ParseIT: A Question-Answer based Tool to Learn Parsing Techniques

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ABSTRACT

Parsing (also called syntax analysis) techniques cover a substantial portion of any undergraduate Compiler Design course. We present ParseIT, a tool to help students understand the parsing techniques through question-answering. ParseIT automates the generation of tutorial questions based on the Context Free Grammar provided by the student and generates feedback for the student solutions. The tool generates multiple-choice questions (MCQs) and fill in the blank type questions, and evaluates students’ attempts. It provides hints for incorrect attempts, again in terms of MCQs. The hints questions are generated for any correct choice that is missed or any incorrect choice that is selected. Another interesting form of hint generated is an input string that helps the students identify incorrectly filled cells of a parsing table. We also present results of a user study conducted to measure the effectiveness of ParseIT.

Author Keywords
Intelligent Tutoring; Education; Programming; Compilers; E-Learning

INTRODUCTION

Compiler design is an important subject in the computer science curriculum for undergraduates [8]. Compilers are one of the success stories of Computer Science, where sound theoretical concepts (e.g. Automata, Grammars, Graph Theory, Lattice Theory etc.) are backed by practical implementations (Lexical analyzers, Parsers, Code Optimizers etc.) to solve the real world problem of fast and resource-efficient compilation. Most existing compiler courses [2, 7, 6, 9] divide the curriculum into modules corresponding to the phases of compilation. Instructors discuss the theory in lectures while students typically work on a semester-long project implementing a compiler for some small language.

In a typical course, about 15%-22% of the total time is spent on syntax analysis phase (also called parsing techniques, see Table 1). A number of concepts are introduced to explain the internals of parsers, for example first sets, follow sets, item set, goto and closure sets, parse tables and the parsing algorithms [2], making the understanding difficult. While parser generators (YACC and its variants) allow the students to experiment with grammars, the working of the parser generated by the tools is still opaque.

Recent development in technologies has enabled institutions to offer courses to large number of students. These massive-open-online courses (MOOCs) [5, 14, 19] digitize the contents of the topics (lecture videos, notes etc), and allow students to access the contents beyond physical boundaries of classrooms. The increase in number of students has added challenges for the instructor for the tutoring aspects, such as the creation of new problems for assignments, solving these problems, grading, and helping the students master a concept through hands-on exercises. These challenges have prompted researchers to develop automated tutoring systems to help the student to explore a course based on his skills and learning speed [3, 11, 21, 18, 15].

In this paper, we present ParseIT, a tool for teaching parsing techniques. ParseIT helps students to understand the parsing concepts through automatically generated problems and hints. Problems are generated based on a Context Free Grammar (CFG) given as input. The tool evaluates the solutions attempted by the user for these problems. Upon evaluation, if the solutions provided by the users are incorrect, it generates hint questions. The problems generated by the tool follow a general Multiple Choice Question (MCQ) pattern, where a user is given a problem with a set of possible choices, 1 or more of which are correct. The incorrect solutions are the ones where a correct option is not chosen, or an incorrect option is chosen, or both. The hints are generated in the forms

| Institute | Course Name | #/Duration of Lectures | % |
|-----------|-------------|------------------------|---|
| Stanford  | Intro. to Compilers [7] | 4/18 | 22% |
| IIT Kanpur | Compiler Design [10] | 6/35 | 17% |
| Coursera | Compilers [6] | 4 modules/18 modules (4 hours)/(19 hours) | 22% |
| Saylor   | Compilers [9] | 28 hours/146 hours | 19% |

The generated parsers do produce debugging information when used with appropriate options, but this is of little didactical value as one needs to know the parsing algorithms to understand it.
of (simplified) questions to direct student toward the correct solution. Hint generation procedures involve different types of algorithms, of which the input string generation algorithm is notable. For an incorrect parse table provided by the user, this algorithm enables the creation of an input string that distinguishes a successful parse from an unsuccessful one.

We describe some of the systems developed by other for teaching compiler concepts in Sec. 2. The tool itself is described in Sec. 3. Input string generation algorithms for LL and LR parsers are given in Sec. 4. We present a summary of the user study in Sec. 5, and conclude in Sec. 6.

