who read your program will be confused.

  All the escape sequences used in string literals in C can be used in Bison as well, except that you must not use a null character within a string literal. Also, unlike Standard C, trigraphs have no special meaning in Bison string literals, nor is backslash-newline allowed. A literal string token must contain two or more characters; for a token containing just one character, use a character token (see above).

How you choose to write a terminal symbol has no effect on its grammatical meaning. That depends only on where it appears in rules and on when the parser function returns that symbol.

The value returned by `yylex` is always one of the terminal symbols, except that a zero or negative value signifies end-of-input. Whichever way you write the token kind in the grammar rules, you write it the same way in the definition of `yylex`. The numeric code for a character token kind is simply the positive numeric code of the character, so `yylex` can use the identical value to generate the requisite code, though you may need to convert it to `unsigned char` to avoid sign-extension on hosts where `char` is signed. Each named token kind becomes a C macro in the parser implementation file, so `yylex` can use the name to stand for the code. (This is why periods don't make sense in terminal symbols.) See Section 4.3.1 [Calling Convention for `yylex`], page 100.

If `yylex` is defined in a separate file, you need to arrange for the token-kind definitions to be available there. Use the `-d` option when you run Bison, so that it will write these definitions into a separate header file `name.tab.h` which you can include in the other source files that need it. See Chapter 9 [Invoking Bison], page 154.

If you want to write a grammar that is portable to any Standard C host, you must use only nonnull character tokens taken from the basic execution character set of Standard C. This set consists of the ten digits, the 52 lower- and upper-case English letters, and the characters in the following C-language string:

```
"\a\b\t\n\v\f\r !\"#%&'()*+,-./:;<=>?[\\]^_{|}~"
```

The `yylex` function and Bison must use a consistent character set and encoding for character tokens. For example, if you run Bison in an ASCII environment, but then compile and run the resulting program in an environment that uses an incompatible character set like EBCDIC, the resulting program may not work because the tables generated by Bison will assume ASCII numeric values for character tokens. It is standard practice for software

distributions to contain C source files that were generated by Bison in an ASCII environment, so installers on platforms that are incompatible with ASCII must rebuild those files before compiling them.

The symbol `error` is a terminal symbol reserved for error recovery (see Chapter 6 [Error Recovery], page 130); you shouldn't use it for any other purpose. In particular, `yylex` should never return this value. The default value of the error token is 256, unless you explicitly assigned 256 to one of your tokens with a `%token` declaration.

3.3 Grammar Rules

A Bison grammar is a list of rules.

3.3.1 Syntax of Grammar Rules

A Bison grammar rule has the following general form:

```
result: components...;
```

where *result* is the nonterminal symbol that this rule describes, and *components* are various terminal and nonterminal symbols that are put together by this rule (see Section 3.2 [Symbols, Terminal and Nonterminal], page 52).

For example,

```
exp: exp '+' exp;
```

says that two groupings of type `exp`, with a '+' token in between, can be combined into a larger grouping of type `exp`.

White space in rules is significant only to separate symbols. You can add extra white space as you wish.

Scattered among the components can be *actions* that determine the semantics of the rule. An action looks like this:

```
{C statements}
```

This is an example of *braced code*, that is, C code surrounded by braces, much like a compound statement in C. Braced code can contain any sequence of C tokens, so long as its braces are balanced. Bison does not check the braced code for correctness directly; it merely copies the code to the parser implementation file, where the C compiler can check it.

Within braced code, the balanced-brace count is not affected by braces within comments, string literals, or character constants, but it is affected by the C digraphs '<%' and '%>' that represent braces. At the top level braced code must be terminated by '}' and not by a digraph. Bison does not look for trigraphs, so if braced code uses trigraphs you should ensure that they do not affect the nesting of braces or the boundaries of comments, string literals, or character constants.

Usually there is only one action and it follows the components. See Section 3.4.6 [Actions], page 59.

Multiple rules for the same *result* can be written separately or can be joined with the vertical-bar character '|' as follows:

```
result:
  rule1-components...
| rule2-components...
...
;
```

They are still considered distinct rules even when joined in this way.

3.3.2 Empty Rules

A rule is said to be *empty* if its right-hand side (*components*) is empty. It means that *result* in the previous example can match the empty string. As another example, here is how to define an optional semicolon:

```
semicolon.opt: | ";";
```

It is easy not to see an empty rule, especially when | is used. The `%empty` directive allows to make explicit that a rule is empty on purpose:

```
semicolon.opt:
  %empty
| ";"
;
```

Flagging a non-empty rule with `%empty` is an error. If run with `-Wempty-rule`, `bison` will report empty rules without `%empty`. Using `%empty` enables this warning, unless `-Wno-empty-rule` was specified.

The `%empty` directive is a Bison extension, it does not work with Yacc. To remain compatible with POSIX Yacc, it is customary to write a comment '`/* empty */`' in each rule with no components:

```
semicolon.opt:
  /* empty */
| ";"
;
```

3.3.3 Recursive Rules

A rule is called *recursive* when its *result* nonterminal appears also on its right hand side. Nearly all Bison grammars need to use recursion, because that is the only way to define a sequence of any number of a particular thing. Consider this recursive definition of a comma-separated sequence of one or more expressions:

```
expseq1:
  exp
| expseq1 ',' exp
;
```

Since the recursive use of `expseq1` is the leftmost symbol in the right hand side, we call this *left recursion*. By contrast, here the same construct is defined using *right recursion*:

```
expseq1:
  exp
| exp ',' expseq1
;
```

Any kind of sequence can be defined using either left recursion or right recursion, but you should always use left recursion, because it can parse a sequence of any number of elements with bounded stack space. Right recursion uses up space on the Bison stack in proportion to the number of elements in the sequence, because all the elements must be shifted onto the stack before the rule can be applied even once. See Chapter 5 [The Bison Parser Algorithm], page 111, for further explanation of this.

Indirect or *mutual* recursion occurs when the result of the rule does not appear directly on its right hand side, but does appear in rules for other nonterminals which do appear on its right hand side.

For example:

```
expr:
  primary
| primary '+' primary
;

primary:
  constant
| '(' expr ')'
;
```

defines two mutually-recursive nonterminals, since each refers to the other.

3.4 Defining Language Semantics

The grammar rules for a language determine only the syntax. The semantics are determined by the semantic values associated with various tokens and groupings, and by the actions taken when various groupings are recognized.

For example, the calculator calculates properly because the value associated with each expression is the proper number; it adds properly because the action for the grouping '$x + y$' is to add the numbers associated with x and y.

3.4.1 Data Types of Semantic Values

In a simple program it may be sufficient to use the same data type for the semantic values of all language constructs. This was true in the RPN and infix calculator examples (see Section 2.1 [Reverse Polish Notation Calculator], page 27).

Bison normally uses the type `int` for semantic values if your program uses the same data type for all language constructs. To specify some other type, define the `%define` variable `api.value.type` like this:

```
%define api.value.type {double}
```

or

```
%define api.value.type {struct semantic_type}
```

The value of `api.value.type` should be a type name that does not contain parentheses or square brackets.

Alternatively, instead of relying of Bison's `%define` support, you may rely on the C/C++ preprocessor and define `YYSTYPE` as a macro, like this:

```
#define YYSTYPE double
```

This macro definition must go in the prologue of the grammar file (see Section 3.1 [Outline of a Bison Grammar], page 46). If compatibility with POSIX Yacc matters to you, use this. Note however that Bison cannot know YYSTYPE's value, not even whether it is defined, so there are services it cannot provide. Besides this works only for languages that have a preprocessor.

3.4.2 More Than One Value Type

In most programs, you will need different data types for different kinds of tokens and groupings. For example, a numeric constant may need type `int` or `long`, while a string constant needs type `char *`, and an identifier might need a pointer to an entry in the symbol table.

To use more than one data type for semantic values in one parser, Bison requires you to do two things:

- Specify the entire collection of possible data types. There are several options:
  - let Bison compute the union type from the tags you assign to symbols;
  - use the `%union` Bison declaration (see Section 3.4.4 [The Union Declaration], page 58);
  - define the `%define` variable `api.value.type` to be a union type whose members are the type tags (see Section 3.4.5 [Providing a Structured Semantic Value Type], page 59);
  - use a `typedef` or a `#define` to define YYSTYPE to be a union type whose member names are the type tags.
- Choose one of those types for each symbol (terminal or nonterminal) for which semantic values are used. This is done for tokens with the `%token` Bison declaration (see Section 3.7.2 [Token Kind Names], page 70) and for groupings with the `%nterm`/`%type` Bison declarations (see Section 3.7.4 [Nonterminal Symbols], page 72).

3.4.3 Generating the Semantic Value Type

The special value `union` of the `%define` variable `api.value.type` instructs Bison that the type tags (used with the `%token`, `%nterm` and `%type` directives) are genuine types, not names of members of YYSTYPE.

For example:

```
%define api.value.type union
%token <int> INT "integer"
%token <int> 'n'
%nterm <int> expr
%token <char const *> ID "identifier"
```

generates an appropriate value of YYSTYPE to support each symbol type. The name of the member of YYSTYPE for tokens than have a declared identifier *id* (such as INT and ID above, but not `'n'`) is *id*. The other symbols have unspecified names on which you should not depend; instead, relying on C casts to access the semantic value with the appropriate type:

```
/* For an "integer". */
yylval.INT = 42;
return INT;
```

```
/* For an 'n', also declared as int. */
*((int*)&yylval) = 42;
return 'n';

/* For an "identifier". */
yylval.ID = "42";
return ID;
```

If the `%define` variable `api.token.prefix` is defined (see Section 3.7.14 [%define Summary], page 84), then it is also used to prefix the union member names. For instance, with '`%define api.token.prefix {TOK_}`':

```
/* For an "integer". */
yylval.TOK_INT = 42;
return TOK_INT;
```

This Bison extension cannot work if `%yacc` (or `-y`/`--yacc`) is enabled, as POSIX mandates that Yacc generate tokens as macros (e.g., '`#define INT 258`', or '`#define TOK_INT 258`').

A similar feature is provided for C++ that in addition overcomes C++ limitations (that forbid non-trivial objects to be part of a `union`): '`%define api.value.type variant`', see Section 10.1.4.2 [++ Variants-title⟨undefined⟩], page 171.

3.4.4 The Union Declaration

The `%union` declaration specifies the entire collection of possible data types for semantic values. The keyword `%union` is followed by braced code containing the same thing that goes inside a `union` in C.

For example:

```
%union {
  double val;
  symrec *tptr;
}
```

This says that the two alternative types are `double` and `symrec *`. They are given names `val` and `tptr`; these names are used in the `%token`, `%nterm` and `%type` declarations to pick one of the types for a terminal or nonterminal symbol (see Section 3.7.4 [Nonterminal Symbols], page 72).

As an extension to POSIX, a tag is allowed after the `%union`. For example:

```
%union value {
  double val;
  symrec *tptr;
}
```

specifies the union tag `value`, so the corresponding C type is `union value`. If you do not specify a tag, it defaults to `YYSTYPE` (see Section 3.7.14 [%define Summary], page 84).

As another extension to POSIX, you may specify multiple `%union` declarations; their contents are concatenated. However, only the first `%union` declaration can specify a tag.

Note that, unlike making a `union` declaration in C, you need not write a semicolon after the closing brace.

3.4.5 Providing a Structured Semantic Value Type

Instead of `%union`, you can define and use your own union type `YYSTYPE` if your grammar contains at least one '`<type>`' tag. For example, you can put the following into a header file `parser.h`:

```
union YYSTYPE {
  double val;
  symrec *tptr;
};
```

and then your grammar can use the following instead of `%union`:

```
%{
#include "parser.h"
%}
%define api.value.type {union YYSTYPE}
%nterm <val> expr
%token <tptr> ID
```

Actually, you may also provide a `struct` rather that a `union`, which may be handy if you want to track information for every symbol (such as preceding comments).

The type you provide may even be structured and include pointers, in which case the type tags you provide may be composite, with '`.`' and '`->`' operators.

3.4.6 Actions

An action accompanies a syntactic rule and contains C code to be executed each time an instance of that rule is recognized. The task of most actions is to compute a semantic value for the grouping built by the rule from the semantic values associated with tokens or smaller groupings.

An action consists of braced code containing C statements, and can be placed at any position in the rule; it is executed at that position. Most rules have just one action at the end of the rule, following all the components. Actions in the middle of a rule are tricky and used only for special purposes (see Section 3.4.8 [Actions in Midrule], page 61).

The C code in an action can refer to the semantic values of the components matched by the rule with the construct `$n`, which stands for the value of the nth component. The semantic value for the grouping being constructed is `$$`. In addition, the semantic values of symbols can be accessed with the named references construct `$name` or `$[name]`. Bison translates both of these constructs into expressions of the appropriate type when it copies the actions into the parser implementation file. `$$` (or `$name`, when it stands for the current grouping) is translated to a modifiable lvalue, so it can be assigned to.

Here is a typical example:

```
exp:
...
| exp '+' exp    { $$ = $1 + $3; }
```

Or, in terms of named references:

```
exp[result]:
...
| exp[left] '+' exp[right]  { $result = $left + $right; }
```

This rule constructs an `exp` from two smaller `exp` groupings connected by a plus-sign token. In the action, `$1` and `$3` (`$left` and `$right`) refer to the semantic values of the two component `exp` groupings, which are the first and third symbols on the right hand side of the rule. The sum is stored into `$$` (`$result`) so that it becomes the semantic value of the addition-expression just recognized by the rule. If there were a useful semantic value associated with the '`+`' token, it could be referred to as `$2`.

See Section 3.6 [Named References], page 69, for more information about using the named references construct.

Note that the vertical-bar character '`|`' is really a rule separator, and actions are attached to a single rule. This is a difference with tools like Flex, for which '`|`' stands for either "or", or "the same action as that of the next rule". In the following example, the action is triggered only when '`b`' is found:

```
a-or-b: 'a'|'b'   { a_or_b_found = 1; };
```

If you don't specify an action for a rule, Bison supplies a default: `$$ = $1`. Thus, the value of the first symbol in the rule becomes the value of the whole rule. Of course, the default action is valid only if the two data types match. There is no meaningful default action for an empty rule; every empty rule must have an explicit action unless the rule's value does not matter.

`$n` with *n* zero or negative is allowed for reference to tokens and groupings on the stack *before* those that match the current rule. This is a very risky practice, and to use it reliably you must be certain of the context in which the rule is applied. Here is a case in which you can use this reliably:

```
foo:
  expr bar '+' expr  { ... }
| expr bar '-' expr  { ... }
;

bar:
  %empty    { previous_expr = $0; }
;
```

As long as `bar` is used only in the fashion shown here, `$0` always refers to the `expr` which precedes `bar` in the definition of `foo`.

It is also possible to access the semantic value of the lookahead token, if any, from a semantic action. This semantic value is stored in `yylval`. See Section 4.5 [Special Features for Use in Actions], page 107.

3.4.7 Data Types of Values in Actions

If you have chosen a single data type for semantic values, the `$$` and `$n` constructs always have that data type.

If you have used `%union` to specify a variety of data types, then you must declare a choice among these types for each terminal or nonterminal symbol that can have a semantic value. Then each time you use `$$` or `$n`, its data type is determined by which symbol it refers to in the rule. In this example,

```
exp:
  ...
| exp '+' exp    { $$ = $1 + $3; }
```

`$1` and `$3` refer to instances of `exp`, so they all have the data type declared for the nonterminal symbol `exp`. If `$2` were used, it would have the data type declared for the terminal symbol `'+'`, whatever that might be.

Alternatively, you can specify the data type when you refer to the value, by inserting '`<type>`' after the '`$`' at the beginning of the reference. For example, if you have defined types as shown here:

```
%union {
  int itype;
  double dtype;
}
```

then you can write `$<itype>1` to refer to the first subunit of the rule as an integer, or `$<dtype>1` to refer to it as a double.

3.4.8 Actions in Midrule

Occasionally it is useful to put an action in the middle of a rule. These actions are written just like usual end-of-rule actions, but they are executed before the parser even recognizes the following components.

3.4.8.1 Using Midrule Actions

A midrule action may refer to the components preceding it using `$n`, but it may not refer to subsequent components because it is run before they are parsed.

The midrule action itself counts as one of the components of the rule. This makes a difference when there is another action later in the same rule (and usually there is another at the end): you have to count the actions along with the symbols when working out which number n to use in `$n`.

The midrule action can also have a semantic value. The action can set its value with an assignment to `$$`, and actions later in the rule can refer to the value using `$n`. Since there is no symbol to name the action, there is no way to declare a data type for the value in advance, so you must use the '`$<...>n`' construct to specify a data type each time you refer to this value.

There is no way to set the value of the entire rule with a midrule action, because assignments to `$$` do not have that effect. The only way to set the value for the entire rule is with an ordinary action at the end of the rule.

Here is an example from a hypothetical compiler, handling a `let` statement that looks like '`let (variable) statement`' and serves to create a variable named *variable* temporarily for the duration of *statement*. To parse this construct, we must put *variable* into the symbol table while *statement* is parsed, then remove it afterward. Here is how it is done:

```
stmt:
  "let" '(' var ')'
    {
      $<context>$ = push_context ();
      declare_variable ($3);
    }
  stmt
    {
      $$ = $6;
      pop_context ($<context>5);
    }
```

As soon as 'let (*variable*)' has been recognized, the first action is run. It saves a copy of the current semantic context (the list of accessible variables) as its semantic value, using alternative `context` in the data-type union. Then it calls `declare_variable` to add the new variable to that list. Once the first action is finished, the embedded statement `stmt` can be parsed.

Note that the midrule action is component number 5, so the 'stmt' is component number 6. Named references can be used to improve the readability and maintainability (see Section 3.6 [Named References], page 69):

```
stmt:
  "let" '(' var ')'
    {
      $<context>let = push_context ();
      declare_variable ($3);
    }[let]
  stmt
    {
      $$ = $6;
      pop_context ($<context>let);
    }
```

After the embedded statement is parsed, its semantic value becomes the value of the entire `let`-statement. Then the semantic value from the earlier action is used to restore the prior list of variables. This removes the temporary `let`-variable from the list so that it won't appear to exist while the rest of the program is parsed.

Because the types of the semantic values of midrule actions are unknown to Bison, type-based features (e.g., '%printer', '%destructor') do not work, which could result in memory leaks. They also forbid the use of the `variant` implementation of the `api.value.type` in C++ (see Section 10.1.4.2 [++ Variants-title⟨undefined⟩], page 171).

See Section 3.4.8.2 [Typed Midrule Actions], page 62, for one way to address this issue, and Section 3.4.8.3 [Midrule Action Translation], page 63, for another: turning mid-action actions into regular actions.

3.4.8.2 Typed Midrule Actions

In the above example, if the parser initiates error recovery (see Chapter 6 [Error Recovery], page 130) while parsing the tokens in the embedded statement `stmt`, it might discard the

previous semantic context `$<context>5` without restoring it. Thus, `$<context>5` needs a destructor (see Section 3.7.7 [Freeing Discarded Symbols], page 73), and Bison needs the type of the semantic value (`context`) to select the right destructor.

As an extension to Yacc's midrule actions, Bison offers a means to type their semantic value: specify its type tag ('`<...>`' before the midrule action.

Consider the previous example, with an untyped midrule action:

```
stmt:
  "let" '(' var ')'
    {
      $<context>$ = push_context (); // ***
      declare_variable ($3);
    }
  stmt
    {
      $$ = $6;
      pop_context ($<context>5);     // ***
    }
```

If instead you write:

```
stmt:
  "let" '(' var ')'
    <context>{                        // ***
      $$ = push_context ();          // ***
      declare_variable ($3);
    }
  stmt
    {
      $$ = $6;
      pop_context ($5);              // ***
    }
```

then `%printer` and `%destructor` work properly (no more leaks!), C++ `variant`s can be used, and redundancy is reduced (`<context>` is specified once).

3.4.8.3 Midrule Action Translation

Midrule actions are actually transformed into regular rules and actions. The various reports generated by Bison (textual, graphical, etc., see Section 8.2 [Understanding Your Parser], page 138) reveal this translation, best explained by means of an example. The following rule:

```
exp: { a(); } "b" { c(); } { d(); } "e" { f(); };
```

is translated into:

```
$@1: %empty { a(); };
$@2: %empty { c(); };
$@3: %empty { d(); };
exp: $@1 "b" $@2 $@3 "e" { f(); };
```

with new nonterminal symbols `$@n`, where n is a number.

A midrule action is expected to generate a value if it uses `$$`, or the (final) action uses `$n` where *n* denote the midrule action. In that case its nonterminal is rather named `@n`:

```
exp: { a(); } "b" { $$ = c(); } { d(); } "e" { f = $1; };
```

is translated into

```
@1: %empty { a(); };
@2: %empty { $$ = c(); };
$@3: %empty { d(); };
exp: @1 "b" @2 $@3 "e" { f = $1; }
```

There are probably two errors in the above example: the first midrule action does not generate a value (it does not use `$$` although the final action uses it), and the value of the second one is not used (the final action does not use `$3`). Bison reports these errors when the `midrule-value` warnings are enabled (see Chapter 9 [Invoking Bison], page 154):

```
$ bison -Wmidrule-value mid.y
mid.y:2.6-13: warning: unset value: $$
    2 | exp: { a(); } "b" { $$ = c(); } { d(); } "e" { f = $1; };
      |      ~~~~~~~~
mid.y:2.19-31: warning: unused value: $3
    2 | exp: { a(); } "b" { $$ = c(); } { d(); } "e" { f = $1; };
      |                   ~~~~~~~~~~~~~
```

It is sometimes useful to turn midrule actions into regular actions, e.g., to factor them, or to escape from their limitations. For instance, as an alternative to *typed* midrule action, you may bury the midrule action inside a nonterminal symbol and to declare a printer and a destructor for that symbol:

```
%nterm <context> let
%destructor { pop_context ($$); } let
%printer { print_context (yyo, $$); } let

%%

stmt:
  let stmt
    {
      $$ = $2;
      pop_context ($let);
    };

let:
  "let" '(' var ')'
    {
      $let = push_context ();
      declare_variable ($var);
    };
```

3.4.8.4 Conflicts due to Midrule Actions

Taking action before a rule is completely recognized often leads to conflicts since the parser must commit to a parse in order to execute the action. For example, the following two rules, without midrule actions, can coexist in a working parser because the parser can shift the open-brace token and look at what follows before deciding whether there is a declaration or not:

```
compound:
  '{' declarations statements '}'
| '{' statements '}'
;
```

But when we add a midrule action as follows, the rules become nonfunctional:

```
compound:
  { prepare_for_local_variables (); }
    '{' declarations statements '}'
|   '{' statements '}'
;
```

Now the parser is forced to decide whether to run the midrule action when it has read no farther than the open-brace. In other words, it must commit to using one rule or the other, without sufficient information to do it correctly. (The open-brace token is what is called the *lookahead* token at this time, since the parser is still deciding what to do about it. See Section 5.1 [Lookahead Tokens], page 111.)

You might think that you could correct the problem by putting identical actions into the two rules, like this:

```
compound:
  { prepare_for_local_variables (); }
    '{' declarations statements '}'
| { prepare_for_local_variables (); }
    '{' statements '}'
;
```

But this does not help, because Bison does not realize that the two actions are identical. (Bison never tries to understand the C code in an action.)

If the grammar is such that a declaration can be distinguished from a statement by the first token (which is true in C), then one solution which does work is to put the action after the open-brace, like this:

```
compound:
  '{' { prepare_for_local_variables (); }
    declarations statements '}'
| '{' statements '}'
;
```

Now the first token of the following declaration or statement, which would in any case tell Bison which rule to use, can still do so.

Another solution is to bury the action inside a nonterminal symbol which serves as a subroutine:

```
subroutine:
  %empty  { prepare_for_local_variables (); }
;

compound:
  subroutine '{' declarations statements '}'
| subroutine '{' statements '}'
;
```

Now Bison can execute the action in the rule for `subroutine` without deciding which rule for `compound` it will eventually use.

3.5 Tracking Locations

Though grammar rules and semantic actions are enough to write a fully functional parser, it can be useful to process some additional information, especially symbol locations.

The way locations are handled is defined by providing a data type, and actions to take when rules are matched.

3.5.1 Data Type of Locations

Defining a data type for locations is much simpler than for semantic values, since all tokens and groupings always use the same type.

You can specify the type of locations by defining a macro called `YYLTYPE`, just as you can specify the semantic value type by defining a `YYSTYPE` macro (see Section 3.4.1 [Data Types of Semantic Values], page 56). When `YYLTYPE` is not defined, Bison uses a default structure type with four members:

```
typedef struct YYLTYPE
{
  int first_line;
  int first_column;
  int last_line;
  int last_column;
} YYLTYPE;
```

While default locations represent a range in the source file(s), this is not a requirement. It could be a single point or just a line number, or even more complex structures.

When `YYLTYPE` is not defined, at the beginning of the parsing, Bison initializes all these fields to 1 for `yylloc`. To initialize `yylloc` with a custom location type (or to chose a different initialization), use the `%initial-action` directive. See Section 3.7.6 [Performing Actions before Parsing], page 73.

3.5.2 Actions and Locations

Actions are not only useful for defining language semantics, but also for describing the behavior of the output parser with locations.

The most obvious way for building locations of syntactic groupings is very similar to the way semantic values are computed. In a given rule, several constructs can be used to access the locations of the elements being matched. The location of the nth component of the right hand side is `@n`, while the location of the left hand side grouping is `@$`.

In addition, the named references construct `@name` and `@[name]` may also be used to address the symbol locations. See Section 3.6 [Named References], page 69, for more information about using the named references construct.

Here is a basic example using the default data type for locations:

```
exp:
  ...
| exp '/' exp
    {
      @$.first_column = @1.first_column;
      @$.first_line = @1.first_line;
      @$.last_column = @3.last_column;
      @$.last_line = @3.last_line;
      if ($3)
        $$ = $1 / $3;
      else
        {
          $$ = 1;
          fprintf (stderr, "%d.%d-%d.%d: division by zero",
                   @3.first_line, @3.first_column,
                   @3.last_line, @3.last_column);
        }
    }
```

As for semantic values, there is a default action for locations that is run each time a rule is matched. It sets the beginning of `@$` to the beginning of the first symbol, and the end of `@$` to the end of the last symbol.

With this default action, the location tracking can be fully automatic. The example above simply rewrites this way:

```
exp:
  ...
| exp '/' exp
    {
      if ($3)
        $$ = $1 / $3;
      else
        {
          $$ = 1;
          fprintf (stderr, "%d.%d-%d.%d: division by zero",
                   @3.first_line, @3.first_column,
                   @3.last_line, @3.last_column);
        }
    }
```

It is also possible to access the location of the lookahead token, if any, from a semantic action. This location is stored in `yylloc`. See Section 4.5 [Special Features for Use in Actions], page 107.

3.5.3 Default Action for Locations

Actually, actions are not the best place to compute locations. Since locations are much more general than semantic values, there is room in the output parser to redefine the default action to take for each rule. The `YYLLOC_DEFAULT` macro is invoked each time a rule is matched, before the associated action is run. It is also invoked while processing a syntax error, to compute the error's location. Before reporting an unresolvable syntactic ambiguity, a GLR parser invokes `YYLLOC_DEFAULT` recursively to compute the location of that ambiguity.

Most of the time, this macro is general enough to suppress location dedicated code from semantic actions.

The `YYLLOC_DEFAULT` macro takes three parameters. The first one is the location of the grouping (the result of the computation). When a rule is matched, the second parameter identifies locations of all right hand side elements of the rule being matched, and the third parameter is the size of the rule's right hand side. When a GLR parser reports an ambiguity, which of multiple candidate right hand sides it passes to `YYLLOC_DEFAULT` is undefined. When processing a syntax error, the second parameter identifies locations of the symbols that were discarded during error processing, and the third parameter is the number of discarded symbols.

By default, `YYLLOC_DEFAULT` is defined this way:

```
# define YYLLOC_DEFAULT(Cur, Rhs, N)                     \
do                                                       \
  if (N)                                                 \
    {                                                    \
      (Cur).first_line   = YYRHSLOC(Rhs, 1).first_line;   \
      (Cur).first_column = YYRHSLOC(Rhs, 1).first_column; \
      (Cur).last_line    = YYRHSLOC(Rhs, N).last_line;    \
      (Cur).last_column  = YYRHSLOC(Rhs, N).last_column;  \
    }                                                    \
  else                                                   \
    {                                                    \
      (Cur).first_line   = (Cur).last_line   =           \
        YYRHSLOC(Rhs, 0).last_line;                      \
      (Cur).first_column = (Cur).last_column =           \
        YYRHSLOC(Rhs, 0).last_column;                    \
    }                                                    \
while (0)
```

where `YYRHSLOC (rhs, k)` is the location of the kth symbol in *rhs* when k is positive, and the location of the symbol just before the reduction when k and n are both zero.

When defining `YYLLOC_DEFAULT`, you should consider that:

- All arguments are free of side-effects. However, only the first one (the result) should be modified by `YYLLOC_DEFAULT`.

- For consistency with semantic actions, valid indexes within the right hand side range from 1 to n. When n is zero, only 0 is a valid index, and it refers to the symbol just before the reduction. During error processing n is always positive.

- Your macro should parenthesize its arguments, if need be, since the actual arguments may not be surrounded by parentheses. Also, your macro should expand to something that can be used as a single statement when it is followed by a semicolon.

3.6 Named References

As described in the preceding sections, the traditional way to refer to any semantic value or location is a *positional reference*, which takes the form `$n`, `$$`, `@n`, and `@$`. However, such a reference is not very descriptive. Moreover, if you later decide to insert or remove symbols in the right-hand side of a grammar rule, the need to renumber such references can be tedious and error-prone.

To avoid these issues, you can also refer to a semantic value or location using a *named reference*. First of all, original symbol names may be used as named references. For example:

```
invocation: op '(' args ')'
    { $invocation = new_invocation ($op, $args, @invocation); }
```

Positional and named references can be mixed arbitrarily. For example:

```
invocation: op '(' args ')'
    { $$ = new_invocation ($op, $args, @$); }
```

However, sometimes regular symbol names are not sufficient due to ambiguities:

```
exp: exp '/' exp
    { $exp = $exp / $exp; } // $exp is ambiguous.

exp: exp '/' exp
    { $$ = $1 / $exp; } // One usage is ambiguous.

exp: exp '/' exp
    { $$ = $1 / $3; } // No error.
```

When ambiguity occurs, explicitly declared names may be used for values and locations. Explicit names are declared as a bracketed name after a symbol appearance in rule definitions. For example:

```
exp[result]: exp[left] '/' exp[right]
    { $result = $left / $right; }
```

In order to access a semantic value generated by a midrule action, an explicit name may also be declared by putting a bracketed name after the closing brace of the midrule action code:

```
exp[res]: exp[x] '+' {$left = $x;}[left] exp[right]
    { $res = $left + $right; }
```

In references, in order to specify names containing dots and dashes, an explicit bracketed syntax `$[name]` and `@[name]` must be used:

```
if-stmt: "if" '(' expr ')' "then" then.stmt ';'
    { $[if-stmt] = new_if_stmt ($expr, $[then.stmt]); }
```

It often happens that named references are followed by a dot, dash or other C punctuation marks and operators. By default, Bison will read '`$name.suffix`' as a reference to symbol value `$name` followed by '`.suffix`', i.e., an access to the `suffix` field of the semantic value.

In order to force Bison to recognize '`name.suffix`' in its entirety as the name of a semantic value, the bracketed syntax '`$[name.suffix]`' must be used.

3.7 Bison Declarations

The *Bison declarations* section of a Bison grammar defines the symbols used in formulating the grammar and the data types of semantic values. See Section 3.2 [Symbols, Terminal and Nonterminal], page 52.

All token kind names (but not single-character literal tokens such as '`+`' and '`*`') must be declared. Nonterminal symbols must be declared if you need to specify which data type to use for the semantic value (see Section 3.4.2 [More Than One Value Type], page 57).

The first rule in the grammar file also specifies the start symbol, by default. If you want some other symbol to be the start symbol, you must declare it explicitly (see Section 1.1 [Languages and Context-Free Grammars], page 14).

3.7.1 Require a Version of Bison

You may require the minimum version of Bison to process the grammar. If the requirement is not met, `bison` exits with an error (exit status 63).

```
%require "version"
```

Some deprecated behaviors are disabled for some required *version*:

`"3.2"` (or better)

        The C++ deprecated files `position.hh` and `stack.hh` are no longer generated.

`"3.4"` (or better)

        To comply with the recommendations of the Graphviz team (`https://marc.info/?l=graphviz-devel&m=129418103126092`), use the `.gv` extension instead of `.dot` for the name of the generated DOT file. See Section 8.3 [Visualizing Your Parser], page 145.

3.7.2 Token Kind Names

The basic way to declare a token kind name (terminal symbol) is as follows:

```
%token name
```

Bison will convert this into a definition in the parser, so that the function `yylex` (if it is in this file) can use the name *name* to stand for this token kind's code.

Alternatively, you can use `%left`, `%right`, `%precedence`, or `%nonassoc` instead of `%token`, if you wish to specify associativity and precedence. See Section 3.7.3 [Operator Precedence], page 71. However, for clarity, we recommend to use these directives only to declare associativity and precedence, and not to add string aliases, semantic types, etc.

You can explicitly specify the numeric code for a token kind by appending a nonnegative decimal or hexadecimal integer value in the field immediately following the token name:

```
%token NUM 300
%token XNUM 0x12d // a GNU extension
```

It is generally best, however, to let Bison choose the numeric codes for all token kinds. Bison will automatically select codes that don't conflict with each other or with normal characters.

In the event that the stack type is a union, you must augment the `%token` or other token declaration to include the data type alternative delimited by angle-brackets (see Section 3.4.2 [More Than One Value Type], page 57).

For example:

```
%union {                 /* define stack type */
  double val;
  symrec *tptr;
}
%token <val> NUM       /* define token NUM and its type */
```

You can associate a literal string token with a token kind name by writing the literal string at the end of a `%token` declaration which declares the name. For example:

```
%token ARROW "=>"
```

For example, a grammar for the C language might specify these names with equivalent literal string tokens:

```
%token  <operator>  OR        "||"
%token  <operator>  LE 134  "<="
%left  OR  "<="
```

Once you equate the literal string and the token kind name, you can use them interchangeably in further declarations or the grammar rules. The `yylex` function can use the token name or the literal string to obtain the token kind code (see Section 4.3.1 [Calling Convention for `yylex`], page 100).

String aliases allow for better error messages using the literal strings instead of the token names, such as 'syntax error, unexpected ||, expecting number or (' rather than 'syntax error, unexpected OR, expecting NUM or LPAREN'.

String aliases may also be marked for internationalization (see Section 4.6.2 [Token Internationalization], page 109):

```
%token
    OR      "||"
    LPAREN "("
    RPAREN ")"
    '\n'   _("end of line")
  <double>
    NUM    _("number")
```

would produce in French 'erreur de syntaxe, || inattendu, attendait nombre ou (' rather than 'erreur de syntaxe, || inattendu, attendait number ou ('.

3.7.3 Operator Precedence

Use the `%left`, `%right`, `%nonassoc`, or `%precedence` declaration to declare a token and specify its precedence and associativity, all at once. These are called *precedence declarations*. See Section 5.3 [Operator Precedence], page 114, for general information on operator precedence.

The syntax of a precedence declaration is nearly the same as that of `%token`: either

```
%left symbols...
```

or

```
%left <type> symbols...
```

And indeed any of these declarations serves the purposes of `%token`. But in addition, they specify the associativity and relative precedence for all the *symbols*:

- The associativity of an operator *op* determines how repeated uses of the operator nest: whether '*x op y op z*' is parsed by grouping *x* with *y* first or by grouping *y* with *z* first. `%left` specifies left-associativity (grouping *x* with *y* first) and `%right` specifies right-associativity (grouping *y* with *z* first). `%nonassoc` specifies no associativity, which means that '*x op y op z*' is considered a syntax error.

  `%precedence` gives only precedence to the *symbols*, and defines no associativity at all. Use this to define precedence only, and leave any potential conflict due to associativity enabled.

- The precedence of an operator determines how it nests with other operators. All the tokens declared in a single precedence declaration have equal precedence and nest together according to their associativity. When two tokens declared in different precedence declarations associate, the one declared later has the higher precedence and is grouped first.

For backward compatibility, there is a confusing difference between the argument lists of `%token` and precedence declarations. Only a `%token` can associate a literal string with a token kind name. A precedence declaration always interprets a literal string as a reference to a separate token. For example:

```
%left  OR "<="         // Does not declare an alias.
%left  OR 134 "<=" 135 // Declares 134 for OR and 135 for "<=".
```

3.7.4 Nonterminal Symbols

When you use `%union` to specify multiple value types, you must declare the value type of each nonterminal symbol for which values are used. This is done with a `%type` declaration, like this:

```
%type <type> nonterminal...
```

Here *nonterminal* is the name of a nonterminal symbol, and *type* is the name given in the `%union` to the alternative that you want (see Section 3.4.4 [The Union Declaration], page 58). You can give any number of nonterminal symbols in the same `%type` declaration, if they have the same value type. Use spaces to separate the symbol names.

While POSIX Yacc allows `%type` only for nonterminals, Bison accepts that this directive be also applied to terminal symbols. To declare exclusively nonterminal symbols, use the safer `%nterm`:

```
%nterm <type> nonterminal...
```

3.7.5 Syntax of Symbol Declarations

The syntax of the various directives to declare symbols is as follows.

```
%token tag? ( id number? string? )+ ( tag ( id number? string? )+ )*
%left  tag? ( id number?)+ ( tag ( id number? )+ )*
%type  tag? ( id | char | string )+ ( tag ( id | char | string )+ )*
%nterm tag? id+ ( tag id+ )*
```

where *tag* denotes a type tag such as '`<ival>`', *id* denotes an identifier such as '`NUM`', *number* a decimal or hexadecimal integer such as '`300`' or '`0x12d`', *char* a character literal such as '`'+'`', and *string* a string literal such as '`"number"`'. The postfix quantifiers are '`?`' (zero or one), '`*`' (zero or more) and '`+`' (one or more).

The directives `%precedence`, `%right` and `%nonassoc` behave like `%left`.

3.7.6 Performing Actions before Parsing

Sometimes your parser needs to perform some initializations before parsing. The `%initial-action` directive allows for such arbitrary code.

`%initial-action { `*code*` }`   [Directive]
> Declare that the braced *code* must be invoked before parsing each time `yyparse` is called. The *code* may use `$$` (or `$<`*tag*`>$`) and `@$` — initial value and location of the lookahead — and the `%parse-param`.

For instance, if your locations use a file name, you may use

```
%parse-param { char const *file_name };
%initial-action
{
  @$.initialize (file_name);
};
```

3.7.7 Freeing Discarded Symbols

During error recovery (see Chapter 6 [Error Recovery], page 130), symbols already pushed on the stack and tokens coming from the rest of the file are discarded until the parser falls on its feet. If the parser runs out of memory, or if it returns via `YYABORT` or `YYACCEPT`, all the symbols on the stack must be discarded. Even if the parser succeeds, it must discard the start symbol.

When discarded symbols convey heap based information, this memory is lost. While this behavior can be tolerable for batch parsers, such as in traditional compilers, it is unacceptable for programs like shells or protocol implementations that may parse and execute indefinitely.

The `%destructor` directive defines code that is called when a symbol is automatically discarded.

`%destructor { `*code*` } `*symbols*   [Directive]
> Invoke the braced *code* whenever the parser discards one of the *symbols*. Within *code*, `$$` (or `$<`*tag*`>$`) designates the semantic value associated with the discarded symbol, and `@$` designates its location. The additional parser parameters are also available (see Section 4.1 [The Parser Function `yyparse`], page 98).
>
> When a symbol is listed among *symbols*, its `%destructor` is called a per-symbol `%destructor`. You may also define a per-type `%destructor` by listing a semantic type tag among *symbols*. In that case, the parser will invoke this *code* whenever it discards any grammar symbol that has that semantic type tag unless that symbol has its own per-symbol `%destructor`.
>
> Finally, you can define two different kinds of default `%destructor`s. You can place each of `<*>` and `<>` in the *symbols* list of exactly one `%destructor` declaration in your

grammar file. The parser will invoke the *code* associated with one of these whenever it discards any user-defined grammar symbol that has no per-symbol and no per-type `%destructor`. The parser uses the *code* for `<*>` in the case of such a grammar symbol for which you have formally declared a semantic type tag (`%token`, `%nterm`, and `%type` count as such a declaration, but `$<tag>$` does not). The parser uses the *code* for `<>` in the case of such a grammar symbol that has no declared semantic type tag.

