The Bison Parser Generator
Shift/Reduce Parsing

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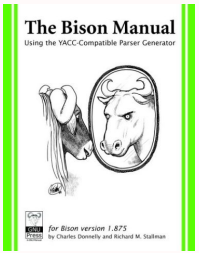
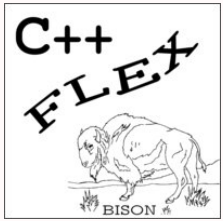
Brian A. Malloy





1. Parsing Overview

- Parsing methods partition into two approaches:
  1. **Top-down**: Find a derivation of a string, starting the start symbol, and performing a top-down expansion of the formal grammar rules.
  2. Examples of Top-down: Table driven LL, and recursive descent
  3. **Bottom-up**: parser starts with the input, and attempts to rewrite it to the start symbol
  4. Examples of bottom-up: SLR, LALR, IELR, LR, GLR
  5. Bison is LALR(1)

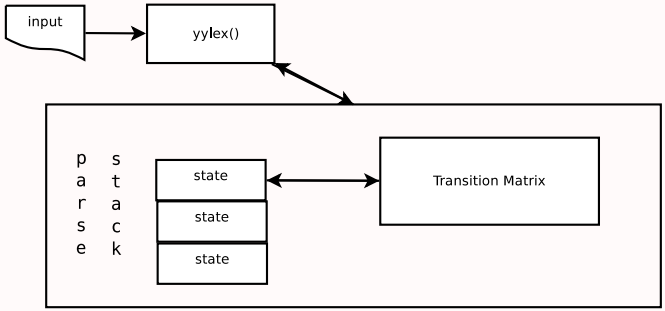
2. Why Understand Bison?

- We want to build an interpreter for Python:
  $\Rightarrow$ we need a parser
- Developing a parser is a challenging task, made even more so if you don't understand how the parser generator works.
- Understanding Bison can help:
  - To insert semantic actions
  - To remove conflicts,
  - to insert error recovery routines,
  - to develop a new grammar.

3. Bison Overview

- Bison performs a bottom-up parse, with 1 symbol look-ahead.
- bison consists of:
  1. A stack (PDA) with current states,
  2. a transition matrix to derive a new state,
  3. a table of user-defined actions, and
  4. an interpreter to choreograph the actions.
- All of this is packaged in yyparse(), a function that calls yylex to get the next token.

3.1. Visualizing Bison



3.2. Shift/Reduce Parsing: shift

- Bison looks for rules that might match the tokens seen so far.
- Bison creates a set of states, each of which reflects a possible position in one or more partially parsed rules
- Each time bison "reads" a token that doesn't complete a rule it pushes the token onto the stack and goes to a new state.
- This action is called a **shift**.

3.3. Shift/reduce parsing: reduce

- When the symbols at the top of the stack match the right hand side (RHS) of a rule, it pops the RHS symbols off the stack, pushes the LHS onto the stack, and switches to a new state.
- When Bison reduces a rule it can execute user code associated with the rule.

3.4. Five Operations of yyparse()

1. accept: this happens only once
2. shift <state>
3. reduce <formulation number>
4. goto <new state>
5. error: for tokens that shouldn't appear in the current state

4. The Pointer Model

- Shows a pointer moving through grammar
- The pointer starts at the start rule

```
%token A B C
%%
start: ↑ A B C
```

- If A and B are read, move pointer:

```
%token A B C
%%
start: A B ↑ C
```

4.1. More than one Pointer

- Example, assume we read A, B:

```
%%
start: x | y
x: A B ↑ C D
y: A B ↑ E F
```

- Pointers can disappear in two ways:
  1. A rule doesn't work; Eg next token C

     ```
     %%
     start: x | y
     x: A B C ↑ D
     y: A B E F
     ```

  2. Ponters merge into a common subrule

- For merge example, assume we read A

```
start: x | y
x: A ↑ B z R
y: A ↑ B z S
z: C D
```

- After A B C, there is only one pointer:

```
start: x | y
x: A B z R
y: A B z S
z: C ↑ D
```

- After A B C D, there are two pointers

```
start: x | y
x: A B z ↑ R
y: A B z ↑ S
```

4.2. Reductions

- If there is only one pointer at the end of a rule, we reduce. E.g., assume an A is read:

```
%%
start: x | y
x: A ↑
y: B
```

- After A, there is only one pointer in x, and rule x is reduced.
- Similarly, if B is read, there is only one pointer in y, and rule y is reduced.

5. Bison Conflicts: Two kinds

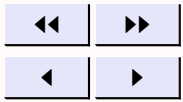
- Reduce/reduce conflict: two pointers at the end of two rules.

```
%%
start: x | y
x: A ↑
y: A ↑
```

- Never a conflict if only one arrow:

```
%%
start: x | y
x: z R
y: z S
z: A B ↑
```

- After z is reduced, there are two pointers. Why?



