

# sidBison: A Stepwise Interactive Debugger for Bison

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## 0.1 A note on formal grammars

This document is aimed at audiences who have some familiarity with formal grammars or concrete syntax trees. Some familiarity with using **Lex**, **Flex**, **YACC** or **Bison** is not required, but will allow for deeper understanding of the posed problem. If not, I strongly recommend reading the Bison user manual at <http://www.gnu.org/software/bison/manual/>.

# Chapter 1

## Introduction

### 1.1 Machine generated parsers

A parser, in its most general sense, is a machine that examines a string of characters and acts according to the rules of a formal grammar. In computer science, parsers have widespread applications, ranging from Natural Language Processing to compiler generation. Programmers often use these systems to place information in forms about which they can more easily reason.

Early parsers were developed well before a theory of formal grammars was developed, and were painstakingly written into punchcards. With Backhaus and Naur's formalization of EBNF notation for describing languages, programs were soon contracted this tedious job. Recursive Descent parser generating machines soon became the standard, helping programmers put in grammars and get out entire parsers. While these top-down methods were easily understandable and debuggable, the generated machines could not deal with several everyday scenarios, including left-recursion. This led to the generation of **Bottom Up** parsing methods and their generators. These fantastically complex systems could process most everyday grammars, and preserved the EBNF abstraction afforded earlier to programmers. However, in doing so, these programs became very complex, involving several tables, automata and stacks. They quickly became too complex for most programmers to understand.

### 1.2 Bison

Bison is a very popular bottom-up (LALR) parser generator that was built for the GNU project. According to the GNU website:

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) parser tables. As an experimental feature, Bison can also generate 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.- *GNU Bison*

### 1.2.1 Basic Actions

The **Bison** parser-generator employs a *bottom-up* parsing mechanism. The program uses an input specification to generate a push-down automaton as well as a token stack. Transitions between states are executed on the basis of encountered tokens. **Bison** has three basic actions:

1. **shift** : As **Bison** encounters input tokens, it pushes them onto the token stack.
2. **reduce** : When the last  $k$  shifted tokens match a rule, they are merged to form the non-terminal specified in the left hand side of the rule. This is now stored on the token stack. The push down automata then 'pops' back to a previous state.
3. **lookahead** : **Bison** often looks *ahead* at the next coming token before performing a shift or reduce action, in order to better ascertain what to do.

**Bison** 'attempts' to use shifts and reductions (with the aid of lookaheads) to fit input to a specified **start** symbol in the specification.

### 1.2.2 Lookaheads

While the need for a look-ahead may not be apparent, the following example shows its effectiveness.

<pre>Digit : 1   2   3  Number : Digit           Digit Number</pre>
---

On input 12 the parser requires the look-ahead to know that after the digit 1 has been shifted, it should not immediately be reduced to the rule **Number**.

### 1.2.3 Limitations

While **Bison** is able to produce parsers for a wide range of grammars, its underlying LALR(1) parser table implementation is limited to certain forms. Certain specifications can cause shift-reduce and reduce-reduce conflicts, where there is ambiguity in what action should be executed.

### Shift-Reduce Conflicts

```
E -> a E
      | a
```

In the grammar above, we see that when parsing terminal **a**, there could be a reduce action to **E** and a shift action in order to parse the rule **a E**. In such a situation, an LR parser would not be able to decide on a 'correct' option. **BISON** shifts in such a situation, which may not echo the programmers intent.

### Reduce-Reduce conflicts

```
X -> Y a | Z b
Y -> a
Z -> a
```

In the grammar above, we see that the terminal **a** could be reduced to **Y** or **Z**. Bottom-up parsers, like **BISON**, do not have a resolution strategy in such a situation.

A list of sources that further explain the functioning of Bison-generated parsers can be found in the Appendix.