**RELATED WORK**

Several efforts exist to automate teaching phases of compilers and to help developing a compiler as a course project. LISA [18] helps students learn compiler technology through animations and visualizations. The tool uses animations to explain the working of 3 phases of compilers, namely, lexical analysis, syntax analysis, and semantic analysis. Lexical analysis is taught using animations in DFAs. For syntax analysis, animations are shown for the construction of syntax trees and for semantic analysis, animations are shown for the node visits of the semantic tree and evaluation of attributes. Students understand the working of phases by modifying the specification and observing the corresponding changes in the animation.

Lorenzo et. al. [16] present a system for test-case based automated evaluation of compiler projects. Test cases (inputs and corresponding desired outputs) designed by the instructor are given as input to students’ compilers. The tool then assesses the compiler in three distinct steps–compilation, execution, and correction. The system automatically generates different reports (for instructors and students) by analyzing the logs generated at each of these steps.

Demaille et. al. [12, 13] introduce several tools to improve the teaching of compiler construction projects and make it relevant to the core curriculum. They made changes to Bison [4] to provide detailed textual and graphical descriptions of the LALR automata, allow the use of named symbols in actions (instead of $1$, $2$, etc.), and use Generalized LR (GLR) as backend. Waite [24] proposed 3 strategies for teaching compilers—software project, application of theory and support for communicating with a computer. Various other tools are also available to teach different phases of compiler like understanding code generation [22], and understanding symbol tables through animations [23].

Our work is different in that we use question-answering as means to explain the working of parsing technology and to guide the students towards the construction of correct parse table.

**THE ParseIT TOOL**

*ParseIT* takes as input a context free grammar and uses it as a basis for generating questions. These questions are in the form of MCQ² and deal with various concepts related to parsing. The normal workflow involves the following steps:

1. The user provides an input grammar and the choice of topic. The topics refer to the concepts related to parsing such as FIRST set, FOLLOW set, LL Parsing Table, LL Parsing Moves, LR(0) Item-sets, SLR Parsing Table, SLR Parsing Moves, etc.
2. A primary multiple choice question is generated based on the above two pieces of information.
3. If the user answers the problem incorrectly, then hints are generated for the same question in the form of questions.
4. When a correct solution to the problem is received, another question for the same topic is generated and presented to the user.

In the preprocessing step, the system takes a grammar as input and generates the information required for correct solutions. In particular, the tool generates the FIRST set and the FOLLOW set for all non-terminals, LL Parsing Table, LR(0) items, canonical set of items for SLR parser and SLR parsing table.

For primary problem for the selected topic, *ParseIT* uses the data-structures to form MCQs having multiple correct answers. Users have to select all valid options, and no invalid option, for the answer to be deemed correct. The options are also generated using the preprocessed data.

In the answer evaluation step, the solution given by the user is compared with the solution computed by the tool in the preprocessing step. If the solutions match, then the control transfers back to the primary problem generation step to generate the next question. However, if the solution is wrong, the tool collects: a) the incorrect options which are selected, and b) the correct options which are not selected by the user and passes them to the hint generation step.³

For hints, *ParseIT* generates multiple hint questions for each of the incorrect choices. These questions are MCQs having a single correct choice. These questions help the user to revise the concept required to get correct solution to the primary question.

**Problem Generation**

Parsing techniques require solving three main types of problems: a) computation of sets of elements, for example, FIRST, FOLLOW, LR Items, GOTO, CLOSURE, b) computation of entries in a parse table, and c) steps of a parser on a given input string.

Since all the sets and tables are computed by *ParseIT* in the preprocessing step, generation of questions is easy. The details are given in a technical report [1]. For a question, the set of candidate choices is obtained by adding to the set of correct choices a few mutations (addition/removal of a term)

²MCQs have their advantages as well as disadvantages [17]. We chose MCQ as it is easier for the system to evaluate student choices as compared to the free form text answers.
³In the rest of the paper, unless specified otherwise, we use the term incorrect choice for both the types of mistakes, i.e., the missing valid choice and the selected invalid choice.
or using a term from the solution for another similar problem. Evaluation of user solution is a simple comparison with the computed solution.

**Hint Generation**

*ParseIT* generates 2 types of hint questions to guide the user into reaching the correct solution of the primary problem and understanding her mistakes.