- Shift/reduce conflict: One pointer wants to shift, the other pointer wants to reduce:

```
%%
start: x | y
x: A ↑ R
y: A ↑
```

6. Parse Tree Helps




7. Bison & Ambiguity

- In the face of ambiguity, bison will make a choice, unless the user specifies otherwise.
- The user can set the precedence, refactor the grammar to remove conflicts, or suppress conflict warnings using `%expect n`
- Default action for Shift/Reduce conflict: shift.
- Default action for Reduce/Reduce conflict: choose the rule that appears first in the grammar.

8. Parser States

- You can generate name.output by supplying the -v flag to bison (-v ⇒ verbose)
- name.output is a description of the state machine generated by bison, including:
  - Listing of the grammar rules
  - Rules that are never used
  - Summary of the conflicts
  - All of the parser states

8.1. States in name.output

- For each state, bison lists
  - The rules and positions that correspond to the state,
  - the shifts and reductions the parser will make when it reads various tokens in the state,
  - and the state it will switch to after a reduction produces a non-terminal in that state,
  - the conflicts in each state.

8.2. What are States

- Each state corresponds to a unique combination of possible pointers in the bison grammar.
- Bison assigns a number to each state:

```
State 0 conflicts: 1 shift/reduce
```

- Numbers can differ across bison implementations; the actual number isn't significant.

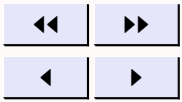
9. Tracing reduce/reduce

```
start: a Y | b Y;
a:     X ;
b:     X ;
```

- We will trace bison as it parses the above ambiguous grammar
- assume the input is X Y ⟨eof⟩
- bison always starts at state 0, shift 0; i.e., push 0 onto the stack.

```
(1) Starting parse
(2) Entering state 0
(3) Reading a token: –(end of buffer or a NUL)
(4) X
(5) –accepting rule at line 10 ("X")
(6) Next token is token X ()
(7) Shifting token X ()
(8) Entering state 1
```

- (1) Bison announces the start of the parse
- (2) Bison always begins in state 0
- (3) Bison is about to read a token
- (4) reads X
- (5) This line is debug info from Flex
- (8) Bison enters state 1, stack is:
  (1, x) (0, -)



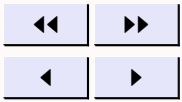
```
state 1
    3 a: X ↑ (arrow shows where we are before next token)
    4 b: X ↑
    Y             reduce using rule 3 (a)
    Y             [reduce using rule 4 (a)]
    $default      reduce using rule 3 (a)
```

```
(1) Reducing stack by rule 3 (line 12):
(2) $1 = token X ()
(3) -> $$ = nterm a ()
(4) Stack now 0
(5) Entering state 3
```

- (1) line 12 is in parse.y
- (3) nterm a is non-terminal a
- (5) stack is: (3, a) (0, -)

(1) Reading a token: –accepting rule at line 12 (”
(2) ”)
(3) –(end of buffer or a NUL)
(4) Y
(5) –accepting rule at line 11 (”Y”)
(6) Next token is token Y ()
(7) Shifting token Y ()
(8) Entering state 6

- (1), (3), (5) is from Flex
- (7) and (8) push (6, Y) onto stack
- stack is:
  (6, Y)
  (3, a)
  (0, -)



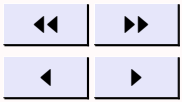
```
state 6
    1 start: a Y ↑
    $default      reduce using rule 1 (start)
```

```
(1) Reducing stack by rule 1 (line 9):
(2)      $1 = nterm a ()
(3)      $2 = token Y ()
(4) -> $$ = nterm start ()
(5) Stack now 0
(6) Entering state 2
```

- recall that stack is: (6, Y) (3, a) (0, -)
- (1) reduce by rule 1 pops Y and a off stack
- $default & (4) pushes start onto stack
- (5) says stack is state 0, start: goto state 2

```
state 0
    0 $accept: ↑ start $end
    ...
    start:      goto state 2
```

- Above, on **start** goto state 2
- stack is:
  (2, start),
  (0, -)



```
state 2
    0 $accept: ↑ start $end
    $end shift, and goto state 5
```

- Bison now reads $eof, shifts it onto the stack, and goes to state 5
- stack is:
  (5, $end)
  (2, start)
  (0. -)

(1) –EOF (start condition 0)
(2) Now at end of input.
(3) Shifting token $end ()
(4) Entering state 5

- Recall, stack is:
  (5, $end)
  (2, start)
  (0. -)

```
(1) Entering state 5
(2) Stack now 0 2 5
(3) Cleanup: popping token $end ()
(4) Cleanup: popping nterm start ()
(5) Syntactically correct.
```

9.1. Some notes on reduce/reduce

- The arrow (bison uses a dot) shows where we are in the grammar before reading the next token.
- For **reduce/reduce** conflicts, the two arrows are always at the end of the rules.
- In a conflict, the rule not used is shown in brackets
- In state 1, bison chose to reduce to a by rule 3 because with **reduce/reduce** conflicts it chooses the earliest one in the grammar.