## 1.3 Programmer Errors

Real-world Bison specifications are often very large. Much like any other language, larger specifications create greater room for programmer error. As a result, while generated parsers may accept input, they often do not behave in a way intended by programmers. Debugging these machine-generated parsers is a non-trivial task. While both Bison and iBison provide error messaging in terms of the underlying parser implementation, it is not easy to examine the semantics of a specification. A user needs to be familiar not only with the specified grammar, but also LR parsing to correct errors in their code.

Presented below are Bison specifications that do not accept the exact set of strings a programmer might expect.

### 1.3.1 Small Specifications: Calculator Language

Defined below is an attempt to specify the grammar for a simple calculator language that accepts integers and performs addition, subtraction, multiplication and division. While this grammar may seem to specify the calculator language at first, it cannot parse any string with more than one operator. For instance, the string `1 + 1 + 1` is not accepted.

```
Digit : 1
```

```

    | 2
    | 3
    | 4
    | 5
    | 6
    | 7
    | 8
    | 9
    | 0

Number : Digit
       | Digit Number

Operator : +
         | -
         | *
         | /

Expression : Number
           | Number Operator Number

```

While the specification is quite small, it is surprisingly hard to instinctively find the error in the grammar.

### 1.3.2 Large Specifications: JSON

Larger grammars, by virtue of their size, are hard to debug. The specification in **Appendix 6.3** is intended to describe JSON strings. Upon closer inspection, one might notice that the grammar can parse only 2 members with value separators. Identifying which rule causes the error is almost impossible without traversing the whole grammar. A step-through debugging approach can be hard to execute manually.

As a result of the complexity of these systems, parser generators like **Bison** are quickly losing ground to parser combinator libraries like **Parsec**. Increasing the accessibility of these systems could help bottom up parser generators re-emerge as a staple of the average language designer's work bench.



## Chapter 2

# Stepwise Interactive Debugger for Bison

`iBison` is a version of `Bison` 2.3 that was built by S.K. Popuri at the University of Illinois at Chicago. It generates an interactive interface that allows a user to step through the parsing process, presenting information in terms of a push-down automaton and its state and token stacks. Stepwise Interactive Debugger for Bison (`sidBison`), leverages this responsive design to allow for debugging at the grammar level. The system is modelled on `gdb`-style debuggers, allowing for not only the identification of errors in `Bison` specifications but also those in input strings, maintaining an abstraction barrier between grammars and parser-generated state tables.

The goal of this project is to simplify the parser-generation process for programmers who are not well-versed with the underlying implementation. Debuggers preserving such abstraction barriers could be particularly useful in the process of democratizing language design workbenches.

### 2.1 Using `sidBison`

The `sidBison` system requires a `Bison` specification and lexer shared object in order to debug a string. A more detailed setup process as well as examples are described in the Appendix.

### 2.2 Complete Instruction Set

The `sidBison` instruction set is designed to reinforce the abstraction barrier between a `Bison` specification and the underlying parser implementation.

1. **`crule`**: Returns the current rule being parsed in the `Bison` specification.

2. **steprule** : Steps to the next rule in the Bison specification
3. **str**: Identifies the current position in the entire parsing process.
4. **br** : Allows the user to break when a particular token is encountered.
5. **step** : Steps to the next action taken by the parser
6. **ctkn** : Displays the current token being looked at by the parser.
7. **rulepos** : Identifies current position in the rule being parsed.
8. **test** <filename> : Accepts the input string as a file.
9. **quit** : Ends the sidBison program

The implementation of these commands is described in the Technical Approach section.

## 2.3 Usability

The success of **sidBison** is pinned on its usability. It should be able to aid a user with the examples presented earlier. This is predicated on the idea that:

1. Humans generally find EBNF easier to understand than push down automata.
2. The ability to step through specifications presents bottom-up parsing in an understandable, linear manner.

These criteria are evaluated in two case studies presented later.

## Chapter 3

# Implementing the Instruction Set

`sidBison` is designed to be a step-through debugger at the grammar level, and is built on top of `iBison`'s interactive debugging mechanism. The mathematical underpinnings of the system involve mapping `Bison` and `iBison` constructs like

1. Push Down Automata
2. State Stacks
3. Token Stacks
4. Lookaheads

to Extended Backus Naur Form (EBNF) grammar rules. As a result, each command takes the form of a mathematical function in terms of these variables.