- **Hint_MCQ:** Multiple choice questions are generated about the options selected by the user. These are typically generated when the user’s solution for a primary problem either contains an incorrect option or omits a correct option\(^4\). These help the user to understand that (a) the rules for the concept under test can not result in the particular incorrect option, and (b) the omitted option is a part of the correct solution and the rules that are used to get that option.

- **Hint_String:** These types of questions are generated for filling LL/LR parsing tables of grammars having no conflicts (i.e., no duplicate entries in the cells). If the questioned cell of a parsing table is filled incorrectly, then the tool automatically generates an input string that exercises the contents of that cell during parsing. Due to incorrectly filled entry, the parsing with incorrect table for the string fails, thus hinting user that something is wrong with her solution.

**Example 3.1.** Consider the grammar:

\[
E \rightarrow T + E \mid T \\
T \rightarrow 0 \mid 1
\]

one of the questions generated for FIRST set is:\(^5\)

**Question:** Which symbols should be included in FIRST\[T\]?

**Options:** (a) 1 (b) 0 (c) +

For a user selected symbol \(\psi\), the hint questions are necessarily generated if the selection \(\psi\) is incorrect. Even for a correct answer, the hints questions are generated with some low probability. The hint questions are of the form:

**HintQ:** According to which of the following rules, the symbol \(\psi\) is a part of FIRST\[T\]?

1. If \(X\) is a terminal, then FIRST\(X\) is \(\{X\}\).
2. If \(X\) is a nonterminal and \(X \rightarrow Y_1 Y_2 \ldots Y_k\) is a production for some \(k \geq 1\), then place \(a\) in FIRST\(X\) if for some \(i\), \(a \in \text{FIRST}(Y_i)\), and \(\varepsilon\) is in all of FIRST\(\{Y_1\}, \ldots, \text{FIRST}(Y_{i-1})\). If \(\varepsilon\) is in \(\text{FIRST}(Y_i)\) for all \(j = 1, 2, \ldots, k\), then add \(\varepsilon\) to FIRST\(X\).
3. If \(X \rightarrow \varepsilon\) is a production, then add \(\varepsilon\) to FIRST\(X\).
4. No valid rule for this symbol.

If this hint question is asked for incorrect option (‘+’), the answer is option ‘4’. If a user selects any other option, the same question is repeated. For a correct option, say ‘0’, the expected answer is option ‘2’.

After these hint questions, question \(Q_1\) is repeated. If it is answered correctly, then next question \(Q_2\) is generated. Otherwise, the above process is repeated.

**Example 3.2.** Consider the grammar:

\[
S \rightarrow a A B b \\
A \rightarrow c \mid \varepsilon \\
B \rightarrow d \mid \varepsilon
\]

The following question (Hint_MCQ) is generated for the entries of LL parsing table:

**Question:** Which grammar rule should be included in the cell \([B, b]\) of the parsing table? (A partially filled parse table is shown to the user.)

**Options:** (a) \(A \rightarrow c\) (b) \(A \rightarrow \varepsilon\) (c) \(B \rightarrow d\) (d) \(B \rightarrow \varepsilon\)

For a production \(\pi\) selected by the user, the hint questions generated could be:

**HintQ:** According to which of the following rules, the production \(\pi\) is in cell \([B, b]\)?

1. \(\pi\) is production \(B \rightarrow \alpha\), and \(b \in \text{FIRST}(\alpha)\)
2. \(\pi\) is production \(B \rightarrow \alpha, \varepsilon \in \text{FIRST}(\alpha)\)
   and \(b \in \text{FOLLOW}(B)\)

**Example 3.3.** For the question of Example 3.2. The correct answer is \((d) B \rightarrow \varepsilon\). If a user selects an incorrect choice, *ParseIT* can generate a string that will not be parsed correctly by the user’s parse table. Say the user selects choice \((c) B \rightarrow d\). *ParseIT* will generate string \(ab\), and ask the hint question (Hint_String):

**HintQ:** LL-parsing on input \(ab\) with your parse table is failing. Can you fix the error by selecting the correct choice? (Parser movements shown to the user omitted for brevity)

**Options:** (a) \(A \rightarrow c\) (b) \(A \rightarrow \varepsilon\) (c) \(B \rightarrow \varepsilon\)

The most interesting feature of *ParseIT* is the generation of an input string to exercise incorrect entry in an incorrectly filled parse table. We describe this in brief.