For example:

```
%union { char *string; }
%token <string> STRING1 STRING2
%nterm <string> string1 string2
%union { char character; }
%token <character> CHR
%nterm <character> chr
%token TAGLESS

%destructor { } <character>
%destructor { free ($$); } <*>
%destructor { free ($$); printf ("%d", @$.first_line); } STRING1 string1
%destructor { printf ("Discarding tagless symbol.\n"); } <>
```

guarantees that, when the parser discards any user-defined symbol that has a semantic type tag other than `<character>`, it passes its semantic value to `free` by default. However, when the parser discards a `STRING1` or a `string1`, it uses the third `%destructor`, which frees it and prints its line number to `stdout` (`free` is invoked only once). Finally, the parser merely prints a message whenever it discards any symbol, such as `TAGLESS`, that has no semantic type tag.

A Bison-generated parser invokes the default `%destructor`s only for user-defined as opposed to Bison-defined symbols. For example, the parser will not invoke either kind of default `%destructor` for the special Bison-defined symbols `$accept`, `$undefined`, or `$end` (see Appendix A [Bison Symbols], page 208), none of which you can reference in your grammar. It also will not invoke either for the `error` token (see Appendix A [Bison Symbols], page 208), which is always defined by Bison regardless of whether you reference it in your grammar. However, it may invoke one of them for the end token (token 0) if you redefine it from `$end` to, for example, `END`:

```
%token END 0
```

Finally, Bison will never invoke a `%destructor` for an unreferenced midrule semantic value (see Section 3.4.8 [Actions in Midrule], page 61). That is, Bison does not consider a midrule to have a semantic value if you do not reference `$$` in the midrule's action or `$n` (where *n* is the right-hand side symbol position of the midrule) in any later action in that rule. However, if you do reference either, the Bison-generated parser will invoke the `<>` `%destructor` whenever it discards the midrule symbol.

Discarded symbols are the following:

- stacked symbols popped during the first phase of error recovery,
- incoming terminals during the second phase of error recovery,

- the current lookahead and the entire stack (except the current right-hand side symbols) when the parser returns immediately, and
- the current lookahead and the entire stack (including the current right-hand side symbols) when the C++ parser (`lalr1.cc`) catches an exception in `parse`,
- the start symbol, when the parser succeeds.

The parser can *return immediately* because of an explicit call to `YYABORT` or `YYACCEPT`, or failed error recovery, or memory exhaustion.

Right-hand side symbols of a rule that explicitly triggers a syntax error via `YYERROR` are not discarded automatically. As a rule of thumb, destructors are invoked only when user actions cannot manage the memory.

3.7.8 Printing Semantic Values

When run-time traces are enabled (see Section 8.5 [Tracing Your Parser], page 148), the parser reports its actions, such as reductions. When a symbol involved in an action is reported, only its kind is displayed, as the parser cannot know how semantic values should be formatted.

The `%printer` directive defines code that is called when a symbol is reported. Its syntax is the same as `%destructor` (see Section 3.7.7 [Freeing Discarded Symbols], page 73).

`%printer { code } symbols`   [Directive]

    Invoke the braced *code* whenever the parser displays one of the *symbols*. Within *code*, `yyo` denotes the output stream (a `FILE*` in C, and an `std::ostream&` in C++), `$$` (or `$<tag>$`) designates the semantic value associated with the symbol, and `@$` its location. The additional parser parameters are also available (see Section 4.1 [The Parser Function yyparse], page 98).

    The *symbols* are defined as for `%destructor` (see Section 3.7.7 [Freeing Discarded Symbols], page 73.): they can be per-type (e.g., '`<ival>`'), per-symbol (e.g., '`exp`', '`NUM`', '`"float"`'), typed per-default (i.e., '`<*>`', or untyped per-default (i.e., '`<>`').

For example:

```
%union { char *string; }
%token <string> STRING1 STRING2
%nterm <string> string1 string2
%union { char character; }
%token <character> CHR
%nterm <character> chr
%token TAGLESS

%printer { fprintf (yyo, "'%c'", $$); } <character>
%printer { fprintf (yyo, "&%p", $$); } <*>
%printer { fprintf (yyo, "\"%s\"", $$); } STRING1 string1
%printer { fprintf (yyo, "<>"); } <>
```

guarantees that, when the parser print any symbol that has a semantic type tag other than `<character>`, it display the address of the semantic value by default. However, when the parser displays a `STRING1` or a `string1`, it formats it as a string in double quotes. It

performs only the second `%printer` in this case, so it prints only once. Finally, the parser print '<>' for any symbol, such as `TAGLESS`, that has no semantic type tag. See Section 8.5.2 [Enabling Debug Traces for `mfcalc`], page 150, for a complete example.

3.7.9 Suppressing Conflict Warnings

Bison normally warns if there are any conflicts in the grammar (see Section 5.2 [Shift/Reduce Conflicts], page 112), but most real grammars have harmless shift/reduce conflicts which are resolved in a predictable way and would be difficult to eliminate. It is desirable to suppress the warning about these conflicts unless the number of conflicts changes. You can do this with the `%expect` declaration.

The declaration looks like this:

```
%expect n
```

Here n is a decimal integer. The declaration says there should be n shift/reduce conflicts and no reduce/reduce conflicts. Bison reports an error if the number of shift/reduce conflicts differs from n, or if there are any reduce/reduce conflicts.

For deterministic parsers, reduce/reduce conflicts are more serious, and should be eliminated entirely. Bison will always report reduce/reduce conflicts for these parsers. With GLR parsers, however, both kinds of conflicts are routine; otherwise, there would be no need to use GLR parsing. Therefore, it is also possible to specify an expected number of reduce/reduce conflicts in GLR parsers, using the declaration:

```
%expect-rr n
```

You may wish to be more specific in your specification of expected conflicts. To this end, you can also attach `%expect` and `%expect-rr` modifiers to individual rules. The interpretation of these modifiers differs from their use as declarations. When attached to rules, they indicate the number of states in which the rule is involved in a conflict. You will need to consult the output resulting from `-v` to determine appropriate numbers to use. For example, for the following grammar fragment, the first rule for `empty_dims` appears in two states in which the '[' token is a lookahead. Having determined that, you can document this fact with an `%expect` modifier as follows:

```
dims:
  empty_dims
| '[' expr ']' dims
;

empty_dims:
  %empty   %expect 2
| empty_dims '[' ']'
;
```

Mid-rule actions generate implicit rules that are also subject to conflicts (see Section 3.4.8.4 [Conflicts due to Midrule Actions], page 65). To attach an `%expect` or `%expect-rr` annotation to an implicit mid-rule action's rule, put it before the action. For example,

```
%glr-parser
%expect-rr 1
```

```
%%

clause:
  "condition" %expect-rr 1 { value_mode(); } '(' exprs ')'
| "condition" %expect-rr 1 { class_mode(); } '(' types ')'
;
```

Here, the appropriate mid-rule action will not be determined until after the '(' token is shifted. Thus, the two actions will clash with each other, and we should expect one reduce/reduce conflict for each.

In general, using %expect involves these steps:

- Compile your grammar without %expect. Use the -v option to get a verbose list of where the conflicts occur. Bison will also print the number of conflicts.

- Check each of the conflicts to make sure that Bison's default resolution is what you really want. If not, rewrite the grammar and go back to the beginning.

- Add an %expect declaration, copying the number n from the number that Bison printed. With GLR parsers, add an %expect-rr declaration as well.

- Optionally, count up the number of states in which one or more conflicted reductions for particular rules appear and add these numbers to the affected rules as %expect-rr or %expect modifiers as appropriate. Rules that are in conflict appear in the output listing surrounded by square brackets or, in the case of reduce/reduce conflicts, as reductions having the same lookahead symbol as a square-bracketed reduction in the same state.

Now Bison will report an error if you introduce an unexpected conflict, but will keep silent otherwise.

3.7.10 The Start-Symbol

Bison assumes by default that the start symbol for the grammar is the first nonterminal specified in the grammar specification section. The programmer may override this restriction with the %start declaration as follows:

```
%start symbol
```

3.7.11 A Pure (Reentrant) Parser

A *reentrant* program is one which does not alter in the course of execution; in other words, it consists entirely of *pure* (read-only) code. Reentrancy is important whenever asynchronous execution is possible; for example, a nonreentrant program may not be safe to call from a signal handler. In systems with multiple threads of control, a nonreentrant program must be called only within interlocks.

Normally, Bison generates a parser which is not reentrant. This is suitable for most uses, and it permits compatibility with Yacc. (The standard Yacc interfaces are inherently nonreentrant, because they use statically allocated variables for communication with yylex, including yylval and yylloc.)

Alternatively, you can generate a pure, reentrant parser. The Bison declaration '%define api.pure' says that you want the parser to be reentrant. It looks like this:

```
%define api.pure full
```

The result is that the communication variables `yylval` and `yylloc` become local variables in `yyparse`, and a different calling convention is used for the lexical analyzer function `yylex`. See Section 4.3.6 [Calling Conventions for Pure Parsers], page 103, for the details of this. The variable `yynerrs` becomes local in `yyparse` in pull mode but it becomes a member of `yypstate` in push mode. (see Section 4.4.1 [The Error Reporting Function `yyerror`], page 104). The convention for calling `yyparse` itself is unchanged.

Whether the parser is pure has nothing to do with the grammar rules. You can generate either a pure parser or a nonreentrant parser from any valid grammar.

3.7.12 A Push Parser

A pull parser is called once and it takes control until all its input is completely parsed. A push parser, on the other hand, is called each time a new token is made available.

A push parser is typically useful when the parser is part of a main event loop in the client's application. This is typically a requirement of a GUI, when the main event loop needs to be triggered within a certain time period.

Normally, Bison generates a pull parser. The following Bison declaration says that you want the parser to be a push parser (see Section 3.7.14 [%define Summary], page 84):

```
%define api.push-pull push
```

In almost all cases, you want to ensure that your push parser is also a pure parser (see Section 3.7.11 [A Pure (Reentrant) Parser], page 77). The only time you should create an impure push parser is to have backwards compatibility with the impure Yacc pull mode interface. Unless you know what you are doing, your declarations should look like this:

```
%define api.pure full
%define api.push-pull push
```

There is a major notable functional difference between the pure push parser and the impure push parser. It is acceptable for a pure push parser to have many parser instances, of the same type of parser, in memory at the same time. An impure push parser should only use one parser at a time.

When a push parser is selected, Bison will generate some new symbols in the generated parser. `yypstate` is a structure that the generated parser uses to store the parser's state. `yypstate_new` is the function that will create a new parser instance. `yypstate_delete` will free the resources associated with the corresponding parser instance. Finally, `yypush_parse` is the function that should be called whenever a token is available to provide the parser. A trivial example of using a pure push parser would look like this:

```
int status;
yypstate *ps = yypstate_new ();
do {
  status = yypush_parse (ps, yylex (), NULL);
} while (status == YYPUSH_MORE);
yypstate_delete (ps);
```

If the user decided to use an impure push parser, a few things about the generated parser will change. The `yychar` variable becomes a global variable instead of a local one in the `yypush_parse` function. For this reason, the signature of the `yypush_parse` function is

changed to remove the token as a parameter. A nonreentrant push parser example would thus look like this:

```
extern int yychar;
int status;
yypstate *ps = yypstate_new ();
do {
  yychar = yylex ();
  status = yypush_parse (ps);
} while (status == YYPUSH_MORE);
yypstate_delete (ps);
```

That's it. Notice the next token is put into the global variable `yychar` for use by the next invocation of the `yypush_parse` function.

Bison also supports both the push parser interface along with the pull parser interface in the same generated parser. In order to get this functionality, you should replace the '`%define api.push-pull push`' declaration with the '`%define api.push-pull both`' declaration. Doing this will create all of the symbols mentioned earlier along with the two extra symbols, `yyparse` and `yypull_parse`. `yyparse` can be used exactly as it normally would be used. However, the user should note that it is implemented in the generated parser by calling `yypull_parse`. This makes the `yyparse` function that is generated with the '`%define api.push-pull both`' declaration slower than the normal `yyparse` function. If the user calls the `yypull_parse` function it will parse the rest of the input stream. It is possible to `yypush_parse` tokens to select a subgrammar and then `yypull_parse` the rest of the input stream. If you would like to switch back and forth between between parsing styles, you would have to write your own `yypull_parse` function that knows when to quit looking for input. An example of using the `yypull_parse` function would look like this:

```
yypstate *ps = yypstate_new ();
yypull_parse (ps); /* Will call the lexer */
yypstate_delete (ps);
```

Adding the '`%define api.pure`' declaration does exactly the same thing to the generated parser with '`%define api.push-pull both`' as it did for '`%define api.push-pull push`'.

3.7.13 Bison Declaration Summary

Here is a summary of the declarations used to define a grammar:

%union   [Directive]
> Declare the collection of data types that semantic values may have (see Section 3.4.4 [The Union Declaration], page 58).

%token   [Directive]
> Declare a terminal symbol (token kind name) with no precedence or associativity specified (see Section 3.7.2 [Token Kind Names], page 70).

%right   [Directive]
> Declare a terminal symbol (token kind name) that is right-associative (see Section 3.7.3 [Operator Precedence], page 71).

%left   [Directive]

> Declare a terminal symbol (token kind name) that is left-associative (see Section 3.7.3 [Operator Precedence], page 71).

%nonassoc   [Directive]

> Declare a terminal symbol (token kind name) that is nonassociative (see Section 3.7.3 [Operator Precedence], page 71). Using it in a way that would be associative is a syntax error.

%nterm   [Directive]

> Declare the type of semantic values for a nonterminal symbol (see Section 3.7.4 [Nonterminal Symbols], page 72).

%type   [Directive]

> Declare the type of semantic values for a symbol (see Section 3.7.4 [Nonterminal Symbols], page 72).

%start   [Directive]

> Specify the grammar's start symbol (see Section 3.7.10 [The Start-Symbol], page 77).

%expect   [Directive]

> Declare the expected number of shift/reduce conflicts, either overall or for a given rule (see Section 3.7.9 [Suppressing Conflict Warnings], page 76).

%expect-rr   [Directive]

> Declare the expected number of reduce/reduce conflicts, either overall or for a given rule (see Section 3.7.9 [Suppressing Conflict Warnings], page 76).

In order to change the behavior of `bison`, use the following directives:

%code {*code*}   [Directive]
%code *qualifier* {*code*}   [Directive]

> Insert *code* verbatim into the output parser source at the default location or at the location specified by *qualifier*. See Section 3.7.15 [%code Summary], page 94.

%debug   [Directive]

> Instrument the parser for traces. Obsoleted by '**%define parse.trace**'. See Section 8.5 [Tracing Your Parser], page 148.

%define *variable*   [Directive]
%define *variable* *value*   [Directive]
%define *variable* {*value*}   [Directive]
%define *variable* "*value*"   [Directive]

> Define a variable to adjust Bison's behavior. See Section 3.7.14 [%define Summary], page 84.

%defines   [Directive]

> Write a parser header file containing definitions for the token kind names defined in the grammar as well as a few other declarations. If the parser implementation file is named `name.c` then the parser header file is named `name.h`.

For C parsers, the parser header file declares `YYSTYPE` unless `YYSTYPE` is already defined as a macro or you have used a `<type>` tag without using `%union`. Therefore, if you are using a `%union` (see Section 3.4.2 [More Than One Value Type], page 57) with components that require other definitions, or if you have defined a `YYSTYPE` macro or type definition (see Section 3.4.1 [Data Types of Semantic Values], page 56), you need to arrange for these definitions to be propagated to all modules, e.g., by putting them in a prerequisite header that is included both by your parser and by any other module that needs `YYSTYPE`.

Unless your parser is pure, the parser header file declares `yylval` as an external variable. See Section 3.7.11 [A Pure (Reentrant) Parser], page 77.

If you have also used locations, the parser header file declares `YYLTYPE` and `yylloc` using a protocol similar to that of the `YYSTYPE` macro and `yylval`. See Section 3.5 [Tracking Locations], page 66.

This parser header file is normally essential if you wish to put the definition of `yylex` in a separate source file, because `yylex` typically needs to be able to refer to the above-mentioned declarations and to the token kind codes. See Section 4.3.4 [Semantic Values of Tokens], page 102.

If you have declared `%code requires` or `%code provides`, the output header also contains their code. See Section 3.7.15 [%code Summary], page 94.

The generated header is protected against multiple inclusions with a C preprocessor guard: ‘`YY_PREFIX_FILE_INCLUDED`’, where *PREFIX* and *FILE* are the prefix (see Section 3.8 [Multiple Parsers in the Same Program], page 95) and generated file name turned uppercase, with each series of non alphanumerical characters converted to a single underscore.

For instance with ‘`%define api.prefix {calc}`’ and ‘`%defines "lib/parse.h"`’, the header will be guarded as follows.

```
#ifndef YY_CALC_LIB_PARSE_H_INCLUDED
# define YY_CALC_LIB_PARSE_H_INCLUDED
...
#endif /* ! YY_CALC_LIB_PARSE_H_INCLUDED */
```

`%defines` *defines-file*   [Directive]
    Same as above, but save in the file *defines-file*.

`%destructor`   [Directive]
    Specify how the parser should reclaim the memory associated to discarded symbols. See Section 3.7.7 [Freeing Discarded Symbols], page 73.

`%file-prefix "`*prefix*`"`   [Directive]
    Specify a prefix to use for all Bison output file names. The names are chosen as if the grammar file were named *prefix*`.y`.

`%language "`*language*`"`   [Directive]
    Specify the programming language for the generated parser. Currently supported languages include C, C++, and Java. *language* is case-insensitive.

`%locations`   [Directive]

> Generate the code processing the locations (see Section 4.5 [Special Features for Use in Actions], page 107). This mode is enabled as soon as the grammar uses the special '`@n`' tokens, but if your grammar does not use it, using '`%locations`' allows for more accurate syntax error messages.

`%name-prefix "prefix"`   [Directive]

> Obsoleted by '`%define api.prefix {prefix}`'. See Section 3.8 [Multiple Parsers in the Same Program], page 95. For C++ parsers, see the '`%define api.namespace`' documentation in this section.

> Rename the external symbols used in the parser so that they start with *prefix* instead of '`yy`'. The precise list of symbols renamed in C parsers is `yyparse`, `yylex`, `yyerror`, `yynerrs`, `yylval`, `yychar`, `yydebug`, and (if locations are used) `yylloc`. If you use a push parser, `yypush_parse`, `yypull_parse`, `yypstate`, `yypstate_new` and `yypstate_delete` will also be renamed. For example, if you use '`%name-prefix "c_"`', the names become `c_parse`, `c_lex`, and so on.

> Contrary to defining `api.prefix`, some symbols are *not* renamed by `%name-prefix`, for instance `YYDEBUG`, `YYTOKENTYPE`, `yytoken_kind_t`, `YYSTYPE`, `YYLTYPE`.

`%no-lines`   [Directive]

> Don't generate any `#line` preprocessor commands in the parser implementation file. Ordinarily Bison writes these commands in the parser implementation file so that the C compiler and debuggers will associate errors and object code with your source file (the grammar file). This directive causes them to associate errors with the parser implementation file, treating it as an independent source file in its own right.

`%output "file"`   [Directive]

> Generate the parser implementation in `file`.

`%pure-parser`   [Directive]

> Deprecated version of '`%define api.pure`' (see Section 3.7.14 [%define Summary], page 84), for which Bison is more careful to warn about unreasonable usage.

`%require "version"`   [Directive]

> Require version *version* or higher of Bison. See Section 3.7.1 [Require a Version of Bison], page 70.

`%skeleton "file"`   [Directive]

> Specify the skeleton to use.

> If *file* does not contain a `/`, *file* is the name of a skeleton file in the Bison installation directory. If it does, *file* is an absolute file name or a file name relative to the directory of the grammar file. This is similar to how most shells resolve commands.

`%token-table`   [Directive]

> This feature is obsolescent, avoid it in new projects.

> Generate an array of token names in the parser implementation file. The name of the array is `yytname`; `yytname[i]` is the name of the token whose internal Bison token code is *i*. The first three elements of `yytname` correspond to the predefined tokens

`"$end"`, `"error"`, and `"$undefined"`; after these come the symbols defined in the grammar file.

The name in the table includes all the characters needed to represent the token in Bison. For single-character literals and literal strings, this includes the surrounding quoting characters and any escape sequences. For example, the Bison single-character literal `'+'` corresponds to a three-character name, represented in C as `"'+'"`; and the Bison two-character literal string `"\\/"` corresponds to a five-character name, represented in C as `"\"\\\\/\""`.

When you specify `%token-table`, Bison also generates macro definitions for macros `YYNTOKENS`, `YYNNTS`, and `YYNRULES`, and `YYNSTATES`:

`YYNTOKENS`

> The number of terminal symbols, i.e., the highest token code, plus one.

`YYNNTS`   The number of nonterminal symbols.

`YYNRULES`   The number of grammar rules,

`YYNSTATES`

> The number of parser states (see Section 5.5 [Parser States], page 117).

Here's code for looking up a multicharacter token in `yytname`, assuming that the characters of the token are stored in `token_buffer`, and assuming that the token does not contain any characters like '"' that require escaping.

```
for (int i = 0; i < YYNTOKENS; i++)
  if (yytname[i]
      && yytname[i][0] == '"'
      && ! strncmp (yytname[i] + 1, token_buffer,
                    strlen (token_buffer))
      && yytname[i][strlen (token_buffer) + 1] == '"'
      && yytname[i][strlen (token_buffer) + 2] == 0)
    break;
```

This method is discouraged: the primary purpose of string aliases is forging good error messages, not describing the spelling of keywords. In addition, looking for the token kind at runtime incurs a (small but noticeable) cost.

Finally, `%token-table` is incompatible with the `custom` and `detailed` values of the `parse.error` `%define` variable.

`%verbose`   [Directive]

> Write an extra output file containing verbose descriptions of the parser states and what is done for each type of lookahead token in that state. See Section 8.2 [Understanding Your Parser], page 138, for more information.

`%yacc`   [Directive]

> Pretend the option `--yacc` was given, i.e., imitate Yacc, including its naming conventions. Only makes sense with the `yacc.c` skeleton. See Section 9.1.3 [Tuning the Parser], page 161, for more.
>
> Of course `%yacc` is a Bison extension...

3.7.14 %define Summary

There are many features of Bison's behavior that can be controlled by assigning the feature a single value. For historical reasons, some such features are assigned values by dedicated directives, such as %start, which assigns the start symbol. However, newer such features are associated with variables, which are assigned by the %define directive:

%define *variable*	[Directive]
%define *variable value*	[Directive]
%define *variable* {*value*}	[Directive]
%define *variable* "*value*"	[Directive]

      Define *variable* to *value*.

      The type of the values depend on the syntax. Braces denote value in the target language (e.g., a namespace, a type, etc.). Keyword values (no delimiters) denote finite choice (e.g., a variation of a feature). String values denote remaining cases (e.g., a file name).

      It is an error if a *variable* is defined by %define multiple times, but see Section 9.1.3 [-D *name*[=*value*]], page 161.

    The rest of this section summarizes variables and values that %define accepts.

    Some *variable*s take Boolean values. In this case, Bison will complain if the variable definition does not meet one of the following four conditions:

1. *value* is true

2. *value* is omitted (or "" is specified). This is equivalent to true.

3. *value* is false.

4. *variable* is never defined. In this case, Bison selects a default value.

    What *variable*s are accepted, as well as their meanings and default values, depend on the selected target language and/or the parser skeleton (see Section 3.7.13 [Bison Declaration Summary], page 79, see Section 3.7.13 [Bison Declaration Summary], page 79). Unaccepted *variable*s produce an error. Some of the accepted *variable*s are described below.

%define api.filename.type {*type*}   [Directive]
- Language(s): C++
- Purpose: Define the type of file names in Bison's default location and position types. See Section 10.1.5.3 [Exposing the Location Classes], page 174.
- Accepted Values: Any type that is printable (via streams) and comparable (with == and !=).
- Default Value: const std::string.
- History: Introduced in Bison 2.0 as filename_type (with std::string as default), renamed as api.filename.type in Bison 3.7 (with const std::string as default).

%define api.header.include {"*header.h*"}   [Directive]
%define api.header.include {<*header.h*>}   [Directive]
- Languages(s): C (yacc.c)

- Purpose: Specify how the generated parser should include the generated header. Historically, when option `-D/--defines` was used, `bison` generated a header and pasted an exact copy of it into the generated parser implementation file. Since Bison 3.6, it is `#include`d as '`"basename.h"`', instead of duplicated, unless *file* is '`y.tab`', see below.

  The `api.header.include` variable allows to control how the generated parser `#include`s the generated header. For instance:

        %define api.header.include {"parse.h"}

  or

        %define api.header.include {<parser/parse.h>}

  Using `api.header.include` does not change the name of the generated header, only how it is included.

  To work around limitations of Automake's `ylwrap` (which runs `bison` with `--yacc`), `api.header.include` is *not* predefined when the output file is `y.tab.c`. Define it to avoid the duplication.

- Accepted Values: An argument for `#include`.
- Default Value: '`"header-basename"`', unless the header file is `y.tab.h`, where *header-basename* is the name of the generated header, without directory part. For instance with `bison -d calc/parse.y`, `api.header.include` defaults to '`"parse.h"`', not '`"calc/parse.h"`'.
- History: Introduced in Bison 3.4. Defaults to '`"basename.h"`' since Bison 3.7, unless the header file is `y.tab.h`.

`%define api.location.file "file"`   [Directive]
`%define api.location.file none`   [Directive]

- Language(s): C++
- Purpose: Define the name of the file in which Bison's default location and position types are generated. See Section 10.1.5.3 [Exposing the Location Classes], page 174.
- Accepted Values:

  `none`   If locations are enabled, generate the definition of the `position` and `location` classes in the header file if `%defines`, otherwise in the parser implementation.

  `"file"`   Generate the definition of the `position` and `location` classes in *file*. This file name can be relative (to where the parser file is output) or absolute.

- Default Value: Not applicable if locations are not enabled, or if a user location type is specified (see `api.location.type`). Otherwise, Bison's `location` is generated in `location.hh` (see Section 10.1.5.2 [++ location-title⟨undefined⟩], page 174).
- History: Introduced in Bison 3.2.

`%define api.location.include {"file"}`   [Directive]
`%define api.location.include {<file>}`   [Directive]

- Language(s): C++

- Purpose: Specify how the generated file that defines the `position` and `location` classes is included. This makes sense when the `location` class is exposed to the rest of your application/library in another directory. See Section 10.1.5.3 [Exposing the Location Classes], page 174.

- Accepted Values: Argument for `#include`.

- Default Value: '`"dir/location.hh"`' where *dir* is the directory part of the output. For instance `src/parse` if `--output=src/parse/parser.cc` was given.

- History: Introduced in Bison 3.2.

`%define api.location.type {type}`   [Directive]
- Language(s): C, C++, Java

- Purpose: Define the location type. See Section 10.1.5.4 [User Defined Location Type], page 175.

- Accepted Values: String

- Default Value: none

- History: Introduced in Bison 2.7 for C++ and Java, in Bison 3.4 for C. Was originally named `location_type` in Bison 2.5 and 2.6.

`%define api.namespace {namespace}`   [Directive]
- Languages(s): C++

- Purpose: Specify the namespace for the parser class. For example, if you specify:

      `%define api.namespace {foo::bar}`

  Bison uses `foo::bar` verbatim in references such as:

      `foo::bar::parser::semantic_type`

  However, to open a namespace, Bison removes any leading `::` and then splits on any remaining occurrences:

      ```
      namespace foo { namespace bar {
        class position;
        class location;
      } }
      ```

- Accepted Values: Any absolute or relative C++ namespace reference without a trailing "`::`". For example, "`foo`" or "`::foo::bar`".

- Default Value: yy, unless you used the obsolete '`%name-prefix "prefix"`' directive.

`%define api.parser.class {name}`   [Directive]
- Language(s): C++, Java

- Purpose: The name of the parser class.

- Accepted Values: Any valid identifier.

- Default Value: In C++, `parser`. In Java, `YYParser` or `api.prefixParser` (see Section 10.2.1 [Java Bison Interface], page 187).

- History: Introduced in Bison 3.3 to replace `parser_class_name`.

%define api.prefix {*prefix*}   [Directive]
- Language(s): All
- Purpose: Rename exported symbols. See Section 3.8 [Multiple Parsers in the Same Program], page 95.
- Accepted Values: String
- Default Value: `YY` for Java, `yy` otherwise.
- History: introduced in Bison 2.6

%define api.pure *purity*   [Directive]
- Language(s): C
- Purpose: Request a pure (reentrant) parser program. See Section 3.7.11 [A Pure (Reentrant) Parser], page 77.
- Accepted Values: `true`, `false`, `full`

  The value may be omitted: this is equivalent to specifying `true`, as is the case for Boolean values.

  When `%define api.pure full` is used, the parser is made reentrant. This changes the signature for `yylex` (see Section 4.3.6 [Calling Conventions for Pure Parsers], page 103), and also that of `yyerror` when the tracking of locations has been activated, as shown below.

  The `true` value is very similar to the `full` value, the only difference is in the signature of `yyerror` on Yacc parsers without `%parse-param`, for historical reasons.

  I.e., if '`%locations %define api.pure`' is passed then the prototypes for `yyerror` are:

  ```
  void yyerror (char const *msg);                    // Yacc parsers.
  void yyerror (YYLTYPE *locp, char const *msg);  // GLR parsers.
  ```

  But if '`%locations %define api.pure %parse-param {int *nastiness}`' is used, then both parsers have the same signature:

  ```
  void yyerror (YYLTYPE *llocp, int *nastiness, char const *msg);
  ```

  (see Section 4.4.1 [The Error Reporting Function yyerror], page 104)
- Default Value: `false`
- History: the `full` value was introduced in Bison 2.7

%define api.push-pull *kind*   [Directive]
- Language(s): C (deterministic parsers only), Java
- Purpose: Request a pull parser, a push parser, or both. See Section 3.7.12 [A Push Parser], page 78.
- Accepted Values: `pull`, `push`, `both`
- Default Value: `pull`

%define api.symbol.prefix {*prefix*}   [Directive]
- Languages(s): all
- Purpose: Add a prefix to the name of the symbol kinds. For instance

  ```
  %define api.symbol.prefix {S_}
  ```

```
%token FILE for ERROR
%%
start: FILE for ERROR;
```

generates this definition in C:

```
/* Symbol kind.  */
enum yysymbol_kind_t
{
  S_YYEMPTY = -2,   /* No symbol.  */
  S_YYEOF = 0,      /* $end  */
  S_YYERROR = 1,    /* error  */
  S_YYUNDEF = 2,    /* $undefined  */
  S_FILE = 3,       /* FILE  */
  S_for = 4,        /* for  */
  S_ERROR = 5,      /* ERROR  */
  S_YYACCEPT = 6,   /* $accept  */
  S_start = 7       /* start  */
};
```

- Accepted Values: Any non empty string. Must be a valid identifier in the target language (typically a non empty sequence of letters, underscores, and —not at the beginning— digits).

  The empty prefix is invalid:

  - in C it would create collision with the YYERROR macro, and potentially token kind definitions and symbol kind definitions would collide;

  - unnamed symbols (such as ''+'') have a name which starts with a digit;

  - even in languages with scoped enumerations such as Java, an empty prefix is dangerous: symbol names may collide with the target language keywords, or with other members of the SymbolKind class.

- Default Value: YYSYMBOL_ in C. S_ in C++, D and Java.

- History: introduced in Bison 3.6.

%define api.token.constructor   [Directive]

- Language(s): C++

- Purpose: When variant-based semantic values are enabled (see Section 10.1.4.2 [++ Variants-title⟨undefined⟩], page 171), request that symbols be handled as a whole (type, value, and possibly location) in the scanner. See Section 10.1.7.2 [Complete Symbols], page 179, for details.

- Accepted Values: Boolean.

- Default Value: false

- History: introduced in Bison 3.0.

%define api.token.prefix {*prefix*}   [Directive]

- Languages(s): all

- Purpose: Add a prefix to the token names when generating their definition in the target language. For instance

  ```
  %define api.token.prefix {TOK_}
  ```

```
%token FILE for ERROR
%%
start: FILE for ERROR;
```

generates the definition of the symbols `TOK_FILE`, `TOK_for`, and `TOK_ERROR` in the generated source files. In particular, the scanner must use these prefixed token names, while the grammar itself may still use the short names (as in the sample rule given above). The generated informational files (`*.output`, `*.xml`, `*.gv`) are not modified by this prefix.

Bison also prefixes the generated member names of the semantic value union. See Section 3.4.3 [Generating the Semantic Value Type], page 57, for more details.

See Section 10.1.8.3 [++ Parser-title⟨undefined⟩], page 183, and Section 10.1.8.4 [++ Scanner-title⟨undefined⟩], page 185, for a complete example.

- Accepted Values: Any string. Must be a valid identifier prefix in the target language (typically, a possibly empty sequence of letters, underscores, and —not at the beginning— digits).

- Default Value: empty

- History: introduced in Bison 3.0.

%define api.token.raw   [Directive]
- Language(s): all

- Purpose: The output files normally define the enumeration of the *token kinds* with Yacc-compatible token codes: sequential numbers starting at 257 except for single character tokens which stand for themselves (e.g., in ASCII, ``'a''` is numbered 65). The parser however uses *symbol kinds* which are assigned numbers sequentially starting at 0. Therefore each time the scanner returns an (external) token kind, it must be mapped to the (internal) symbol kind.

  When `api.token.raw` is set, the code of the token kinds are forced to coincide with the symbol kind. This saves one table lookup per token to map them from the token kind to the symbol kind, and also saves the generation of the mapping table. The gain is typically moderate, but in extreme cases (very simple user actions), a 10% improvement can be observed.

  When `api.token.raw` is set, the grammar cannot use character literals (such as ``'a''`).

- Accepted Values: Boolean.

- Default Value: `false`

- History: introduced in Bison 3.5. Was initially introduced in Bison 1.25 as '`%raw`', but never worked and was removed in Bison 1.29.

%define api.value.automove   [Directive]
- Language(s): C++

- Purpose: Let occurrences of semantic values of the right-hand sides of a rule be implicitly turned in rvalues. When enabled, a grammar such as:

```
exp:
  "number"        { $$ = make_number ($1); }
```

```
              | exp "+" exp  { $$ = make_binary (add, $1, $3); }
              | "(" exp ")"  { $$ = $2; }
```
is actually compiled as if you had written:
```
        exp:
          "number"      { $$ = make_number (std::move ($1)); }
        | exp "+" exp  { $$ = make_binary (add,
                                           std::move ($1),
                                           std::move ($3)); }
        | "(" exp ")"  { $$ = std::move ($2); }
```
Using a value several times with automove enabled is typically an error. For instance, instead of:
```
        exp: "twice" exp  { $$ = make_binary (add, $2, $2); }
```
write:
```
        exp: "twice" exp { auto v = $2; $$ = make_binary (add, v, v); }
```
It is tempting to use `std::move` on one of the v, but the argument evaluation order in C++ is unspecified.

- Accepted Values: Boolean.
- Default Value: `false`
- History: introduced in Bison 3.2

`%define api.value.type` *support*   [Directive]
`%define api.value.type {type}`   [Directive]
- Language(s): all
- Purpose: The type for semantic values.
- Accepted Values:

  '`{}`'   This grammar has no semantic value at all. This is not properly
               supported yet.

  '`union-directive`' (C, C++)
               The type is defined thanks to the `%union` directive. You don't have
               to define `api.value.type` in that case, using `%union` suffices. See
               Section 3.4.4 [The Union Declaration], page 58. For instance:
```
                    %define api.value.type union-directive
                    %union
                    {
                      int ival;
                      char *sval;
                    }
                    %token <ival> INT "integer"
                    %token <sval> STR "string"
```
  '`union`' (C, C++)
               The symbols are defined with type names, from which Bison will
               generate a `union`. For instance:
```
                    %define api.value.type union
```

```
%token <int> INT "integer"
%token <char *> STR "string"
```

Most C++ objects cannot be stored in a `union`, use '`variant`' instead.

'variant' (C++)

This is similar to `union`, but special storage techniques are used to allow any kind of C++ object to be used. For instance:

```
%define api.value.type variant
%token <int> INT "integer"
%token <std::string> STR "string"
```

See Section 10.1.4.2 [++ Variants-title⟨undefined⟩], page 171.

'{*type*}'   Use this *type* as semantic value.

```
%code requires
{
  struct my_value
  {
    enum
    {
      is_int, is_str
    } kind;
    union
    {
      int ival;
      char *sval;
    } u;
  };
}
%define api.value.type {struct my_value}
%token <u.ival> INT "integer"
%token <u.sval> STR "string"
```

- Default Value:
  - `union-directive` if `%union` is used, otherwise . . .
  - `int` if type tags are used (i.e., '`%token <type>`. . .' or '`%nterm <type>`. . .' is used), otherwise . . .
  - undefined.
- History: introduced in Bison 3.0. Was introduced for Java only in 2.3b as `stype`.

`%define api.value.union.name` *name*   [Directive]
- Language(s): C
- Purpose: The tag of the generated `union` (*not* the name of the `typedef`). This variable is set to `id` when '`%union id`' is used. There is no clear reason to give this union a name.
- Accepted Values: Any valid identifier.
- Default Value: `YYSTYPE`.
- History: Introduced in Bison 3.0.3.

%define lr.default-reduction *when*   [Directive]

- Language(s): all

- Purpose: Specify the kind of states that are permitted to contain default reductions. See Section 5.8.2 [Default Reductions], page 124.

- Accepted Values: `most`, `consistent`, `accepting`

- Default Value:

    - `accepting` if `lr.type` is `canonical-lr`.

    - `most` otherwise.

- History: introduced as `lr.default-reductions` in 2.5, renamed as `lr.default-reduction` in 3.0.

%define lr.keep-unreachable-state   [Directive]

- Language(s): all

- Purpose: Request that Bison allow unreachable parser states to remain in the parser tables. See Section 5.8.4 [Unreachable States], page 127.

- Accepted Values: Boolean

- Default Value: `false`

- History: introduced as `lr.keep_unreachable_states` in 2.3b, renamed as `lr.keep-unreachable-states` in 2.5, and as `lr.keep-unreachable-state` in 3.0.

%define lr.type *type*   [Directive]

- Language(s): all

- Purpose: Specify the type of parser tables within the LR(1) family. See Section 5.8.1 [LR Table Construction], page 122.

- Accepted Values: `lalr`, `ielr`, `canonical-lr`

- Default Value: `lalr`

%define *namespace* {*namespace*}   [Directive]

   Obsoleted by `api.namespace`

%define parse.assert   [Directive]

- Languages(s): C, C++

- Purpose: Issue runtime assertions to catch invalid uses. In C, some important invariants in the implementation of the parser are checked when this option is enabled.

   In C++, when variants are used (see Section 10.1.4.2 [++ Variants-title⟨undefined⟩], page 171), symbols must be constructed and destroyed properly. This option checks these constraints using runtime type information (RTTI). Therefore the generated code cannot be compiled with RTTI disabled (via compiler options such as `-fno-rtti`).

- Accepted Values: Boolean

- Default Value: `false`

%define parse.error *verbosity*   [Directive]
- Languages(s): all
- Purpose: Control the generation of syntax error messages. See Section 4.4 [Error Reporting], page 104.
- Accepted Values:
  - `simple` Error messages passed to `yyerror` are simply `"syntax error"`.
  - `detailed` Error messages report the unexpected token, and possibly the expected ones. However, this report can often be incorrect when LAC is not enabled (see Section 5.8.3 [LAC], page 125). Token name internationalization is supported.
  - `verbose` Similar (but inferior) to `detailed`.

    Error messages report the unexpected token, and possibly the expected ones. However, this report can often be incorrect when LAC is not enabled (see Section 5.8.3 [LAC], page 125).

    Does not support token internationalization. Using non-ASCII characters in token aliases is not portable.
  - `custom` The user is in charge of generating the syntax error message by defining the `yyreport_syntax_error` function. See Section 4.4.2 [The Syntax Error Reporting Function `yyreport_syntax_error`], page 105.
- Default Value: `simple`
- History: introduced in 3.0 with support for `simple` and `verbose`. Values `custom` and `detailed` were introduced in 3.6.