### 3.1 `step`

The `step` command allows the user to step forward to the next action taken by the underlying parser debugger. It is the simplest command for the `sidBison` system. The rule is of the form  $f_1(ss, ts, ct) \rightarrow (ss', ts', tc')$ , where:

1.  $ss$  and  $ss'$  are state stacks.
2.  $ts$  and  $ts'$  are token stacks.
3.  $ct$  and  $ct'$  are current tokens.

`step` provides the basis of mapping actions in term of the underlying parser to those involving `Bison` specifications. It maps a new *lookahead* to encountering a new token, a shift to adding the token to the string, and a reduce registers as a parsed string. Several of the more complicated `sidBison` commands leverage `step`.

## 3.2 steprule

The **steprule** command takes the user to the next rule encountered by the parser. Thus, it presents a step-wise debugging abstraction in terms of the user-provided grammar specification instead of parser-generator options.

The command is implemented by stepping through **iBison** state change till a reduce action is executed. As a result it has the mathematical form  $f_2 : \text{Parser Automaton} \rightarrow (ss', ts')$ , where :

1.  $ss'$  represents a new state stack, and by extension a new current state.
2.  $ts'$  represents a new token stack.

## 3.3 crule

The **crule** command returns the current rule being parsed by Bison generated parser. It takes the form of a mathematical function  $f_3 : (\text{Parser Automaton}, \text{Current State}, \text{State Stack}) \rightarrow (\text{Backhaus Naur Form Rule})$ .

In general, a bottom-up parser can not predict the non-terminal to which a partially known sequence of tokens will be reduced. Even judging if a reduction will ever take place is a undecidable problem. As a result, the command cannot be implemented utilizing a single instance of a single-pass parser like **Bison**. **crule** therefore utilizes a concurrent, time-travelling heuristic.

A secondary **iBison** process is spawned and is placed in the same state as the primary one. This secondary debugger is then stepped forward to the first parser *reduce* action where the state stack has either shrunk, or has the same size with a different top element. The reduced rule is precisely the production being parsed.

## 3.4 rulepos

**rulepos** enumerates current positions within rules in which the parser may be. It is implemented by examining the rules and positions associated with the current rule in the underlying automaton. It has the mathematical form  $f_4 : cs \rightarrow [(\text{Backhaus Naur Form Rule}, p)]$ , where  $cs$  represents the current state and  $p$  represents a position in the rule.

## 3.5 str

The **str** command returns the current position in the overall parsing process. It is implemented by displaying the contents of the **iBison** token stack. It has mathematical form  $f_5 : cs \rightarrow str_{ss}$ , where  $cs$  represents the current state and  $str_{ss}$  is a string representation of the state stack.

### 3.6 ctkn

The `ctkn` command displays the token the parser is currently dealing with. It is implemented by presenting newer of the look-ahead token and the top element of the token stack.

### 3.7 br

The `br` command allows the user to break when a particular token is encountered. This functionality is provided by stepping till the `ctkn` equals the token provided. Thus it has mathematical form  $f_6 : tkn \rightarrow (cs', ss')$ , where:

1.  $ss'$  represents a new state stack, and by extension a new current state.
2.  $ts'$  represents a new token stack.
3.  $tkn$  represents the input token.

## Chapter 4

# Case Studies

Aside from being able to remap a Bison automaton to its specification, **sidBison** can be considered successful only if it proves to be a useful tool for Bison users unfamiliar with bottom-up parsing. While ease of use and intuitiveness are very hard to quantify, user case studies are a good way to get a sense for the system's effectiveness.

### 4.1 Case Study 1: Minimal exposure to parser generators

'Buggy' grammars will be presented to two groups of programming languages students. Group one will be given the grammars with just the **iBison** system, while Group 2 will be given **iBison** with the **sidBison** wrapper. The relative average time taken by members of the two groups as well as their general behaviour will be used as an evaluation criterion.