**Input String Generation**

A parsing table is a two-dimensional array used to parse an input string. A grammar is considered LL/LR if the corresponding LL/LR parsing table has no duplicate entries. We generate hints of type Hint_String for grammars accepted by LL\(0\), LL\(1\) or SLR parsers. For simplicity, we assume at most one mistake (in some non-empty entry) in the table. If a non-empty cell of the parsing table is filled incorrectly by the user, then there exists a string accepted by the grammar that exercises the cell, but can not be parsed by the user filled (incorrect) parsing table. *ParseIT* generates such an input string. Then the corresponding question is to ask the user to parse the string using her incorrect table. The failure to parse the string serves as a hint that the table has errors in it.

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\(^{4}\)Hints are sometimes generated even when the user solution is correct (with a small probability). Otherwise, whenever the hint is generated, the user will know that her original answer was wrong, and may change it without understanding the concept.

\(^{5}\)The interaction with *ParseIT* (questions and hints generated) are formatted for readability.
Input String Generation for LL Parsing

*ParseIT* creates a graph $G$ for the grammar as follows: All the symbols in the grammar appear as the vertices of the graph, edges are created from the symbol on the left side to each of the symbols on the right side of a rule. An edge is labeled with the shortest rule (i.e. the rule with the smallest number of symbols on the RHS) used for creating it. For each non-terminal, *ParseIT* also computes and records a terminal-only string derivable from that non-terminal. Terminal-only string for a terminal $t$ is $t$ itself.

Assume that, for the incorrectly filled cell, $N$ represents the row label (non-terminal) and $t$ represents the column label (terminal). Let $S$ be the start symbol of the grammar. We start with a string $str1 = S$ and traverse $G$ from start node (labeled $S$) to the node labeled $N$ on the shortest path. During traversal, the non-terminal corresponding to the source vertex in the string $str1$ is replaced by the label on the outgoing edge traversed. On reaching the node labeled $N$, all symbols in $str1$, except last $N$, are replaced by their terminal-only strings.

In the next step, the tool finds the shortest path from the node labeled $N$ to the node labeled $t$. This path is traversed in the same way as described above to give a string $str2$. $N$ in $str1$ is replaced by $str2$ to get the final input string.

Note that the process described above is similar to constructing a parse tree, the difference being that we are creating a parse tree for an unknown string! The following example explains the algorithm.

**EXAMPLE 4.1.** Consider the grammar in Fig. 1(a). The correct LL parsing table $M$ for this grammar is shown in Fig. 1(b). Fig. 1(c) shows the graph generated by *ParseIT* for this grammar.

Suppose a user fills the cell $M[T][3]$ incorrectly. In order to build the desired input string to exercise this cell, *ParseIT* will compute the shortest path from the start symbol $E$ to $T'$ (the non-terminal representing the erroneous cell) using Dijkstra’s shortest path algorithm (Fig. 1(c)). The traversal of this path results in the following sequence of strings being generated:

$$E \rightarrow TE' \rightarrow FT'E'$$

Since the target non-terminal, $T'$, is reached, all other non-terminals are replaced by their terminal-only strings (id for $F$ and $E$ for $E'$):

$$FT'E' \rightarrow \text{id}T'\epsilon \equiv \text{id}T'$$

Next *ParseIT* finds the shortest path from $T'$ to $\epsilon$ (Fig. 1(c)), and expands it:

$$\text{id}T' \rightarrow \text{id} * FT' \rightarrow \text{id} * (E)T'$$

Non-terminals are replaced by terminal-only strings ($E$ by id, $T'$ by $\epsilon$) to give the desired input string:

$$\text{id} * (E)T' \rightarrow \text{id} * (\text{id})$$

Note that $T'$ is not treated especially again as we have already taken care of exercising the desired entry, $M[T'][3]$. 

![Graph for the example grammar. The shortest paths from $E$ to $T'$ and from $T'$ to $\epsilon$ are highlighted.](image)

Figure 1. Input string generation for LL parsing.