%define parse.lac *when*   [Directive]
- Languages(s): C (deterministic parsers only)
- Purpose: Enable LAC (lookahead correction) to improve syntax error handling. See Section 5.8.3 [LAC], page 125.
- Accepted Values: `none`, `full`
- Default Value: `none`

%define parse.trace   [Directive]
- Languages(s): C, C++, Java
- Purpose: Require parser instrumentation for tracing. See Section 8.5 [Tracing Your Parser], page 148.

  In C/C++, define the macro `YYDEBUG` (or *prefix*`DEBUG` with '`%define api.prefix {`*prefix*`}`'), see Section 3.8 [Multiple Parsers in the Same Program], page 95) to 1 in the parser implementation file if it is not already defined, so that the debugging facilities are compiled.
- Accepted Values: Boolean
- Default Value: `false`

%define *parser_class_name* {*name*}   [Directive]
    Obsoleted by `api.parser.class`

3.7.15 %code Summary

The `%code` directive inserts code verbatim into the output parser source at any of a pre-defined set of locations. It thus serves as a flexible and user-friendly alternative to the traditional Yacc prologue, `%{code%}`. This section summarizes the functionality of `%code` for the various target languages supported by Bison. For a detailed discussion of how to use `%code` in place of `%{code%}` for C/C++ and why it is advantageous to do so, see Section 3.1.2 [Prologue Alternatives], page 47.

`%code {code}`   [Directive]

> This is the unqualified form of the `%code` directive. It inserts *code* verbatim at a language-dependent default location in the parser implementation.
>
> For C/C++, the default location is the parser implementation file after the usual contents of the parser header file. Thus, the unqualified form replaces `%{code%}` for most purposes.
>
> For Java, the default location is inside the parser class.

`%code qualifier {code}`   [Directive]

> This is the qualified form of the `%code` directive. *qualifier* identifies the purpose of *code* and thus the location(s) where Bison should insert it. That is, if you need to specify location-sensitive *code* that does not belong at the default location selected by the unqualified `%code` form, use this form instead.

For any particular qualifier or for the unqualified form, if there are multiple occurrences of the `%code` directive, Bison concatenates the specified code in the order in which it appears in the grammar file.

Not all qualifiers are accepted for all target languages. Unaccepted qualifiers produce an error. Some of the accepted qualifiers are:

`requires`

> - Language(s): C, C++
> - Purpose: This is the best place to write dependency code required for `YYSTYPE` and `YYLTYPE`. In other words, it's the best place to define types referenced in `%union` directives. If you use `#define` to override Bison's default `YYSTYPE` and `YYLTYPE` definitions, then it is also the best place. However you should rather `%define api.value.type` and `api.location.type`.
> - Location(s): The parser header file and the parser implementation file before the Bison-generated `YYSTYPE` and `YYLTYPE` definitions.

`provides`

> - Language(s): C, C++
> - Purpose: This is the best place to write additional definitions and declarations that should be provided to other modules.
> - Location(s): The parser header file and the parser implementation file after the Bison-generated `YYSTYPE`, `YYLTYPE`, and token definitions.

`top`

> - Language(s): C, C++

- Purpose: The unqualified `%code` or `%code requires` should usually be more appropriate than `%code top`. However, occasionally it is necessary to insert code much nearer the top of the parser implementation file. For example:

  ```
  %code top {
    #define _GNU_SOURCE
    #include <stdio.h>
  }
  ```

- Location(s): Near the top of the parser implementation file.

imports

- Language(s): Java
- Purpose: This is the best place to write Java import directives.
- Location(s): The parser Java file after any Java package directive and before any class definitions.

Though we say the insertion locations are language-dependent, they are technically skeleton-dependent. Writers of non-standard skeletons however should choose their locations consistently with the behavior of the standard Bison skeletons.

3.8 Multiple Parsers in the Same Program

Most programs that use Bison parse only one language and therefore contain only one Bison parser. But what if you want to parse more than one language with the same program? Then you need to avoid name conflicts between different definitions of functions and variables such as `yyparse`, `yylval`. To use different parsers from the same compilation unit, you also need to avoid conflicts on types and macros (e.g., `YYSTYPE`) exported in the generated header.

The easy way to do this is to define the `%define` variable `api.prefix`. With different `api.prefix`s it is guaranteed that headers do not conflict when included together, and that compiled objects can be linked together too. Specifying '`%define api.prefix {prefix}`' (or passing the option `-Dapi.prefix={prefix}`, see Chapter 9 [Invoking Bison], page 154) renames the interface functions and variables of the Bison parser to start with *prefix* instead of 'yy', and all the macros to start by *PREFIX* (i.e., *prefix* upper-cased) instead of 'YY'.

The renamed symbols include `yyparse`, `yylex`, `yyerror`, `yynerrs`, `yylval`, `yylloc`, `yychar` and `yydebug`. If you use a push parser, `yypush_parse`, `yypull_parse`, `yypstate`, `yypstate_new` and `yypstate_delete` will also be renamed. The renamed macros include `YYSTYPE`, `YYLTYPE`, and `YYDEBUG`, which is treated specifically — more about this below.

For example, if you use '`%define api.prefix {c}`', the names become `cparse`, `clex`, . . ., `CSTYPE`, `CLTYPE`, and so on.

Users of Flex must update the signature of the generated `yylex` function. Since the Flex scanner usually includes the generated header of the parser (to get the definitions of the tokens, etc.), the most convenient way is to insert the declaration of `yylex` in the `provides` section:

```
%define api.prefix {c}
// Emitted in the header file, after the definition of YYSTYPE.
%code provides
{
```

```
  // Tell Flex the expected prototype of yylex.
  #define YY_DECL                              \
    int clex (CSTYPE *yylval, CLTYPE *yylloc)

  // Declare the scanner.
  YY_DECL;
}
```

The `%define` variable `api.prefix` works in two different ways. In the implementation
file, it works by adding macro definitions to the beginning of the parser implementation file,
defining `yyparse` as *prefix*`parse`, and so on:

```
#define YYSTYPE CTYPE
#define yyparse cparse
#define yylval  clval
...
YYSTYPE yylval;
int yyparse (void);
```

This effectively substitutes one name for the other in the entire parser implementation
file, thus the "original" names (`yylex`, `YYSTYPE`, . . .) are also usable in the parser imple-
mentation file.

However, in the parser header file, the symbols are defined renamed, for instance:

```
extern CSTYPE clval;
int cparse (void);
```

The macro `YYDEBUG` is commonly used to enable the tracing support in parsers. To
comply with this tradition, when `api.prefix` is used, `YYDEBUG` (not renamed) is used as a
default value:

```
/* Debug traces. */
#ifndef CDEBUG
# if defined YYDEBUG
#  if YYDEBUG
#   define CDEBUG 1
#  else
#   define CDEBUG 0
#  endif
# else
#  define CDEBUG 0
# endif
#endif
#if CDEBUG
extern int cdebug;
#endif
```

Prior to Bison 2.6, a feature similar to `api.prefix` was provided by the obsolete directive `%name-prefix` (see Appendix A [Bison Symbols], page 208) and the option `--name-prefix` (see Section 9.1.4 [Output Files], page 162).

4 Parser C-Language Interface

The Bison parser is actually a C function named `yyparse`. Here we describe the interface conventions of `yyparse` and the other functions that it needs to use.

Keep in mind that the parser uses many C identifiers starting with 'yy' and 'YY' for internal purposes. If you use such an identifier (aside from those in this manual) in an action or in epilogue in the grammar file, you are likely to run into trouble.

4.1 The Parser Function `yyparse`

You call the function `yyparse` to cause parsing to occur. This function reads tokens, executes actions, and ultimately returns when it encounters end-of-input or an unrecoverable syntax error. You can also write an action which directs `yyparse` to return immediately without reading further.

`int yyparse (void)` [Function]
> The value returned by `yyparse` is 0 if parsing was successful (return is due to end-of-input).
>
> The value is 1 if parsing failed because of invalid input, i.e., input that contains a syntax error or that causes `YYABORT` to be invoked.
>
> The value is 2 if parsing failed due to memory exhaustion.

In an action, you can cause immediate return from `yyparse` by using these macros:

`YYACCEPT` [Macro]
> Return immediately with value 0 (to report success).

`YYABORT` [Macro]
> Return immediately with value 1 (to report failure).

If you use a reentrant parser, you can optionally pass additional parameter information to it in a reentrant way. To do so, use the declaration `%parse-param`:

`%parse-param {argument-declaration} ...` [Directive]
> Declare that one or more *argument-declaration* are additional `yyparse` arguments. The *argument-declaration* is used when declaring functions or prototypes. The last identifier in *argument-declaration* must be the argument name.

Here's an example. Write this in the parser:

```
%parse-param {int *nastiness} {int *randomness}
```

Then call the parser like this:

```
{
  int nastiness, randomness;
  ...  /* Store proper data in nastiness and randomness. */
  value = yyparse (&nastiness, &randomness);
  ...
}
```

In the grammar actions, use expressions like this to refer to the data:

```
exp: ...     { ...; *randomness += 1; ... }
```

Using the following:

```
%parse-param {int *randomness}
```

Results in these signatures:

```
void yyerror (int *randomness, const char *msg);
int  yyparse (int *randomness);
```

Or, if both `%define api.pure full` (or just `%define api.pure`) and `%locations` are used:

```
void yyerror (YYLTYPE *llocp, int *randomness, const char *msg);
int  yyparse (int *randomness);
```

4.2 Push Parser Interface

You call the function `yypstate_new` to create a new parser instance. This function is available if either the '`%define api.push-pull push`' or '`%define api.push-pull both`' declaration is used. See Section 3.7.12 [A Push Parser], page 78.

`yypstate* yypstate_new (void)`   [Function]
> Return a valid parser instance if there is memory available, 0 otherwise. In impure mode, it will also return 0 if a parser instance is currently allocated.

You call the function `yypstate_delete` to delete a parser instance. function is available if either the '`%define api.push-pull push`' or '`%define api.push-pull both`' declaration is used. See Section 3.7.12 [A Push Parser], page 78.

`void yypstate_delete (yypstate *yyps)`   [Function]
> Reclaim the memory associated with a parser instance. After this call, you should no longer attempt to use the parser instance.

You call the function `yypush_parse` to parse a single token. This function is available if either the '`%define api.push-pull push`' or '`%define api.push-pull both`' declaration is used. See Section 3.7.12 [A Push Parser], page 78.

`int yypush_parse (yypstate *yyps)`   [Function]
> The value returned by `yypush_parse` is the same as for `yyparse` with the following exception: it returns `YYPUSH_MORE` if more input is required to finish parsing the grammar.
>
> After `yypush_parse` returned, the instance may be consulted. For instance check `yynerrs` to see whether there were (possibly recovered) syntax errors.
>
> After `yypush_parse` returns a status other than `YYPUSH_MORE`, the parser instance `yyps` may be reused for a new parse.

The fact that the parser state is reusable even after an error simplifies reuse. For example, a calculator application which parses each input line as an expression can just keep reusing the same `yyps` even if an input was invalid.

You call the function `yypull_parse` to parse the rest of the input stream. This function is available if the '`%define api.push-pull both`' declaration is used. See Section 3.7.12 [A Push Parser], page 78.

`int yypull_parse (yypstate *yyps)`   [Function]
>   The value returned by `yypull_parse` is the same as for `yyparse`.

>   The parser instance `yyps` may be reused for new parses.

`int yypstate_expected_tokens (const yypstate *yyps,`   [Function]
>   `yysymbol_kind_t argv[], int argc)`
>   Fill *argv* with the expected tokens, which never includes `YYSYMBOL_YYEMPTY`,
>   `YYSYMBOL_YYerror`, or `YYSYMBOL_YYUNDEF`.

>   Never put more than *argc* elements into *argv*, and on success return the number of
>   tokens stored in *argv*. If there are more expected tokens than *argc*, fill *argv* up to
>   *argc* and return 0. If there are no expected tokens, also return 0, but set `argv[0]` to
>   `YYSYMBOL_YYEMPTY`.

>   When LAC is enabled, may return a negative number on errors, such as `YYENOMEM` on
>   memory exhaustion.

>   If *argv* is null, return the size needed to store all the possible values, which is always
>   less than `YYNTOKENS`.

4.3 The Lexical Analyzer Function `yylex`

The *lexical analyzer* function, `yylex`, recognizes tokens from the input stream and returns
them to the parser. Bison does not create this function automatically; you must write it so
that `yyparse` can call it. The function is sometimes referred to as a lexical scanner.

In simple programs, `yylex` is often defined at the end of the Bison grammar file. If
`yylex` is defined in a separate source file, you need to arrange for the token-kind definitions
to be available there. To do this, use the `-d` option when you run Bison, so that it will write
these definitions into the separate parser header file, `name.tab.h`, which you can include in
the other source files that need it. See Chapter 9 [Invoking Bison], page 154.

4.3.1 Calling Convention for `yylex`

The value that `yylex` returns must be the positive numeric code for the kind of token it
has just found; a zero or negative value signifies end-of-input.

When a token kind is referred to in the grammar rules by a name, that name in the parser
implementation file becomes an enumerator of the enum `yytoken_kind_t` whose definition
is the proper numeric code for that token kind. So `yylex` should use the name to indicate
that type. See Section 3.2 [Symbols, Terminal and Nonterminal], page 52.

When a token is referred to in the grammar rules by a character literal, the numeric
code for that character is also the code for the token kind. So `yylex` can simply return
that character code, possibly converted to `unsigned char` to avoid sign-extension. The null
character must not be used this way, because its code is zero and that signifies end-of-input.

Here is an example showing these things:

```
int
yylex (void)
{
  ...
  if (c == EOF)     /* Detect end-of-input. */
```

```
      return YYEOF;
    ...
    else if (c == '+' || c == '-')
      return c;        /* Assume token kind for '+' is '+'. */
    ...
    else
      return INT;    /* Return the kind of the token. */
    ...
  }
```

This interface has been designed so that the output from the `lex` utility can be used without change as the definition of `yylex`.

4.3.2 Special Tokens

In addition to the user defined tokens, Bison generates a few special tokens that `yylex` may return.

The `YYEOF` token denotes the end of file, and signals to the parser that there is nothing left afterwards. See Section 4.3.1 [Calling Convention for `yylex`], page 100, for an example.

Returning `YYUNDEF` tells the parser that some lexical error was found. It will emit an error message about an "invalid token", and enter error-recovery (see Chapter 6 [Error Recovery], page 130). Returning an unknown token kind results in the exact same behavior.

Returning `YYerror` requires the parser to enter error-recovery *without* emitting an error message. This way the lexical analyzer can produce an accurate error messages about the invalid input (something the parser cannot do), and yet benefit from the error-recovery features of the parser.

```
    int
    yylex (void)
    {
      ...
      switch (c)
        {
          ...
          case '0': case '1': case '2': case '3': case '4':
          case '5': case '6': case '7': case '8': case '9':
            ...
            return TOK_NUM;
          ...
          case EOF:
            return YYEOF;
          default:
            yyerror ("syntax error: invalid character: %c", c);
            return YYerror;
        }
    }
```

4.3.3 Finding Tokens by String Literals

If the grammar uses literal string tokens, there are two ways that `yylex` can determine the token kind codes for them:

- If the grammar defines symbolic token names as aliases for the literal string tokens, `yylex` can use these symbolic names like all others. In this case, the use of the literal string tokens in the grammar file has no effect on `yylex`.

  This is the preferred approach.

- `yylex` can search for the multicharacter token in the `yytname` table. This method is discouraged: the primary purpose of string aliases is forging good error messages, not describing the spelling of keywords. In addition, looking for the token kind at runtime incurs a (small but noticeable) cost.

  The `yytname` table is generated only if you use the `%token-table` declaration. See Section 3.7.13 [Bison Declaration Summary], page 79.

4.3.4 Semantic Values of Tokens

In an ordinary (nonreentrant) parser, the semantic value of the token must be stored into the global variable `yylval`. When you are using just one data type for semantic values, `yylval` has that type. Thus, if the type is `int` (the default), you might write this in `yylex`:

```
...
yylval = value;  /* Put value onto Bison stack. */
return INT;      /* Return the kind of the token. */
...
```

When you are using multiple data types, `yylval`'s type is a union made from the `%union` declaration (see Section 3.4.4 [The Union Declaration], page 58). So when you store a token's value, you must use the proper member of the union. If the `%union` declaration looks like this:

```
%union {
  int intval;
  double val;
  symrec *tptr;
}
```

then the code in `yylex` might look like this:

```
...
yylval.intval = value; /* Put value onto Bison stack. */
return INT;            /* Return the kind of the token. */
...
```

4.3.5 Textual Locations of Tokens

If you are using the '`@n`'-feature (see Section 3.5 [Tracking Locations], page 66) in actions to keep track of the textual locations of tokens and groupings, then you must provide this information in `yylex`. The function `yyparse` expects to find the textual location of a token just parsed in the global variable `yylloc`. So `yylex` must store the proper data in that variable.

By default, the value of `yylloc` is a structure and you need only initialize the members that are going to be used by the actions. The four members are called `first_line`, `first_column`, `last_line` and `last_column`. Note that the use of this feature makes the parser noticeably slower.

The data type of `yylloc` has the name `YYLTYPE`.

4.3.6 Calling Conventions for Pure Parsers

When you use the Bison declaration `%define api.pure full` to request a pure, reentrant parser, the global communication variables `yylval` and `yylloc` cannot be used. (See Section 3.7.11 [A Pure (Reentrant) Parser], page 77.) In such parsers the two global variables are replaced by pointers passed as arguments to `yylex`. You must declare them as shown here, and pass the information back by storing it through those pointers.

```
int
yylex (YYSTYPE *lvalp, YYLTYPE *llocp)
{
  ...
  *lvalp = value;  /* Put value onto Bison stack. */
  return INT;      /* Return the kind of the token. */
  ...
}
```

If the grammar file does not use the '`@`' constructs to refer to textual locations, then the type `YYLTYPE` will not be defined. In this case, omit the second argument; `yylex` will be called with only one argument.

If you wish to pass additional arguments to `yylex`, use `%lex-param` just like `%parse-param` (see Section 4.1 [The Parser Function `yyparse`], page 98). To pass additional arguments to both `yylex` and `yyparse`, use `%param`.

`%lex-param {`*argument-declaration*`} ...`   [Directive]
    Specify that *argument-declaration* are additional `yylex` argument declarations. You may pass one or more such declarations, which is equivalent to repeating `%lex-param`.

`%param {`*argument-declaration*`} ...`   [Directive]
    Specify that *argument-declaration* are additional `yylex`/`yyparse` argument declaration. This is equivalent to '`%lex-param {`*argument-declaration*`} ...` `%parse-param {`*argument-declaration*`} ...`'. You may pass one or more declarations, which is equivalent to repeating `%param`.

For instance:

```
%lex-param   {scanner_mode *mode}
%parse-param {parser_mode *mode}
%param       {environment_type *env}
```

results in the following signatures:

```
int yylex  (scanner_mode *mode, environment_type *env);
int yyparse (parser_mode *mode, environment_type *env);
```

If '`%define api.pure full`' is added:

```
int yylex  (YYSTYPE *lvalp, scanner_mode *mode, environment_type *env);
```

```
    int yyparse (parser_mode *mode, environment_type *env);
```
and finally, if both '`%define api.pure full`' and `%locations` are used:
```
    int yylex    (YYSTYPE *lvalp, YYLTYPE *llocp,
                  scanner_mode *mode, environment_type *env);
    int yyparse (parser_mode *mode, environment_type *env);
```

4.4 Error Reporting

During its execution the parser may have error messages to pass to the user, such as syntax error, or memory exhaustion. How this message is delivered to the user must be specified by the developer.

4.4.1 The Error Reporting Function `yyerror`

The Bison parser detects a *syntax error* (or *parse error*) whenever it reads a token which cannot satisfy any syntax rule. An action in the grammar can also explicitly proclaim an error, using the macro `YYERROR` (see Section 4.5 [Special Features for Use in Actions], page 107).

The Bison parser expects to report the error by calling an error reporting function named `yyerror`, which you must supply. It is called by `yyparse` whenever a syntax error is found, and it receives one argument. For a syntax error, the string is normally `"syntax error"`.

If you invoke '`%define parse.error detailed`' (or '`custom`') in the Bison declarations section (see Section 3.1.3 [The Bison Declarations Section], page 51), then Bison provides a more verbose and specific error message string instead of just plain `"syntax error"`. However, that message sometimes contains incorrect information if LAC is not enabled (see Section 5.8.3 [LAC], page 125).

The parser can detect one other kind of error: memory exhaustion. This can happen when the input contains constructions that are very deeply nested. It isn't likely you will encounter this, since the Bison parser normally extends its stack automatically up to a very large limit. But if memory is exhausted, `yyparse` calls `yyerror` in the usual fashion, except that the argument string is `"memory exhausted"`.

In some cases diagnostics like `"syntax error"` are translated automatically from English to some other language before they are passed to `yyerror`. See Section 4.6 [Parser Internationalization], page 109.

The following definition suffices in simple programs:
```
    void
    yyerror (char const *s)
    {
      fprintf (stderr, "%s\n", s);
    }
```

After `yyerror` returns to `yyparse`, the latter will attempt error recovery if you have written suitable error recovery grammar rules (see Chapter 6 [Error Recovery], page 130). If recovery is impossible, `yyparse` will immediately return 1.

Obviously, in location tracking pure parsers, `yyerror` should have an access to the current location. With `%define api.pure`, this is indeed the case for the GLR parsers, but

not for the Yacc parser, for historical reasons, and this is the why `%define api.pure full` should be preferred over `%define api.pure`.

When `%locations %define api.pure full` is used, `yyerror` has the following signature:

```
void yyerror (YYLTYPE *locp, char const *msg);
```

The prototypes are only indications of how the code produced by Bison uses `yyerror`. Bison-generated code always ignores the returned value, so `yyerror` can return any type, including `void`. Also, `yyerror` can be a variadic function; that is why the message is always passed last.

Traditionally `yyerror` returns an `int` that is always ignored, but this is purely for historical reasons, and `void` is preferable since it more accurately describes the return type for `yyerror`.

The variable `yynerrs` contains the number of syntax errors reported so far. Normally this variable is global; but if you request a pure parser (see Section 3.7.11 [A Pure (Reentrant) Parser], page 77) then it is a local variable which only the actions can access.

4.4.2 The Syntax Error Reporting Function `yyreport_syntax_error`

If you invoke '`%define parse.error custom`' (see Section 3.1.3 [The Bison Declarations Section], page 51), then the parser no longer passes syntax error messages to `yyerror`, rather it delegates that task to the user by calling the `yyreport_syntax_error` function.

The following functions and types are "`static`": they are defined in the implementation file (`*.c`) and available only from there. They are meant to be used from the grammar's epilogue.

`static int yyreport_syntax_error (const yypcontext_t *ctx)`   [Function]
>   Report a syntax error to the user. Return 0 on success, `YYENOMEM` on memory exhaustion. Whether it uses `yyerror` is up to the user.

Use the following types and functions to build the error message.

`yypcontext_t`   [Type]
>   An opaque type that captures the circumstances of the syntax error.

`yysymbol_kind_t`   [Type]
>   An enum of all the grammar symbols, tokens and nonterminals. Its enumerators are forged from the symbol names:

```
enum yysymbol_kind_t
{
  YYSYMBOL_YYEMPTY = -2,     /* No symbol.  */
  YYSYMBOL_YYEOF = 0,        /* "end of file"  */
  YYSYMBOL_YYerror = 1,      /* error  */
  YYSYMBOL_YYUNDEF = 2,      /* "invalid token"  */
  YYSYMBOL_PLUS = 3,         /* "+"  */
  YYSYMBOL_MINUS = 4,        /* "-"  */
  [...]
  YYSYMBOL_VAR = 14,         /* "variable"  */
  YYSYMBOL_NEG = 15,         /* NEG  */
```

```
            YYSYMBOL_YYACCEPT = 16,      /* $accept  */
            YYSYMBOL_exp = 17,           /* exp  */
            YYSYMBOL_input = 18          /* input  */
          };
          typedef enum yysymbol_kind_t yysymbol_kind_t;
```

static yysymbol_kind_t yypcontext_token (const yypcontext_t   [Function]
        *ctx)
    The "unexpected" token: the symbol kind of the lookahead token that caused the
    syntax error. Returns `YYSYMBOL_YYEMPTY` if there is no lookahead.

static YYLTYPE * yypcontext_location (const yypcontext_t   [Function]
        *ctx)
    The location of the syntax error (that of the unexpected token).

static int yypcontext_expected_tokens (const yypcontext_t   [Function]
        *ctx, yysymbol_kind_t argv[], int argc)
    Fill *argv* with the expected tokens, which never includes `YYSYMBOL_YYEMPTY`,
    `YYSYMBOL_YYerror`, or `YYSYMBOL_YYUNDEF`.

    Never put more than *argc* elements into *argv*, and on success return the number of
    tokens stored in *argv*. If there are more expected tokens than *argc*, fill *argv* up to
    argc and return 0. If there are no expected tokens, also return 0, but set `argv[0]` to
    `YYSYMBOL_YYEMPTY`.

    When LAC is enabled, may return a negative number on errors, such as `YYENOMEM` on
    memory exhaustion.

    If *argv* is null, return the size needed to store all the possible values, which is always
    less than `YYNTOKENS`.

static const char * yysymbol_name (symbol_kind_t *symbol*)   [Function]
    The name of the symbol whose kind is *symbol*, possibly translated.

    A custom syntax error function looks as follows. This implementation is inappropriate
for internationalization, see the `c/bistromathic` example for a better alternative.

```
static int
yyreport_syntax_error (const yypcontext_t *ctx)
{
  int res = 0;
  YY_LOCATION_PRINT (stderr, *yypcontext_location (ctx));
  fprintf (stderr, ": syntax error");
  // Report the tokens expected at this point.
  {
    enum { TOKENMAX = 5 };
    yysymbol_kind_t expected[TOKENMAX];
    int n = yypcontext_expected_tokens (ctx, expected, TOKENMAX);
    if (n < 0)
      // Forward errors to yyparse.
      res = n;
    else
```

```
            for (int i = 0; i < n; ++i)
              fprintf (stderr, "%s %s",
                       i == 0 ? ": expected" : " or", yysymbol_name (expected[i]));
        }
        // Report the unexpected token.
        {
          yysymbol_kind_t lookahead = yypcontext_token (ctx);
          if (lookahead != YYSYMBOL_YYEMPTY)
            fprintf (stderr, " before %s", yysymbol_name (lookahead));
        }
        fprintf (stderr, "\n");
        return res;
      }
```

You still must provide a `yyerror` function, used for instance to report memory exhaustion.

4.5 Special Features for Use in Actions

Here is a table of Bison constructs, variables and macros that are useful in actions.

`$$`   [Variable]

   Acts like a variable that contains the semantic value for the grouping made by the
   current rule. See Section 3.4.6 [Actions], page 59.

`$n`   [Variable]

   Acts like a variable that contains the semantic value for the *n*th component of the
   current rule. See Section 3.4.6 [Actions], page 59.

`$<typealt>$`   [Variable]

   Like `$$` but specifies alternative *typealt* in the union specified by the `%union` decla-
   ration. See Section 3.4.7 [Data Types of Values in Actions], page 60.

`$<typealt>n`   [Variable]

   Like `$n` but specifies alternative *typealt* in the union specified by the `%union` decla-
   ration. See Section 3.4.7 [Data Types of Values in Actions], page 60.

`YYABORT ;`   [Macro]

   Return immediately from `yyparse`, indicating failure. See Section 4.1 [The Parser
   Function `yyparse`], page 98.

`YYACCEPT ;`   [Macro]

   Return immediately from `yyparse`, indicating success. See Section 4.1 [The Parser
   Function `yyparse`], page 98.

`YYBACKUP (token, value);`   [Macro]

   Unshift a token. This macro is allowed only for rules that reduce a single value, and
   only when there is no lookahead token. It is also disallowed in GLR parsers. It installs
   a lookahead token with token kind *token* and semantic value *value*; then it discards
   the value that was going to be reduced by this rule.

If the macro is used when it is not valid, such as when there is a lookahead token already, then it reports a syntax error with a message 'cannot back up' and performs ordinary error recovery.

In either case, the rest of the action is not executed.

YYEMPTY   [Value]

Value stored in `yychar` when there is no lookahead token.

YYEOF   [Value]

Value stored in `yychar` when the lookahead is the end of the input stream.

YYERROR ;   [Macro]

Cause an immediate syntax error. This statement initiates error recovery just as if the parser itself had detected an error; however, it does not call `yyerror`, and does not print any message. If you want to print an error message, call `yyerror` explicitly before the 'YYERROR;' statement. See Chapter 6 [Error Recovery], page 130.

YYRECOVERING   [Macro]

The expression `YYRECOVERING ()` yields 1 when the parser is recovering from a syntax error, and 0 otherwise. See Chapter 6 [Error Recovery], page 130.

yychar   [Variable]

Variable containing either the lookahead token, or `YYEOF` when the lookahead is the end of the input stream, or `YYEMPTY` when no lookahead has been performed so the next token is not yet known. Do not modify `yychar` in a deferred semantic action (see Section 1.5.3 [GLR Semantic Actions], page 22). See Section 5.1 [Lookahead Tokens], page 111.

yyclearin ;   [Macro]

Discard the current lookahead token. This is useful primarily in error rules. Do not invoke `yyclearin` in a deferred semantic action (see Section 1.5.3 [GLR Semantic Actions], page 22). See Chapter 6 [Error Recovery], page 130.

yyerrok ;   [Macro]

Resume generating error messages immediately for subsequent syntax errors. This is useful primarily in error rules. See Chapter 6 [Error Recovery], page 130.

yylloc   [Variable]

Variable containing the lookahead token location when `yychar` is not set to `YYEMPTY` or `YYEOF`. Do not modify `yylloc` in a deferred semantic action (see Section 1.5.3 [GLR Semantic Actions], page 22). See Section 3.5.2 [Actions and Locations], page 66.

yylval   [Variable]

Variable containing the lookahead token semantic value when `yychar` is not set to `YYEMPTY` or `YYEOF`. Do not modify `yylval` in a deferred semantic action (see Section 1.5.3 [GLR Semantic Actions], page 22). See Section 3.4.6 [Actions], page 59.

@$ [Value]

Acts like a structure variable containing information on the textual location of the grouping made by the current rule. See Section 3.5 [Tracking Locations], page 66.

@n   [Value]

    Acts like a structure variable containing information on the textual location of the *n*th component of the current rule. See Section 3.5 [Tracking Locations], page 66.

4.6 Parser Internationalization

A Bison-generated parser can print diagnostics, including error and tracing messages. By default, they appear in English. However, Bison also supports outputting diagnostics in the user's native language. To make this work, the user should set the usual environment variables. See Section "The User's View" in *GNU* `gettext` *utilities*. For example, the shell command 'export LC_ALL=fr_CA.UTF-8' might set the user's locale to French Canadian using the UTF-8 encoding. The exact set of available locales depends on the user's installation.

4.6.1 Enabling Internationalization

The maintainer of a package that uses a Bison-generated parser enables the internationalization of the parser's output through the following steps. Here we assume a package that uses GNU Autoconf and GNU Automake.

1. Into the directory containing the GNU Autoconf macros used by the package —often called m4— copy the `bison-i18n.m4` file installed by Bison under 'share/aclocal/bison-i18n.m4' in Bison's installation directory. For example:

   ```
   cp /usr/local/share/aclocal/bison-i18n.m4 m4/bison-i18n.m4
   ```

2. In the top-level `configure.ac`, after the `AM_GNU_GETTEXT` invocation, add an invocation of `BISON_I18N`. This macro is defined in the file `bison-i18n.m4` that you copied earlier. It causes `configure` to find the value of the `BISON_LOCALEDIR` variable, and it defines the source-language symbol `YYENABLE_NLS` to enable translations in the Bison-generated parser.

3. In the `main` function of your program, designate the directory containing Bison's runtime message catalog, through a call to 'bindtextdomain' with domain name 'bison-runtime'. For example:

   ```
   bindtextdomain ("bison-runtime", BISON_LOCALEDIR);
   ```

   Typically this appears after any other call `bindtextdomain (PACKAGE, LOCALEDIR)` that your package already has. Here we rely on 'BISON_LOCALEDIR' to be defined as a string through the `Makefile`.

4. In the `Makefile.am` that controls the compilation of the `main` function, make 'BISON_LOCALEDIR' available as a C preprocessor macro, either in 'DEFS' or in 'AM_CPPFLAGS'. For example:

   ```
   DEFS = @DEFS@ -DBISON_LOCALEDIR='"$(BISON_LOCALEDIR)"'
   ```

   or:

   ```
   AM_CPPFLAGS = -DBISON_LOCALEDIR='"$(BISON_LOCALEDIR)"'
   ```

5. Finally, invoke the command `autoreconf` to generate the build infrastructure.

4.6.2 Token Internationalization

When the `%define` variable `parse.error` is set to `custom` or `detailed`, token aliases can be internationalized:

```
%token
    '\n'    _("end of line")
  <double>
    NUM     _("number")
  <symrec*>
    FUN     _("function")
    VAR     _("variable")
```

The remainder of the grammar may freely use either the token symbol (`FUN`) or its alias (`"function"`), but not with the internationalization marker (`_("function")`).

If at least one token alias is internationalized, then the generated parser will use both `N_` and `_`, that must be defined (see Section "The Programmer's View" in *GNU* `gettext` *utilities*). They are used only on string aliases marked for translation. In other words, even if your catalog features a translation for "function", then with

```
%token
  <symrec*>
    FUN       "function"
    VAR     _("variable")
```

"function" will appear untranslated in debug traces and error messages.

Unless defined by the user, the end-of-file token, `YYEOF`, is provided "end of file" as an alias. It is also internationalized if the user internationalized tokens. To map it to another string, use:

```
%token END 0 _("end of input")
```

5 The Bison Parser Algorithm

As Bison reads tokens, it pushes them onto a stack along with their semantic values. The stack is called the *parser stack*. Pushing a token is traditionally called *shifting*.

For example, suppose the infix calculator has read '`1 + 5 *`', with a '`3`' to come. The stack will have four elements, one for each token that was shifted.

But the stack does not always have an element for each token read. When the last n tokens and groupings shifted match the components of a grammar rule, they can be combined according to that rule. This is called *reduction*. Those tokens and groupings are replaced on the stack by a single grouping whose symbol is the result (left hand side) of that rule. Running the rule's action is part of the process of reduction, because this is what computes the semantic value of the resulting grouping.

For example, if the infix calculator's parser stack contains this:

```
1 + 5 * 3
```

and the next input token is a newline character, then the last three elements can be reduced to 15 via the rule:

```
expr: expr '*' expr;
```

Then the stack contains just these three elements:

```
1 + 15
```

At this point, another reduction can be made, resulting in the single value 16. Then the newline token can be shifted.

The parser tries, by shifts and reductions, to reduce the entire input down to a single grouping whose symbol is the grammar's start-symbol (see Section 1.1 [Languages and Context-Free Grammars], page 14).

This kind of parser is known in the literature as a bottom-up parser.

5.1 Lookahead Tokens

The Bison parser does *not* always reduce immediately as soon as the last n tokens and groupings match a rule. This is because such a simple strategy is inadequate to handle most languages. Instead, when a reduction is possible, the parser sometimes "looks ahead" at the next token in order to decide what to do.

When a token is read, it is not immediately shifted; first it becomes the *lookahead token*, which is not on the stack. Now the parser can perform one or more reductions of tokens and groupings on the stack, while the lookahead token remains off to the side. When no more reductions should take place, the lookahead token is shifted onto the stack. This does not mean that all possible reductions have been done; depending on the token kind of the lookahead token, some rules may choose to delay their application.

Here is a simple case where lookahead is needed. These three rules define expressions which contain binary addition operators and postfix unary factorial operators ('`!`'), and allow parentheses for grouping.

```
expr:
  term '+' expr
| term
;
```

```
term:
  '(' expr ')'
| term '!'
| "number"
;
```

Suppose that the tokens '1 + 2' have been read and shifted; what should be done? If the following token is ')', then the first three tokens must be reduced to form an `expr`. This is the only valid course, because shifting the ')' would produce a sequence of symbols `term ')'`, and no rule allows this.

If the following token is '!', then it must be shifted immediately so that '2 !' can be reduced to make a `term`. If instead the parser were to reduce before shifting, '1 + 2' would become an `expr`. It would then be impossible to shift the '!' because doing so would produce on the stack the sequence of symbols `expr '!'`. No rule allows that sequence.

The lookahead token is stored in the variable `yychar`. Its semantic value and location, if any, are stored in the variables `yylval` and `yylloc`. See Section 4.5 [Special Features for Use in Actions], page 107.

5.2 Shift/Reduce Conflicts

Suppose we are parsing a language which has if-then and if-then-else statements, with a pair of rules like this:

```
if_stmt:
  "if" expr "then" stmt
| "if" expr "then" stmt "else" stmt
;
```

Here `"if"`, `"then"` and `"else"` are terminal symbols for specific keyword tokens.

When the `"else"` token is read and becomes the lookahead token, the contents of the stack (assuming the input is valid) are just right for reduction by the first rule. But it is also legitimate to shift the `"else"`, because that would lead to eventual reduction by the second rule.

This situation, where either a shift or a reduction would be valid, is called a *shift/reduce conflict*. Bison is designed to resolve these conflicts by choosing to shift, unless otherwise directed by operator precedence declarations. To see the reason for this, let's contrast it with the other alternative.

Since the parser prefers to shift the `"else"`, the result is to attach the else-clause to the innermost if-statement, making these two inputs equivalent:

```
if x then if y then win; else lose;

if x then do; if y then win; else lose; end;
```

But if the parser chose to reduce when possible rather than shift, the result would be to attach the else-clause to the outermost if-statement, making these two inputs equivalent:

```
if x then if y then win; else lose;

if x then do; if y then win; end; else lose;
```

The conflict exists because the grammar as written is ambiguous: either parsing of the simple nested if-statement is legitimate. The established convention is that these ambiguities are resolved by attaching the else-clause to the innermost if-statement; this is what Bison accomplishes by choosing to shift rather than reduce. (It would ideally be cleaner to write an unambiguous grammar, but that is very hard to do in this case.) This particular ambiguity was first encountered in the specifications of Algol 60 and is called the "dangling `else`" ambiguity.

To assist the grammar author in understanding the nature of each conflict, Bison can be asked to generate "counterexamples". In the present case it actually even proves that the grammar is ambiguous by exhibiting a string with two different parses:

```
Example: "if" expr "then" "if" expr "then" stmt • "else" stmt
Shift derivation
  if_stmt
  → "if" expr "then" stmt
                    → if_stmt
                       → "if" expr "then" stmt • "else" stmt
Example: "if" expr "then" "if" expr "then" stmt • "else" stmt
Reduce derivation
  if_stmt
  → "if" expr "then" stmt                              "else" stmt
                    → if_stmt
                       → "if" expr "then" stmt •
```

See Section 8.1 [Generation of Counterexamples], page 135, for more details.

To avoid warnings from Bison about predictable, *legitimate* shift/reduce conflicts, you can use the `%expect n` declaration. There will be no warning as long as the number of shift/reduce conflicts is exactly *n*, and Bison will report an error if there is a different number. See Section 3.7.9 [Suppressing Conflict Warnings], page 76. However, we don't recommend the use of `%expect` (except '`%expect 0`'!), as an equal number of conflicts does not mean that they are the *same*. When possible, you should rather use precedence directives to *fix* the conflicts explicitly (see Section 5.3.6 [Using Precedence For Non Operators], page 116).

The definition of `if_stmt` above is solely to blame for the conflict, but the conflict does not actually appear without additional rules. Here is a complete Bison grammar file that actually manifests the conflict:

```
%%
stmt:
  expr
| if_stmt
;

if_stmt:
  "if" expr "then" stmt
| "if" expr "then" stmt "else" stmt
;
```

```
expr:
  "identifier"
;
```

5.3 Operator Precedence

Another situation where shift/reduce conflicts appear is in arithmetic expressions. Here shifting is not always the preferred resolution; the Bison declarations for operator precedence allow you to specify when to shift and when to reduce.