### 4.2 Case Study 2: Some exposure to parser generators

Students in **Comp 181: Compilers** who have used **ML Yacc** will be given the **sidBison** tool for a parsing project. Their feedback will also be used as evaluation criteria.

## Chapter 5

# Additional Work

The ultimate aim of this project is to make parser-generator systems more accessible.

1. Given enough time, the `sidBison` system could be expanded to deal with LL parser generator systems such as ANTLR.
2. `sidBison` could also be ported to YACC implementations in languages like C++, F Sharp and ML.
3. Syntax highlighting and IDE support for Bison files could help improve the readability and debug-ability of grammar specifications.
4. Just In Time compiling within an IDE could help highlight potential conflicts in the specification while it is being written.

## Chapter 6

# Appendix

### 6.1 Using sidBison

Given an iBison implementation `ibison`, a Flex file `lexer.l`, and a Bison file `parser.y`, the files can be prepared for input to `sidBison` as follows:

```
ibison -d parser.y
flex lexer.l
gcc -c -fPIC lex.yy.c
gcc -shared -o lex.so lex.yy.o
```

This requires the `LD_LIBRARY_PATH` environment variable to include the directory in which `lexer.so` is available and the `BISON_PKGDATADIR` variable points to the `ibison\data` directory. `sidBison` can now be run with `parser.y` and `lex.so` as command-line arguments.

### 6.2 Examples

#### 6.2.1 Calculator

Presented below are Flex and Bison files that represent a calculator. These can be debugged with `sidBison` are presented below.

**Lexer file: `calcparser.l`**

```
%{
# include "calcparser.tab.h"
# undef yywrap
```



```

# define yywrap() 1
%}

%option noyywrap

int    [0-9]+
blank  [ \t]

%%
{blank}+
[\n]+
\+      return OPERATOR_PLUS;
-       return OPERATOR_MINUS;
\*      return OPERATOR_MULT;
\/      return OPERATOR_DIV;
\(      return LPAREN;
\)      return RPAREN;
{int}   return NUMBER;
.       {fprintf(stderr,"Invalid token!\n");}
%%

```

#### Grammar file: calcparser.y

```

%{
/* A simple calculator */
void yyerror(const char *s);
%}

%token      NUMBER
%token      OPERATOR_PLUS
%token      OPERATOR_MINUS
%token      OPERATOR_MULT
%token      OPERATOR_DIV
%token      LPAREN
%token      RPAREN
%left OPERATOR_PLUS OPERATOR_MINUS
%left OPERATOR_MULT OPERATOR_DIV
%%
exp: exp OPERATOR_PLUS exp
   | exp OPERATOR_MINUS exp
   | exp OPERATOR_MULT exp
   | exp OPERATOR_DIV exp
   | LPAREN exp RPAREN
   | NUMBER

```

```

;
%%
void
yyerror(const char *s)
{
    fprintf(stderr, "Syntax error: %s\n", s);
}

```

## 6.2.2 Programmable Computable Functions

PCF is a simple typed functional language proposed by Dana Scott in 1969. Flex and Bison files that can be debugged with `sidBison` are presented below.

**Lexer file: pcf.l**

```

%{
# include "pcf.tab.h"
# undef yywrap
# define yywrap() 1

%}

%option noyywrap

blank [ \t]
word [a-zA-Z][a-zA-Z0-9]*

%%
{blank}+
[\n]+
0          return ZERO;
:          return COLON;
"true"     return TRUE;
"false"    return FALSE;
\.         return DOT;
\(         return LPAREN;
\)         return RPAREN;
"fix"      return FIX;
"zero"     return ZEROFUNC;
"succ"     return SUCC;
"pred"     return PRED;
"if"       return IF;
"then"     return THEN;

```

```

"else"      return ELSE;
"fn"        return FN;
"nat"       return NAT;
"bool"      return BOOL;
"->"        return ARROW;
{word}      return IDEN;
.           {fprintf(stderr, "Invalid token!\n");}

%%