Input String Generation for LR Parsing

The parse table for LR parsers consists of two sub-tables: *Action* table and *Goto* table [2]. The action table describes the interaction between a state in parsing and a terminal while the goto table describes the interaction between a state and a non-terminal. The action table has two types of entries: *shift* entries, that push a state on the parsing stack; and *reduce* entries that remove a certain number of states from the parsing stack. The entries in goto table are also shift entries (similar to those in the action table) in that they also push a state in the parsing stack.

Both types of shift entries look only at the top of the parsing stack and the current symbol (terminal or non-terminal) to decide the move. For reduce entries, on the other hand, the top few entries of the stack must *match* states corresponding to the right-hand side of a rule. As a result, the input string generation for LR parsing needs to setup the parsing stack properly and uses heuristics to pick appropriate reduce rules from the parse table to make sure that the parser stack is in accept state at the end of input.

Assume $L$ denotes an LR parsing table, $s$ represents the row label (state) and $a$ represents the column label (non-terminal or terminal, including the special end marker $\$) for an incorrectly filled cell, $L[s][a]$. *ParseIT* computes a terminal-only string corresponding to each non-terminal, and a de-
termistic finite automaton (DFA) to recognize viable prefixes [2]. All the states corresponding to the item-sets containing item(s) with a dot at the end position are referred to as the reduce states of the DFA. The tool maintains a stack, a prefix string, and a set $X$ of possible next symbols.

Assume $L$ denotes a LR parsing table, $s$ represents the row label (state) and $\alpha$ represents the column label (non-terminal or terminal, including the special end marker $\$) for an incorrectly filled cell, $L[s][\alpha]$. ParseIT computes a terminal-only string corresponding to each non-terminal, and a deterministic finite automaton (DFA) to recognize viable prefixes [2]. All the states corresponding to the item-sets containing item(s) with dot at the end position are referred to as the reduce states of the DFA. The tool maintains a stack, a prefix string, and a set $X$ of possible next symbols.

In the viable prefix DFA, a path from initial state, $s_0$, to the state $s$ is traversed. Labels for the nodes (states) and the edges (terminal/non-terminals) along the path are pushed on the stack in the order in which they appear during traversal. The prefix string is generated by concatenating the edge labels traversed, and replacing every non-terminal by its terminal-only string. The next steps differs depending on the type of correct entry in the cell $L[s][\alpha]$.

**Shift Entry**

If the correct entry for $L[s][\alpha]$ is a shift entry (either in action or in goto sub-table), then, in the DFA, there will be an outgoing edge with label $\alpha$ from the node for state $s$ to a state $s_\alpha$. Symbol $\alpha$ is pushed onto the stack and its terminal-only string is appended to the partial input string. State $s_\alpha$ is also pushed on the stack. A path is then found from $s_\alpha$ to $s_r$, one of the reduce states. All the node labels and the edge labels along the path are pushed onto the stack in that order. The partial input string is appended with the terminal-only string for the path.

The column labels (symbols) corresponding to non-empty cells in row for $s_r$ in the parse table are added to the set of next symbol $X$. The next action is performed on the set according to the following heuristics:

- If row $s_r$ contains both shift and reduce actions: We chose reduce action over shift actions. Any of the symbols in $X$ corresponding to the columns for reduce action can come next in the input string to force the reduction on stack. We differ the exact choice of symbol until we need to make a shift move (next point).
- If row $s_r$ contains only shift actions: We compute the number of symbols between the dot and the end of RHS in each rule for each state. We choose to shift to the state having the smallest value. In case of tie, any of the states involved in the tie is chosen. Partial string is updated by concatenating the terminal-only string corresponding to the column label of the entry chosen for shift.

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6We chose the shortest distance reduce state from $s_\alpha$, to generate shorter input string.

7Note that all reduce actions in a row will be the same.
Now state 2 is on top of the stack. The corresponding row contains non empty entries, s3 and s4, for columns labeled a and d. This restricts the choice for next symbol to {a, d} (Fig. 3(d)).

Using the heuristic to shift to a state where dot is closest to the right end of RHS of some rule, we prefer a shift to state 4 (C → a d) has · at the right end, compared to C → aC in state 3, where · is 1 symbol away from the right end.) This forces the next symbol to be d. Since we have narrowed down the next symbol to a unique choice, the symbol is appended to the partial string and corresponding shift is made on the stack. Set X is cleared (Fig. 3(e)).