5.3.1 When Precedence is Needed

Consider the following ambiguous grammar fragment (ambiguous because the input '1 - 2 * 3' can be parsed in two different ways):

```
expr:
  expr '-' expr
| expr '*' expr
| expr '<' expr
| '(' expr ')'
...
;
```

Suppose the parser has seen the tokens '1', '-' and '2'; should it reduce them via the rule for the subtraction operator? It depends on the next token. Of course, if the next token is ')', we must reduce; shifting is invalid because no single rule can reduce the token sequence '- 2)' or anything starting with that. But if the next token is '*' or '<', we have a choice: either shifting or reduction would allow the parse to complete, but with different results.

To decide which one Bison should do, we must consider the results. If the next operator token *op* is shifted, then it must be reduced first in order to permit another opportunity to reduce the difference. The result is (in effect) '1 - (2 *op* 3)'. On the other hand, if the subtraction is reduced before shifting *op*, the result is '(1 - 2) *op* 3'. Clearly, then, the choice of shift or reduce should depend on the relative precedence of the operators '-' and *op*: '*' should be shifted first, but not '<'.

What about input such as '1 - 2 - 5'; should this be '(1 - 2) - 5' or should it be '1 - (2 - 5)'? For most operators we prefer the former, which is called *left association*. The latter alternative, *right association*, is desirable for assignment operators. The choice of left or right association is a matter of whether the parser chooses to shift or reduce when the stack contains '1 - 2' and the lookahead token is '-': shifting makes right-associativity.

5.3.2 Specifying Operator Precedence

Bison allows you to specify these choices with the operator precedence declarations %left and %right. Each such declaration contains a list of tokens, which are operators whose precedence and associativity is being declared. The %left declaration makes all those operators left-associative and the %right declaration makes them right-associative. A third alternative is %nonassoc, which declares that it is a syntax error to find the same operator twice "in a row". The last alternative, %precedence, allows to define only precedence and no associativity at all. As a result, any associativity-related conflict that remains will

be reported as an compile-time error. The directive `%nonassoc` creates run-time error: using the operator in a associative way is a syntax error. The directive `%precedence` creates compile-time errors: an operator *can* be involved in an associativity-related conflict, contrary to what expected the grammar author.

The relative precedence of different operators is controlled by the order in which they are declared. The first precedence/associativity declaration in the file declares the operators whose precedence is lowest, the next such declaration declares the operators whose precedence is a little higher, and so on.

5.3.3 Specifying Precedence Only

Since POSIX Yacc defines only `%left`, `%right`, and `%nonassoc`, which all defines precedence and associativity, little attention is paid to the fact that precedence cannot be defined without defining associativity. Yet, sometimes, when trying to solve a conflict, precedence suffices. In such a case, using `%left`, `%right`, or `%nonassoc` might hide future (associativity related) conflicts that would remain hidden.

The dangling `else` ambiguity (see Section 5.2 [Shift/Reduce Conflicts], page 112) can be solved explicitly. This shift/reduce conflicts occurs in the following situation, where the period denotes the current parsing state:

        if *e1* then if   *e2* then *s1* ● else *s2*

The conflict involves the reduction of the rule '`IF expr THEN stmt`', which precedence is by default that of its last token (`THEN`), and the shifting of the token `ELSE`. The usual disambiguation (attach the `else` to the closest `if`), shifting must be preferred, i.e., the precedence of `ELSE` must be higher than that of `THEN`. But neither is expected to be involved in an associativity related conflict, which can be specified as follows.

```
%precedence THEN
%precedence ELSE
```

The unary-minus is another typical example where associativity is usually over-specified, see Section 2.2 [Infix Notation Calculator: `calc`], page 33. The `%left` directive is traditionally used to declare the precedence of `NEG`, which is more than needed since it also defines its associativity. While this is harmless in the traditional example, who knows how `NEG` might be used in future evolutions of the grammar. . .

5.3.4 Precedence Examples

In our example, we would want the following declarations:

```
%left '<'
%left '-'
%left '*'
```

In a more complete example, which supports other operators as well, we would declare them in groups of equal precedence. For example, '`+`' is declared with '`-`':

```
%left '<' '>' '=' "!=" "<=" ">="
%left '+' '-'
%left '*' '/'
```

5.3.5 How Precedence Works

The first effect of the precedence declarations is to assign precedence levels to the terminal symbols declared. The second effect is to assign precedence levels to certain rules: each rule gets its precedence from the last terminal symbol mentioned in the components. (You can also specify explicitly the precedence of a rule. See Section 5.4 [Context-Dependent Precedence], page 116.)

Finally, the resolution of conflicts works by comparing the precedence of the rule being considered with that of the lookahead token. If the token's precedence is higher, the choice is to shift. If the rule's precedence is higher, the choice is to reduce. If they have equal precedence, the choice is made based on the associativity of that precedence level. The verbose output file made by `-v` (see Chapter 9 [Invoking Bison], page 154) says how each conflict was resolved.

Not all rules and not all tokens have precedence. If either the rule or the lookahead token has no precedence, then the default is to shift.

5.3.6 Using Precedence For Non Operators

Using properly precedence and associativity directives can help fixing shift/reduce conflicts that do not involve arithmetic-like operators. For instance, the "dangling `else`" problem (see Section 5.2 [Shift/Reduce Conflicts], page 112) can be solved elegantly in two different ways.

In the present case, the conflict is between the token `"else"` willing to be shifted, and the rule '`if_stmt: "if" expr "then" stmt`', asking for reduction. By default, the precedence of a rule is that of its last token, here `"then"`, so the conflict will be solved appropriately by giving `"else"` a precedence higher than that of `"then"`, for instance as follows:

```
%precedence "then"
%precedence "else"
```

Alternatively, you may give both tokens the same precedence, in which case associativity is used to solve the conflict. To preserve the shift action, use right associativity:

```
%right "then" "else"
```

Neither solution is perfect however. Since Bison does not provide, so far, "scoped" precedence, both force you to declare the precedence of these keywords with respect to the other operators your grammar. Therefore, instead of being warned about new conflicts you would be unaware of (e.g., a shift/reduce conflict due to '`if test then 1 else 2 + 3`' being ambiguous: '`if test then 1 else (2 + 3)`' or '`(if test then 1 else 2) + 3`'?), the conflict will be already "fixed".

5.4 Context-Dependent Precedence

Often the precedence of an operator depends on the context. This sounds outlandish at first, but it is really very common. For example, a minus sign typically has a very high precedence as a unary operator, and a somewhat lower precedence (lower than multiplication) as a binary operator.

The Bison precedence declarations can only be used once for a given token; so a token has only one precedence declared in this way. For context-dependent precedence, you need to use an additional mechanism: the `%prec` modifier for rules.

The `%prec` modifier declares the precedence of a particular rule by specifying a terminal symbol whose precedence should be used for that rule. It's not necessary for that symbol to appear otherwise in the rule. The modifier's syntax is:

```
%prec terminal-symbol
```

and it is written after the components of the rule. Its effect is to assign the rule the precedence of *terminal-symbol*, overriding the precedence that would be deduced for it in the ordinary way. The altered rule precedence then affects how conflicts involving that rule are resolved (see Section 5.3 [Operator Precedence], page 114).

Here is how `%prec` solves the problem of unary minus. First, declare a precedence for a fictitious terminal symbol named `UMINUS`. There are no tokens of this type, but the symbol serves to stand for its precedence:

```
...
%left '+' '-'
%left '*'
%left UMINUS
```

Now the precedence of `UMINUS` can be used in specific rules:

```
exp:
  ...
| exp '-' exp
  ...
| '-' exp %prec UMINUS
```

5.5 Parser States

The function `yyparse` is implemented using a finite-state machine. The values pushed on the parser stack are not simply token kind codes; they represent the entire sequence of terminal and nonterminal symbols at or near the top of the stack. The current state collects all the information about previous input which is relevant to deciding what to do next.

Each time a lookahead token is read, the current parser state together with the kind of lookahead token are looked up in a table. This table entry can say, "Shift the lookahead token." In this case, it also specifies the new parser state, which is pushed onto the top of the parser stack. Or it can say, "Reduce using rule number *n*." This means that a certain number of tokens or groupings are taken off the top of the stack, and replaced by one grouping. In other words, that number of states are popped from the stack, and one new state is pushed.

There is one other alternative: the table can say that the lookahead token is erroneous in the current state. This causes error processing to begin (see Chapter 6 [Error Recovery], page 130).

5.6 Reduce/Reduce Conflicts

A reduce/reduce conflict occurs if there are two or more rules that apply to the same sequence of input. This usually indicates a serious error in the grammar.

For example, here is an erroneous attempt to define a sequence of zero or more `word` groupings.

```
sequence:
  %empty          { printf ("empty sequence\n"); }
| maybeword
| sequence word  { printf ("added word %s\n", $2); }
;

maybeword:
  %empty    { printf ("empty maybeword\n"); }
| word      { printf ("single word %s\n", $1); }
;
```

The error is an ambiguity: as counterexample generation would demonstrate (see Section 8.1 [Generation of Counterexamples], page 135), there is more than one way to parse a single `word` into a `sequence`. It could be reduced to a `maybeword` and then into a `sequence` via the second rule. Alternatively, nothing-at-all could be reduced into a `sequence` via the first rule, and this could be combined with the `word` using the third rule for `sequence`.

There is also more than one way to reduce nothing-at-all into a `sequence`. This can be done directly via the first rule, or indirectly via `maybeword` and then the second rule.

You might think that this is a distinction without a difference, because it does not change whether any particular input is valid or not. But it does affect which actions are run. One parsing order runs the second rule's action; the other runs the first rule's action and the third rule's action. In this example, the output of the program changes.

Bison resolves a reduce/reduce conflict by choosing to use the rule that appears first in the grammar, but it is very risky to rely on this. Every reduce/reduce conflict must be studied and usually eliminated. Here is the proper way to define `sequence`:

```
sequence:
  %empty          { printf ("empty sequence\n"); }
| sequence word  { printf ("added word %s\n", $2); }
;
```

Here is another common error that yields a reduce/reduce conflict:

```
sequence:
  %empty
| sequence words
| sequence redirects
;

words:
  %empty
| words word
;

redirects:
  %empty
| redirects redirect
;
```

The intention here is to define a sequence which can contain either `word` or `redirect` groupings. The individual definitions of `sequence`, `words` and `redirects` are error-free, but the three together make a subtle ambiguity: even an empty input can be parsed in infinitely many ways!

Consider: nothing-at-all could be a `words`. Or it could be two `words` in a row, or three, or any number. It could equally well be a `redirects`, or two, or any number. Or it could be a `words` followed by three `redirects` and another `words`. And so on.

Here are two ways to correct these rules. First, to make it a single level of sequence:

```
sequence:
  %empty
| sequence word
| sequence redirect
;
```

Second, to prevent either a `words` or a `redirects` from being empty:

```
sequence:
  %empty
| sequence words
| sequence redirects
;

words:
  word
| words word
;

redirects:
  redirect
| redirects redirect
;
```

Yet this proposal introduces another kind of ambiguity! The input 'word word' can be parsed as a single `words` composed of two 'word's, or as two one-`word` `words` (and likewise for `redirect`/`redirects`). However this ambiguity is now a shift/reduce conflict, and therefore it can now be addressed with precedence directives.

To simplify the matter, we will proceed with `word` and `redirect` being tokens: `"word"` and `"redirect"`.

To prefer the longest `words`, the conflict between the token `"word"` and the rule '`sequence: sequence words`' must be resolved as a shift. To this end, we use the same techniques as exposed above, see Section 5.3.6 [Using Precedence For Non Operators], page 116. One solution relies on precedences: use `%prec` to give a lower precedence to the rule:

```
%precedence "word"
%precedence "sequence"
%%
```

```
sequence:
  %empty
| sequence word      %prec "sequence"
| sequence redirect  %prec "sequence"
;

words:
  word
| words "word"
;
```

Another solution relies on associativity: provide both the token and the rule with the same precedence, but make them right-associative:

```
%right "word" "redirect"
%%
sequence:
  %empty
| sequence word      %prec "word"
| sequence redirect  %prec "redirect"
;
```

5.7 Mysterious Conflicts

Sometimes reduce/reduce conflicts can occur that don't look warranted. Here is an example:

```
%%
def: param_spec return_spec ',';
param_spec:
  type
| name_list ':' type
;

return_spec:
  type
| name ':' type
;

type: "id";

name: "id";
name_list:
  name
| name ',' name_list
;
```

It would seem that this grammar can be parsed with only a single token of lookahead: when a `param_spec` is being read, an `"id"` is a `name` if a comma or colon follows, or a `type` if another `"id"` follows. In other words, this grammar is LR(1). Yet Bison finds one

reduce/reduce conflict, for which counterexample generation (see Section 8.1 [Generation of Counterexamples], page 135) would find a *nonunifying* example.

This is because Bison does not handle all LR(1) grammars *by default*, for historical reasons. In this grammar, two contexts, that after an `"id"` at the beginning of a `param_spec` and likewise at the beginning of a `return_spec`, are similar enough that Bison assumes they are the same. They appear similar because the same set of rules would be active—the rule for reducing to a `name` and that for reducing to a `type`. Bison is unable to determine at that stage of processing that the rules would require different lookahead tokens in the two contexts, so it makes a single parser state for them both. Combining the two contexts causes a conflict later. In parser terminology, this occurrence means that the grammar is not LALR(1).

For many practical grammars (specifically those that fall into the non-LR(1) class), the limitations of LALR(1) result in difficulties beyond just mysterious reduce/reduce conflicts. The best way to fix all these problems is to select a different parser table construction algorithm. Either IELR(1) or canonical LR(1) would suffice, but the former is more efficient and easier to debug during development. See Section 5.8.1 [LR Table Construction], page 122, for details.

If you instead wish to work around LALR(1)'s limitations, you can often fix a mysterious conflict by identifying the two parser states that are being confused, and adding something to make them look distinct. In the above example, adding one rule to `return_spec` as follows makes the problem go away:

```
...
return_spec:
  type
| name ':' type
| "id" "bogus"        /* This rule is never used. */
;
```

This corrects the problem because it introduces the possibility of an additional active rule in the context after the `"id"` at the beginning of `return_spec`. This rule is not active in the corresponding context in a `param_spec`, so the two contexts receive distinct parser states. As long as the token `"bogus"` is never generated by `yylex`, the added rule cannot alter the way actual input is parsed.

In this particular example, there is another way to solve the problem: rewrite the rule for `return_spec` to use `"id"` directly instead of via `name`. This also causes the two confusing contexts to have different sets of active rules, because the one for `return_spec` activates the altered rule for `return_spec` rather than the one for `name`.

```
param_spec:
  type
| name_list ':' type
;

return_spec:
  type
| "id" ':' type
;
```

For a more detailed exposition of LALR(1) parsers and parser generators, see [DeRemer 1982], page 229.

5.8 Tuning LR

The default behavior of Bison's LR-based parsers is chosen mostly for historical reasons, but that behavior is often not robust. For example, in the previous section, we discussed the mysterious conflicts that can be produced by LALR(1), Bison's default parser table construction algorithm. Another example is Bison's `%define parse.error verbose` directive, which instructs the generated parser to produce verbose syntax error messages, which can sometimes contain incorrect information.

In this section, we explore several modern features of Bison that allow you to tune fundamental aspects of the generated LR-based parsers. Some of these features easily eliminate shortcomings like those mentioned above. Others can be helpful purely for understanding your parser.

5.8.1 LR Table Construction

For historical reasons, Bison constructs LALR(1) parser tables by default. However, LALR does not possess the full language-recognition power of LR. As a result, the behavior of parsers employing LALR parser tables is often mysterious. We presented a simple example of this effect in Section 5.7 [Mysterious Conflicts], page 120.

As we also demonstrated in that example, the traditional approach to eliminating such mysterious behavior is to restructure the grammar. Unfortunately, doing so correctly is often difficult. Moreover, merely discovering that LALR causes mysterious behavior in your parser can be difficult as well.

Fortunately, Bison provides an easy way to eliminate the possibility of such mysterious behavior altogether. You simply need to activate a more powerful parser table construction algorithm by using the `%define lr.type` directive.

`%define lr.type` *type*   [Directive]
>   Specify the type of parser tables within the LR(1) family. The accepted values for
>   *type* are:
>   - `lalr` (default)
>   - `ielr`
>   - `canonical-lr`

For example, to activate IELR, you might add the following directive to you grammar file:

        `%define lr.type ielr`

For the example in Section 5.7 [Mysterious Conflicts], page 120, the mysterious conflict is then eliminated, so there is no need to invest time in comprehending the conflict or restructuring the grammar to fix it. If, during future development, the grammar evolves such that all mysterious behavior would have disappeared using just LALR, you need not fear that continuing to use IELR will result in unnecessarily large parser tables. That is, IELR generates LALR tables when LALR (using a deterministic parsing algorithm) is sufficient to support the full language-recognition power of LR. Thus, by enabling IELR

at the start of grammar development, you can safely and completely eliminate the need to consider LALR's shortcomings.

While IELR is almost always preferable, there are circumstances where LALR or the canonical LR parser tables described by Knuth (see [Knuth 1965], page 229) can be useful. Here we summarize the relative advantages of each parser table construction algorithm within Bison:

- LALR

  There are at least two scenarios where LALR can be worthwhile:

  - GLR without static conflict resolution.

    When employing GLR parsers (see Section 1.5 [Writing GLR Parsers], page 17), if you do not resolve any conflicts statically (for example, with `%left` or `%precedence`), then the parser explores all potential parses of any given input. In this case, the choice of parser table construction algorithm is guaranteed not to alter the language accepted by the parser. LALR parser tables are the smallest parser tables Bison can currently construct, so they may then be preferable. Nevertheless, once you begin to resolve conflicts statically, GLR behaves more like a deterministic parser in the syntactic contexts where those conflicts appear, and so either IELR or canonical LR can then be helpful to avoid LALR's mysterious behavior.

  - Malformed grammars.

    Occasionally during development, an especially malformed grammar with a major recurring flaw may severely impede the IELR or canonical LR parser table construction algorithm. LALR can be a quick way to construct parser tables in order to investigate such problems while ignoring the more subtle differences from IELR and canonical LR.

- IELR

  IELR (Inadequacy Elimination LR) is a minimal LR algorithm. That is, given any grammar (LR or non-LR), parsers using IELR or canonical LR parser tables always accept exactly the same set of sentences. However, like LALR, IELR merges parser states during parser table construction so that the number of parser states is often an order of magnitude less than for canonical LR. More importantly, because canonical LR's extra parser states may contain duplicate conflicts in the case of non-LR grammars, the number of conflicts for IELR is often an order of magnitude less as well. This effect can significantly reduce the complexity of developing a grammar.

- Canonical LR

  While inefficient, canonical LR parser tables can be an interesting means to explore a grammar because they possess a property that IELR and LALR tables do not. That is, if `%nonassoc` is not used and default reductions are left disabled (see Section 5.8.2 [Default Reductions], page 124), then, for every left context of every canonical LR state, the set of tokens accepted by that state is guaranteed to be the exact set of tokens that is syntactically acceptable in that left context. It might then seem that an advantage of canonical LR parsers in production is that, under the above constraints, they are guaranteed to detect a syntax error as soon as possible without performing any unnecessary reductions. However, IELR parsers that use LAC are also able to

achieve this behavior without sacrificing `%nonassoc` or default reductions. For details and a few caveats of LAC, see Section 5.8.3 [LAC], page 125.

For a more detailed exposition of the mysterious behavior in LALR parsers and the benefits of IELR, see [Denny 2008], page 229, and [Denny 2010 November], page 229.

5.8.2 Default Reductions

After parser table construction, Bison identifies the reduction with the largest lookahead set in each parser state. To reduce the size of the parser state, traditional Bison behavior is to remove that lookahead set and to assign that reduction to be the default parser action. Such a reduction is known as a *default reduction*.

Default reductions affect more than the size of the parser tables. They also affect the behavior of the parser:

- Delayed `yylex` invocations.

  A *consistent state* is a state that has only one possible parser action. If that action is a reduction and is encoded as a default reduction, then that consistent state is called a *defaulted state*. Upon reaching a defaulted state, a Bison-generated parser does not bother to invoke `yylex` to fetch the next token before performing the reduction. In other words, whether default reductions are enabled in consistent states determines how soon a Bison-generated parser invokes `yylex` for a token: immediately when it *reaches* that token in the input or when it eventually *needs* that token as a lookahead to determine the next parser action. Traditionally, default reductions are enabled, and so the parser exhibits the latter behavior.

  The presence of defaulted states is an important consideration when designing `yylex` and the grammar file. That is, if the behavior of `yylex` can influence or be influenced by the semantic actions associated with the reductions in defaulted states, then the delay of the next `yylex` invocation until after those reductions is significant. For example, the semantic actions might pop a scope stack that `yylex` uses to determine what token to return. Thus, the delay might be necessary to ensure that `yylex` does not look up the next token in a scope that should already be considered closed.

- Delayed syntax error detection.

  When the parser fetches a new token by invoking `yylex`, it checks whether there is an action for that token in the current parser state. The parser detects a syntax error if and only if either (1) there is no action for that token or (2) the action for that token is the error action (due to the use of `%nonassoc`). However, if there is a default reduction in that state (which might or might not be a defaulted state), then it is impossible for condition 1 to exist. That is, all tokens have an action. Thus, the parser sometimes fails to detect the syntax error until it reaches a later state.

  While default reductions never cause the parser to accept syntactically incorrect sentences, the delay of syntax error detection can have unexpected effects on the behavior of the parser. However, the delay can be caused anyway by parser state merging and the use of `%nonassoc`, and it can be fixed by another Bison feature, LAC. We discuss the effects of delayed syntax error detection and LAC more in the next section (see Section 5.8.3 [LAC], page 125).

For canonical LR, the only default reduction that Bison enables by default is the accept action, which appears only in the accepting state, which has no other action and is thus a

defaulted state. However, the default accept action does not delay any `yylex` invocation or syntax error detection because the accept action ends the parse.

For LALR and IELR, Bison enables default reductions in nearly all states by default. There are only two exceptions. First, states that have a shift action on the `error` token do not have default reductions because delayed syntax error detection could then prevent the `error` token from ever being shifted in that state. However, parser state merging can cause the same effect anyway, and LAC fixes it in both cases, so future versions of Bison might drop this exception when LAC is activated. Second, GLR parsers do not record the default reduction as the action on a lookahead token for which there is a conflict. The correct action in this case is to split the parse instead.

To adjust which states have default reductions enabled, use the `%define lr.default-reduction` directive.

`%define lr.default-reduction` *where*   [Directive]

> Specify the kind of states that are permitted to contain default reductions. The accepted values of *where* are:
>
> - `most` (default for LALR and IELR)
> - `consistent`
> - `accepting` (default for canonical LR)

5.8.3 LAC

Canonical LR, IELR, and LALR can suffer from a couple of problems upon encountering a syntax error. First, the parser might perform additional parser stack reductions before discovering the syntax error. Such reductions can perform user semantic actions that are unexpected because they are based on an invalid token, and they cause error recovery to begin in a different syntactic context than the one in which the invalid token was encountered. Second, when verbose error messages are enabled (see Section 4.4 [Error Reporting], page 104), the expected token list in the syntax error message can both contain invalid tokens and omit valid tokens.

The culprits for the above problems are `%nonassoc`, default reductions in inconsistent states (see Section 5.8.2 [Default Reductions], page 124), and parser state merging. Because IELR and LALR merge parser states, they suffer the most. Canonical LR can suffer only if `%nonassoc` is used or if default reductions are enabled for inconsistent states.

LAC (Lookahead Correction) is a new mechanism within the parsing algorithm that solves these problems for canonical LR, IELR, and LALR without sacrificing `%nonassoc`, default reductions, or state merging. You can enable LAC with the `%define parse.lac` directive.

`%define parse.lac` *value*   [Directive]

> Enable LAC to improve syntax error handling.
>
> - `none` (default)
> - `full`

This feature is currently only available for deterministic parsers in C and C++.

Conceptually, the LAC mechanism is straight-forward. Whenever the parser fetches a new token from the scanner so that it can determine the next parser action, it immediately suspends normal parsing and performs an exploratory parse using a temporary copy of the normal parser state stack. During this exploratory parse, the parser does not perform user semantic actions. If the exploratory parse reaches a shift action, normal parsing then resumes on the normal parser stacks. If the exploratory parse reaches an error instead, the parser reports a syntax error. If verbose syntax error messages are enabled, the parser must then discover the list of expected tokens, so it performs a separate exploratory parse for each token in the grammar.

There is one subtlety about the use of LAC. That is, when in a consistent parser state with a default reduction, the parser will not attempt to fetch a token from the scanner because no lookahead is needed to determine the next parser action. Thus, whether default reductions are enabled in consistent states (see Section 5.8.2 [Default Reductions], page 124) affects how soon the parser detects a syntax error: immediately when it *reaches* an erroneous token or when it eventually *needs* that token as a lookahead to determine the next parser action. The latter behavior is probably more intuitive, so Bison currently provides no way to achieve the former behavior while default reductions are enabled in consistent states.

Thus, when LAC is in use, for some fixed decision of whether to enable default reductions in consistent states, canonical LR and IELR behave almost exactly the same for both syntactically acceptable and syntactically unacceptable input. While LALR still does not support the full language-recognition power of canonical LR and IELR, LAC at least enables LALR's syntax error handling to correctly reflect LALR's language-recognition power.

There are a few caveats to consider when using LAC:

- Infinite parsing loops.

  IELR plus LAC does have one shortcoming relative to canonical LR. Some parsers generated by Bison can loop infinitely. LAC does not fix infinite parsing loops that occur between encountering a syntax error and detecting it, but enabling canonical LR or disabling default reductions sometimes does.

- Verbose error message limitations.

  Because of internationalization considerations, Bison-generated parsers limit the size of the expected token list they are willing to report in a verbose syntax error message. If the number of expected tokens exceeds that limit, the list is simply dropped from the message. Enabling LAC can increase the size of the list and thus cause the parser to drop it. Of course, dropping the list is better than reporting an incorrect list.

- Performance.

  Because LAC requires many parse actions to be performed twice, it can have a performance penalty. However, not all parse actions must be performed twice. Specifically, during a series of default reductions in consistent states and shift actions, the parser never has to initiate an exploratory parse. Moreover, the most time-consuming tasks in a parse are often the file I/O, the lexical analysis performed by the scanner, and the user's semantic actions, but none of these are performed during the exploratory parse. Finally, the base of the temporary stack used during an exploratory parse is a pointer into the normal parser state stack so that the stack is never physically copied. In our experience, the performance penalty of LAC has proved insignificant for practical grammars.

While the LAC algorithm shares techniques that have been recognized in the parser community for years, for the publication that introduces LAC, see [Denny 2010 May], page 229.

5.8.4 Unreachable States

If there exists no sequence of transitions from the parser's start state to some state s, then Bison considers s to be an *unreachable state*. A state can become unreachable during conflict resolution if Bison disables a shift action leading to it from a predecessor state.

By default, Bison removes unreachable states from the parser after conflict resolution because they are useless in the generated parser. However, keeping unreachable states is sometimes useful when trying to understand the relationship between the parser and the grammar.

`%define lr.keep-unreachable-state` *value*   [Directive]
> Request that Bison allow unreachable states to remain in the parser tables. *value* must be a Boolean. The default is `false`.

There are a few caveats to consider:

- Missing or extraneous warnings.

  Unreachable states may contain conflicts and may use rules not used in any other state. Thus, keeping unreachable states may induce warnings that are irrelevant to your parser's behavior, and it may eliminate warnings that are relevant. Of course, the change in warnings may actually be relevant to a parser table analysis that wants to keep unreachable states, so this behavior will likely remain in future Bison releases.

- Other useless states.

  While Bison is able to remove unreachable states, it is not guaranteed to remove other kinds of useless states. Specifically, when Bison disables reduce actions during conflict resolution, some goto actions may become useless, and thus some additional states may become useless. If Bison were to compute which goto actions were useless and then disable those actions, it could identify such states as unreachable and then remove those states. However, Bison does not compute which goto actions are useless.

5.9 Generalized LR (GLR) Parsing

Bison produces *deterministic* parsers that choose uniquely when to reduce and which reduction to apply based on a summary of the preceding input and on one extra token of lookahead. As a result, normal Bison handles a proper subset of the family of context-free languages. Ambiguous grammars, since they have strings with more than one possible sequence of reductions cannot have deterministic parsers in this sense. The same is true of languages that require more than one symbol of lookahead, since the parser lacks the information necessary to make a decision at the point it must be made in a shift/reduce parser. Finally, as previously mentioned (see Section 5.7 [Mysterious Conflicts], page 120), there are languages where Bison's default choice of how to summarize the input seen so far loses necessary information.

When you use the '`%glr-parser`' declaration in your grammar file, Bison generates a parser that uses a different algorithm, called Generalized LR (or GLR). A Bison GLR parser

uses the same basic algorithm for parsing as an ordinary Bison parser, but behaves differently in cases where there is a shift/reduce conflict that has not been resolved by precedence rules (see Section 5.3 [Operator Precedence], page 114) or a reduce/reduce conflict. When a GLR parser encounters such a situation, it effectively *splits* into a several parsers, one for each possible shift or reduction. These parsers then proceed as usual, consuming tokens in lock-step. Some of the stacks may encounter other conflicts and split further, with the result that instead of a sequence of states, a Bison GLR parsing stack is what is in effect a tree of states.

In effect, each stack represents a guess as to what the proper parse is. Additional input may indicate that a guess was wrong, in which case the appropriate stack silently disappears. Otherwise, the semantics actions generated in each stack are saved, rather than being executed immediately. When a stack disappears, its saved semantic actions never get executed. When a reduction causes two stacks to become equivalent, their sets of semantic actions are both saved with the state that results from the reduction. We say that two stacks are equivalent when they both represent the same sequence of states, and each pair of corresponding states represents a grammar symbol that produces the same segment of the input token stream.

Whenever the parser makes a transition from having multiple states to having one, it reverts to the normal deterministic parsing algorithm, after resolving and executing the saved-up actions. At this transition, some of the states on the stack will have semantic values that are sets (actually multisets) of possible actions. The parser tries to pick one of the actions by first finding one whose rule has the highest dynamic precedence, as set by the '`%dprec`' declaration. Otherwise, if the alternative actions are not ordered by precedence, but there the same merging function is declared for both rules by the '`%merge`' declaration, Bison resolves and evaluates both and then calls the merge function on the result. Otherwise, it reports an ambiguity.

It is possible to use a data structure for the GLR parsing tree that permits the processing of any LR(1) grammar in linear time (in the size of the input), any unambiguous (not necessarily LR(1)) grammar in quadratic worst-case time, and any general (possibly ambiguous) context-free grammar in cubic worst-case time. However, Bison currently uses a simpler data structure that requires time proportional to the length of the input times the maximum number of stacks required for any prefix of the input. Thus, really ambiguous or nondeterministic grammars can require exponential time and space to process. Such badly behaving examples, however, are not generally of practical interest. Usually, nondeterminism in a grammar is local—the parser is "in doubt" only for a few tokens at a time. Therefore, the current data structure should generally be adequate. On LR(1) portions of a grammar, in particular, it is only slightly slower than with the deterministic LR(1) Bison parser.

For a more detailed exposition of GLR parsers, see [Scott 2000], page 229.

5.10 Memory Management, and How to Avoid Memory Exhaustion

The Bison parser stack can run out of memory if too many tokens are shifted and not reduced. When this happens, the parser function `yyparse` calls `yyerror` and then returns 2.

Because Bison parsers have growing stacks, hitting the upper limit usually results from using a right recursion instead of a left recursion, see Section 3.3.3 [Recursive Rules], page 55.

By defining the macro `YYMAXDEPTH`, you can control how deep the parser stack can become before memory is exhausted. Define the macro with a value that is an integer. This value is the maximum number of tokens that can be shifted (and not reduced) before overflow.

The stack space allowed is not necessarily allocated. If you specify a large value for `YYMAXDEPTH`, the parser normally allocates a small stack at first, and then makes it bigger by stages as needed. This increasing allocation happens automatically and silently. Therefore, you do not need to make `YYMAXDEPTH` painfully small merely to save space for ordinary inputs that do not need much stack.

However, do not allow `YYMAXDEPTH` to be a value so large that arithmetic overflow could occur when calculating the size of the stack space. Also, do not allow `YYMAXDEPTH` to be less than `YYINITDEPTH`.

The default value of `YYMAXDEPTH`, if you do not define it, is 10000.

You can control how much stack is allocated initially by defining the macro `YYINITDEPTH` to a positive integer. For the deterministic parser in C, this value must be a compile-time constant unless you are assuming C99 or some other target language or compiler that allows variable-length arrays. The default is 200.

Do not allow `YYINITDEPTH` to be greater than `YYMAXDEPTH`.

You can generate a deterministic parser containing C++ user code from the default (C) skeleton, as well as from the C++ skeleton (see Section 10.1 [++ Parsers-title⟨undefined⟩], page 166). However, if you do use the default skeleton and want to allow the parsing stack to grow, be careful not to use semantic types or location types that require non-trivial copy constructors. The C skeleton bypasses these constructors when copying data to new, larger stacks.

6 Error Recovery

It is not usually acceptable to have a program terminate on a syntax error. For example, a compiler should recover sufficiently to parse the rest of the input file and check it for errors; a calculator should accept another expression.

In a simple interactive command parser where each input is one line, it may be sufficient to allow `yyparse` to return 1 on error and have the caller ignore the rest of the input line when that happens (and then call `yyparse` again). But this is inadequate for a compiler, because it forgets all the syntactic context leading up to the error. A syntax error deep within a function in the compiler input should not cause the compiler to treat the following line like the beginning of a source file.

You can define how to recover from a syntax error by writing rules to recognize the special token `error`. This is a terminal symbol that is always defined (you need not declare it) and reserved for error handling. The Bison parser generates an `error` token whenever a syntax error happens; if you have provided a rule to recognize this token in the current context, the parse can continue.

For example:

```
stmts:
  %empty
| stmts '\n'
| stmts exp '\n'
| stmts error '\n'
```

The fourth rule in this example says that an error followed by a newline makes a valid addition to any `stmts`.

What happens if a syntax error occurs in the middle of an `exp`? The error recovery rule, interpreted strictly, applies to the precise sequence of a `stmts`, an `error` and a newline. If an error occurs in the middle of an `exp`, there will probably be some additional tokens and subexpressions on the stack after the last `stmts`, and there will be tokens to read before the next newline. So the rule is not applicable in the ordinary way.

But Bison can force the situation to fit the rule, by discarding part of the semantic context and part of the input. First it discards states and objects from the stack until it gets back to a state in which the `error` token is acceptable. (This means that the subexpressions already parsed are discarded, back to the last complete `stmts`.) At this point the `error` token can be shifted. Then, if the old lookahead token is not acceptable to be shifted next, the parser reads tokens and discards them until it finds a token which is acceptable. In this example, Bison reads and discards input until the next newline so that the fourth rule can apply. Note that discarded symbols are possible sources of memory leaks, see Section 3.7.7 [Freeing Discarded Symbols], page 73, for a means to reclaim this memory.

The choice of error rules in the grammar is a choice of strategies for error recovery. A simple and useful strategy is simply to skip the rest of the current input line or current statement if an error is detected:

```
stmt: error ';'  /* On error, skip until ';' is read. */
```

It is also useful to recover to the matching close-delimiter of an opening-delimiter that has already been parsed. Otherwise the close-delimiter will probably appear to be unmatched, and generate another, spurious error message:

```
primary:
  '(' expr ')'
| '(' error ')'
...
;
```

Error recovery strategies are necessarily guesses. When they guess wrong, one syntax error often leads to another. In the above example, the error recovery rule guesses that an error is due to bad input within one `stmt`. Suppose that instead a spurious semicolon is inserted in the middle of a valid `stmt`. After the error recovery rule recovers from the first error, another syntax error will be found straight away, since the text following the spurious semicolon is also an invalid `stmt`.

To prevent an outpouring of error messages, the parser will output no error message for another syntax error that happens shortly after the first; only after three consecutive input tokens have been successfully shifted will error messages resume.

Note that rules which accept the `error` token may have actions, just as any other rules can.

You can make error messages resume immediately by using the macro `yyerrok` in an action. If you do this in the error rule's action, no error messages will be suppressed. This macro requires no arguments; 'yyerrok;' is a valid C statement.

The previous lookahead token is reanalyzed immediately after an error. If this is unacceptable, then the macro `yyclearin` may be used to clear this token. Write the statement 'yyclearin;' in the error rule's action. See Section 4.5 [Special Features for Use in Actions], page 107.

For example, suppose that on a syntax error, an error handling routine is called that advances the input stream to some point where parsing should once again commence. The next symbol returned by the lexical scanner is probably correct. The previous lookahead token ought to be discarded with 'yyclearin;'.

The expression `YYRECOVERING ()` yields 1 when the parser is recovering from a syntax error, and 0 otherwise. Syntax error diagnostics are suppressed while recovering from a syntax error.

7 Handling Context Dependencies

The Bison paradigm is to parse tokens first, then group them into larger syntactic units. In many languages, the meaning of a token is affected by its context. Although this violates the Bison paradigm, certain techniques (known as *kludges*) may enable you to write Bison parsers for such languages.

(Actually, "kludge" means any technique that gets its job done but is neither clean nor robust.)

7.1 Semantic Info in Token Kinds

The C language has a context dependency: the way an identifier is used depends on what its current meaning is. For example, consider this:

```
foo (x);
```

This looks like a function call statement, but if `foo` is a typedef name, then this is actually a declaration of `x`. How can a Bison parser for C decide how to parse this input?

The method used in GNU C is to have two different token kinds, `IDENTIFIER` and `TYPENAME`. When `yylex` finds an identifier, it looks up the current declaration of the identifier in order to decide which token kind to return: `TYPENAME` if the identifier is declared as a typedef, `IDENTIFIER` otherwise.

The grammar rules can then express the context dependency by the choice of token kind to recognize. `IDENTIFIER` is accepted as an expression, but `TYPENAME` is not. `TYPENAME` can start a declaration, but `IDENTIFIER` cannot. In contexts where the meaning of the identifier is *not* significant, such as in declarations that can shadow a typedef name, either `TYPENAME` or `IDENTIFIER` is accepted—there is one rule for each of the two token kinds.

This technique is simple to use if the decision of which kinds of identifiers to allow is made at a place close to where the identifier is parsed. But in C this is not always so: C allows a declaration to redeclare a typedef name provided an explicit type has been specified earlier:

```
typedef int foo, bar;
int baz (void)
{
  static bar (bar);       /* redeclare bar as static variable */
  extern foo foo (foo);  /* redeclare foo as function */
  return foo (bar);
}
```

Unfortunately, the name being declared is separated from the declaration construct itself by a complicated syntactic structure—the "declarator".

As a result, part of the Bison parser for C needs to be duplicated, with all the nonterminal names changed: once for parsing a declaration in which a typedef name can be redefined, and once for parsing a declaration in which that can't be done. Here is a part of the duplication, with actions omitted for brevity:

```
initdcl:
  declarator maybeasm '=' init
| declarator maybeasm
;
```

```
    notype_initdcl:
      notype_declarator maybeasm '=' init
    | notype_declarator maybeasm
    ;
```

Here `initdcl` can redeclare a typedef name, but `notype_initdcl` cannot. The distinction between `declarator` and `notype_declarator` is the same sort of thing.

There is some similarity between this technique and a lexical tie-in (described next), in that information which alters the lexical analysis is changed during parsing by other parts of the program. The difference is here the information is global, and is used for other purposes in the program. A true lexical tie-in has a special-purpose flag controlled by the syntactic context.

7.2 Lexical Tie-ins

One way to handle context-dependency is the *lexical tie-in*: a flag which is set by Bison actions, whose purpose is to alter the way tokens are parsed.

For example, suppose we have a language vaguely like C, but with a special construct 'hex (*hex-expr*)'. After the keyword `hex` comes an expression in parentheses in which all integers are hexadecimal. In particular, the token 'a1b' must be treated as an integer rather than as an identifier if it appears in that context. Here is how you can do it:

```
%{
  int hexflag;
  int yylex (void);
  void yyerror (char const *);
%}
%%
...
expr:
  IDENTIFIER
| constant
| HEX '('          { hexflag = 1; }
    expr ')'       { hexflag = 0; $$ = $4; }
| expr '+' expr  { $$ = make_sum ($1, $3); }
...
;

constant:
  INTEGER
| STRING
;
```

Here we assume that `yylex` looks at the value of `hexflag`; when it is nonzero, all integers are parsed in hexadecimal, and tokens starting with letters are parsed as integers if possible.