```

Parser file: pcf.y

```

%{

/* A simple PCF grammar */

%}

%token ZERO
%token TRUE
%token FALSE
%token IDEN
%token FIX
%token ZEROFUNC
%token LPAREN
%token RPAREN
%token SUCC
%token PRED
%token IF
%token THEN
%token ELSE
%token FN
%token COLON
%token DOT
%token NAT
%token ARROW
%token BOOL

%left ARROW

%%

m : ZERO
  | TRUE

```

```

| FALSE
| var
| zerofunc
| succ
| pred
| ifelse
| fun
| app
| fix

fix : FIX LPAREN m RPAREN

app : LPAREN callfunc argfunc RPAREN

callfunc : m
argfunc : m

tau : NAT
      | BOOL
      | funtau
      | LPAREN funtau RPAREN

funtau : tau ARROW tau

fun : FN var COLON tau DOT m

succ : SUCC LPAREN m RPAREN

pred : PRED LPAREN m RPAREN

zerofunc : ZEROFUNC LPAREN m RPAREN

var : IDEN

ifelse : IF m THEN m ELSE m

%%
/*

app : funcexp argexp

succ : SUCC LPAREN m RPAREN
pred : PRED LPAREN m RPAREN
fix : FIX LPAREN m RPAREN

```

```

funcexp : m
argexp : m

fix : LPAREN m RPAREN

func : FN var COLON tau DOT m

*/
void yyerror (const char *s)
{
    fprintf(stderr, "Syntax error: %s\n", s);
}

```

### 6.2.3 Lambda Calculus

The lambda calculus is a formal system that expresses computation by way of functions. Flex and Bison files that can be debugged with `sidBison` are presented below.

**Lexer file: `lambdacalc.l`**

```

%{
# include "lambdacalc.tab.h"
# undef yywrap
# define yywrap() 1

%}

%option noyywrap

blank [ \t]
word [a-zA-Z][a-zA-Z0-9]*
int [0-9]+

%%
{blank}+
[\n]+
{int}      return CONSTANT;
{word}     return IDENT;
\.         return DOT;
\\         return LAMBDA;
\((       return LPAREN;
\)        return RPAREN;

```

```
.          {fprintf(stderr, "Invalid token!\n");}  
  
%%
```

Grammar file: `lambdacalc.y`

```
%{  
/* Untyped lambda calculus */  
void yyerror(const char *s);  
%}  
  
%token  IDENT  
%token  CONSTANT  
%token  LPAREN  
%token  RPAREN  
%token  LAMBDA  
%token  DOT  
  
%%  
  
exp : var  
    | func  
    | app  
    | CONSTANT  
  
func : LAMBDA var DOT scope  
  
app : LPAREN funcexp argexp RPAREN  
  
scope : exp  
  
funcexp : exp  
  
argexp : exp  
  
var : IDENT  
  
;  
  
%%  
void  
yyerror(const char *s)
```

```
{
    fprintf(stderr, "Syntax error: %s\n", s);
}
```

### 6.2.4 Impcore

Impcore is a simple imperative language used as a pedagogical tool in Comp 105: Programming Languages at Tufts University. A lexer and parser for impcore are presented below:

Lexer file: `imp.l`

```
%{
#include "heading.h"
# include "imp.tab.h"
# undef yywrap
# define yywrap() 1

/* Need to include - in word */

%}

%option noyywrap

blank [ \t]
word [a-zA-Z][a-zA-Z0-9\-*]
int [0-9]+

%%
{blank}+
[\n]+
\(          return LPAREN;
\)          return RPAREN;
\+          return PLUS;
-           return MINUS;
\*          return MUL;
\/          return DIV;
"="         return EQ;
\<          return LT;
\>          return GT;
"val"       return VAL;
"define"    return DEFINE;
"use"       return USE;
"check-expect" return CHECKEXPECT;
```

```

"set"          return SET;
"if"           return IF;
"while"        return WHILE;
"begin"        return BEGN;
"print"        return PRINT;
"check-err"    return CHECKERR;
{int}          {return NUMERAL;}
{word}         {return NAME;}
.              {fprintf(stderr, "Invalid token!\n");}

%%