The process is continued till we get an “accept” on the stack. The remaining configurations for the example are shown in Fig. 3(f). The desired input string to exercise L[s3][d] is partial string at this stage (ignoring the end-marker $), i.e. add.  

Reduce Entry

For generating input corresponding to a shift entry in a cell in the parse table (more precisely, in the goto or action sub-table), the state only at the top of parsing stack is important. For a reduce entry, however, the configuration of stack below the top also plays a vital role as the RHS of the rule, using which reduction takes place, must match the prefix at the top of parsing stack. Thus, input generation algorithm not only needs to construct the next symbols in the (unknown) string, but also the previous symbols that have been already pushed on the stack (and possibly undergone some reductions as well).

For an incorrect entry corresponding to the reduce entry in cell L[s][α], ParseIT generates the input for reduce entries in two stages: in the first stage, the stack is setup to enable the application of the desired reduce rule, i.e., the symbols before α in the input string are guessed. In the second stage, ParseIT generates the symbols that may follow α in the input string, till the end ($). Note that, α can itself be $, in which case no next symbol is needed. The second stage works identically to the generation of input string for incorrect shift entry.

Suppose the correct reduce entry in the cell L[s][α] is \( N \rightarrow \sigma \), then ParseIT guesses the stack to be \( \Omega_N \Sigma_s \), where \( \Omega_N \) represents the sequence of states corresponding to an unknown prefix of the desired input, and \( \Sigma \) is the sequence of states corresponding to σ, the RHS of correct reduce rule in the cell of interest. The input character now seen by the parser is α while a prefix string saves the already seen string—the terminal string derivable from symbols in σ. After reduction by the rule \( N \rightarrow \sigma \), the stack configuration becomes \( \Omega_N \Sigma_s N \alpha_s \), where \( \alpha_s \) is obtained from the goto sub-table entry \( L[s_b][N] \).

If \( \alpha_s \) is known, we can find a satisfying prefix \( \omega \) (the stack configuration \( \Omega \)) by traversing the viable prefix DFA from start state to \( s_b \), and generating the terminal-only string corresponding to the traversed edge labels (node labels and edge labels for \( \Omega \)). However, since we do not know these states, we use non-empty entries in the parse table to guess the possible choices:

\[
S_B = \{ s_b \mid L[s_b][N] \text{ is non-empty} \}
\]

\[
S_A = \{ s_a \mid L[s_a][N] = \alpha_s \}
\]

Thus, \( S_B \) represents the set of possible states before \( N \), and \( S_A \) represents the set of possible states after \( N \) on the stack. Suppose \( t \) is the input character seen by the parser. We refine the choices using the following rules:

1. For \( s_a \in S_A \), if \( L[s_a][r] \) is error (empty), then \( s_a \) is removed from \( S_A \), and all \( s_b \in S_B \) such that \( L[s_b][N] = s_a \) are removed from \( S_B \).
2. If there is a state \( s_a \in S_A \) which has shift entry in \( L[s_a][r] \), we choose it, and ignore all other states from \( S_A \). One of the corresponding states in \( S_B \) (i.e., \( s_b \in S_B \) such that \( L[s_b][N] = s_a \)) is chosen for the before state. We now have a shift entry, \( L[s_a][r] \) to work on, which can be solved as described earlier.
3. If there is no shift entry, we are left with the reduce entries. We choose any such state \( s_a \in S_A \). We now have another instance of reduce entry problem \( L[s_a][r] \), which can be solved recursively. If there is a unit-production cycle in the grammar, care must be taken to avoid choosing the cyclic productions. This can be achieved by marking the productions already used.

The working of ParseIT for reduce entry problem is described in the following example:

**Example 4.3.** Consider the grammar and parse table in Fig. 2. Suppose user makes an incorrect entry in the cell \( L[4][a] \) which contains entry “r3” i.e reduce by \( C \rightarrow d \). The stack (S), partial string (PStr), and the prefix string (Pref) configuration maintained by ParseIT at this stage are shown in Fig. 4(a). Here, d is the RHS of the reduce rule, as well as the terminal-only string. Applying the reduce rule, gives the configuration in Fig 4(b).