The declaration of `hexflag` shown in the prologue of the grammar file is needed to make it accessible to the actions (see Section 3.1.1 [The prologue], page 46). You must also write the code in `yylex` to obey the flag.

7.3 Lexical Tie-ins and Error Recovery

Lexical tie-ins make strict demands on any error recovery rules you have. See Chapter 6 [Error Recovery], page 130.

The reason for this is that the purpose of an error recovery rule is to abort the parsing of one construct and resume in some larger construct. For example, in C-like languages, a typical error recovery rule is to skip tokens until the next semicolon, and then start a new statement, like this:

```
stmt:
  expr ';'
| IF '(' expr ')' stmt { ... }
...
| error ';'  { hexflag = 0; }
;
```

If there is a syntax error in the middle of a 'hex (*expr*)' construct, this error rule will apply, and then the action for the completed 'hex (*expr*)' will never run. So `hexflag` would remain set for the entire rest of the input, or until the next `hex` keyword, causing identifiers to be misinterpreted as integers.

To avoid this problem the error recovery rule itself clears `hexflag`.

There may also be an error recovery rule that works within expressions. For example, there could be a rule which applies within parentheses and skips to the close-parenthesis:

```
expr:
  ...
| '(' expr ')'   { $$ = $2; }
| '(' error ')'
  ...
```

If this rule acts within the `hex` construct, it is not going to abort that construct (since it applies to an inner level of parentheses within the construct). Therefore, it should not clear the flag: the rest of the `hex` construct should be parsed with the flag still in effect.

What if there is an error recovery rule which might abort out of the `hex` construct or might not, depending on circumstances? There is no way you can write the action to determine whether a `hex` construct is being aborted or not. So if you are using a lexical tie-in, you had better make sure your error recovery rules are not of this kind. Each rule must be such that you can be sure that it always will, or always won't, have to clear the flag.

8 Debugging Your Parser

Developing a parser can be a challenge, especially if you don't understand the algorithm (see Chapter 5 [The Bison Parser Algorithm], page 111). This chapter explains how to understand and debug a parser.

The most frequent issue users face is solving their conflicts. To fix them, the first step is understanding how they arise in a given grammar. This is made much easier by automated generation of counterexamples, cover in the first section (see Section 8.1 [Generation of Counterexamples], page 135).

In most cases though, looking at the structure of the automaton is still needed. The following sections explain how to generate and read the detailed structural description of the automaton. There are several formats available:

– as text, see Section 8.2 [Understanding Your Parser], page 138;

– as a graph, see Section 8.3 [Visualizing Your Parser], page 145;

– or as a markup report that can be turned, for instance, into HTML, see Section 8.4 [Visualizing your parser in multiple formats], page 148.

The last section focuses on the dynamic part of the parser: how to enable and understand the parser run-time traces (see Section 8.5 [Tracing Your Parser], page 148).

8.1 Generation of Counterexamples

Solving conflicts is probably the most delicate part of the design of an LR parser, as demonstrated by the number of sections devoted to them in this very documentation. To solve a conflict, one must understand it: when does it occur? Is it because of a flaw in the grammar? Is it rather because LR(1) cannot cope with this grammar?

On difficulty is that conflicts occur in the *automaton*, and it can be tricky to related them to issues in the *grammar* itself. With experience and patience, analysis the detailed description of the automaton (see Section 8.2 [Understanding Your Parser], page 138) allows to find example strings that reach these conflicts.

That task is made much easier thanks to the generation of counterexamples, initially developed by Chinawat Isradisaikul and Andrew Myers (see [Isradisaikul 2015], page 229).

As a first example, see the grammar of Section 5.2 [Shift/Reduce Conflicts], page 112, which features one shift/reduce conflict:

```
$ bison if-then-else.y
if-then-else.y: warning: 1 shift/reduce conflict [-Wconflicts-sr]
if-then-else.y: note: rerun with option '-Wcounterexamples' to generate con-
flict counterexamples
```

Let's rerun `bison` with the option `-Wcex/-Wcounterexamples`:

```
if-then-else.y: warning: 1 shift/reduce conflict [-Wconflicts-sr]
if-then-else.y: warning: shift/reduce conflict on token "else" [-Wcounterexamples]
```

```
Example: "if" expr "then" "if" expr "then" stmt • "else" stmt
Shift derivation
  if_stmt
  → "if" expr "then" stmt
                      → if_stmt
                        → "if" expr "then" stmt • "else" stmt
Example: "if" expr "then" "if" expr "then" stmt • "else" stmt
Reduce derivation
  if_stmt
  → "if" expr "then" stmt                               "else" stmt
                      → if_stmt
                        → "if" expr "then" stmt •
```

This shows two different derivations for one single expression, which proves that the grammar is ambiguous.

As a more delicate example, consider the example grammar of Section 5.6 [Reduce/Reduce Conflicts], page 117, which features a reduce/reduce conflict:

```
%%
sequence:
  %empty
| maybeword
| sequence "word"
;
maybeword:
  %empty
| "word"
;
```

Bison generates the following counterexamples:

```
$ bison -Wcex sequence.y
sequence.y: warning: 1 shift/reduce conflict [-Wconflicts-sr]
sequence.y: warning: 2 reduce/reduce conflicts [-Wconflicts-rr]

sequence.y: warning: shift/reduce conflict on token "word" [-Wcounterexamples]
  Example: • "word"
  Shift derivation
    sequence
    → maybeword
      → • "word"
  Example: • "word"
  Reduce derivation
    sequence
    → sequence "word"
      → •
```

```
sequence.y: warning: reduce/reduce conflict on tokens $end, "word" [-Wcounterexamples]
  Example: •
  First reduce derivation
    sequence
    → •
  Example: •
  Second reduce derivation
    sequence
    → maybeword
        → •
sequence.y: warning: shift/reduce conflict on token "word" [-Wcounterexamples]
  Example: • "word"
  Shift derivation
    sequence
    → maybeword
        → • "word"
  Example: • "word"
  Reduce derivation
    sequence
    → sequence     "word"
      → maybeword
          → •
sequence.y:8.3-45: warning: rule useless in parser due to conflicts [-Wother]
    8 |   %empty    { printf ("empty maybeword\n"); }
      |   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

Each of these three conflicts, again, prove that the grammar is ambiguous. For instance, the second conflict (the reduce/reduce one) shows that the grammar accept the empty input in two different ways.

Sometimes, the search will not find an example that can be derived in two ways. In these cases, counterexample generation will provide two examples that are the same up until the dot. Most notably, this will happen when your grammar requires a stronger parser (more lookahead, LR instead of LALR). The following example isn't LR(1):

```
%token ID
%%
s: a ID
a: expr
expr: %empty | expr ID ','
```

bison reports:

```
ids.y: warning: 1 shift/reduce conflict [-Wconflicts-sr]
ids.y: warning: shift/reduce conflict on token ID [-Wcounterexamples]
```

```
      First example: expr • ID ',' ID $end
      Shift derivation
        $accept
        → s                           $end
          → a                       ID
            → expr
              → expr • ID ','
      Second example: expr • ID $end
      Reduce derivation
        $accept
        → s                $end
          → a          ID
            → expr •
  ids.y:4.4-7: warning: rule useless in parser due to conflicts [-Wother]
      4 | a: expr
        |    ^~~~
```

This conflict is caused by the parser not having enough information to know the difference between these two examples. The parser would need an additional lookahead token to know whether or not a comma follows the ID after expr. These types of conflicts tend to be more difficult to fix, and usually need a rework of the grammar. In this case, it can be fixed by changing around the recursion: expr: ID | ',' expr ID.

Alternatively, you might also want to consider using a GLR parser (see Section 1.5 [Writing GLR Parsers], page 17).

On occasions, it is useful to look at counterexamples *in situ*: with the automaton report (See Section 8.2 [Understanding Your Parser], page 138, in particular [State 8], page 142).

8.2 Understanding Your Parser

Bison parsers are *shift/reduce automata* (see Chapter 5 [The Bison Parser Algorithm], page 111). In some cases (much more frequent than one would hope), looking at this automaton is required to tune or simply fix a parser.

The textual file is generated when the options --report or --verbose are specified, see Chapter 9 [Invoking Bison], page 154. Its name is made by removing '.tab.c' or '.c' from the parser implementation file name, and adding '.output' instead. Therefore, if the grammar file is foo.y, then the parser implementation file is called foo.tab.c by default. As a consequence, the verbose output file is called foo.output.

The following grammar file, calc.y, will be used in the sequel:

```
%union
{
  int ival;
  const char *sval;
}
%token <ival> NUM
%nterm <ival> exp
```

```
%token <sval> STR
%nterm <sval> useless
%left '+' '-'
%left '*'
%%
exp:
  exp '+' exp
| exp '-' exp
| exp '*' exp
| exp '/' exp
| NUM
;
useless: STR;
%%
```

bison reports:

```
calc.y: warning: 1 nonterminal useless in grammar [-Wother]
calc.y: warning: 1 rule useless in grammar [-Wother]
calc.y:19.1-7: warning: nonterminal useless in grammar: useless [-Wother]
   19 | useless: STR;
      | ^~~~~~~
calc.y: warning: 7 shift/reduce conflicts [-Wconflicts-sr]
calc.y: note: rerun with option '-Wcounterexamples' to generate conflict counterexamples
```

Going back to the calc example, when given `--report=state`, in addition to `calc.tab.c`, it creates a file `calc.output` with contents detailed below. The order of the output and the exact presentation might vary, but the interpretation is the same.

The first section reports useless tokens, nonterminals and rules. Useless nonterminals and rules are removed in order to produce a smaller parser, but useless tokens are preserved, since they might be used by the scanner (note the difference between "useless" and "unused" below):

```
Nonterminals useless in grammar
    useless

Terminals unused in grammar
    STR

Rules useless in grammar
    6 useless: STR
```

The next section lists states that still have conflicts.

```
State 8 conflicts: 1 shift/reduce
State 9 conflicts: 1 shift/reduce
State 10 conflicts: 1 shift/reduce
State 11 conflicts: 4 shift/reduce
```

Then Bison reproduces the exact grammar it used:

```
Grammar

    0 $accept: exp $end
```

```
1 exp: exp '+' exp
2    | exp '-' exp
3    | exp '*' exp
4    | exp '/' exp
5    | NUM
```

and reports the uses of the symbols:

```
Terminals, with rules where they appear


$end (0) 0
'*' (42) 3
'+' (43) 1
'-' (45) 2
'/' (47) 4
error (256)
NUM <ival> (258) 5
STR <sval> (259)


Nonterminals, with rules where they appear


$accept (9)
    on left: 0
exp <ival> (10)
    on left: 1 2 3 4 5
    on right: 0 1 2 3 4
```

Bison then proceeds onto the automaton itself, describing each state with its set of *items*, also known as *dotted rules*. Each item is a production rule together with a point ('.') marking the location of the input cursor.

```
State 0


0 $accept: • exp $end


NUM  shift, and go to state 1


exp  go to state 2
```

This reads as follows: "state 0 corresponds to being at the very beginning of the parsing, in the initial rule, right before the start symbol (here, exp). When the parser returns to this state right after having reduced a rule that produced an exp, the control flow jumps to state 2. If there is no such transition on a nonterminal symbol, and the lookahead is a NUM, then this token is shifted onto the parse stack, and the control flow jumps to state 1. Any other lookahead triggers a syntax error."

Even though the only active rule in state 0 seems to be rule 0, the report lists NUM as a lookahead token because NUM can be at the beginning of any rule deriving an exp. By default Bison reports the so-called *core* or *kernel* of the item set, but if you want to see more detail you can invoke bison with --report=itemset to list the derived items as well:

```
State 0

    0 $accept: • exp $end
    1 exp: • exp '+' exp
    2    | • exp '-' exp
    3    | • exp '*' exp
    4    | • exp '/' exp
    5    | • NUM

    NUM  shift, and go to state 1

    exp  go to state 2
```

In the state 1. . .

```
State 1

    5 exp: NUM •

    $default  reduce using rule 5 (exp)
```

the rule 5, 'exp: NUM;', is completed. Whatever the lookahead token ('$default'), the parser will reduce it. If it was coming from State 0, then, after this reduction it will return to state 0, and will jump to state 2 ('exp: go to state 2').

```
State 2

    0 $accept: exp • $end
    1 exp: exp • '+' exp
    2    | exp • '-' exp
    3    | exp • '*' exp
    4    | exp • '/' exp

    $end  shift, and go to state 3
    '+'   shift, and go to state 4
    '-'   shift, and go to state 5
    '*'   shift, and go to state 6
    '/'   shift, and go to state 7
```

In state 2, the automaton can only shift a symbol. For instance, because of the item 'exp: exp • '+' exp', if the lookahead is '+' it is shifted onto the parse stack, and the automaton jumps to state 4, corresponding to the item 'exp: exp '+' • exp'. Since there is no default action, any lookahead not listed triggers a syntax error.

The state 3 is named the *final state*, or the *accepting state*:

```
State 3

    0 $accept: exp $end •

    $default  accept
```

the initial rule is completed (the start symbol and the end-of-input were read), the parsing exits successfully.

The interpretation of states 4 to 7 is straightforward, and is left to the reader.

```
State 4

    1 exp: exp '+' • exp

    NUM  shift, and go to state 1

    exp  go to state 8


State 5

    2 exp: exp '-' • exp

    NUM  shift, and go to state 1

    exp  go to state 9


State 6

    3 exp: exp '*' • exp

    NUM  shift, and go to state 1

    exp  go to state 10


State 7

    4 exp: exp '/' • exp

    NUM  shift, and go to state 1

    exp  go to state 11
```

As was announced in beginning of the report, 'State 8 conflicts: 1 shift/reduce':

```
State 8

    1 exp: exp • '+' exp
    1    | exp '+' exp •
    2    | exp • '-' exp
    3    | exp • '*' exp
    4    | exp • '/' exp
```

```
'*'  shift, and go to state 6
'/'  shift, and go to state 7

'/'      [reduce using rule 1 (exp)]
$default  reduce using rule 1 (exp)
```

Indeed, there are two actions associated to the lookahead '/': either shifting (and going to state 7), or reducing rule 1. The conflict means that either the grammar is ambiguous, or the parser lacks information to make the right decision. Indeed the grammar is ambiguous, as, since we did not specify the precedence of '/', the sentence 'NUM + NUM / NUM' can be parsed as 'NUM + (NUM / NUM)', which corresponds to shifting '/', or as '(NUM + NUM) / NUM', which corresponds to reducing rule 1.

Because in deterministic parsing a single decision can be made, Bison arbitrarily chose to disable the reduction, see Section 5.2 [Shift/Reduce Conflicts], page 112. Discarded actions are reported between square brackets.

Note that all the previous states had a single possible action: either shifting the next token and going to the corresponding state, or reducing a single rule. In the other cases, i.e., when shifting *and* reducing is possible or when *several* reductions are possible, the lookahead is required to select the action. State 8 is one such state: if the lookahead is '*' or '/' then the action is shifting, otherwise the action is reducing rule 1. In other words, the first two items, corresponding to rule 1, are not eligible when the lookahead token is '*', since we specified that '*' has higher precedence than '+'. More generally, some items are eligible only with some set of possible lookahead tokens. When run with `--report=lookahead`, Bison specifies these lookahead tokens:

```
State 8

    1 exp: exp • '+' exp
    1    | exp '+' exp •  [$end, '+', '-', '/']
    2    | exp • '-' exp
    3    | exp • '*' exp
    4    | exp • '/' exp

    '*'  shift, and go to state 6
    '/'  shift, and go to state 7

    '/'      [reduce using rule 1 (exp)]
    $default  reduce using rule 1 (exp)
```

Note however that while 'NUM + NUM / NUM' is ambiguous (which results in the conflicts on '/'), 'NUM + NUM * NUM' is not: the conflict was solved thanks to associativity and precedence directives. If invoked with `--report=solved`, Bison includes information about the solved conflicts in the report:

```
Conflict between rule 1 and token '+' resolved as reduce (%left '+').
Conflict between rule 1 and token '-' resolved as reduce (%left '-').
Conflict between rule 1 and token '*' resolved as shift ('+' < '*').
```

When given `--report=counterexamples`, bison will generate counterexamples within the report, augmented with the corresponding items (see Section 8.1 [Generation of Counterexamples], page 135).

```
shift/reduce conflict on token '/':
    1 exp: exp '+' exp •
    4 exp: exp • '/' exp
  Example: exp '+' exp • '/' exp
  Shift derivation
    exp
    → exp '+' exp
                → exp • '/' exp
  Example: exp '+' exp • '/' exp
  Reduce derivation
    exp
    → exp                '/' exp
        → exp '+' exp •
```

This shows two separate derivations in the grammar for the same exp: 'e1 + e2 / e3'. The derivations show how your rules would parse the given example. Here, the first derivation completes a reduction when seeing '/', causing 'e1 + e2' to be grouped as an exp. The second derivation shifts on '/', resulting in 'e2 / e3' being grouped as an exp. Therefore, it is easy to see that adding `%precedence` directives would fix this conflict.

The remaining states are similar:

```
State 9

    1 exp: exp • '+' exp
    2    | exp • '-' exp
    2    | exp '-' exp •
    3    | exp • '*' exp
    4    | exp • '/' exp

    '*'  shift, and go to state 6
    '/'  shift, and go to state 7

    '/'      [reduce using rule 2 (exp)]
    $default  reduce using rule 2 (exp)
```

```
     State 10

         1 exp: exp • '+' exp
         2    | exp • '-' exp
         3    | exp • '*' exp
         3    | exp '*' exp •
         4    | exp • '/' exp

         '/'  shift, and go to state 7

         '/'        [reduce using rule 3 (exp)]
         $default  reduce using rule 3 (exp)

     State 11

         1 exp: exp • '+' exp
         2    | exp • '-' exp
         3    | exp • '*' exp
         4    | exp • '/' exp
         4    | exp '/' exp •

         '+'  shift, and go to state 4
         '-'  shift, and go to state 5
         '*'  shift, and go to state 6
         '/'  shift, and go to state 7

         '+'        [reduce using rule 4 (exp)]
         '-'        [reduce using rule 4 (exp)]
         '*'        [reduce using rule 4 (exp)]
         '/'        [reduce using rule 4 (exp)]
         $default  reduce using rule 4 (exp)
```

Observe that state 11 contains conflicts not only due to the lack of precedence of '/' with respect to '+', '-', and '*', but also because the associativity of '/' is not specified.

Bison may also produce an HTML version of this output, via an XML file and XSLT processing (see Section 8.4 [Visualizing your parser in multiple formats], page 148).

8.3 Visualizing Your Parser

As another means to gain better understanding of the shift/reduce automaton corresponding to the Bison parser, a DOT file can be generated. Note that debugging a real grammar with this is tedious at best, and impractical most of the times, because the generated files are huge (the generation of a PDF or PNG file from it will take very long, and more often than not it will fail due to memory exhaustion). This option was rather designed for beginners, to help them understand LR parsers.

This file is generated when the `--graph` option is specified (see Chapter 9 [Invoking Bison], page 154). Its name is made by removing '.tab.c' or '.c' from the parser implementation file name, and adding '.gv' instead. If the grammar file is `foo.y`, the Graphviz

output file is called `foo.gv`. A DOT file may also be produced via an XML file and XSLT processing (see Section 8.4 [Visualizing your parser in multiple formats], page 148).

The following grammar file, `rr.y`, will be used in the sequel:

```
%%
exp: a ";" | b ".";
a: "0";
b: "0";
```

The graphical output (see Figure 8.1) is very similar to the textual one, and as such it is easier understood by making direct comparisons between them. See Chapter 8 [Debugging Your Parser], page 135, for a detailed analysis of the textual report.
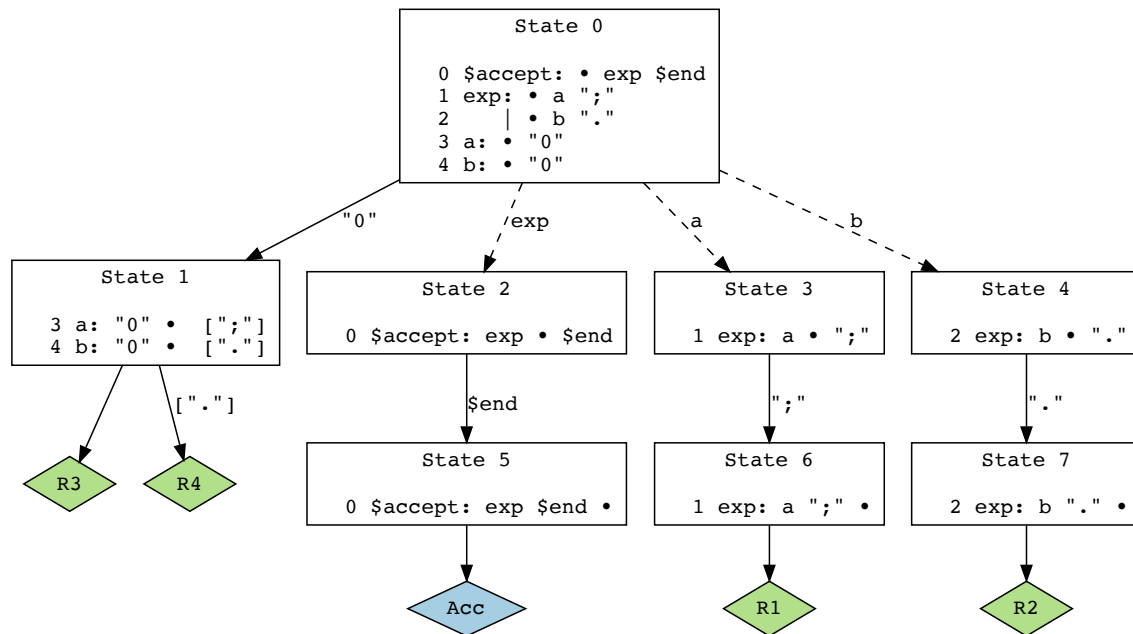
Figure 8.1: A graphical rendering of the parser.

Graphical Representation of States

The items (dotted rules) for each state are grouped together in graph nodes. Their numbering is the same as in the verbose file. See the following points, about transitions, for examples

When invoked with `--report=lookaheads`, the lookahead tokens, when needed, are shown next to the relevant rule between square brackets as a comma separated list. This is the case in the figure for the representation of reductions, below.

The transitions are represented as directed edges between the current and the target states.

Graphical Representation of Shifts

Shifts are shown as solid arrows, labeled with the lookahead token for that shift. The following describes a reduction in the `rr.output` file:

```
State 3

    1 exp: a • ";"

    ";"  shift, and go to state 6
```

A Graphviz rendering of this portion of the graph could be:

```
        ┌─────────────────────┐
        │       State 3       │
        │  1 exp: a • "."     │
        └─────────────────────┘
                   │
                  "."
                   ▼
        ┌─────────────────────┐
        │       State 6       │
        │  1 exp: a "." •     │
        └─────────────────────┘
```
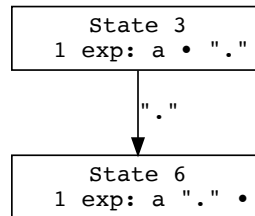
Graphical Representation of Reductions

Reductions are shown as solid arrows, leading to a diamond-shaped node bearing the number of the reduction rule. The arrow is labeled with the appropriate comma separated lookahead tokens. If the reduction is the default action for the given state, there is no such label.

This is how reductions are represented in the verbose file `rr.output`:

```
State 1

    3 a: "0" •  [";"]
    4 b: "0" •  ["."]

    "."      reduce using rule 4 (b)
    $default  reduce using rule 3 (a)
```

A Graphviz rendering of this portion of the graph could be:

```
        ┌─────────────────────────┐
        │         State 1         │
        │  3 a: "0" •  ["."]      │
        │  4 b: "0" •  [";"]      │
        └─────────────────────────┘
            │               │
            │             [";"]
            ▼               ▼
          ◇ R3           ◇ R4
```
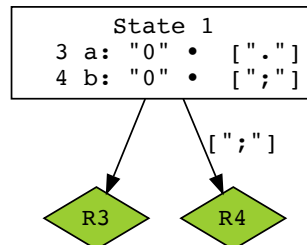
When unresolved conflicts are present, because in deterministic parsing a single decision can be made, Bison can arbitrarily choose to disable a reduction, see Section 5.2 [Shift/Reduce Conflicts], page 112. Discarded actions are distinguished by a red filling color on these nodes, just like how they are reported between square brackets in the verbose file.

The reduction corresponding to the rule number 0 is the acceptation state. It is shown as a blue diamond, labeled "Acc".

Graphical Representation of Gotos

The 'go to' jump transitions are represented as dotted lines bearing the name of the rule being jumped to.

8.4 Visualizing your parser in multiple formats

Bison supports two major report formats: textual output (see Section 8.2 [Understanding Your Parser], page 138) when invoked with option `--verbose`, and DOT (see Section 8.3 [Visualizing Your Parser], page 145) when invoked with option `--graph`. However, another alternative is to output an XML file that may then be, with `xsltproc`, rendered as either a raw text format equivalent to the verbose file, or as an HTML version of the same file, with clickable transitions, or even as a DOT. The `.output` and DOT files obtained via XSLT have no difference whatsoever with those obtained by invoking `bison` with options `--verbose` or `--graph`.

The XML file is generated when the options `-x` or `--xml[=FILE]` are specified, see Chapter 9 [Invoking Bison], page 154. If not specified, its name is made by removing '`.tab.c`' or '`.c`' from the parser implementation file name, and adding '`.xml`' instead. For instance, if the grammar file is `foo.y`, the default XML output file is `foo.xml`.

Bison ships with a `data/xslt` directory, containing XSL Transformation files to apply to the XML file. Their names are non-ambiguous:

`xml2dot.xsl`

> Used to output a copy of the DOT visualization of the automaton.

`xml2text.xsl`

> Used to output a copy of the '`.output`' file.

`xml2xhtml.xsl`

> Used to output an xhtml enhancement of the '`.output`' file.

Sample usage (requires `xsltproc`):

```
$ bison -x gr.y
$ bison --print-datadir
/usr/local/share/bison
$ xsltproc /usr/local/share/bison/xslt/xml2xhtml.xsl gr.xml >gr.html
```

8.5 Tracing Your Parser

When a Bison grammar compiles properly but parses "incorrectly", the `yydebug` parser-trace feature helps figuring out why.

8.5.1 Enabling Traces

There are several means to enable compilation of trace facilities, in decreasing order of preference:

the variable '`parse.trace`'

> Add the '`%define parse.trace`' directive (see Section 3.7.14 [%define Summary], page 84), or pass the `-Dparse.trace` option (see Section 9.1.3 [Tuning

the Parser], page 161). This is a Bison extension. Unless POSIX and Yacc portability matter to you, this is the preferred solution.

the option `-t` (POSIX Yacc compliant)

the option `--debug` (Bison extension)

Use the `-t` option when you run Bison (see Chapter 9 [Invoking Bison], page 154). With '`%define api.prefix {c}`', it defines `CDEBUG` to 1, otherwise it defines `YYDEBUG` to 1.

the directive '`%debug`' (deprecated)

Add the `%debug` directive (see Section 3.7.13 [Bison Declaration Summary], page 79). This Bison extension is maintained for backward compatibility with previous versions of Bison; use `%define parse.trace` instead.

the macro `YYDEBUG` (C/C++ only)

Define the macro `YYDEBUG` to a nonzero value when you compile the parser. This is compliant with POSIX Yacc. You could use `-DYYDEBUG=1` as a compiler option or you could put '`#define YYDEBUG 1`' in the prologue of the grammar file (see Section 3.1.1 [The prologue], page 46).

If the `%define` variable `api.prefix` is used (see Section 3.8 [Multiple Parsers in the Same Program], page 95), for instance '`%define api.prefix {c}`', then if `CDEBUG` is defined, its value controls the tracing feature (enabled if and only if nonzero); otherwise tracing is enabled if and only if `YYDEBUG` is nonzero.

We suggest that you always enable the trace option so that debugging is always possible.

In C the trace facility outputs messages with macro calls of the form `YYFPRINTF (stderr, format, args)` where *format* and *args* are the usual `printf` format and variadic arguments. If you define `YYDEBUG` to a nonzero value but do not define `YYFPRINTF`, `<stdio.h>` is automatically included and `YYFPRINTF` is defined to `fprintf`.

Once you have compiled the program with trace facilities, the way to request a trace is to store a nonzero value in the variable `yydebug`. You can do this by making the C code do it (in `main`, perhaps), or you can alter the value with a C debugger.

Each step taken by the parser when `yydebug` is nonzero produces a line or two of trace information, written on `stderr`. The trace messages tell you these things:

- Each time the parser calls `yylex`, what kind of token was read.
- Each time a token is shifted, the depth and complete contents of the state stack (see Section 5.5 [Parser States], page 117).
- Each time a rule is reduced, which rule it is, and the complete contents of the state stack afterward.

To make sense of this information, it helps to refer to the automaton description file (see Section 8.2 [Understanding Your Parser], page 138). This file shows the meaning of each state in terms of positions in various rules, and also what each state will do with each possible input token. As you read the successive trace messages, you can see that the parser is functioning according to its specification in the listing file. Eventually you will arrive at the place where something undesirable happens, and you will see which parts of the grammar are to blame.

The parser implementation file is a C/C++/Java program and you can use debuggers on it, but it's not easy to interpret what it is doing. The parser function is a finite-state machine interpreter, and aside from the actions it executes the same code over and over. Only the values of variables show where in the grammar it is working.

8.5.2 Enabling Debug Traces for `mfcalc`

The debugging information normally gives the token kind of each token read, but not its semantic value. The `%printer` directive allows specify how semantic values are reported, see Section 3.7.8 [Printing Semantic Values], page 75.

As a demonstration of `%printer`, consider the multi-function calculator, `mfcalc` (see Section 2.5 [Multi-Function Calculator: `mfcalc`], page 39). To enable run-time traces, and semantic value reports, insert the following directives in its prologue:

```
/* Generate the parser description file. */
%verbose
/* Enable run-time traces (yydebug). */
%define parse.trace

/* Formatting semantic values. */
%printer { fprintf (yyo, "%s", $$->name); } VAR;
%printer { fprintf (yyo, "%s()", $$->name); } FUN;
%printer { fprintf (yyo, "%g", $$); } <double>;
```

The `%define` directive instructs Bison to generate run-time trace support. Then, activation of these traces is controlled at run-time by the `yydebug` variable, which is disabled by default. Because these traces will refer to the "states" of the parser, it is helpful to ask for the creation of a description of that parser; this is the purpose of (admittedly ill-named) `%verbose` directive.

The set of `%printer` directives demonstrates how to format the semantic value in the traces. Note that the specification can be done either on the symbol type (e.g., `VAR` or `FUN`), or on the type tag: since `<double>` is the type for both `NUM` and `exp`, this printer will be used for them.

Here is a sample of the information provided by run-time traces. The traces are sent onto standard error.

```
$ echo 'sin(1-1)' | ./mfcalc -p
Starting parse
Entering state 0
Reducing stack by rule 1 (line 34):
-> $$ = nterm input ()
Stack now 0
Entering state 1
```

This first batch shows a specific feature of this grammar: the first rule (which is in line 34 of `mfcalc.y` can be reduced without even having to look for the first token. The resulting left-hand symbol (`$$`) is a valueless ('()') `input` nonterminal (`nterm`).

Then the parser calls the scanner.

```
Reading a token
Next token is token FUN (sin())
```

```
    Shifting token FUN (sin())
    Entering state 6
```

That token (`token`) is a function (`FUN`) whose value is 'sin' as formatted per our `%printer`
specification: 'sin()'. The parser stores (`Shifting`) that token, and others, until it can do
something about it.

```
    Reading a token
    Next token is token '(' ()
    Shifting token '(' ()
    Entering state 14
    Reading a token
    Next token is token NUM (1.000000)
    Shifting token NUM (1.000000)
    Entering state 4
    Reducing stack by rule 6 (line 44):
       $1 = token NUM (1.000000)
    -> $$ = nterm exp (1.000000)
    Stack now 0 1 6 14
    Entering state 24
```

The previous reduction demonstrates the `%printer` directive for `<double>`: both the token
`NUM` and the resulting nonterminal `exp` have '1' as value.

```
    Reading a token
    Next token is token '-' ()
    Shifting token '-' ()
    Entering state 17
    Reading a token
    Next token is token NUM (1.000000)
    Shifting token NUM (1.000000)
    Entering state 4
    Reducing stack by rule 6 (line 44):
       $1 = token NUM (1.000000)
    -> $$ = nterm exp (1.000000)
    Stack now 0 1 6 14 24 17
    Entering state 26
    Reading a token
    Next token is token ')' ()
    Reducing stack by rule 11 (line 49):
       $1 = nterm exp (1.000000)
       $2 = token '-' ()
       $3 = nterm exp (1.000000)
    -> $$ = nterm exp (0.000000)
    Stack now 0 1 6 14
    Entering state 24
```

The rule for the subtraction was just reduced. The parser is about to discover the end of
the call to `sin`.

```
    Next token is token ')' ()
```

```
Shifting token ')' ()
Entering state 31
Reducing stack by rule 9 (line 47):
   $1 = token FUN (sin())
   $2 = token '(' ()
   $3 = nterm exp (0.000000)
   $4 = token ')' ()
-> $$ = nterm exp (0.000000)
Stack now 0 1
Entering state 11
```

Finally, the end-of-line allow the parser to complete the computation, and display its result.

```
Reading a token
Next token is token '\n' ()
Shifting token '\n' ()
Entering state 22
Reducing stack by rule 4 (line 40):
   $1 = nterm exp (0.000000)
   $2 = token '\n' ()
⇒ 0
-> $$ = nterm line ()
Stack now 0 1
Entering state 10
Reducing stack by rule 2 (line 35):
   $1 = nterm input ()
   $2 = nterm line ()
-> $$ = nterm input ()
Stack now 0
Entering state 1
```

The parser has returned into state 1, in which it is waiting for the next expression to evaluate, or for the end-of-file token, which causes the completion of the parsing.

```
Reading a token
Now at end of input.
Shifting token $end ()
Entering state 2
Stack now 0 1 2
Cleanup: popping token $end ()
Cleanup: popping nterm input ()
```

8.5.3 The `YYPRINT` Macro

The `%printer` directive was introduced in Bison 1.50 (November 2002). Before then, `YYPRINT` provided a similar feature, but only for terminal symbols and only with the `yacc.c` skeleton.

`YYPRINT (stream, token, value);`   [Macro]
    Deprecated, will be removed eventually.

If you define `YYPRINT`, it should take three arguments. The parser will pass a standard I/O stream, the numeric code for the token kind, and the token value (from `yylval`).

For `yacc.c` only. Obsoleted by `%printer`.

Here is an example of `YYPRINT` suitable for the multi-function calculator (see Section 2.5.1 [Declarations for `mfcalc`], page 39):

```
%{
  static void print_token_value (FILE *file, int type, YYSTYPE value);
  #define YYPRINT(File, Type, Value)            \
    print_token_value (File, Type, Value)
%}

... %% ... %% ...

static void
print_token_value (FILE *file, yytoken_kind_t kind, YYSTYPE value)
{
  if (kind == VAR)
    fprintf (file, "%s", value.tptr->name);
  else if (kind == NUM)
    fprintf (file, "%d", value.val);
}
```

See Section 8.5.2 [Enabling Debug Traces for `mfcalc`], page 150, for the proper use of `%printer`.

9 Invoking Bison

The usual way to invoke Bison is as follows:

```
$ bison file
```

Here *file* is the grammar file name, which usually ends in '.y'. The parser implementation file's name is made by replacing the '.y' with '.tab.c' and removing any leading directory. Thus, the 'bison foo.y' file name yields foo.tab.c, and the 'bison hack/foo.y' file name yields foo.tab.c. It's also possible, in case you are writing C++ code instead of C in your grammar file, to name it foo.ypp or foo.y++. Then, the output files will take an extension like the given one as input (respectively foo.tab.cpp and foo.tab.c++). This feature takes effect with all options that manipulate file names like -o or -d.

For example:

```
$ bison -d file.yxx
```

will produce file.tab.cxx and file.tab.hxx, and

```
$ bison -d -o output.c++ file.y
```

will produce output.c++ and output.h++.

For compatibility with POSIX, the standard Bison distribution also contains a shell script called yacc that invokes Bison with the -y option.

The exit status of bison is:

0 (success)

when there were no errors. Warnings, which are diagnostics about dubious constructs, do not change the exit status, unless they are turned into errors (see [-Werror], page 160).

1 (failure)   when there were errors. No file was generated (except the reports generated by --verbose, etc.). In particular, the output files that possibly existed were not changed.

63 (mismatch)

when bison does not meet the version requirements of the grammar file. See Section 3.7.1 [Require a Version of Bison], page 70. No file was generated or changed.

9.1 Bison Options

Bison supports both traditional single-letter options and mnemonic long option names. Long option names are indicated with -- instead of -. Abbreviations for option names are allowed as long as they are unique. When a long option takes an argument, like --file-prefix, connect the option name and the argument with '='.

Here is a list of options that can be used with Bison. It is followed by a cross key alphabetized by long option.

9.1.1 Operation Modes

Options controlling the global behavior of `bison`.

`-h`
`--help`   Print a summary of the command-line options to Bison and exit.

`-V`
`--version`
       Print the version number of Bison and exit.

`--print-localedir`
       Print the name of the directory containing locale-dependent data.

`--print-datadir`
       Print the name of the directory containing skeletons, CSS and XSLT.

`-u`

`--update`   Update the grammar file (remove duplicates, update deprecated directives, etc.)
and exit (i.e., do not generate any of the output files). Leaves a backup of the
original file with a ~ appended. For instance:

```
$ cat foo.y
%error-verbose
%define parse.error verbose
%%
exp:;
$ bison -u foo.y
foo.y:1.1-14: warning: deprecated directive, use '%define parse.error ver-
bose' [-Wdeprecated]
    1 | %error-verbose
      | ^~~~~~~~~~~~~~
foo.y:2.1-27: warning: %define variable 'parse.error' redefined [-
Wother]
    2 | %define parse.error verbose
      | ^~~~~~~~~~~~~~~~~~~~~~~~~~~
foo.y:1.1-14:      previous definition
    1 | %error-verbose
      | ^~~~~~~~~~~~~~
bison: file 'foo.y' was updated (backup: 'foo.y~')
$ cat foo.y
%define parse.error verbose
%%
exp:;
```

       See the documentation of `--feature=fixit` below for more details.

`-f [feature]`
`--feature[=feature]`
       Activate miscellaneous *feature*s. *Feature* can be one of:

caret
diagnostics-show-caret
       Show caret errors, in a manner similar to GCC's `-fdiagnostics-show-caret`, or Clang's `-fcaret-diagnostics`. The location provided with the message is used to quote the corresponding line of the source file, underlining the important part of it with carets (`^`). Here is an example, using the following file `in.y`:

```
%nterm <ival> exp
%%
exp: exp '+' exp { $exp = $1 + $2; };
```

       When invoked with `-fcaret` (or nothing), Bison will report:

```
in.y:3.20-23: error: ambiguous reference: '$exp'
    3 | exp: exp '+' exp { $exp = $1 + $2; };
      |                    ^~~~
in.y:3.1-3:       refers to: $exp at $$
    3 | exp: exp '+' exp { $exp = $1 + $2; };
      | ^~~
in.y:3.6-8:       refers to: $exp at $1
    3 | exp: exp '+' exp { $exp = $1 + $2; };
      |      ^~~
in.y:3.14-16:     refers to: $exp at $3
    3 | exp: exp '+' exp { $exp = $1 + $2; };
      |               ^~~
in.y:3.32-33: error: $2 of 'exp' has no declared type
    3 | exp: exp '+' exp { $exp = $1 + $2; };
      |                                ^~
```

       Whereas, when invoked with `-fno-caret`, Bison will only report:

```
in.y:3.20-23: error: ambiguous reference: '$exp'
in.y:3.1-3:       refers to: $exp at $$
in.y:3.6-8:       refers to: $exp at $1
in.y:3.14-16:     refers to: $exp at $3
in.y:3.32-33: error: $2 of 'exp' has no declared type
```

       This option is activated by default.

fixit
diagnostics-parseable-fixits
       Show machine-readable fixes, in a manner similar to GCC's and Clang's `-fdiagnostics-parseable-fixits`.

       Fix-its are generated for duplicate directives:

```
$ cat foo.y
%define api.prefix {foo}
%define api.prefix {bar}
%%
exp:;
```

```
$ bison -ffixit foo.y
foo.y:2.1-24: error: %define variable 'api.prefix' redefined
    2 | %define api.prefix {bar}
      | ˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜
foo.y:1.1-24:      previous definition
    1 | %define api.prefix {foo}
      | ˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜
fix-it:"foo.y":{2:1-2:25}:""
foo.y: warning: fix-its can be applied.  Rerun with op-
tion '--update'. [-Wother]
```

They are also generated to update deprecated directives, unless
`-Wno-deprecated` was given:

```
$ cat /tmp/foo.yy
%error-verbose
%name-prefix "foo"
%%
exp:;
$ bison foo.y
foo.y:1.1-14: warning: deprecated directive, use '%de-
fine parse.error verbose' [-Wdeprecated]
    1 | %error-verbose
      | ˜˜˜˜˜˜˜˜˜˜˜˜˜˜
foo.y:2.1-18: warning: deprecated directive, use '%de-
fine api.prefix {foo}' [-Wdeprecated]
    2 | %name-prefix "foo"
      | ˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜˜
foo.y: warning: fix-its can be applied.  Rerun with op-
tion '--update'. [-Wother]
```

The fix-its are applied by `bison` itself when given the option
`-u`/`--update`. See its documentation above.

syntax-only

> Do not generate the output files. The name of this feature is some-
> what misleading as more than just checking the syntax is done:
> every stage is run (including checking for conflicts for instance),
> except the generation of the output files.

9.1.2 Diagnostics

Options controlling the diagnostics.

`-W [category]`
`--warnings[=category]`

> Output warnings falling in *category*. *category* can be one of:

> conflicts-sr
> conflicts-rr

>> S/R and R/R conflicts. These warnings are enabled by default.
>> However, if the `%expect` or `%expect-rr` directive is specified, an

unexpected number of conflicts is an error, and an expected number of conflicts is not reported, so `-W` and `--warning` then have no effect on the conflict report.

`counterexamples`

`cex`   Provide counterexamples for conflicts. See Section 8.1 [Generation of Counterexamples], page 135. Counterexamples take time to compute. The option `-Wcex` should be used by the developer when working on the grammar; it hardly makes sense to use it in a CI.

`dangling-alias`

Report string literals that are not bound to a token symbol.

String literals, which allow for better error messages, are (too) liberally accepted by Bison, which might result in silent errors. For instance

```
%type <exVal> cond "condition"
```

does not define "condition" as a string alias to `cond`—nonterminal symbols do not have string aliases. It is rather equivalent to

```
%nterm <exVal> cond
%token <exVal> "condition"
```

i.e., it gives the '`"condition"`' token the type `exVal`.

Also, because string aliases do not need to be defined, typos such as '`"baz"`' instead of '`"bar"`' will be not reported.

The option `-Wdangling-alias` catches these situations. On

```
%token BAR "bar"
%type <ival> foo "foo"
%%
foo: "baz" {}
```

`bison -Wdangling-alias` reports

```
warning: string literal not attached to a symbol
      | %type <ival> foo "foo"
      |                   ~~~~~
warning: string literal not attached to a symbol
      | foo: "baz" {}
      |      ~~~~~
```

`deprecated`

Deprecated constructs whose support will be removed in future versions of Bison.

`empty-rule`

Empty rules without `%empty`. See Section 3.3.2 [Empty Rules], page 55. Disabled by default, but enabled by uses of `%empty`, unless `-Wno-empty-rule` was specified.

`midrule-values`

> Warn about midrule values that are set but not used within any of the actions of the parent rule. For example, warn about unused `$2` in:
>
> ```
> exp: '1' { $$ = 1; } '+' exp { $$ = $1 + $4; };
> ```
>
> Also warn about midrule values that are used but not set. For example, warn about unset `$$` in the midrule action in:
>
> ```
> exp: '1' { $1 = 1; } '+' exp { $$ = $2 + $4; };
> ```
>
> These warnings are not enabled by default since they sometimes prove to be false alarms in existing grammars employing the Yacc constructs `$0` or `$-n` (where *n* is some positive integer).

`precedence`

> Useless precedence and associativity directives. Disabled by default.
>
> Consider for instance the following grammar:
>
> ```
> %nonassoc "="
> %left "+"
> %left "*"
> %precedence "("
> %%
> stmt:
>   exp
> | "var" "=" exp
> ;
>
> exp:
>   exp "+" exp
> | exp "*" "number"
> | "(" exp ")"
> | "number"
> ;
> ```
>
> Bison reports:
>
> ```
> warning: useless precedence and associativity for "="
>         | %nonassoc "="
>         |           ^~~
>
> warning: useless associativity for "*", use %precedence
>         | %left "*"
>         |       ^~~
>
> warning: useless precedence for "("
>         | %precedence "("
>         |             ^~~
> ```
>
> One would get the exact same parser with the following directives instead:

```
                              %left "+"
                              %precedence "*"
```

yacc   Incompatibilities with POSIX Yacc.

other   All warnings not categorized above. These warnings are enabled by default.

          This category is provided merely for the sake of completeness. Future releases of Bison may move warnings from this category to new, more specific categories.

all   All the warnings except `counterexamples`, `dangling-alias` and `yacc`.

none   Turn off all the warnings.

error   See `-Werror`, below.

A category can be turned off by prefixing its name with 'no-'. For instance, `-Wno-yacc` will hide the warnings about POSIX Yacc incompatibilities.

`-Werror`   Turn enabled warnings for every *category* into errors, unless they are explicitly disabled by `-Wno-error=category`.

`-Werror=category`

          Enable warnings falling in *category*, and treat them as errors.

          category is the same as for `--warnings`, with the exception that it may not be prefixed with 'no-' (see above).

          Note that the precedence of the '=' and ',' operators is such that the following commands are *not* equivalent, as the first will not treat S/R conflicts as errors.

```
        $ bison -Werror=yacc,conflicts-sr input.y
        $ bison -Werror=yacc,error=conflicts-sr input.y
```

`-Wno-error`

          Do not turn enabled warnings for every *category* into errors, unless they are explicitly enabled by `-Werror=category`.

`-Wno-error=category`

          Deactivate the error treatment for this *category*. However, the warning itself won't be disabled, or enabled, by this option.

`--color`   Equivalent to `--color=always`.

`--color=when`

          Control whether diagnostics are colorized, depending on *when*:

always
yes   Enable colorized diagnostics.

never
no   Disable colorized diagnostics.

auto (default)
tty   Diagnostics will be colorized if the output device is a tty, i.e. when the output goes directly to a text screen or terminal emulator window.

`--style=`*`file`*

>   Specifies the CSS style *file* to use when colorizing. It has an effect only when
>   the `--color` option is effective. The `bison-default.css` file provide a good
>   example from which to define your own style file. See the documentation of
>   libtextstyle for more details.

9.1.3 Tuning the Parser

Options changing the generated parsers.

`-t`

`--debug`   In the parser implementation file, define the macro `YYDEBUG` to 1 if it is not
            already defined, so that the debugging facilities are compiled. See Section 8.5
            [Tracing Your Parser], page 148.

`-D `*`name`*`[=`*`value`*`]`
`--define=`*`name`*`[=`*`value`*`]`
`-F `*`name`*`[=`*`value`*`]`
`--force-define=`*`name`*`[=`*`value`*`]`

>   Each of these is equivalent to '`%define `*`name`*` `*`value`*`'` (see Section 3.7.14
>   [%define Summary], page 84).   Note that the delimiters are part of
>   *value*:   `-Dapi.value.type=union`, `-Dapi.value.type={union}` and
>   `-Dapi.value.type="union"` correspond to '`%define api.value.type union`',
>   '`%define api.value.type {union}`' and '`%define api.value.type "union"`'.
>
>   Bison processes multiple definitions for the same *name* as follows:
>
>   - Bison quietly ignores all command-line definitions for *name* except the last.
>
>   - If that command-line definition is specified by a `-D` or `--define`, Bison
>   reports an error for any `%define` definition for *name*.
>
>   - If that command-line definition is specified by a `-F` or `--force-define`
>   instead, Bison quietly ignores all `%define` definitions for *name*.
>
>   - Otherwise, Bison reports an error if there are multiple `%define` definitions
>   for *name*.
>
>   You should avoid using `-F` and `--force-define` in your make files unless you
>   are confident that it is safe to quietly ignore any conflicting `%define` that may
>   be added to the grammar file.

`-L `*`language`*
`--language=`*`language`*

>   Specify the programming language for the generated parser, as if `%language` was
>   specified (see Section 3.7.13 [Bison Declaration Summary], page 79). Currently
>   supported languages include C, C++, and Java. *language* is case-insensitive.

`--locations`

>   Pretend that `%locations` was specified. See Section 3.7.13 [Bison Declaration
>   Summary], page 79.

`-p` *prefix*

`--name-prefix=`*prefix*

> Pretend that `%name-prefix "`*prefix*`"` was specified (see Section 3.7.13 [Bison Declaration Summary], page 79). Obsoleted by `-Dapi.prefix=`*prefix*. See Section 3.8 [Multiple Parsers in the Same Program], page 95.

`-l`

`--no-lines`

> Don't put any `#line` preprocessor commands in the parser implementation file. Ordinarily Bison puts them in the parser implementation file so that the C compiler and debuggers will associate errors with your source file, the grammar file. This option causes them to associate errors with the parser implementation file, treating it as an independent source file in its own right.

`-S` *file*

`--skeleton=`*file*

> Specify the skeleton to use, similar to `%skeleton` (see Section 3.7.13 [Bison Declaration Summary], page 79).
>
> If *file* does not contain a `/`, *file* is the name of a skeleton file in the Bison installation directory. If it does, *file* is an absolute file name or a file name relative to the current working directory. This is similar to how most shells resolve commands.

`-k`

`--token-table`

> Pretend that `%token-table` was specified. See Section 3.7.13 [Bison Declaration Summary], page 79.

`-y`

`--yacc`   Act more like the traditional `yacc` command. This can cause different diagnostics to be generated (it implies `-Wyacc`), and may change behavior in other minor ways. Most importantly, imitate Yacc's output file name conventions, so that the parser implementation file is called `y.tab.c`, and the other outputs are called `y.output` and `y.tab.h`. Also, generate `#define` statements in addition to an `enum` to associate token codes with token kind names. Thus, the following shell script can substitute for Yacc, and the Bison distribution contains such a script for compatibility with POSIX:

```
#! /bin/sh
bison -y "$@"
```

> The `-y`/`--yacc` option is intended for use with traditional Yacc grammars. This option only makes sense for the default C skeleton, `yacc.c`. If your grammar uses Bison extensions Bison cannot be Yacc-compatible, even if this option is specified.

9.1.4 Output Files

Options controlling the output.

`--defines[=`*`file`*`]`

> Pretend that `%defines` was specified, i.e., write an extra output file containing definitions for the token kind names defined in the grammar, as well as a few other declarations. See Section 3.7.13 [Bison Declaration Summary], page 79.

`-d`   This is the same as `--defines` except `-d` does not accept a *file* argument since POSIX Yacc requires that `-d` can be bundled with other short options.

`-b` *`file-prefix`*
`--file-prefix=`*`prefix`*

> Pretend that `%file-prefix` was specified, i.e., specify prefix to use for all Bison output file names. See Section 3.7.13 [Bison Declaration Summary], page 79.

`-r` *`things`*
`--report=`*`things`*

> Write an extra output file containing verbose description of the comma separated list of *things* among:
>
> `state`   Description of the grammar, conflicts (resolved and unresolved), and parser's automaton.
>
> `itemset`   Implies `state` and augments the description of the automaton with the full set of items for each state, instead of its core only.
>
> `lookahead`
> > Implies `state` and augments the description of the automaton with each rule's lookahead set.
>
> `solved`   Implies `state`. Explain how conflicts were solved thanks to precedence and associativity directives.
>
> `counterexamples`
> `cex`   Look for counterexamples for the conflicts. See Section 8.1 [Generation of Counterexamples], page 135. Counterexamples take time to compute. The option `-rcex` should be used by the developer when working on the grammar; it hardly makes sense to use it in a CI.
>
> `all`   Enable all the items.
>
> `none`   Do not generate the report.

`--report-file=`*`file`*

> Specify the *file* for the verbose description.

`-v`
`--verbose`

> Pretend that `%verbose` was specified, i.e., write an extra output file containing verbose descriptions of the grammar and parser. See Section 3.7.13 [Bison Declaration Summary], page 79.

`-o` *`file`*
`--output=`*`file`*

> Specify the *file* for the parser implementation file.

> The names of the other output files are constructed from *file* as described under the `-v` and `-d` options.

`-g [file]`
`--graph[=file]`
> Output a graphical representation of the parser's automaton computed by Bison, in Graphviz (`http://www.graphviz.org/`) DOT (`http://www.graphviz.org/doc/info/lang.html`) format. *file* is optional. If omitted and the grammar file is `foo.y`, the output file will be `foo.gv` if the `%required` version is 3.4 or better, `foo.dot` otherwise.

`-x [file]`
`--xml[=file]`
> Output an XML report of the parser's automaton computed by Bison. *file* is optional. If omitted and the grammar file is `foo.y`, the output file will be `foo.xml`.

`-M old=new`
`--file-prefix-map=old=new`
> Replace prefix *old* with *new* when writing file paths in output files

9.2 Option Cross Key

Here is a list of options, alphabetized by long option, to help you find the corresponding short option and directive.

Long Option	Short Option	Bison Directive
`--color[=when]`		
`--debug`	`-t`	`%debug`
`--define=name[=value]`	`-D name[=value]`	`%define name [value]`
`--defines[=file]`	`-d`	`%defines ["file"]`
`--feature[=features]`	`-f [features]`	
`--file-prefix-map=old=new`	`-M old=new`	
`--file-prefix=prefix`	`-b prefix`	`%file-prefix "prefix"`
`--force-define=name[=value]`	`-F name[=value]`	`%define name [value]`
`--graph[=file]`	`-g [file]`	
`--help`	`-h`	
`--language=language`	`-L language`	`%language "language"`
`--locations`		`%locations`
`--name-prefix=prefix`	`-p prefix`	`%name-prefix "prefix"`
`--no-lines`	`-l`	`%no-lines`
`--output=file`	`-o file`	`%output "file"`
`--print-datadir`		
`--print-localedir`		
`--report-file=file`		
`--report=things`	`-r things`	
`--skeleton=file`	`-S file`	`%skeleton "file"`
`--style=file`		
`--token-table`	`-k`	`%token-table`

```
--update                        -u
--verbose                       -v                      %verbose
--version                       -V
--warnings[=category]           -W [category]
--xml[=file]                    -x [file]
--yacc                          -y                      %yacc
```

9.3 Yacc Library

The Yacc library contains default implementations of the `yyerror` and `main` functions. These default implementations are normally not useful, but POSIX requires them. To use the Yacc library, link your program with the `-ly` option. Note that Bison's implementation of the Yacc library is distributed under the terms of the GNU General Public License (see [GNU GENERAL PUBLIC LICENSE], page 3).

If you use the Yacc library's `yyerror` function, you should declare `yyerror` as follows:

```
int yyerror (char const *);
```

The `int` value returned by this `yyerror` is ignored.

The implementation of Yacc library's `main` function is:

```
int main (void)
{
  setlocale (LC_ALL, "");
  return yyparse ();
}
```

so if you use it, the internationalization support is enabled (e.g., error messages are translated), and your `yyparse` function should have the following type signature:

```
int yyparse (void);
```

10 Parsers Written In Other Languages

In addition to C, Bison can generate parsers in C++ and Java. This chapter is devoted to these languages. The reader is expected to understand how Bison works; read the introductory chapters first if you don't.

10.1 C++ Parsers

The Bison parser in C++ is an object, an instance of the class `yy::parser`.

10.1.1 A Simple C++ Example

This tutorial about C++ parsers is based on a simple, self contained example. The following sections are the reference manual for Bison with C++, the last one showing a fully blown example (see Section 10.1.8 [++ Example-title⟨undefined⟩], page 181).

To look nicer, our example will be in C++14. It is not required: Bison supports the original C++98 standard.

A Bison file has three parts. In the first part, the prologue, we start by making sure we run a version of Bison which is recent enough, and that we generate C++.

```
%require "3.2"
%language "c++"
```

Let's dive directly into the middle part: the grammar. Our input is a simple list of strings, that we display once the parsing is done.

```
%%
result:
  list  { std::cout << $1 << '\n'; }
;


%nterm <std::vector<std::string>> list;
list:
  %empty     { /* Generates an empty string list */ }
| list item  { $$ = $1; $$.push_back ($2); }
;
```

We used a vector of strings as a semantic value! To use genuine C++ objects as semantic values—not just PODs—we cannot rely on the union that Bison uses by default to store them, we need *variants* (see Section 10.1.4.2 [++ Variants-title⟨undefined⟩], page 171):

```
%define api.value.type variant
```

Obviously, the rule for `result` needs to print a vector of strings. In the prologue, we add:

```
%code
{
  // Print a list of strings.
  auto
  operator<< (std::ostream& o, const std::vector<std::string>& ss)
    -> std::ostream&
  {
```

```
      o << '{';
      const char *sep = "";
      for (const auto& s: ss)
        {
          o << sep << s;
          sep = ", ";
        }
      return o << '}';
    }
  }
```

You may want to move it into the yy namespace to avoid leaking it in your default namespace. We recommend that you keep the actions simple, and move details into auxiliary functions, as we did with operator<<.

Our list of strings will be built from two types of items: numbers and strings:

```
%nterm <std::string> item;
%token <std::string> TEXT;
%token <int> NUMBER;
item:
  TEXT
| NUMBER  { $$ = std::to_string ($1); }
;
```

In the case of TEXT, the implicit default action applies: $$ = $1.

Our scanner deserves some attention. The traditional interface of yylex is not type safe: since the token kind and the token value are not correlated, you may return a NUMBER with a string as semantic value. To avoid this, we use *token constructors* (see Section 10.1.7.2 [Complete Symbols], page 179). This directive:

```
%define api.token.constructor
```

requests that Bison generates the functions make_TEXT and make_NUMBER, but also make_YYEOF, for the end of input.

Everything is in place for our scanner:

```
%code
{
  namespace yy
  {
    // Return the next token.
    auto yylex () -> parser::symbol_type
    {
      static int count = 0;
      switch (int stage = count++)
        {
        case 0:
          return parser::make_TEXT ("I have three numbers for you.");
        case 1: case 2: case 3:
          return parser::make_NUMBER (stage);
```

```
          case 4:
            return parser::make_TEXT ("And that's all!");
          default:
            return parser::make_YYEOF ();
          }
      }
    }
  }
```

In the epilogue, the third part of a Bison grammar file, we leave simple details: the error reporting function, and the main function.

```
  %%
  namespace yy
  {
    // Report an error to the user.
    auto parser::error (const std::string& msg) -> void
    {
      std::cerr << msg << '\n';
    }
  }

  int main ()
  {
    yy::parser parse;
    return parse ();
  }
```

Compile, and run!

```
  $ bison simple.yy -o simple.cc
  $ g++ -std=c++14 simple.cc -o simple
  $ ./simple
  {I have three numbers for you., 1, 2, 3, And that's all!}
```

10.1.2 C++ Bison Interface

The C++ deterministic parser is selected using the skeleton directive, '`%skeleton "lalr1.cc"`'. See Section 3.7.13 [Bison Declaration Summary], page 79.

When run, `bison` will create several entities in the 'yy' namespace. Use the '`%define api.namespace`' directive to change the namespace name, see Section 3.7.14 [%define Summary], page 84. The various classes are generated in the following files:

`file`.hh   (Assuming the extension of the grammar file was '`.yy`'.) The declaration of the C++ parser class and auxiliary types. By default, this file is not generated (see Section 3.7.13 [Bison Declaration Summary], page 79).

`file`.cc   The implementation of the C++ parser class. The basename and extension of these two files (`file`.hh and `file`.cc) follow the same rules as with regular C parsers (see Chapter 9 [Invoking Bison], page 154).

`location.hh`

> Generated when both `%defines` and `%locations` are enabled, this file contains the definition of the classes `position` and `location`, used for location tracking. It is not generated if '`%define api.location.file none`' is specified, or if user defined locations are used. See Section 10.1.5 [++ Location Values-title⟨undefined⟩], page 172.

`position.hh`
`stack.hh`   Useless legacy files. To get rid of then, use '`%require "3.2"`' or newer.

All these files are documented using Doxygen; run `doxygen` for a complete and accurate documentation.

10.1.3 C++ Parser Interface

The output files `file.hh` and `file.cc` declare and define the parser class in the namespace yy. The class name defaults to `parser`, but may be changed using '`%define api.parser.class {name}`'. The interface of this class is detailed below. It can be extended using the `%parse-param` feature: its semantics is slightly changed since it describes an additional member of the parser class, and an additional argument for its constructor.

`token`   [Type of `parser`]

> A structure that contains (only) the `token_kind_type` enumeration, which defines the tokens. To refer to the token `FOO`, use `yy::parser::token::FOO`. The scanner can use '`typedef yy::parser::token token;`' to "import" the token enumeration (see Section 10.1.8.4 [++ Scanner-title⟨undefined⟩], page 185).

`token_kind_type`   [Type of `parser`]

> An enumeration of the token kinds. Its enumerators are forged from the token names, with a possible token prefix (see [`api.token.prefix`], page 88):

```
/// Token kinds.
struct token
{
  enum token_kind_type
  {
    YYEMPTY = -2,                  // No token.
    YYEOF = 0,                     // "end of file"
    YYerror = 256,                 // error
    YYUNDEF = 257,                 // "invalid token"
    PLUS = 258,                    // "+"
    MINUS = 259,                   // "-"
    [...]
    VAR = 271,                     // "variable"
    NEG = 272                      // NEG
  };
};

/// Token kind, as returned by yylex.
typedef token::token_kind_type token_kind_type;
```

`semantic_type`   [Type of `parser`]
> The types for semantic values. See Section 10.1.4 [++ Semantic Values-title⟨undefined⟩], page 171.

`location_type`   [Type of `parser`]
> The type of locations, if location tracking is enabled. See Section 10.1.5 [++ Location Values-title⟨undefined⟩], page 172.

`syntax_error`   [Type of `parser`]
> This class derives from `std::runtime_error`. Throw instances of it from the scanner or from the actions to raise parse errors. This is equivalent with first invoking `error` to report the location and message of the syntax error, and then to invoke `YYERROR` to enter the error-recovery mode. But contrary to `YYERROR` which can only be invoked from user actions (i.e., written in the action itself), the exception can be thrown from functions invoked from the user action.

`parser ()`   [Constructor on `parser`]
`parser (type1 arg1, ...)`   [Constructor on `parser`]
> Build a new parser object. There are no arguments, unless '`%parse-param {type1 arg1}`' was used.

`syntax_error (const location_type& l, const`   [Constructor on `syntax_error`]
>   `std::string& m)`
`syntax_error (const std::string& m)`   [Constructor on `syntax_error`]
> Instantiate a syntax-error exception.

`int operator() ()`   [Method on `parser`]
`int parse ()`   [Method on `parser`]
> Run the syntactic analysis, and return 0 on success, 1 otherwise. Both routines are equivalent, `operator()` being more C++ish.
>
> The whole function is wrapped in a `try`/`catch` block, so that when an exception is thrown, the `%destructor`s are called to release the lookahead symbol, and the symbols pushed on the stack.
>
> Exception related code in the generated parser is protected by CPP guards (`#if`) and disabled when exceptions are not supported (i.e., passing `-fno-exceptions` to the C++ compiler).

`std::ostream& debug_stream ()`   [Method on `parser`]
`void set_debug_stream (std::ostream& o)`   [Method on `parser`]
> Get or set the stream used for tracing the parsing. It defaults to `std::cerr`.

`debug_level_type debug_level ()`   [Method on `parser`]
`void set_debug_level (debug_level_type l)`   [Method on `parser`]
> Get or set the tracing level (an integral). Currently its value is either 0, no trace, or nonzero, full tracing.

```
void error (const location_type& l, const                    [Method on parser]
       std::string& m)
void error (const std::string& m)                            [Method on parser]
```
    The definition for this member function must be supplied by the user: the parser uses
    it to report a parser error occurring at *l*, described by *m*. If location tracking is not
    enabled, the second signature is used.

10.1.4 C++ Semantic Values

Bison supports two different means to handle semantic values in C++. One is alike the C
interface, and relies on unions. As C++ practitioners know, unions are inconvenient in C++,
therefore another approach is provided, based on variants.

10.1.4.1 C++ Unions

The `%union` directive works as for C, see Section 3.4.4 [The Union Declaration], page 58.
In particular it produces a genuine `union`, which have a few specific features in C++.

  − The type `YYSTYPE` is defined but its use is discouraged: rather you should refer to the
    parser's encapsulated type `yy::parser::semantic_type`.

  − Non POD (Plain Old Data) types cannot be used. C++98 forbids any instance of classes
    with constructors in unions: only *pointers* to such objects are allowed. C++11 relaxed
    this constraints, but at the cost of safety.

    Because objects have to be stored via pointers, memory is not reclaimed automatically:
using the `%destructor` directive is the only means to avoid leaks. See Section 3.7.7 [Freeing
Discarded Symbols], page 73.

10.1.4.2 C++ Variants

Bison provides a *variant* based implementation of semantic values for C++. This alleviates
all the limitations reported in the previous section, and in particular, object types can be
used without pointers.

    To enable variant-based semantic values, set the `%define` variable `api.value.type` to
`variant` (see Section 3.7.14 [%define Summary], page 84). Then `%union` is ignored; instead
of using the name of the fields of the `%union` to "type" the symbols, use genuine types.

    For instance, instead of:

```
%union
{
  int ival;
  std::string* sval;
}
%token <ival> NUMBER;
%token <sval> STRING;
```

write:

```
%token <int> NUMBER;
%token <std::string> STRING;
```

`STRING` is no longer a pointer, which should fairly simplify the user actions in the gram-
mar and in the scanner (in particular the memory management).

Since C++ features destructors, and since it is customary to specialize `operator<<` to support uniform printing of values, variants also typically simplify Bison printers and destructors.

Variants are stricter than unions. When based on unions, you may play any dirty game with `yylval`, say storing an `int`, reading a `char*`, and then storing a `double` in it. This is no longer possible with variants: they must be initialized, then assigned to, and eventually, destroyed. As a matter of fact, Bison variants forbid the use of alternative types such as '`$<int>2`' or '`$<std::string>$`', even in midrule actions. It is mandatory to use typed midrule actions (see Section 3.4.8.2 [Typed Midrule Actions], page 62).

`T& emplace<T> ()`   [Method on `semantic_type`]
`T& emplace<T> (const T& t)`   [Method on `semantic_type`]
> Available in C++98/C++03 only. Default construct/copy-construct from *t*. Return a reference to where the actual value may be stored. Requires that the variant was not initialized yet.

`T& emplace<T, U> (U&&... u)`   [Method on `semantic_type`]
> Available in C++11 and later only. Build a variant of type `T` from the variadic forwarding references *u*....

Warning: We do not use Boost.Variant, for two reasons. First, it appeared unacceptable to require Boost on the user's machine (i.e., the machine on which the generated parser will be compiled, not the machine on which `bison` was run). Second, for each possible semantic value, Boost.Variant not only stores the value, but also a tag specifying its type. But the parser already "knows" the type of the semantic value, so that would be duplicating the information.

We do not use C++17's `std::variant` either: we want to support all the C++ standards, and of course `std::variant` also stores a tag to record the current type.

Therefore we developed light-weight variants whose type tag is external (so they are really like `unions` for C++ actually). There is a number of limitations in (the current implementation of) variants:

- Alignment must be enforced: values should be aligned in memory according to the most demanding type. Computing the smallest alignment possible requires metaprogramming techniques that are not currently implemented in Bison, and therefore, since, as far as we know, `double` is the most demanding type on all platforms, alignments are enforced for `double` whatever types are actually used. This may waste space in some cases.

- There might be portability issues we are not aware of.

As far as we know, these limitations *can* be alleviated. All it takes is some time and/or some talented C++ hacker willing to contribute to Bison.

10.1.5 C++ Location Values

When the directive `%locations` is used, the C++ parser supports location tracking, see Section 3.5 [Tracking Locations], page 66.

By default, two auxiliary classes define a `position`, a single point in a file, and a `location`, a range composed of a pair of `positions` (possibly spanning several files). If

the `%define` variable `api.location.type` is defined, then these classes will not be generated, and the user defined type will be used.

10.1.5.1 C++ `position`

`filename_type`   [Type of `position`]
> The base type for file names. Defaults to `const std::string`. See [`api.filename.type`], page 84, to change its definition.

`counter_type`   [Type of `position`]
> The type used to store line and column numbers. Defined as `int`.

`position (filename_type* file = nullptr,`   [Constructor on `position`]
>   `counter_type line = 1, counter_type col = 1)`
> Create a `position` denoting a given point. Note that `file` is not reclaimed when the `position` is destroyed: memory managed must be handled elsewhere.

`void initialize (filename_type* file = nullptr,`   [Method on `position`]
>   `counter_type line = 1, counter_type col = 1)`
> Reset the position to the given values.

`filename_type* file`   [Instance Variable of `position`]
> The name of the file. It will always be handled as a pointer, the parser will never duplicate nor deallocate it.

`counter_type line`   [Instance Variable of `position`]
> The line, starting at 1.

`void lines (counter_type height = 1)`   [Method on `position`]
> If *height* is not null, advance by *height* lines, resetting the column number. The resulting line number cannot be less than 1.

`counter_type column`   [Instance Variable of `position`]
> The column, starting at 1.

`void columns (counter_type width = 1)`   [Method on `position`]
> Advance by *width* columns, without changing the line number. The resulting column number cannot be less than 1.

`position& operator+= (counter_type width)`   [Method on `position`]
`position operator+ (counter_type width)`   [Method on `position`]
`position& operator-= (counter_type width)`   [Method on `position`]
`position operator- (counter_type width)`   [Method on `position`]
> Various forms of syntactic sugar for `columns`.

`bool operator== (const position& that)`   [Method on `position`]
`bool operator!= (const position& that)`   [Method on `position`]
> Whether `*this` and `that` denote equal/different positions.

`std::ostream& operator<< (std::ostream& o, const position& p)`   [Function]
> Report *p* on *o* like this: '*file*:*line*.*column*', or '*line*.*column*' if *file* is null.

10.1.5.2 C++ `location`

`location (const position& *begin*, const position&`   [Constructor on `location`]
        end)
> Create a `Location` from the endpoints of the range.

`location (const position& *pos* = *position*())`   [Constructor on `location`]
`location (filename_type* *file*, counter_type`   [Constructor on `location`]
        line, counter_type *col*)
> Create a `Location` denoting an empty range located at a given point.

`void initialize (filename_type* *file* = *nullptr*,`   [Method on `location`]
        `counter_type *line* = *1*, counter_type *col* = *1*)`
> Reset the location to an empty range at the given values.

`position begin`   [Instance Variable of `location`]
`position end`   [Instance Variable of `location`]
> The first, inclusive, position of the range, and the first beyond.

`void columns (counter_type *width* = *1*)`   [Method on `location`]
`void lines (counter_type *height* = *1*)`   [Method on `location`]
> Forwarded to the `end` position.

`location operator+ (counter_type *width*)`   [Method on `location`]
`location operator+= (counter_type *width*)`   [Method on `location`]
`location operator- (counter_type *width*)`   [Method on `location`]
`location operator-= (counter_type *width*)`   [Method on `location`]
> Various forms of syntactic sugar for `columns`.

`location operator+ (const location& *end*)`   [Method on `location`]
`location operator+= (const location& *end*)`   [Method on `location`]
> Join two locations: starts at the position of the first one, and ends at the position of
> the second.

`void step ()`   [Method on `location`]
> Move `begin` onto `end`.

`bool operator== (const location& *that*)`   [Method on `location`]
`bool operator!= (const location& *that*)`   [Method on `location`]
> Whether `*this` and `that` denote equal/different ranges of positions.

`std::ostream& operator<< (std::ostream& *o*, const location& *p*)`   [Function]
> Report *p* on *o*, taking care of special cases such as: no `filename` defined, or equal
> filename/line or column.

10.1.5.3 Exposing the Location Classes

When both `%defines` and `%locations` are enabled, Bison generates an additional file:
`location.hh`. If you don't use locations outside of the parser, you may avoid its creation
with '`%define api.location.file none`'.

However this file is useful if, for instance, your parser builds an abstract syntax tree decorated with locations: you may use Bison's `location` type independently of Bison's parser. You may name the file differently, e.g., '`%define api.location.file "include/ast/location.hh"`': this name can have directory components, or even be absolute. The way the location file is included is controlled by `api.location.include`.

This way it is possible to have several parsers share the same location file.

For instance, in `src/foo/parser.yy`, generate the `include/ast/loc.hh` file:

```
// src/foo/parser.yy
%locations
%define api.namespace {foo}
%define api.location.file "include/ast/loc.hh"
%define api.location.include {<ast/loc.hh>}
```

and use it in `src/bar/parser.yy`:

```
// src/bar/parser.yy
%locations
%define api.namespace {bar}
%code requires {#include <ast/loc.hh>}
%define api.location.type {bar::location}
```

Absolute file names are supported; it is safe in your `Makefile` to pass the flag `-Dapi.location.file='"$(top_srcdir)/include/ast/loc.hh"'` to `bison` for `src/foo/parser.yy`. The generated file will not have references to this absolute path, thanks to '`%define api.location.include {<ast/loc.hh>}`'. Adding '`-I $(top_srcdir)/include`' to your `CPPFLAGS` will suffice for the compiler to find `ast/loc.hh`.

10.1.5.4 User Defined Location Type

Instead of using the built-in types you may use the `%define` variable `api.location.type` to specify your own type:

```
%define api.location.type {LocationType}
```

The requirements over your *LocationType* are:

- it must be copyable;
- in order to compute the (default) value of `@$` in a reduction, the parser basically runs

```
@$.begin = @1.begin;
@$.end   = @N.end; // The location of last right-hand side symbol.
```

  so there must be copyable `begin` and `end` members;
- alternatively you may redefine the computation of the default location, in which case these members are not required (see Section 3.5.3 [Default Action for Locations], page 68);
- if traces are enabled, then there must exist an '`std::ostream& operator<< (std::ostream& o, const LocationType& s)`' function.

In programs with several C++ parsers, you may also use the `%define` variable `api.location.type` to share a common set of built-in definitions for `position` and `location`. For instance, one parser `master/parser.yy` might use:

```
%defines
%locations
%define api.namespace {master::}
```

to generate the `master/position.hh` and `master/location.hh` files, reused by other parsers as follows:

```
%define api.location.type {master::location}
%code requires { #include <master/location.hh> }
```

10.1.6 C++ Parser Context

When '`%define parse.error custom`' is used (see Section 4.4.2 [The Syntax Error Reporting Function `yyreport_syntax_error`], page 105), the user must define the following function.

void report_syntax_error (const context_type&*ctx*)   [Method on `parser`]
        const
      Report a syntax error to the user. Whether it uses `yyerror` is up to the user.

    Use the following types and functions to build the error message.

context   [Type of `parser`]
      A type that captures the circumstances of the syntax error.

symbol_kind_type   [Type of `parser`]
      An enum of all the grammar symbols, tokens and nonterminals. Its enumerators are forged from the symbol names:

```
struct symbol_kind
{
  enum symbol_kind_type
  {
    S_YYEMPTY = -2,      // No symbol.
    S_YYEOF = 0,         // "end of file"
    S_YYERROR = 1,       // error
    S_YYUNDEF = 2,       // "invalid token"
    S_PLUS = 3,          // "+"
    S_MINUS = 4,         // "-"
    [...]
    S_VAR = 14,          // "variable"
    S_NEG = 15,          // NEG
    S_YYACCEPT = 16,     // $accept
    S_exp = 17,          // exp
    S_input = 18         // input
  };
};
typedef symbol_kind::symbol_kind_t symbol_kind_type;
```

const symbol_type& lookahead () const   [Method on `context`]
      The "unexpected" token: the lookahead that caused the syntax error.

`symbol_kind_type token () const`   [Method on `context`]

> The symbol kind of the lookahead token that caused the syntax error. Returns `symbol_kind::S_YYEMPTY` if there is no lookahead.

`const location& location () const`   [Method on `context`]

> The location of the syntax error (that of the lookahead).

`int expected_tokens (symbol_kind_type argv[], int`   [Method on `context`]
>   `argc) const`
> Fill *argv* with the expected tokens, which never includes `symbol_kind::S_YYEMPTY`, `symbol_kind::S_YYERROR`, or `symbol_kind::S_YYUNDEF`.

> Never put more than *argc* elements into *argv*, and on success return the number of tokens stored in *argv*. If there are more expected tokens than *argc*, fill *argv* up to *argc* and return 0. If there are no expected tokens, also return 0, but set `argv[0]` to `symbol_kind::S_YYEMPTY`.

> If *argv* is null, return the size needed to store all the possible values, which is always less than `YYNTOKENS`.

`const char * symbol_name (symbol_kind_t symbol)`   [Method on `parser`]
>   `const`
> The name of the symbol whose kind is *symbol*, possibly translated.

> Returns a `std::string` when `parse.error` is `verbose`.

A custom syntax error function looks as follows. This implementation is inappropriate for internationalization, see the `c/bistromathic` example for a better alternative.