```

Parser file: imp.y

```

%{
/* Leaving unit-test out of def */
#include "heading.h"
#include <stdio.h>
void yyerror(const char *s);
int yylex(void);
%}

%token  VAL
%token  DEFINE
%token  LPAREN
%token  RPAREN
%token  USE
%token  CHECKEXPECT
%token  SET
%token  IF
%token  WHILE
%token  BEGN
%token  PLUS
%token  MINUS
%token  MUL
%token  DIV
%token  EQ
%token  LT
%token  GT
%token  PRINT
%token  CHECKERR
%token  NUMERAL
%token  NAME

```



%%

program :  
| def program

def : LPAREN VAL variablename exp RPAREN  
| LPAREN DEFINE functionname formals exp RPAREN  
| LPAREN USE filename RPAREN  
| unittest

| exp

unittest : LPAREN CHECKEXPECT exp exp RPAREN  
| LPAREN CHECKERR exp RPAREN

exp : literal  
| variablename  
| LPAREN SET variablename exp RPAREN  
| LPAREN IF exp exp exp RPAREN  
| LPAREN WHILE exp exp RPAREN  
| LPAREN BEGN expstar  
| LPAREN function expstar

expstar : RPAREN  
| exp expstar

formals : LPAREN variablenamestar

variablenamestar : RPAREN  
| variablename variablenamestar

literal : NUMERAL

function : functionname  
| primitive

primitive : PLUS  
| MINUS

```

        | MUL
        | DIV
        | EQ
        | LT
        | GT
        | PRINT

variablename : NAME
functionname : NAME
filename : NAME

;

%%
void
yyerror(const char *s)
{
    fprintf(stderr, "Syntax error: %s\n", s);
}

```

## 6.3 JSON Grammar

```

JSON-text : ws value ws

begin-array      : ws %x5B ws ; [ left square bracket
begin-object     : ws %x7B ws ; { left curly bracket
end-array        : ws %x5D ws ; ] right square bracket
end-object       : ws %x7D ws ; } right curly bracket
name-separator   : ws %x3A ws ; : colon
value-separator  : ws %x2C ws ; , comma

ws :
    | %x20 |           ; Space
    | %x09 |           ; Horizontal tab
    | %x0A |           ; Line feed or New line
    | %x0D |           ; Carriage return

```

; Empty string

```

value : false | null | true | object
       | array | number | string

false : %x66.61.6c.73.65    ; false

null  : %x6e.75.6c.6c       ; null

true  : %x74.72.75.65       ; true

object : begin-object
        [ member ( value-separator member ) ]
        end-object

member : string name-separator value

array : begin-array [ value *( value-separator value ) ]
        end-array

number : [ minus ] int [ frac ] [ exp ]

decimal-point : %x2E        ; .

digit1-9 : %x31-39          ; 1-9

e : %x65 | %x45              ; e E

exp : e [ minus | plus ] 1*DIGIT

frac : decimal-point 1*DIGIT

int : zero | ( digit1-9 *DIGIT )

minus : %x2D                  ; -

plus  : %x2B                  ; +

zero  : %x30                  ; 0

string : quotation-mark *char quotation-mark

char : unescaped
      | escape (
        %x22 |                ; "    quotation mark    U+0022
        %x5C |                ; \    reverse solidus   U+005C
        %x2F |                ; |    solidus           U+002F

```

%x62	; b	backspace	U+0008
%x66	; f	form feed	U+000C
%x6E	; n	line feed	U+000A
%x72	; r	carriage return	U+000D
%x74	; t	tab	U+0009
%x75 4HEXDIG )	; uXXXX		U+XXXX
escape : %x5C ; \			
quotation-mark : %x22 ; "			
unescaped : %x20-21   %x23-5B   %x5D-10FFFF			

## 6.4 Source Code

Source code can be found at <https://github.com/sidprasad/sidbison/>.

# Bibliography

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