From parse table, the possible choices for \( s_b \) are \( S_B = \{0, 2, 3\} \), and the choices for \( s_a \) are \( S_A = \{2, 5, 6\} \). We refine the choices using the steps defined above:

1. Since \( L[5][a] \) is an error entry, state 5 is removed from \( S_A \) and corresponding state 2 is removed from \( S_B \).

}\]

Figure 3. Configurations of ParseIT while generating string for incorrect shift entry for LR grammar.
Attempt2 (Attempt3) means correct solutions using up to one (two) hint(s) from ParseIT.

2. Out of the remaining states in $S_A$, L[2][a] has a shift entry and L[6][a] has a reduce entry. We chose 2 for $s_a$, and corresponding state 0 for $s_b$.

We get configuration in Fig 4(c). Since $s_b$ is 0, the start state itself, $\omega$ is empty string (Fig 4(d)).

The problem is now changed to shift entry problem L[2][a], having partial string da (prefix and partial string concatenated). The configurations during the solution for the shift problem are as in Fig 4(e). So, dad is the desired input to exercise cell L[4][a].

USER STUDY
To verify the effectiveness of ParseIT, we implemented the tool in Java. The prototype implementation is available as a JAR file from anonymous Dropbox link [20]. A web interface was created for the user study.

The user study was conducted with with 16 students who have already done an introductory course on Compiler Design. We used 2 grammars and created 22 questions of 1 mark each related to various sub-topics in parsing. The question papers are code named P1 and P2. The students were randomly divided into 4 groups of 4 students each, G1–G4.
Each group solved one question paper using ParseIT, and the other using pen and paper (offline mode). To maintain equality between the two approaches, we provided a cheat sheet containing the required rules to each student for offline mode. Further, the sequence of ParseIT mode and offline mode was alternated. In particular, the groups solved the grammar in the following order:

- G1: P2 using offline followed by P1 using ParseIT
- G2: P1 using ParseIT followed by P2 using offline
- G3: P2 using ParseIT followed by P1 using offline
- G4: P1 using offline followed by P2 using ParseIT

The students were asked to fill a survey about the effectiveness of ParseIT after solving both the papers.

Fig. 5 shows the average of marks for groups while Fig. 6 shows average marks across sessions, we found that average marks for G4 remain unchanged while for G1 it reduced by 0.5. For both G2 and G3, the average marks increased by 1. If we include the correct answer after a hint is taken during ParseIT mode, we found that most students could get nearly full marks across the groups (average over all students improved to 21.75 from 18.50 for ParseIT without hints and 19.18 for offline). The biggest improvement was of 7 marks, for 3 students.

Even though the data set is small, it shows that online platform itself does not make a big difference in the understanding of parser concepts, but the hints’ mechanism that results in improvements in marks. The hints allow students to correct their mistakes early. It is also easy to figure out the source of confusion for students, which can be of help to the instructor. The post study survey also corroborated our inference: 15 students accepted that the hints provided a better understanding of parsing, and helped reach the correct solution. One student had a negative feedback as he commented that “Hints are produced as questions, which increases confusion as the user has already answered it wrong.”. However, generating hints in other forms (say natural language sentence) is an area of future long-term research.

CONCLUSIONS AND FUTURE WORK

In this paper, we described ParseIT for teaching parsing techniques. Our approach is question-answering based: problems are generated automatically and given to students to explain the working of a parser. Further, the hints provided by the tool are also in forms of targeted questions that help a student discover her mistake and revise the concept at the same time. ParseIT allows students to learn the techniques at their own pace, according to their convenience. The user study shows that the interactive nature of ParseIT helps users to learn from their own mistakes through experiments, and reduce the burden on teachers and teaching assistants.

Similar tools exist to teach few other phases of a compiler. In future, we plan to integrate these tools with ParseIT, and develop new tools to automate tutoring of all the phases of the compiler. We also plan to build animations around these concepts to improve student experience and understanding. An interesting question that will require user study over a longer period is whether the hints just helps the students select the correct answer during the exam, or do they have a lasting learning effect. Our plan is to deploy ParseIT in a large class teaching Compilers, to understand its impact on learning.

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