```
void
yy::parser::report_syntax_error (const context& ctx)
{
  int res = 0;
  std::cerr << ctx.location () << ": syntax error";
  // Report the tokens expected at this point.
  {
    enum { TOKENMAX = 5 };
    symbol_kind_type expected[TOKENMAX];
    int n = ctx.expected_tokens (ctx, expected, TOKENMAX);
    for (int i = 0; i < n; ++i)
      std::cerr << i == 0 ? ": expected " : " or "
                << symbol_name (expected[i]);
  }
  // Report the unexpected token.
  {
    symbol_kind_type lookahead = ctx.token ();
    if (lookahead != symbol_kind::S_YYEMPTY)
      std::cerr << " before " << symbol_name (lookahead));
  }
  std::cerr << '\n';
}
```

You still must provide a `yyerror` function, used for instance to report memory exhaustion.

10.1.7 C++ Scanner Interface

The parser invokes the scanner by calling `yylex`. Contrary to C parsers, C++ parsers are always pure: there is no point in using the '`%define api.pure`' directive. The actual interface with `yylex` depends whether you use unions, or variants.

10.1.7.1 Split Symbols

The generated parser expects `yylex` to have the following prototype.

int yylex (semantic_type* *yylval*, location_type* *yylloc*,   [Function]
      type1 arg1, . . .)
int yylex (semantic_type* *yylval*, *type1 arg1*, . . .)   [Function]
    Return the next token. Its kind is the return value, its semantic value and location
    (if enabled) being *yylval* and *yylloc*. Invocations of '`%lex-param {type1 arg1}`' yield
    additional arguments.

Note that when using variants, the interface for `yylex` is the same, but `yylval` is handled differently.

Regular union-based code in Lex scanner typically looks like:

```
[0-9]+   {
           yylval->ival = text_to_int (yytext);
           return yy::parser::token::INTEGER;
         }
[a-z]+   {
           yylval->sval = new std::string (yytext);
           return yy::parser::token::IDENTIFIER;
         }
```

Using variants, `yylval` is already constructed, but it is not initialized. So the code would look like:

```
[0-9]+   {
           yylval->emplace<int> () = text_to_int (yytext);
           return yy::parser::token::INTEGER;
         }
[a-z]+   {
           yylval->emplace<std::string> () = yytext;
           return yy::parser::token::IDENTIFIER;
         }
```

or

```
[0-9]+   {
           yylval->emplace (text_to_int (yytext));
           return yy::parser::token::INTEGER;
         }
[a-z]+   {
           yylval->emplace (yytext);
```

```
                return yy::parser::token::IDENTIFIER;
            }
```

10.1.7.2 Complete Symbols

With both `%define api.value.type variant` and `%define api.token.constructor`, the parser defines the type `symbol_type`, and expects `yylex` to have the following prototype.

`parser::symbol_type yylex ()`   [Function]
`parser::symbol_type yylex (type1 arg1, ...)`   [Function]
>   Return a *complete* symbol, aggregating its type (i.e., the traditional value returned by `yylex`), its semantic value, and possibly its location. Invocations of '`%lex-param {type1 arg1}`' yield additional arguments.

`symbol_type`   [Type of `parser`]
>   A "complete symbol", that binds together its kind, value and (when applicable) location.

`symbol_kind_type kind () const`   [Method on `symbol_type`]
>   The kind of this symbol.

`const char * name () const`   [Method on `symbol_type`]
>   The name of the kind of this symbol.
>
>   Returns a `std::string` when `parse.error` is verbose.

   For each token kind, Bison generates named constructors as follows.

`symbol_type (int token, const`   [Constructor on `parser::symbol_type`]
        `value_type& value, const location_type& location)`
`symbol_type (int token, const`   [Constructor on `parser::symbol_type`]
        `location_type& location)`
`symbol_type (int token, const`   [Constructor on `parser::symbol_type`]
        `value_type& value)`
`symbol_type (int token)`   [Constructor on `parser::symbol_type`]
>   Build a complete terminal symbol for the token kind *token* (including the `api.token.prefix`), whose semantic value, if it has one, is *value* of adequate *value_type*. Pass the *location* iff location tracking is enabled.
>
>   Consistency between *token* and *value_type* is checked via an `assert`.

   For instance, given the following declarations:

```
    %define api.token.prefix {TOK_}
    %token <std::string> IDENTIFIER;
    %token <int> INTEGER;
    %token ':';
```

you may use these constructors:

```
    symbol_type (int token, const std::string&, const location_type&);
    symbol_type (int token, const int&, const location_type&);
    symbol_type (int token, const location_type&);
```

Correct matching between token kinds and value types is checked via `assert`; for instance, '`symbol_type (ID, 42)`' would abort. Named constructors are preferable (see below), as they offer better type safety (for instance '`make_ID (42)`' would not even compile), but symbol_type constructors may help when token kinds are discovered at run-time, e.g.,

```
[a-z]+   {
             if (auto i = lookup_keyword (yytext))
               return yy::parser::symbol_type (i, loc);
             else
               return yy::parser::make_ID (yytext, loc);
         }
```

Note that it is possible to generate and compile type incorrect code (e.g. '`symbol_type (':', yytext, loc)`'). It will fail at run time, provided the assertions are enabled (i.e., `-DNDEBUG` was not passed to the compiler). Bison supports an alternative that guarantees that type incorrect code will not even compile. Indeed, it generates *named constructors* as follows.

`symbol_type make_token (const value_type& value,`   [Method on `parser`]
        `const location_type& location)`
`symbol_type make_token (const location_type&`   [Method on `parser`]
        `location)`
`symbol_type make_token (const value_type& value)`   [Method on `parser`]
`symbol_type make_token ()`   [Method on `parser`]
    Build a complete terminal symbol for the token kind *token* (not including the `api.token.prefix`), whose semantic value, if it has one, is *value* of adequate *value_type*. Pass the *location* iff location tracking is enabled.

For instance, given the following declarations:

```
%define api.token.prefix {TOK_}
%token <std::string> IDENTIFIER;
%token <int> INTEGER;
%token COLON;
%token EOF 0;
```

Bison generates:

```
symbol_type make_IDENTIFIER (const std::string&, const location_type&);
symbol_type make_INTEGER (const int&, const location_type&);
symbol_type make_COLON (const location_type&);
symbol_type make_EOF (const location_type&);
```

which should be used in a scanner as follows.

```
[a-z]+   return yy::parser::make_IDENTIFIER (yytext, loc);
[0-9]+   return yy::parser::make_INTEGER (text_to_int (yytext), loc);
":"      return yy::parser::make_COLON (loc);
<<EOF>>  return yy::parser::make_EOF (loc);
```

Tokens that do not have an identifier are not accessible: you cannot simply use characters such as '`:`', they must be declared with `%token`, including the end-of-file token.

10.1.8 A Complete C++ Example

This section demonstrates the use of a C++ parser with a simple but complete example. This example should be available on your system, ready to compile, in the directory *.../share/doc/bison/examples/calc++*. It focuses on the use of Bison, therefore the design of the various C++ classes is very naive: no accessors, no encapsulation of members etc. We will use a Lex scanner, and more precisely, a Flex scanner, to demonstrate the various interactions. A hand-written scanner is actually easier to interface with.

10.1.8.1 Calc++ — C++ Calculator

Of course the grammar is dedicated to arithmetic, a single expression, possibly preceded by variable assignments. An environment containing possibly predefined variables such as `one` and `two`, is exchanged with the parser. An example of valid input follows.

```
three := 3
seven := one + two * three
seven * seven
```

10.1.8.2 Calc++ Parsing Driver

To support a pure interface with the parser (and the scanner) the technique of the "parsing context" is convenient: a structure containing all the data to exchange. Since, in addition to simply launch the parsing, there are several auxiliary tasks to execute (open the file for scanning, instantiate the parser etc.), we recommend transforming the simple parsing context structure into a fully blown *parsing driver* class.

The declaration of this driver class, in `driver.hh`, is as follows. The first part includes the CPP guard and imports the required standard library components, and the declaration of the parser class.

```
#ifndef DRIVER_HH
# define DRIVER_HH
# include <string>
# include <map>
# include "parser.hh"
```

Then comes the declaration of the scanning function. Flex expects the signature of `yylex` to be defined in the macro `YY_DECL`, and the C++ parser expects it to be declared. We can factor both as follows.

```
// Give Flex the prototype of yylex we want ...
# define YY_DECL \
  yy::parser::symbol_type yylex (driver& drv)
// ... and declare it for the parser's sake.
YY_DECL;
```

The `driver` class is then declared with its most obvious members.

```
// Conducting the whole scanning and parsing of Calc++.
class driver
{
public:
  driver ();
```

```
      std::map<std::string, int> variables;

      int result;
```

The main routine is of course calling the parser.

```
      // Run the parser on file F.  Return 0 on success.
      int parse (const std::string& f);
      // The name of the file being parsed.
      std::string file;
      // Whether to generate parser debug traces.
      bool trace_parsing;
```

To encapsulate the coordination with the Flex scanner, it is useful to have member functions to open and close the scanning phase.

```
      // Handling the scanner.
      void scan_begin ();
      void scan_end ();
      // Whether to generate scanner debug traces.
      bool trace_scanning;
      // The token's location used by the scanner.
      yy::location location;
    };
    #endif // ! DRIVER_HH
```

The implementation of the driver (`driver.cc`) is straightforward.

```
    #include "driver.hh"
    #include "parser.hh"

    driver::driver ()
      : trace_parsing (false), trace_scanning (false)
    {
      variables["one"] = 1;
      variables["two"] = 2;
    }
```

The `parse` member function deserves some attention.

```
    int
    driver::parse (const std::string &f)
    {
      file = f;
      location.initialize (&file);
      scan_begin ();
      yy::parser parse (*this);
      parse.set_debug_level (trace_parsing);
      int res = parse ();
      scan_end ();
      return res;
    }
```

10.1.8.3 Calc++ Parser

The grammar file `parser.yy` starts by asking for the C++ deterministic parser skeleton, the creation of the parser header file. Because the C++ skeleton changed several times, it is safer to require the version you designed the grammar for.

```
%skeleton "lalr1.cc" // -*- C++ -*-
%require "3.7.1"
%defines
```

Because our scanner returns only genuine tokens and never simple characters (i.e., it returns 'PLUS', not ''+''), we can avoid conversions.

```
%define api.token.raw
```

This example uses genuine C++ objects as semantic values, therefore, we require the variant-based storage of semantic values. To make sure we properly use it, we enable assertions. To fully benefit from type-safety and more natural definition of "symbol", we enable `api.token.constructor`.

```
%define api.token.constructor
%define api.value.type variant
%define parse.assert
```

Then come the declarations/inclusions needed by the semantic values. Because the parser uses the parsing driver and reciprocally, both would like to include the header of the other, which is, of course, insane. This mutual dependency will be broken using forward declarations. Because the driver's header needs detailed knowledge about the parser class (in particular its inner types), it is the parser's header which will use a forward declaration of the driver. See Section 3.7.15 [%code Summary], page 94.

```
%code requires {
  # include <string>
  class driver;
}
```

The driver is passed by reference to the parser and to the scanner. This provides a simple but effective pure interface, not relying on global variables.

```
// The parsing context.
%param { driver& drv }
```

Then we request location tracking.

```
%locations
```

Use the following two directives to enable parser tracing and detailed error messages. However, detailed error messages can contain incorrect information if lookahead correction is not enabled (see Section 5.8.3 [LAC], page 125).

```
%define parse.trace
%define parse.error detailed
%define parse.lac full
```

The code between '`%code {`' and '`}`' is output in the `*.cc` file; it needs detailed knowledge about the driver.

```
%code {
# include "driver.hh"
}
```

User friendly names are provided for each symbol. To avoid name clashes in the generated
files (see Section 10.1.8.4 [++ Scanner-title⟨undefined⟩], page 185), prefix tokens with `TOK_`
(see Section 3.7.14 [%define Summary], page 84).

```
%define api.token.prefix {TOK_}
%token
  ASSIGN  ":="
  MINUS   "-"
  PLUS    "+"
  STAR    "*"
  SLASH   "/"
  LPAREN  "("
  RPAREN  ")"
;
```

Since we use variant-based semantic values, `%union` is not used, and `%token`, `%nterm` and
`%type` expect genuine types, not type tags.

```
%token <std::string> IDENTIFIER "identifier"
%token <int> NUMBER "number"
%nterm <int> exp
```

No `%destructor` is needed to enable memory deallocation during error recovery; the mem-
ory, for strings for instance, will be reclaimed by the regular destructors. All the values are
printed using their `operator<<` (see Section 3.7.8 [Printing Semantic Values], page 75).

```
%printer { yyo << $$; } <*>;
```

The grammar itself is straightforward (see Section 2.4 [Location Tracking Calculator:
`ltcalc`], page 35).

```
%%
%start unit;
unit: assignments exp  { drv.result = $2; };

assignments:
  %empty                  {}
| assignments assignment {};

assignment:
  "identifier" ":=" exp { drv.variables[$1] = $3; };

%left "+" "-";
%left "*" "/";
exp:
  "number"
| "identifier"  { $$ = drv.variables[$1]; }
| exp "+" exp   { $$ = $1 + $3; }
| exp "-" exp   { $$ = $1 - $3; }
| exp "*" exp   { $$ = $1 * $3; }
| exp "/" exp   { $$ = $1 / $3; }
| "(" exp ")"   { $$ = $2; }
```

```
    %%
```
Finally the `error` member function reports the errors.

```
    void
    yy::parser::error (const location_type& l, const std::string& m)
    {
      std::cerr << l << ": " << m << '\n';
    }
```

10.1.8.4 Calc++ Scanner

In addition to standard headers, the Flex scanner includes the driver's, then the parser's to get the set of defined tokens.

```
    %{ /* -*- C++ -*- */
    # include <cerrno>
    # include <climits>
    # include <cstdlib>
    # include <cstring> // strerror
    # include <string>
    # include "driver.hh"
    # include "parser.hh"
    %}
```

Since our calculator has no `#include`-like feature, we don't need `yywrap`. We don't need the `unput` and `input` functions either, and we parse an actual file, this is not an interactive session with the user. Finally, we enable scanner tracing.

```
    %option noyywrap nounput noinput batch debug
```

The following function will be handy to convert a string denoting a number into a `NUMBER` token.

```
    %{
      // A number symbol corresponding to the value in S.
      yy::parser::symbol_type
      make_NUMBER (const std::string &s, const yy::parser::location_type& loc);
    %}
```

Abbreviations allow for more readable rules.

```
    id     [a-zA-Z][a-zA-Z_0-9]*
    int    [0-9]+
    blank [ \t\r]
```

The following paragraph suffices to track locations accurately. Each time `yylex` is invoked, the begin position is moved onto the end position. Then when a pattern is matched, its width is added to the end column. When matching ends of lines, the end cursor is adjusted, and each time blanks are matched, the begin cursor is moved onto the end cursor to effectively ignore the blanks preceding tokens. Comments would be treated equally.

```
    %{
      // Code run each time a pattern is matched.
      # define YY_USER_ACTION  loc.columns (yyleng);
    %}
```

```
%%
%{
  // A handy shortcut to the location held by the driver.
  yy::location& loc = drv.location;
  // Code run each time yylex is called.
  loc.step ();
%}
{blank}+   loc.step ();
\n+        loc.lines (yyleng); loc.step ();
```

The rules are simple. The driver is used to report errors.

```
"-"        return yy::parser::make_MINUS   (loc);
"+"        return yy::parser::make_PLUS    (loc);
"*"        return yy::parser::make_STAR    (loc);
"/"        return yy::parser::make_SLASH   (loc);
"("        return yy::parser::make_LPAREN (loc);
")"        return yy::parser::make_RPAREN (loc);
":="       return yy::parser::make_ASSIGN (loc);

{int}      return make_NUMBER (yytext, loc);
{id}       return yy::parser::make_IDENTIFIER (yytext, loc);
.          {
              throw yy::parser::syntax_error
                (loc, "invalid character: " + std::string(yytext));
}
<<EOF>>    return yy::parser::make_YYEOF (loc);
%%
```

You should keep your rules simple, both in the parser and in the scanner. Throwing from the auxiliary functions is then very handy to report errors.

```
yy::parser::symbol_type
make_NUMBER (const std::string &s, const yy::parser::location_type& loc)
{
  errno = 0;
  long n = strtol (s.c_str(), NULL, 10);
  if (! (INT_MIN <= n && n <= INT_MAX && errno != ERANGE))
    throw yy::parser::syntax_error (loc, "integer is out of range: " + s);
  return yy::parser::make_NUMBER ((int) n, loc);
}
```

Finally, because the scanner-related driver's member-functions depend on the scanner's data, it is simpler to implement them in this file.

```
    void
    driver::scan_begin ()
    {
      yy_flex_debug = trace_scanning;
      if (file.empty () || file == "-")
        yyin = stdin;
      else if (!(yyin = fopen (file.c_str (), "r")))
        {
          std::cerr << "cannot open " << file << ": " << strerror (errno) << '\n';
          exit (EXIT_FAILURE);
        }
    }

    void
    driver::scan_end ()
    {
      fclose (yyin);
    }
```

10.1.8.5 Calc++ Top Level

The top level file, `calc++.cc`, poses no problem.

```
    #include <iostream>
    #include "driver.hh"

    int
    main (int argc, char *argv[])
    {
      int res = 0;
      driver drv;
      for (int i = 1; i < argc; ++i)
        if (argv[i] == std::string ("-p"))
          drv.trace_parsing = true;
        else if (argv[i] == std::string ("-s"))
          drv.trace_scanning = true;
        else if (!drv.parse (argv[i]))
          std::cout << drv.result << '\n';
        else
          res = 1;
      return res;
    }
```

10.2 Java Parsers

10.2.1 Java Bison Interface

The Java parser skeletons are selected using the `%language "Java"` directive or the `-L java`/`--language=java` option.

When generating a Java parser, 'bison *basename*.y' will create a single Java source file named *basename*.java containing the parser implementation. Using a grammar file without a .y suffix is currently broken. The basename of the parser implementation file can be changed by the %file-prefix directive or the -b/--file-prefix option. The entire parser implementation file name can be changed by the %output directive or the -o/--output option. The parser implementation file contains a single class for the parser.

You can create documentation for generated parsers using Javadoc.

Contrary to C parsers, Java parsers do not use global variables; the state of the parser is always local to an instance of the parser class. Therefore, all Java parsers are "pure", and the %define api.pure directive does nothing when used in Java.

GLR parsers are currently unsupported in Java. Do not use the glr-parser directive.

No header file can be generated for Java parsers. Do not use the %defines directive or the -d/--defines options.

Currently, support for tracing is always compiled in. Thus the '%define parse.trace' and '%token-table' directives and the -t/--debug and -k/--token-table options have no effect. This may change in the future to eliminate unused code in the generated parser, so use '%define parse.trace' explicitly if needed. Also, in the future the %token-table directive might enable a public interface to access the token names and codes.

Getting a "code too large" error from the Java compiler means the code hit the 64KB bytecode per method limitation of the Java class file. Try reducing the amount of code in actions and static initializers; otherwise, report a bug so that the parser skeleton will be improved.

10.2.2 Java Semantic Values

There is no %union directive in Java parsers. Instead, the semantic values' types (class names) should be specified in the %nterm or %token directive:

```
%nterm <Expression> expr assignment_expr term factor
%nterm <Integer> number
```

By default, the semantic stack is declared to have Object members, which means that the class types you specify can be of any class. To improve the type safety of the parser, you can declare the common superclass of all the semantic values using the '%define api.value.type' directive. For example, after the following declaration:

```
%define api.value.type {ASTNode}
```

any %token, %nterm or %type specifying a semantic type which is not a subclass of ASTNode, will cause a compile-time error.

Types used in the directives may be qualified with a package name. Primitive data types are accepted for Java version 1.5 or later. Note that in this case the autoboxing feature of Java 1.5 will be used. Generic types may not be used; this is due to a limitation in the implementation of Bison, and may change in future releases.

Java parsers do not support %destructor, since the language adopts garbage collection. The parser will try to hold references to semantic values for as little time as needed.

Java parsers do not support %printer, as toString() can be used to print the semantic values. This however may change (in a backwards-compatible way) in future versions of Bison.

10.2.3 Java Location Values

When the directive `%locations` is used, the Java parser supports location tracking, see Section 3.5 [Tracking Locations], page 66. An auxiliary user-defined class defines a *position*, a single point in a file; Bison itself defines a class representing a *location*, a range composed of a pair of positions (possibly spanning several files). The location class is an inner class of the parser; the name is `Location` by default, and may also be renamed using `%define api.location.type {class-name}`.

The location class treats the position as a completely opaque value. By default, the class name is `Position`, but this can be changed with `%define api.position.type {class-name}`. This class must be supplied by the user.

`Position begin`   [Instance Variable of `Location`]
`Position end`   [Instance Variable of `Location`]
    The first, inclusive, position of the range, and the first beyond.

`Location (Position loc)`   [Constructor on `Location`]
    Create a `Location` denoting an empty range located at a given point.

`Location (Position begin, Position end)`   [Constructor on `Location`]
    Create a `Location` from the endpoints of the range.

`String toString ()`   [Method on `Location`]
    Prints the range represented by the location. For this to work properly, the position class should override the `equals` and `toString` methods appropriately.

10.2.4 Java Parser Interface

The name of the generated parser class defaults to `YYParser`. The `YY` prefix may be changed using the '`%define api.prefix`'. Alternatively, use '`%define api.parser.class {name}`' to give a custom name to the class. The interface of this class is detailed below.

By default, the parser class has package visibility. A declaration '`%define api.parser.public`' will change to public visibility. Remember that, according to the Java language specification, the name of the `.java` file should match the name of the class in this case. Similarly, you can use `api.parser.abstract`, `api.parser.final` and `api.parser.strictfp` with the `%define` declaration to add other modifiers to the parser class. A single '`%define api.parser.annotations {annotations}`' directive can be used to add any number of annotations to the parser class.

The Java package name of the parser class can be specified using the '`%define package`' directive. The superclass and the implemented interfaces of the parser class can be specified with the `%define api.parser.extends` and '`%define api.parser.implements`' directives.

The parser class defines an inner class, `Location`, that is used for location tracking (see Section 10.2.3 [Java Location Values], page 189), and a inner interface, `Lexer` (see Section 10.2.6 [Java Scanner Interface], page 192). Other than these inner class/interface, and the members described in the interface below, all the other members and fields are preceded with a `yy` or `YY` prefix to avoid clashes with user code.

The parser class can be extended using the `%parse-param` directive. Each occurrence of the directive will add a `protected final` field to the parser class, and an argument to its constructor, which initialize them automatically.

YYParser (*lex_param*, ..., *parse_param*, ...)   [Constructor on YYParser]
> Build a new parser object with embedded %code lexer. There are no parameters,
> unless %params and/or %parse-params and/or %lex-params are used.
>
> Use %code init for code added to the start of the constructor body. This is especially
> useful to initialize superclasses. Use '%define init_throws' to specify any uncaught
> exceptions.

YYParser (Lexer *lexer*, *parse_param*, ...)   [Constructor on YYParser]
> Build a new parser object using the specified scanner. There are no additional pa-
> rameters unless %params and/or %parse-params are used.
>
> If the scanner is defined by %code lexer, this constructor is declared protected
> and is called automatically with a scanner created with the correct %params and/or
> %lex-params.
>
> Use %code init for code added to the start of the constructor body. This is especially
> useful to initialize superclasses. Use '%define init_throws' to specify any uncaught
> exceptions.

boolean parse ()   [Method on YYParser]
> Run the syntactic analysis, and return true on success, false otherwise.

boolean getErrorVerbose ()   [Method on YYParser]
void setErrorVerbose (*boolean* verbose)   [Method on YYParser]
> Get or set the option to produce verbose error messages. These are only available
> with '%define parse.error detailed' (or 'verbose'), which also turns on verbose
> error messages.

void yyerror (String *msg*)   [Method on YYParser]
void yyerror (Position *pos*, String *msg*)   [Method on YYParser]
void yyerror (Location *loc*, String *msg*)   [Method on YYParser]
> Print an error message using the yyerror method of the scanner instance in use. The
> Location and Position parameters are available only if location tracking is active.

boolean recovering ()   [Method on YYParser]
> During the syntactic analysis, return true if recovering from a syntax error. See
> Chapter 6 [Error Recovery], page 130.

java.io.PrintStream getDebugStream ()   [Method on YYParser]
void setDebugStream (java.io.printStream *o*)   [Method on YYParser]
> Get or set the stream used for tracing the parsing. It defaults to System.err.

int getDebugLevel ()   [Method on YYParser]
void setDebugLevel (int *l*)   [Method on YYParser]
> Get or set the tracing level. Currently its value is either 0, no trace, or nonzero, full
> tracing.

String bisonVersion   [Constant of YYParser]
String bisonSkeleton   [Constant of YYParser]
> Identify the Bison version and skeleton used to generate this parser.

If you enabled token internationalization (see Section 4.6.2 [Token Internationalization], page 109), you must provide the parser with the following function:

String i18n (string _s_)   [Static Method of `YYParser`]

> Return the translation of _s_ in the user's language. As an example:

```
%code {
  static ResourceBundle myResources
    = ResourceBundle.getBundle("domain-name");
  static final String i18n(String s) {
    return myResources.getString(s);
  }
}
```

10.2.5 Java Parser Context Interface

The parser context provides information to build error reports when you invoke '`%define parse.error custom`'.

SymbolKind   [Type of `YYParser`]

> An enum of all the grammar symbols, tokens and nonterminals. Its enumerators are forged from the symbol names:

```
public enum SymbolKind
{
  S_YYEOF(0),          /* "end of file"  */
  S_YYERROR(1),        /* error  */
  S_YYUNDEF(2),        /* "invalid token"  */
  S_BANG(3),           /* "!"  */
  S_PLUS(4),           /* "+"  */
  S_MINUS(5),          /* "-"  */
  [...]
  S_NUM(13),           /* "number"  */
  S_NEG(14),           /* NEG  */
  S_YYACCEPT(15),      /* $accept  */
  S_input(16),         /* input  */
  S_line(17);          /* line  */
};
```

String getName ()   [Method on `YYParser.SymbolKind`]

> The name of this symbol, possibly translated.

YYParser.SymbolKind getToken ()   [Method on `YYParser.Context`]

> The kind of the lookahead. Return `null` iff there is no lookahead.

YYParser.Location getLocation ()   [Method on `YYParser.Context`]

> The location of the lookahead.

int getExpectedTokens   [Method on `YYParser.Context`]
          (YYParser.SymbolKind[] _argv_, int _argc_)

> Fill _argv_ with the expected tokens, which never includes `SymbolKind.S_YYERROR`, or `SymbolKind.S_YYUNDEF`.

Never put more than *argc* elements into *argv*, and on success return the number of tokens stored in *argv*. If there are more expected tokens than *argc*, fill *argv* up to *argc* and return 0. If there are no expected tokens, also return 0, but set `argv[0]` to `null`.

If *argv* is null, return the size needed to store all the possible values, which is always less than `YYNTOKENS`.

10.2.6 Java Scanner Interface

There are two possible ways to interface a Bison-generated Java parser with a scanner: the scanner may be defined by `%code lexer`, or defined elsewhere. In either case, the scanner has to implement the `Lexer` inner interface of the parser class. This interface also contain constants for all user-defined token names and the predefined `YYEOF` token.

In the first case, the body of the scanner class is placed in `%code lexer` blocks. If you want to pass parameters from the parser constructor to the scanner constructor, specify them with `%lex-param`; they are passed before `%parse-param`s to the constructor.

In the second case, the scanner has to implement the `Lexer` interface, which is defined within the parser class (e.g., `YYParser.Lexer`). The constructor of the parser object will then accept an object implementing the interface; `%lex-param` is not used in this case.

In both cases, the scanner has to implement the following methods.

void yyerror (Location *loc*, String *msg*)   [Method on `Lexer`]
    This method is defined by the user to emit an error message. The first parameter is omitted if location tracking is not active. Its type can be changed using `%define api.location.type {`*class-name*`}`.

int yylex ()   [Method on `Lexer`]
    Return the next token. Its type is the return value, its semantic value and location are saved and returned by the their methods in the interface. Not needed for push-only parsers.

    Use '`%define lex_throws`' to specify any uncaught exceptions. Default is `java.io.IOException`.

Position getStartPos ()   [Method on `Lexer`]
Position getEndPos ()   [Method on `Lexer`]
    Return respectively the first position of the last token that `yylex` returned, and the first position beyond it. These methods are not needed unless location tracking and pull parsing are active.

    They should return new objects for each call, to avoid that all the symbol share the same Position boundaries.

    The return type can be changed using `%define api.position.type {`*class-name*`}`.

Object getLVal ()   [Method on `Lexer`]
    Return the semantic value of the last token that yylex returned. Not needed for push-only parsers.

    The return type can be changed using '`%define api.value.type {`*class-name*`}`'.

void reportSyntaxError (YYParser.Context *ctx*)   [Method on Lexer]
>   If you invoke '%define parse.error custom' (see Section 3.1.3 [The Bison Declara-
>   tions Section], page 51), then the parser no longer passes syntax error messages to
>   yyerror, rather it delegates that task to the user by calling the reportSyntaxError
>   function.
>
>   Whether it uses yyerror is up to the user.
>
>   Here is an example of a reporting function (see Section 10.2.5 [Java Parser Context
>   Interface], page 191).

```
        public void reportSyntaxError(YYParser.Context ctx) {
          System.err.print(ctx.getLocation() + ": syntax error");
          // Report the expected tokens.
          {
            final int TOKENMAX = 5;
            YYParser.SymbolKind[] arg = new YYParser.SymbolKind[TOKENMAX];
            int n = ctx.getExpectedTokens(arg, TOKENMAX);
            for (int i = 0; i < n; ++i)
              System.err.print((i == 0 ? ": expected " : " or ")
                               + arg[i].getName());
          }
          // Report the unexpected token which triggered the error.
          {
            YYParser.SymbolKind lookahead = ctx.getToken();
            if (lookahead != null)
              System.err.print(" before " + lookahead.getName());
          }
          System.err.println("");
        }
```

>   This   implementation   is   inappropriate   for   internationalization,   see   the
>   c/bistromathic example for a better alternative.

10.2.7 Special Features for Use in Java Actions

The following special constructs can be uses in Java actions. Other analogous C action
features are currently unavailable for Java.

Use '%define throws' to specify any uncaught exceptions from parser actions, and initial
actions specified by %initial-action.

$*n*   [Variable]
>   The semantic value for the *n*th component of the current rule. This may not be
>   assigned to. See Section 10.2.2 [Java Semantic Values], page 188.

$<*typealt*>*n*   [Variable]
>   Like $*n* but specifies a alternative type *typealt*. See Section 10.2.2 [Java Semantic
>   Values], page 188.

$$ [Variable]
>   The semantic value for the grouping made by the current rule. As a value, this is
>   in the base type (Object or as specified by '%define api.value.type') as in not

cast to the declared subtype because casts are not allowed on the left-hand side of Java assignments. Use an explicit Java cast if the correct subtype is needed. See Section 10.2.2 [Java Semantic Values], page 188.

`$<`*`typealt`*`>$`   [Variable]

Same as `$$` since Java always allow assigning to the base type. Perhaps we should use this and `$<>$` for the value and `$$` for setting the value but there is currently no easy way to distinguish these constructs. See Section 10.2.2 [Java Semantic Values], page 188.

`@n`   [Variable]

The location information of the *n*th component of the current rule. This may not be assigned to. See Section 10.2.3 [Java Location Values], page 189.

`@$`   [Variable]

The location information of the grouping made by the current rule. See Section 10.2.3 [Java Location Values], page 189.

`return YYABORT ;`   [Statement]

Return immediately from the parser, indicating failure. See Section 10.2.4 [Java Parser Interface], page 189.

`return YYACCEPT ;`   [Statement]

Return immediately from the parser, indicating success. See Section 10.2.4 [Java Parser Interface], page 189.

`return YYERROR ;`   [Statement]

Start error recovery (without printing an error message). See Chapter 6 [Error Recovery], page 130.

`boolean recovering ()`   [Function]

Return whether error recovery is being done. In this state, the parser reads token until it reaches a known state, and then restarts normal operation. See Chapter 6 [Error Recovery], page 130.

`void yyerror (String `*`msg`*`)`   [Function]
`void yyerror (Position `*`loc`*`, String `*`msg`*`)`   [Function]
`void yyerror (Location `*`loc`*`, String `*`msg`*`)`   [Function]

Print an error message using the `yyerror` method of the scanner instance in use. The `Location` and `Position` parameters are available only if location tracking is active.

10.2.8 Java Push Parser Interface

Normally, Bison generates a pull parser for Java. The following Bison declaration says that you want the parser to be a push parser (see Section 3.7.14 [%define Summary], page 84):

        `%define api.push-pull push`

Most of the discussion about the Java pull Parser Interface, (see Section 10.2.4 [Java Parser Interface], page 189) applies to the push parser interface as well.

When generating a push parser, the method `push_parse` is created with the following signature (depending on if locations are enabled).

```
void push_parse (int token, Object yylval)                    [Method on YYParser]
void push_parse (int token, Object yylval, Location            [Method on YYParser]
        yyloc)
void push_parse (int token, Object yylval, Position            [Method on YYParser]
        yypos)
```
   The primary difference with respect to a pull parser is that the parser method push_parse is invoked repeatedly to parse each token. This function is available if either the "%define api.push-pull push" or "%define api.push-pull both" declaration is used (see Section 3.7.14 [%define Summary], page 84). The Location and Position parameters are available only if location tracking is active.

   The value returned by the push_parse method is one of the following four constants: YYABORT, YYACCEPT, YYERROR, or YYPUSH_MORE. This new value, YYPUSH_MORE, may be returned if more input is required to finish parsing the grammar.

   If api.push-pull is declared as both, then the generated parser class will also implement the parse method. This method's body is a loop that repeatedly invokes the scanner and then passes the values obtained from the scanner to the push_parse method.

   There is one additional complication. Technically, the push parser does not need to know about the scanner (i.e. an object implementing the YYParser.Lexer interface), but it does need access to the yyerror method. Currently, the yyerror method is defined in the YYParser.Lexer interface. Hence, an implementation of that interface is still required in order to provide an implementation of yyerror. The current approach (and subject to change) is to require the YYParser constructor to be given an object implementing the YYParser.Lexer interface. This object need only implement the yyerror method; the other methods can be stubbed since they will never be invoked. The simplest way to do this is to add a trivial scanner implementation to your grammar file using whatever implementation of yyerror is desired. The following code sample shows a simple way to accomplish this.

```
%code lexer
{
  public Object getLVal () {return null;}
  public int yylex () {return 0;}
  public void yyerror (String s) {System.err.println(s);}
}
```

10.2.9 Differences between C/C++ and Java Grammars

The different structure of the Java language forces several differences between C/C++ grammars, and grammars designed for Java parsers. This section summarizes these differences.

● Java lacks a preprocessor, so the YYERROR, YYACCEPT, YYABORT symbols (see Appendix A [Bison Symbols], page 208) cannot obviously be macros. Instead, they should be preceded by return when they appear in an action. The actual definition of these symbols is opaque to the Bison grammar, and it might change in the future. The only meaningful operation that you can do, is to return them. See Section 10.2.7 [Special Features for Use in Java Actions], page 193.

Note that of these three symbols, only `YYACCEPT` and `YYABORT` will cause a return from the `yyparse` method[1].

- Java lacks unions, so `%union` has no effect. Instead, semantic values have a common base type: `Object` or as specified by '`%define api.value.type`'. Angle brackets on `%token`, type, `$n` and `$$` specify subtypes rather than fields of an union. The type of `$$`, even with angle brackets, is the base type since Java casts are not allow on the left-hand side of assignments. Also, `$n` and `@n` are not allowed on the left-hand side of assignments. See Section 10.2.2 [Java Semantic Values], page 188, and Section 10.2.7 [Special Features for Use in Java Actions], page 193.

- The prologue declarations have a different meaning than in C/C++ code.

    `%code imports`
        blocks are placed at the beginning of the Java source code. They may include copyright notices. For a `package` declarations, use '`%define api.package`' instead.

    unqualified `%code`
        blocks are placed inside the parser class.

    `%code lexer`
        blocks, if specified, should include the implementation of the scanner. If there is no such block, the scanner can be any class that implements the appropriate interface (see Section 10.2.6 [Java Scanner Interface], page 192).

    Other `%code` blocks are not supported in Java parsers. In particular, `%{ ... %}` blocks should not be used and may give an error in future versions of Bison.

    The epilogue has the same meaning as in C/C++ code and it can be used to define other classes used by the parser *outside* the parser class.

10.2.10 Java Declarations Summary

This summary only include declarations specific to Java or have special meaning when used in a Java parser.

`%language "Java"`   [Directive]
    Generate a Java class for the parser.

`%lex-param {type name}`   [Directive]
    A parameter for the lexer class defined by `%code lexer` *only*, added as parameters to the lexer constructor and the parser constructor that *creates* a lexer. Default is none. See Section 10.2.6 [Java Scanner Interface], page 192.

`%parse-param {type name}`   [Directive]
    A parameter for the parser class added as parameters to constructor(s) and as fields initialized by the constructor(s). Default is none. See Section 10.2.4 [Java Parser Interface], page 189.

---

[1] Java parsers include the actions in a separate method than `yyparse` in order to have an intuitive syntax that corresponds to these C macros.

`%token <`*`type`*`> `*`token`* ...   [Directive]
> Declare tokens. Note that the angle brackets enclose a Java *type*. See Section 10.2.2 [Java Semantic Values], page 188.

`%nterm <`*`type`*`> `*`nonterminal`* ...   [Directive]
> Declare the type of nonterminals. Note that the angle brackets enclose a Java *type*. See Section 10.2.2 [Java Semantic Values], page 188.

`%code {` *`code`* ... `}`   [Directive]
> Code appended to the inside of the parser class. See Section 10.2.9 [Differences between C/C++ and Java Grammars], page 195.

`%code imports {` *`code`* ... `}`   [Directive]
> Code inserted just after the `package` declaration. See Section 10.2.9 [Differences between C/C++ and Java Grammars], page 195.

`%code init {` *`code`* ... `}`   [Directive]
> Code inserted at the beginning of the parser constructor body. See Section 10.2.4 [Java Parser Interface], page 189.

`%code lexer {` *`code`* ... `}`   [Directive]
> Code added to the body of a inner lexer class within the parser class. See Section 10.2.6 [Java Scanner Interface], page 192.

`%% ` *`code`* ...   [Directive]
> Code (after the second `%%`) appended to the end of the file, *outside* the parser class. See Section 10.2.9 [Differences between C/C++ and Java Grammars], page 195.

`%{` *`code`* ... `%}`   [Directive]
> Not supported. Use `%code imports` instead. See Section 10.2.9 [Differences between C/C++ and Java Grammars], page 195.

`%define api.prefix {`*`prefix`*`}`   [Directive]
> The prefix of the parser class name *prefix*`Parser` if '`%define api.parser.class`' is not used. Default is `YY`. See Section 10.2.1 [Java Bison Interface], page 187.

`%define api.parser.abstract`   [Directive]
> Whether the parser class is declared `abstract`. Default is false. See Section 10.2.1 [Java Bison Interface], page 187.

`%define api.parser.annotations {`*`annotations`*`}`   [Directive]
> The Java annotations for the parser class. Default is none. See Section 10.2.1 [Java Bison Interface], page 187.

`%define api.parser.class {`*`name`*`}`   [Directive]
> The name of the parser class. Default is `YYParser` or *`api.prefix`*`Parser`. See Section 10.2.1 [Java Bison Interface], page 187.

`%define api.parser.extends {`*`superclass`*`}`   [Directive]
> The superclass of the parser class. Default is none. See Section 10.2.1 [Java Bison Interface], page 187.

`%define api.parser.final`   [Directive]
>   Whether the parser class is declared `final`. Default is false. See Section 10.2.1 [Java
>   Bison Interface], page 187.

`%define api.parser.implements {`*`interfaces`*`}`   [Directive]
>   The implemented interfaces of the parser class, a comma-separated list. Default is
>   none. See Section 10.2.1 [Java Bison Interface], page 187.

`%define api.parser.public`   [Directive]
>   Whether the parser class is declared `public`. Default is false. See Section 10.2.1 [Java
>   Bison Interface], page 187.

`%define api.parser.strictfp`   [Directive]
>   Whether the parser class is declared `strictfp`. Default is false. See Section 10.2.1
>   [Java Bison Interface], page 187.

`%define init_throws {`*`exceptions`*`}`   [Directive]
>   The exceptions thrown by `%code init` from the parser class constructor. Default is
>   none. See Section 10.2.4 [Java Parser Interface], page 189.

`%define lex_throws {`*`exceptions`*`}`   [Directive]
>   The exceptions thrown by the `yylex` method of the lexer, a comma-separated list. De-
>   fault is `java.io.IOException`. See Section 10.2.6 [Java Scanner Interface], page 192.

`%define api.location.type {`*`class`*`}`   [Directive]
>   The name of the class used for locations (a range between two positions). This
>   class is generated as an inner class of the parser class by `bison`. Default is `Location`.
>   Formerly named `location_type`. See Section 10.2.3 [Java Location Values], page 189.

`%define api.package {`*`package`*`}`   [Directive]
>   The package to put the parser class in. Default is none. See Section 10.2.1 [Java
>   Bison Interface], page 187. Renamed from `package` in Bison 3.7.

`%define api.position.type {`*`class`*`}`   [Directive]
>   The name of the class used for positions. This class must be supplied by the user.
>   Default is `Position`. Formerly named `position_type`. See Section 10.2.3 [Java
>   Location Values], page 189.

`%define api.value.type {`*`class`*`}`   [Directive]
>   The base type of semantic values. Default is `Object`. See Section 10.2.2 [Java Se-
>   mantic Values], page 188.

`%define throws {`*`exceptions`*`}`   [Directive]
>   The exceptions thrown by user-supplied parser actions and `%initial-action`, a
>   comma-separated list. Default is none. See Section 10.2.4 [Java Parser Interface],
>   page 189.

11 A Brief History of the Greater Ungulates

11.1 The ancestral Yacc

Bison originated as a workalike of a program called Yacc — Yet Another Compiler Compiler.[1] Yacc was written at Bell Labs as part of the very early development of Unix; one of its first uses was to develop the original Portable C Compiler, pcc. The same person, Steven C. Johnson, wrote Yacc and the original pcc.

According to the author[2], Yacc was first invented in 1971 and reached a form recognizably similar to the C version in 1973. Johnson published *A Portable Compiler: Theory and Practice* (see [Johnson 1978], page 229).

Yacc was not itself originally written in C but in its predecessor language, B. This goes far to explain its odd interface, which exposes a large number of global variables rather than bundling them into a C struct. All other Yacc-like programs are descended from the C port of Yacc.

Yacc, through both its deployment in pcc and as a standalone tool for generating other parsers, helped drive the early spread of Unix. Yacc itself, however, passed out of use after around 1990 when workalikes with less restrictive licenses and more features became available.

Original Yacc became generally available when Caldera released the sources of old versions of Unix up to V7 and 32V in 2002. By that time it had been long superseded in practical use by Bison even on Yacc's native Unix variants.

11.2 yacchack

One of the deficiencies of original Yacc was its inability to produce reentrant parsers. This was first remedied by a set of drop-in modifications called "yacchack", published by Eric S. Raymond on USENET around 1983. This code was quickly forgotten when zoo and Berkeley Yacc became available a few years later.

11.3 Berkeley Yacc

Berkeley Yacc was originated in 1985 by Robert Corbett (see [Corbett 1984], page 229). It was originally named "zoo", but by October 1989 it became known as Berkeley Yacc or byacc.

Berkeley Yacc had three advantages over the ancestral Yacc: it generated faster parsers, it could generate reentrant parsers, and the source code was released to the public domain rather than being under an AT&T proprietary license. The better performance came from implementing techniques from DeRemer and Penello's seminal paper on LALR parsing (see [DeRemer 1982], page 229).

Use of byacc spread rapidly due to its public domain license. However, once Bison became available, byacc itself passed out of general use.

---

[1] Because of the acronym, the name is sometimes given as "YACC", but Johnson used "Yacc" in the descriptive paper included in the Version 7 Unix Manual (`https://s3.amazonaws.com/plan9-bell-labs/7thEdMan/v7vol2b.pdf`).

[2] `https://lists.gnu.org/archive/html/bison-patches/2019-02/msg00061.html`

11.4 Bison

Robert Corbett actually wrote two (closely related) LALR parsers in 1985, both using the DeRemer/Penello techniques. One was "zoo", the other was "Byson". In 1987 Richard Stallman began working on Byson; the name changed to Bison and the interface became Yacc-compatible.

The main visible difference between Yacc and Byson/Bison at the time of Byson's first release is that Byson supported the `@n` construct (giving access to the starting and ending line number and character number associated with any of the symbols in the current rule).

There was also the command '`%expect n`' which said not to mention the conflicts if there are n shift/reduce conflicts and no reduce/reduce conflicts. In more recent versions of Bison, `%expect` and its `%expect-rr` variant for reduce/reduce conflicts can be applied to individual rules.

Later versions of Bison added many more new features.

Bison error reporting has been improved in various ways. Notably. ancestral Yacc and Byson did not have carets in error messages.

Compared to Yacc Bison uses a faster but less space-efficient encoding for the parse tables (see [Corbett 1984], page 229), and more modern techniques for generating the lookahead sets (see [DeRemer 1982], page 229). This approach is the standard one since then.

(It has also been plausibly alleged the differences in the algorithms stem mainly from the horrible kludges that Johnson had to perpetrate to make the original Yacc fit in a PDP-11.)

Named references, semantic predicates, `%locations`, `%glr-parser`, `%printer`, %destructor, dumps to DOT, `%parse-param`, `%lex-param`, and dumps to XSLT, LAC, and IELR(1) generation are new in Bison.

Bison also has many features to support C++ that were not present in the ancestral Yacc or Byson.

Bison obsolesced all previous Yacc variants and workalikes generating C by 1995.

11.5 Other Ungulates

The Yacc concept has frequently been ported to other languages. Some of the early ports are extinct along with the languages that hosted them; others have been superseded by parser skeletons shipped with Bison.

However, independent implementations persist. One of the best-known still in use is David Beazley's "PLY" (Python Lex-Yacc) for Python. Another is goyacc, supporting the Go language. An "ocamlyacc" is shipped as part of the Ocaml compiler suite.

12 Frequently Asked Questions

Several questions about Bison come up occasionally. Here some of them are addressed.

12.1 Memory Exhausted

My parser returns with error with a 'memory exhausted' message. What can I do?

This question is already addressed elsewhere, see Section 3.3.3 [Recursive Rules], page 55.

12.2 How Can I Reset the Parser

The following phenomenon has several symptoms, resulting in the following typical questions:

I invoke yyparse several times, and on correct input it works properly; but when a parse error is found, all the other calls fail too. How can I reset the error flag of yyparse?

or

My parser includes support for an '#include'-like feature, in which case I run yyparse from yyparse. This fails although I did specify '%define api.pure full'.

These problems typically come not from Bison itself, but from Lex-generated scanners. Because these scanners use large buffers for speed, they might not notice a change of input file. As a demonstration, consider the following source file, first-line.l:

```
%{
#include <stdio.h>
#include <stdlib.h>
%}
%%
.*\n    ECHO; return 1;
%%
int
yyparse (char const *file)
{
  yyin = fopen (file, "r");
  if (!yyin)
    {
      perror ("fopen");
      exit (EXIT_FAILURE);
    }
```

```
      /* One token only. */
      yylex ();
      if (fclose (yyin) != 0)
        {
          perror ("fclose");
          exit (EXIT_FAILURE);
        }
      return 0;
    }

    int
    main (void)
    {
      yyparse ("input");
      yyparse ("input");
      return 0;
    }
```

If the file `input` contains

```
    input:1: Hello,
    input:2: World!
```

then instead of getting the first line twice, you get:

```
    $ flex -ofirst-line.c first-line.l
    $ gcc  -ofirst-line   first-line.c -ll
    $ ./first-line
    input:1: Hello,
    input:2: World!
```

Therefore, whenever you change `yyin`, you must tell the Lex-generated scanner to discard its current buffer and switch to the new one. This depends upon your implementation of Lex; see its documentation for more. For Flex, it suffices to call '`YY_FLUSH_BUFFER`' after each change to `yyin`. If your Flex-generated scanner needs to read from several input streams to handle features like include files, you might consider using Flex functions like '`yy_switch_to_buffer`' that manipulate multiple input buffers.

If your Flex-generated scanner uses start conditions (see Section "Start conditions" in *The Flex Manual*), you might also want to reset the scanner's state, i.e., go back to the initial start condition, through a call to '`BEGIN (0)`'.

12.3 Strings are Destroyed

My parser seems to destroy old strings, or maybe it loses track of them. Instead of reporting '`"foo", "bar"`', it reports '`"bar", "bar"`', or even '`"foo\nbar", "bar"`'.

This error is probably the single most frequent "bug report" sent to Bison lists, but is only concerned with a misunderstanding of the role of the scanner. Consider the following Lex code:

```
%{
#include <stdio.h>
char *yylval = NULL;
%}
%%
.*     yylval = yytext; return 1;
\n     continue;
%%
int
main ()
{
  /* Similar to using $1, $2 in a Bison action. */
  char *fst = (yylex (), yylval);
  char *snd = (yylex (), yylval);
  printf ("\"%s\", \"%s\"\n", fst, snd);
  return 0;
}
```

If you compile and run this code, you get:

```
$ flex -osplit-lines.c split-lines.l
$ gcc  -osplit-lines   split-lines.c -ll
$ printf 'one\ntwo\n' | ./split-lines
"one
two", "two"
```

this is because yytext is a buffer provided for *reading* in the action, but if you want to keep it, you have to duplicate it (e.g., using strdup). Note that the output may depend on how your implementation of Lex handles yytext. For instance, when given the Lex compatibility option -l (which triggers the option '%array') Flex generates a different behavior:

```
$ flex -l -osplit-lines.c split-lines.l
$ gcc      -osplit-lines   split-lines.c -ll
$ printf 'one\ntwo\n' | ./split-lines
"two", "two"
```

12.4 Implementing Gotos/Loops

> My simple calculator supports variables, assignments, and functions, but how can I implement gotos, or loops?

Although very pedagogical, the examples included in the document blur the distinction to make between the parser—whose job is to recover the structure of a text and to transmit it to subsequent modules of the program—and the processing (such as the execution) of this structure. This works well with so called straight line programs, i.e., precisely those that have a straightforward execution model: execute simple instructions one after the others.

If you want a richer model, you will probably need to use the parser to construct a tree that does represent the structure it has recovered; this tree is usually called the *abstract syntax tree*, or *AST* for short. Then, walking through this tree, traversing it in various ways, will enable treatments such as its execution or its translation, which will result in an interpreter or a compiler.

This topic is way beyond the scope of this manual, and the reader is invited to consult the dedicated literature.

12.5 Multiple start-symbols

> I have several closely related grammars, and I would like to share their implementations. In fact, I could use a single grammar but with multiple entry points.

Bison does not support multiple start-symbols, but there is a very simple means to simulate them. If `foo` and `bar` are the two pseudo start-symbols, then introduce two new tokens, say `START_FOO` and `START_BAR`, and use them as switches from the real start-symbol:

```
%token START_FOO START_BAR;
%start start;
start:
  START_FOO foo
| START_BAR bar;
```

These tokens prevents the introduction of new conflicts. As far as the parser goes, that is all that is needed.

Now the difficult part is ensuring that the scanner will send these tokens first. If your scanner is hand-written, that should be straightforward. If your scanner is generated by Lex, them there is simple means to do it: recall that anything between '`%{ ... %}`' after the first `%%` is copied verbatim in the top of the generated `yylex` function. Make sure a variable `start_token` is available in the scanner (e.g., a global variable or using `%lex-param` etc.), and use the following:

```
    /* Prologue. */
%%
%{
  if (start_token)
    {
      int t = start_token;
      start_token = 0;
      return t;
    }
%}
    /* The rules. */
```

12.6 Secure? Conform?

> Is Bison secure? Does it conform to POSIX?

If you're looking for a guarantee or certification, we don't provide it. However, Bison is intended to be a reliable program that conforms to the POSIX specification for Yacc. If you run into problems, please send us a bug report.

12.7 Enabling Relocatability

It has been a pain for many users of GNU packages for a long time that packages are not relocatable. It means a user cannot copy a program, installed by another user on the same

machine, to his home directory, and have it work correctly (including i18n). So many users need to go through `configure; make; make install` with all its dependencies, options, and hurdles.

Red Hat, Debian, and similar package systems solve the "ease of installation" problem, but they hardwire path names, usually to `/usr` or `/usr/local`. This means that users need root privileges to install a binary package, and prevents installing two different versions of the same binary package.

A relocatable program can be moved or copied to a different location on the file system. It is possible to make symlinks to the installed and moved programs, and invoke them through the symlink. It is possible to do the same thing with a hard link *only* if the hard link file is in the same directory as the real program.

To configure a program to be relocatable, add `--enable-relocatable` to the `configure` command line.

On some OSes the executables remember the location of shared libraries and prefer them over any other search path. Therefore, such an executable will look for its shared libraries first in the original installation directory and only then in the current installation directory. Thus, for reliability, it is best to also give a `--prefix` option pointing to a directory that does not exist now and which never will be created, e.g. `--prefix=/nonexistent`. You may use `DESTDIR=dest-dir` on the `make` command line to avoid installing into that directory.

We do not recommend using a prefix writable by unprivileged users (e.g. `/tmp/inst$$`) because such a directory can be recreated by an unprivileged user after the original directory has been removed. We also do not recommend prefixes that might be behind an automounter (e.g. `$HOME/inst$$`) because of the performance impact of directory searching.

Here's a sample installation run that takes into account all these recommendations:

```
./configure --enable-relocatable --prefix=/nonexistent
make
make install DESTDIR=/tmp/inst$$
```

Installation with `--enable-relocatable` will not work for setuid or setgid executables, because such executables search only system library paths for security reasons. Also, installation with `--enable-relocatable` might not work on OpenBSD, when the package contains shared libraries and libtool versions 1.5.xx are used.

The runtime penalty and size penalty are negligible on GNU/Linux (just one system call more when an executable is launched), and small on other systems (the wrapper program just sets an environment variable and executes the real program).

12.8 I can't build Bison

I can't build Bison because `make` complains that `msgfmt` is not found. What should I do?

Like most GNU packages with internationalization support, that feature is turned on by default. If you have problems building in the `po` subdirectory, it indicates that your system's internationalization support is lacking. You can re-configure Bison with `--disable-nls` to turn off this support, or you can install GNU gettext from `https://ftp.gnu.org/gnu/gettext/` and re-configure Bison. See the file `ABOUT-NLS` for more information.

I can't build Bison because my C compiler is too old.

Except for GLR parsers (which require C99), the C code that Bison generates requires only C89 or later. However, Bison itself requires common C99 features such as declarations after statements. Bison's `configure` script attempts to enable C99 (or later) support on compilers that default to pre-C99. If your compiler lacks these C99 features entirely, GCC may well be a better choice; or you can try upgrading to your compiler's latest version.

12.9 Where can I find help?

I'm having trouble using Bison. Where can I find help?

First, read this fine manual. Beyond that, you can send mail to `help-bison@gnu.org`. This mailing list is intended to be populated with people who are willing to answer questions about using and installing Bison. Please keep in mind that (most of) the people on the list have aspects of their lives which are not related to Bison (!), so you may not receive an answer to your question right away. This can be frustrating, but please try not to honk them off; remember that any help they provide is purely voluntary and out of the kindness of their hearts.

12.10 Bug Reports

I found a bug. What should I include in the bug report?

Before sending a bug report, make sure you are using the latest version. Check `https://ftp.gnu.org/pub/gnu/bison/` or one of its mirrors. Be sure to include the version number in your bug report. If the bug is present in the latest version but not in a previous version, try to determine the most recent version which did not contain the bug.

If the bug is parser-related, you should include the smallest grammar you can which demonstrates the bug. The grammar file should also be complete (i.e., I should be able to run it through Bison without having to edit or add anything). The smaller and simpler the grammar, the easier it will be to fix the bug.

Include information about your compilation environment, including your operating system's name and version and your compiler's name and version. If you have trouble compiling, you should also include a transcript of the build session, starting with the invocation of `configure`. Depending on the nature of the bug, you may be asked to send additional files as well (such as `config.h` or `config.cache`).

Patches are most welcome, but not required. That is, do not hesitate to send a bug report just because you cannot provide a fix.

Send bug reports to `bug-bison@gnu.org`.

12.11 More Languages

Will Bison ever have C++ and Java support? How about *insert your favorite language here*?

C++ and Java support is there now, and is documented. We'd love to add other languages; contributions are welcome.

12.12 Beta Testing

What is involved in being a beta tester?

It's not terribly involved. Basically, you would download a test release, compile it, and use it to build and run a parser or two. After that, you would submit either a bug report or a message saying that everything is okay. It is important to report successes as well as failures because test releases eventually become mainstream releases, but only if they are adequately tested. If no one tests, development is essentially halted.

Beta testers are particularly needed for operating systems to which the developers do not have easy access. They currently have easy access to recent GNU/Linux and Solaris versions. Reports about other operating systems are especially welcome.

12.13 Mailing Lists

How do I join the help-bison and bug-bison mailing lists?

See `http://lists.gnu.org/`.

Appendix A Bison Symbols

`@$`   [Variable]

In an action, the location of the left-hand side of the rule. See Section 3.5 [Tracking Locations], page 66.

`@n`   [Variable]
`@n`   [Symbol]

In an action, the location of the *n*-th symbol of the right-hand side of the rule. See Section 3.5 [Tracking Locations], page 66.

In a grammar, the Bison-generated nonterminal symbol for a midrule action with a semantic value. See Section 3.4.8.3 [Midrule Action Translation], page 63.

`@name`   [Variable]
`@[name]`   [Variable]

In an action, the location of a symbol addressed by *name*. See Section 3.5 [Tracking Locations], page 66.

`$@n`   [Symbol]

In a grammar, the Bison-generated nonterminal symbol for a midrule action with no semantics value. See Section 3.4.8.3 [Midrule Action Translation], page 63.

`$$`   [Variable]

In an action, the semantic value of the left-hand side of the rule. See Section 3.4.6 [Actions], page 59.

`$n`   [Variable]

In an action, the semantic value of the *n*-th symbol of the right-hand side of the rule. See Section 3.4.6 [Actions], page 59.

`$name`   [Variable]
`$[name]`   [Variable]

In an action, the semantic value of a symbol addressed by *name*. See Section 3.4.6 [Actions], page 59.

`%%`   [Delimiter]

Delimiter used to separate the grammar rule section from the Bison declarations section or the epilogue. See Section 1.9 [The Overall Layout of a Bison Grammar], page 26.

`%{code%}`   [Delimiter]

All code listed between '`%{`' and '`%}`' is copied verbatim to the parser implementation file. Such code forms the prologue of the grammar file. See Section 3.1 [Outline of a Bison Grammar], page 46.

`%?{expression}`   [Directive]

Predicate actions. This is a type of action clause that may appear in rules. The expression is evaluated, and if false, causes a syntax error. In GLR parsers during nondeterministic operation, this silently causes an alternative parse to die. During deterministic operation, it is the same as the effect of YYERROR. See Section 1.5.4 [Controlling a Parse with Arbitrary Predicates], page 23.

`/* ... */`   [Construct]
`// ...`   [Construct]
 Comments, as in C/C++.

`:`   [Delimiter]
 Separates a rule's result from its components. See Section 3.3 [Grammar Rules],
 page 54.

`;`   [Delimiter]
 Terminates a rule. See Section 3.3 [Grammar Rules], page 54.

`|`   [Delimiter]
 Separates alternate rules for the same result nonterminal. See Section 3.3 [Grammar
 Rules], page 54.

`<*>`   [Directive]
 Used to define a default tagged `%destructor` or default tagged `%printer`.

 See Section 3.7.7 [Freeing Discarded Symbols], page 73.

`<>`   [Directive]
 Used to define a default tagless `%destructor` or default tagless `%printer`.

 See Section 3.7.7 [Freeing Discarded Symbols], page 73.

`$accept`   [Symbol]
 The predefined nonterminal whose only rule is '`$accept: start $end`', where *start* is
 the start symbol. See Section 3.7.10 [The Start-Symbol], page 77. It cannot be used
 in the grammar.

`%code {code}`   [Directive]
`%code qualifier {code}`   [Directive]
 Insert *code* verbatim into the output parser source at the default location or at the
 location specified by *qualifier*. See Section 3.7.15 [%code Summary], page 94.

`%debug`   [Directive]
 Equip the parser for debugging. See Section 3.7.13 [Bison Declaration Summary],
 page 79.

`%define variable`   [Directive]
`%define variable value`   [Directive]
`%define variable {value}`   [Directive]
`%define variable "value"`   [Directive]
 Define a variable to adjust Bison's behavior. See Section 3.7.14 [%define Summary],
 page 84.

`%defines`   [Directive]
 Bison declaration to create a parser header file, which is usually meant for the scanner.
 See Section 3.7.13 [Bison Declaration Summary], page 79.

`%defines defines-file`   [Directive]
 Same as above, but save in the file *defines-file*. See Section 3.7.13 [Bison Declaration
 Summary], page 79.

%destructor   [Directive]
> Specify how the parser should reclaim the memory associated to discarded symbols.
> See Section 3.7.7 [Freeing Discarded Symbols], page 73.

%dprec   [Directive]
> Bison declaration to assign a precedence to a rule that is used at parse time to resolve
> reduce/reduce conflicts. See Section 1.5 [Writing GLR Parsers], page 17.

%empty   [Directive]
> Bison declaration to declare make explicit that a rule has an empty right-hand side.
> See Section 3.3.2 [Empty Rules], page 55.

$end   [Symbol]
> The predefined token marking the end of the token stream. It cannot be used in the
> grammar.

error   [Symbol]
> A token name reserved for error recovery. This token may be used in grammar rules
> so as to allow the Bison parser to recognize an error in the grammar without halting
> the process. In effect, a sentence containing an error may be recognized as valid.
> On a syntax error, the token `error` becomes the current lookahead token. Actions
> corresponding to `error` are then executed, and the lookahead token is reset to the
> token that originally caused the violation. See Chapter 6 [Error Recovery], page 130.

%error-verbose   [Directive]
> An obsolete directive standing for '`%define parse.error verbose`'.

%file-prefix "_prefix_"   [Directive]
> Bison declaration to set the prefix of the output files. See Section 3.7.13 [Bison
> Declaration Summary], page 79.

%glr-parser   [Directive]
> Bison declaration to produce a GLR parser. See Section 1.5 [Writing GLR Parsers],
> page 17.

%initial-action   [Directive]
> Run user code before parsing. See Section 3.7.6 [Performing Actions before Parsing],
> page 73.

%language   [Directive]
> Specify the programming language for the generated parser. See Section 3.7.13 [Bison
> Declaration Summary], page 79.

%left   [Directive]
> Bison declaration to assign precedence and left associativity to token(s). See
> Section 3.7.3 [Operator Precedence], page 71.

%lex-param {_argument-declaration_} ...   [Directive]
> Bison declaration to specifying additional arguments that `yylex` should accept. See
> Section 4.3.6 [Calling Conventions for Pure Parsers], page 103.

`%merge`   [Directive]
> Bison declaration to assign a merging function to a rule. If there is a reduce/reduce conflict with a rule having the same merging function, the function is applied to the two semantic values to get a single result. See Section 1.5 [Writing GLR Parsers], page 17.

`%name-prefix "prefix"`   [Directive]
> Obsoleted by the `%define` variable `api.prefix` (see Section 3.8 [Multiple Parsers in the Same Program], page 95).

> Rename the external symbols (variables and functions) used in the parser so that they start with *prefix* instead of 'yy'. Contrary to `api.prefix`, do no rename types and macros.

> The precise list of symbols renamed in C parsers is `yyparse`, `yylex`, `yyerror`, `yynerrs`, `yylval`, `yychar`, `yydebug`, and (if locations are used) `yylloc`. If you use a push parser, `yypush_parse`, `yypull_parse`, `yypstate`, `yypstate_new` and `yypstate_delete` will also be renamed. For example, if you use '`%name-prefix "c_"`', the names become `c_parse`, `c_lex`, and so on. For C++ parsers, see the `%define api.namespace` documentation in this section.

`%no-lines`   [Directive]
> Bison declaration to avoid generating `#line` directives in the parser implementation file. See Section 3.7.13 [Bison Declaration Summary], page 79.

`%nonassoc`   [Directive]
> Bison declaration to assign precedence and nonassociativity to token(s). See Section 3.7.3 [Operator Precedence], page 71.

`%nterm`   [Directive]
> Bison declaration to declare nonterminals. See Section 3.7.4 [Nonterminal Symbols], page 72.

`%output "file"`   [Directive]
> Bison declaration to set the name of the parser implementation file. See Section 3.7.13 [Bison Declaration Summary], page 79.

`%param {argument-declaration} ...`   [Directive]
> Bison declaration to specify additional arguments that both `yylex` and `yyparse` should accept. See Section 4.1 [The Parser Function `yyparse`], page 98.

`%parse-param {argument-declaration} ...`   [Directive]
> Bison declaration to specify additional arguments that `yyparse` should accept. See Section 4.1 [The Parser Function `yyparse`], page 98.

`%prec`   [Directive]
> Bison declaration to assign a precedence to a specific rule. See Section 5.4 [Context-Dependent Precedence], page 116.

`%precedence`   [Directive]
> Bison declaration to assign precedence to token(s), but no associativity See Section 3.7.3 [Operator Precedence], page 71.

%pure-parser   [Directive]

> Deprecated version of '%define api.pure' (see Section 3.7.14 [%define Summary],
> page 84), for which Bison is more careful to warn about unreasonable usage.

%require "*version*"   [Directive]

> Require version *version* or higher of Bison. See Section 3.7.1 [Require a Version of
> Bison], page 70.

%right   [Directive]

> Bison declaration to assign precedence and right associativity to token(s). See
> Section 3.7.3 [Operator Precedence], page 71.

%skeleton   [Directive]

> Specify the skeleton to use; usually for development. See Section 3.7.13 [Bison Dec-
> laration Summary], page 79.

%start   [Directive]

> Bison declaration to specify the start symbol. See Section 3.7.10 [The Start-Symbol],
> page 77.

%token   [Directive]

> Bison declaration to declare token(s) without specifying precedence. See Section 3.7.2
> [Token Kind Names], page 70.

%token-table   [Directive]

> Bison declaration to include a token name table in the parser implementation file.
> See Section 3.7.13 [Bison Declaration Summary], page 79.

%type   [Directive]

> Bison declaration to declare symbol value types. See Section 3.7.4 [Nonterminal
> Symbols], page 72.

$undefined   [Symbol]

> The predefined token onto which all undefined values returned by yylex are mapped.
> It cannot be used in the grammar, rather, use error.

%union   [Directive]

> Bison declaration to specify several possible data types for semantic values. See
> Section 3.4.4 [The Union Declaration], page 58.

YYABORT   [Macro]

> Macro to pretend that an unrecoverable syntax error has occurred, by making yyparse
> return 1 immediately. The error reporting function yyerror is not called. See
> Section 4.1 [The Parser Function yyparse], page 98.
>
> For Java parsers, this functionality is invoked using return YYABORT; instead.

YYACCEPT   [Macro]

> Macro to pretend that a complete utterance of the language has been read, by mak-
> ing yyparse return 0 immediately. See Section 4.1 [The Parser Function yyparse],
> page 98.
>
> For Java parsers, this functionality is invoked using return YYACCEPT; instead.

YYBACKUP   [Macro]
> Macro to discard a value from the parser stack and fake a lookahead token. See Section 4.5 [Special Features for Use in Actions], page 107.

yychar   [Variable]
> External integer variable that contains the integer value of the lookahead token. (In a pure parser, it is a local variable within `yyparse`.) Error-recovery rule actions may examine this variable. See Section 4.5 [Special Features for Use in Actions], page 107.

yyclearin   [Variable]
> Macro used in error-recovery rule actions. It clears the previous lookahead token. See Chapter 6 [Error Recovery], page 130.

YYDEBUG   [Macro]
> Macro to define to equip the parser with tracing code. See Section 8.5 [Tracing Your Parser], page 148.

yydebug   [Variable]
> External integer variable set to zero by default. If `yydebug` is given a nonzero value, the parser will output information on input symbols and parser action. See Section 8.5 [Tracing Your Parser], page 148.

YYEMPTY   [Value]
> The pseudo token kind when there is no lookahead token.

YYEOF   [Value]
> The token kind denoting is the end of the input stream.

yyerrok   [Macro]
> Macro to cause parser to recover immediately to its normal mode after a syntax error. See Chapter 6 [Error Recovery], page 130.

YYERROR   [Macro]
> Cause an immediate syntax error. This statement initiates error recovery just as if the parser itself had detected an error; however, it does not call `yyerror`, and does not print any message. If you want to print an error message, call `yyerror` explicitly before the '`YYERROR;`' statement. See Chapter 6 [Error Recovery], page 130.
>
> For Java parsers, this functionality is invoked using `return YYERROR;` instead.

yyerror   [Function]
> User-supplied function to be called by `yyparse` on error. See Section 4.4.1 [The Error Reporting Function `yyerror`], page 104.

YYFPRINTF   [Macro]
> Macro used to output run-time traces in C. See Section 8.5.1 [Enabling Traces], page 148.

YYINITDEPTH   [Macro]
> Macro for specifying the initial size of the parser stack. See Section 5.10 [Memory Management, and How to Avoid Memory Exhaustion], page 128.

yylex [Function]

>   User-supplied lexical analyzer function, called with no arguments to get the next
>   token. See Section 4.3 [The Lexical Analyzer Function `yylex`], page 100.

yylloc [Variable]

>   External variable in which `yylex` should place the line and column numbers associated
>   with a token. (In a pure parser, it is a local variable within `yyparse`, and its address
>   is passed to `yylex`.) You can ignore this variable if you don't use the '`@`' feature
>   in the grammar actions. See Section 4.3.5 [Textual Locations of Tokens], page 102.
>   In semantic actions, it stores the location of the lookahead token. See Section 3.5.2
>   [Actions and Locations], page 66.

YYLTYPE [Type]

>   Data type of `yylloc`. By default in C, a structure with four members (start/end
>   line/column). See Section 3.5.1 [Data Type of Locations], page 66.

yylval [Variable]

>   External variable in which `yylex` should place the semantic value associated with
>   a token. (In a pure parser, it is a local variable within `yyparse`, and its address
>   is passed to `yylex`.) See Section 4.3.4 [Semantic Values of Tokens], page 102. In
>   semantic actions, it stores the semantic value of the lookahead token. See Section 3.4.6
>   [Actions], page 59.

YYMAXDEPTH [Macro]

>   Macro for specifying the maximum size of the parser stack. See Section 5.10 [Memory
>   Management, and How to Avoid Memory Exhaustion], page 128.

yynerrs [Variable]

>   Global variable which Bison increments each time it reports a syntax error. (In a pure
>   parser, it is a local variable within `yyparse`. In a pure push parser, it is a member of
>   `yypstate`.) See Section 4.4.1 [The Error Reporting Function `yyerror`], page 104.

yyparse [Function]

>   The parser function produced by Bison; call this function to start parsing. See
>   Section 4.1 [The Parser Function `yyparse`], page 98.

YYPRINT [Macro]

>   Macro used to output token semantic values. For `yacc.c` only. Deprecated, use
>   `%printer` instead (see Section 3.7.8 [Printing Semantic Values], page 75). See
>   Section 8.5.3 [The `YYPRINT` Macro], page 152.

yypstate_delete [Function]

>   The function to delete a parser instance, produced by Bison in push mode; call this
>   function to delete the memory associated with a parser. See [`yypstate_delete`],
>   page 99. Does nothing when called with a null pointer.

yypstate_new [Function]

>   The function to create a parser instance, produced by Bison in push mode; call this
>   function to create a new parser. See [`yypstate_new`], page 99.

yypull_parse   [Function]

The parser function produced by Bison in push mode; call this function to parse the rest of the input stream. See [`yypull_parse`], page 100.

yypush_parse   [Function]

The parser function produced by Bison in push mode; call this function to parse a single token. See [`yypush_parse`], page 99.

YYRECOVERING   [Macro]

The expression `YYRECOVERING ()` yields 1 when the parser is recovering from a syntax error, and 0 otherwise. See Section 4.5 [Special Features for Use in Actions], page 107.

YYSTACK_USE_ALLOCA   [Macro]

Macro used to control the use of `alloca` when the deterministic parser in C needs to extend its stacks. If defined to 0, the parser will use `malloc` to extend its stacks and memory exhaustion occurs if `malloc` fails (see Section 5.10 [Memory Management, and How to Avoid Memory Exhaustion], page 128). If defined to 1, the parser will use `alloca`. Values other than 0 and 1 are reserved for future Bison extensions. If not defined, `YYSTACK_USE_ALLOCA` defaults to 0.

In the all-too-common case where your code may run on a host with a limited stack and with unreliable stack-overflow checking, you should set `YYMAXDEPTH` to a value that cannot possibly result in unchecked stack overflow on any of your target hosts when `alloca` is called. You can inspect the code that Bison generates in order to determine the proper numeric values. This will require some expertise in low-level implementation details.

YYSTYPE   [Type]

Deprecated in favor of the `%define` variable `api.value.type`. Data type of semantic values; `int` by default. See Section 3.4.1 [Data Types of Semantic Values], page 56.

yysymbol_kind_t   [Type]

An enum of all the symbols, tokens and nonterminals, of the grammar. See Section 4.4.2 [The Syntax Error Reporting Function `yyreport_syntax_error`], page 105. The symbol kinds are used internally by the parser, and should not be confused with the token kinds: the symbol kind of a terminal symbol is not equal to its token kind! (Unless '`%define api.token.raw`' was used.)

yytoken_kind_t   [Type]

An enum of all the *token kinds* declared with `%token` (see Section 3.7.2 [Token Kind Names], page 70). These are the return values for `yylex`. They should not be confused with the *symbol kinds*, used internally by the parser.

YYUNDEF   [Value]

The token kind denoting an unknown token.

Appendix B Glossary

Accepting state

> A state whose only action is the accept action. The accepting state is thus a consistent state. See Section 8.2 [Understanding Your Parser], page 138.

Backus-Naur Form (BNF; also called "Backus Normal Form")

> Formal method of specifying context-free grammars originally proposed by John Backus, and slightly improved by Peter Naur in his 1960-01-02 committee document contributing to what became the Algol 60 report. See Section 1.1 [Languages and Context-Free Grammars], page 14.

Consistent state

> A state containing only one possible action. See Section 5.8.2 [Default Reductions], page 124.

Context-free grammars

> Grammars specified as rules that can be applied regardless of context. Thus, if there is a rule which says that an integer can be used as an expression, integers are allowed *anywhere* an expression is permitted. See Section 1.1 [Languages and Context-Free Grammars], page 14.

Counterexample

> A sequence of tokens and/or nonterminals, with one dot, that demonstrates a conflict. The dot marks the place where the conflict occurs.

> A *unifying* counterexample is a single string that has two different parses; its existence proves that the grammar is ambiguous. When a unifying counterexample cannot be found in reasonable time, a *nonunifying* counterexample is built: *two* different string sharing the prefix up to the dot.

> See Section 8.1 [Generation of Counterexamples], page 135,

Default reduction

> The reduction that a parser should perform if the current parser state contains no other action for the lookahead token. In permitted parser states, Bison declares the reduction with the largest lookahead set to be the default reduction and removes that lookahead set. See Section 5.8.2 [Default Reductions], page 124.

Defaulted state

> A consistent state with a default reduction. See Section 5.8.2 [Default Reductions], page 124.

Dynamic allocation

> Allocation of memory that occurs during execution, rather than at compile time or on entry to a function.

Empty string

> Analogous to the empty set in set theory, the empty string is a character string of length zero.

Finite-state stack machine

> A "machine" that has discrete states in which it is said to exist at each instant in time. As input to the machine is processed, the machine moves from state to state as specified by the logic of the machine. In the case of the parser, the input is the language being parsed, and the states correspond to various stages in the grammar rules. See Chapter 5 [The Bison Parser Algorithm], page 111.

Generalized LR (GLR)

> A parsing algorithm that can handle all context-free grammars, including those that are not LR(1). It resolves situations that Bison's deterministic parsing algorithm cannot by effectively splitting off multiple parsers, trying all possible parsers, and discarding those that fail in the light of additional right context. See Section 5.9 [Generalized LR (GLR) Parsing], page 127.

Grouping A language construct that is (in general) grammatically divisible; for example, 'expression' or 'declaration' in C. See Section 1.1 [Languages and Context-Free Grammars], page 14.

IELR(1) (Inadequacy Elimination LR(1))

> A minimal LR(1) parser table construction algorithm. That is, given any context-free grammar, IELR(1) generates parser tables with the full language-recognition power of canonical LR(1) but with nearly the same number of parser states as LALR(1). This reduction in parser states is often an order of magnitude. More importantly, because canonical LR(1)'s extra parser states may contain duplicate conflicts in the case of non-LR(1) grammars, the number of conflicts for IELR(1) is often an order of magnitude less as well. This can significantly reduce the complexity of developing a grammar. See Section 5.8.1 [LR Table Construction], page 122.

Infix operator

> An arithmetic operator that is placed between the operands on which it performs some operation.

Input stream

> A continuous flow of data between devices or programs.

Kind "Token" and "symbol" are each overloaded to mean either a grammar symbol (kind) or all parse info (kind, value, location) associated with occurrences of that grammar symbol from the input. To disambiguate,

> - we use "token kind" and "symbol kind" to mean both grammar symbols and the values that represent them in a base programming language (C, C++, etc.). The names of the types of these values are typically `token_kind_t`, or `token_kind_type`, or `TokenKind`, depending on the programming language.
> - we use "token" and "symbol" without the word "kind" to mean parsed occurrences, and we append the word "type" to refer to the types that represent them in a base programming language.

> In summary: When you see "kind", interpret "symbol" or "token" to mean a *grammar symbol*. When you don't see "kind" (including when you see "type"), interpret "symbol" or "token" to mean a *parsed symbol*.

LAC (Lookahead Correction)

> A parsing mechanism that fixes the problem of delayed syntax error detection, which is caused by LR state merging, default reductions, and the use of `%nonassoc`. Delayed syntax error detection results in unexpected semantic actions, initiation of error recovery in the wrong syntactic context, and an incorrect list of expected tokens in a verbose syntax error message. See Section 5.8.3 [LAC], page 125.

Language construct

> One of the typical usage schemas of the language. For example, one of the constructs of the C language is the `if` statement. See Section 1.1 [Languages and Context-Free Grammars], page 14.

Left associativity

> Operators having left associativity are analyzed from left to right: 'a+b+c' first computes 'a+b' and then combines with 'c'. See Section 5.3 [Operator Precedence], page 114.

Left recursion

> A rule whose result symbol is also its first component symbol; for example, 'expseq1 : expseq1 ',' exp;'. See Section 3.3.3 [Recursive Rules], page 55.

Left-to-right parsing

> Parsing a sentence of a language by analyzing it token by token from left to right. See Chapter 5 [The Bison Parser Algorithm], page 111.

Lexical analyzer (scanner)

> A function that reads an input stream and returns tokens one by one. See Section 4.3 [The Lexical Analyzer Function `yylex`], page 100.

Lexical tie-in

> A flag, set by actions in the grammar rules, which alters the way tokens are parsed. See Section 7.2 [Lexical Tie-ins], page 133.

Literal string token

> A token which consists of two or more fixed characters. See Section 3.2 [Symbols, Terminal and Nonterminal], page 52.

Lookahead token

> A token already read but not yet shifted. See Section 5.1 [Lookahead Tokens], page 111.

LALR(1)

> The class of context-free grammars that Bison (like most other parser generators) can handle by default; a subset of LR(1). See Section 5.7 [Mysterious Conflicts], page 120.

LR(1)

> The class of context-free grammars in which at most one token of lookahead is needed to disambiguate the parsing of any piece of input.

Nonterminal symbol

> A grammar symbol standing for a grammatical construct that can be expressed through rules in terms of smaller constructs; in other words, a construct that is not a token. See Section 3.2 [Symbols, Terminal and Nonterminal], page 52.

Parser   A function that recognizes valid sentences of a language by analyzing the syntax structure of a set of tokens passed to it from a lexical analyzer.

Postfix operator
             An arithmetic operator that is placed after the operands upon which it performs some operation.

Reduction   Replacing a string of nonterminals and/or terminals with a single nonterminal, according to a grammar rule. See Chapter 5 [The Bison Parser Algorithm], page 111.

Reentrant   A reentrant subprogram is a subprogram which can be in invoked any number of times in parallel, without interference between the various invocations. See Section 3.7.11 [A Pure (Reentrant) Parser], page 77.

Reverse Polish Notation
             A language in which all operators are postfix operators.

Right recursion
             A rule whose result symbol is also its last component symbol; for example, 'expseq1: exp ',' expseq1;'. See Section 3.3.3 [Recursive Rules], page 55.

Semantics   In computer languages, the semantics are specified by the actions taken for each instance of the language, i.e., the meaning of each statement. See Section 3.4 [Defining Language Semantics], page 56.

Shift   A parser is said to shift when it makes the choice of analyzing further input from the stream rather than reducing immediately some already-recognized rule. See Chapter 5 [The Bison Parser Algorithm], page 111.

Single-character literal
             A single character that is recognized and interpreted as is. See Section 1.2 [From Formal Rules to Bison Input], page 15.

Start symbol
             The nonterminal symbol that stands for a complete valid utterance in the language being parsed. The start symbol is usually listed as the first nonterminal symbol in a language specification. See Section 3.7.10 [The Start-Symbol], page 77.

Symbol kind
             A (finite) enumeration of the grammar symbols, as processed by the parser. See Section 3.2 [Symbols, Terminal and Nonterminal], page 52.

Symbol table
             A data structure where symbol names and associated data are stored during parsing to allow for recognition and use of existing information in repeated uses of a symbol. See Section 2.5 [Multi-Function Calculator: `mfcalc`], page 39.

Syntax error
             An error encountered during parsing of an input stream due to invalid syntax. See Chapter 6 [Error Recovery], page 130.

Terminal symbol

> A grammar symbol that has no rules in the grammar and therefore is grammatically indivisible. The piece of text it represents is a token. See Section 1.1 [Languages and Context-Free Grammars], page 14.

Token   A basic, grammatically indivisible unit of a language. The symbol that describes a token in the grammar is a terminal symbol. The input of the Bison parser is a stream of tokens which comes from the lexical analyzer. See Section 3.2 [Symbols, Terminal and Nonterminal], page 52.

Token kind

> A (finite) enumeration of the grammar terminals, as discriminated by the scanner. See Section 3.2 [Symbols, Terminal and Nonterminal], page 52.

Unreachable state

> A parser state to which there does not exist a sequence of transitions from the parser's start state. A state can become unreachable during conflict resolution. See Section 5.8.4 [Unreachable States], page 127.

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