A Template-Based Technique for Automatic Generation of Programming Word Problems

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ABSTRACT

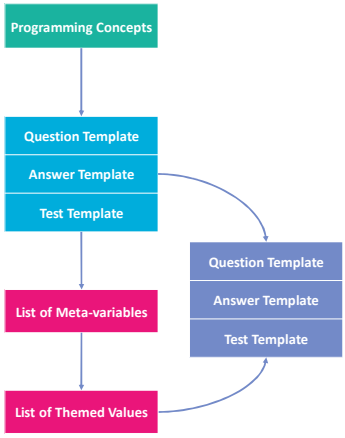
- Programming word problems (PWPs) are questions presented in written text expecting programming language solutions.
- We employed a template-based approach to **automatically generate** PWPs, which includes creating the natural language text questions, the programming language solutions, and test cases.
- To achieve variations in question context, we use meta-variables to create PWPs that differ in their textual themes but exemplify similar programming concepts.
- The approach allows us to generate PWPs much more quickly than writing them individually.

MOTIVATION

- PWPs are one of the most used question types for student practice and assessment in Computer Science.
- To ensure the effectiveness of PWPs, instructors need to provide students with new PWPs as previously-used questions can circulate among students.
- Thus, for educational purposes, there is a demand for a constant supply of fresh PWPs which includes the questions, the corresponding sample answers, and test cases to check student answers.
- Additionally, many research problems in Natural Language Processing rely on machine learning models. These models need a large supply of PWPs as input. Each sample in the input is a PWP question and its corresponding answer.
- Manual generation of PWPs are labour-intensive and can be error-prone.
- Considering the high demand and the difficulty of manual generation, our research explores a potential solution.

MAP

The following diagram shows the flow of generating a new PWP using our software.



META-VARIABLE GRAMMAR

- Meta-variables are "holes" in the templates that are replaced with themed values in the final synthesized PWP.
- The name of a meta-variable indicates its purpose and the type of replacement values it can take.
- Consider the example from the methods section:
  - <name list1> is the name of a list variable.
  - <ppt txt1> is a property described in text.
  - <ppt int2> is a property described with an integer.

METHODS

The following example shows the steps in generating a new PWP, including the question, sample answer, and test cases, using our system:

a. We start by deciding on the programming concepts this PWP is meant to embody.

Programming Concepts	Use of built-in functions
	List offset and operations

b. Based on the programming concepts, we develop a set of templates to address the question, answer, and test cases.

Question Template	Assume that you are given a list named <name list1>. The length of the list is <ppt int1>. Print the <ppt txt1> element in the list.
Answer Template	print(<name list1>[<ppt int2>])
Test Template	def test_1(): <name list1> = [2, [1], 1.33, "0", (4, 5), {}] Student Code* assert <name list1>[<ppt int2>] == Output from Student Code*

c. A list of meta-variables, unique to this set of templates, are extracted by our software.
d. We input theme-specific values to replace the meta-variables with.

Meta-variables and Themed Values	<name list1>	baitNum
	<ppt int1>	6
	<ppt txt1>	Second
	<ppt int2>	1

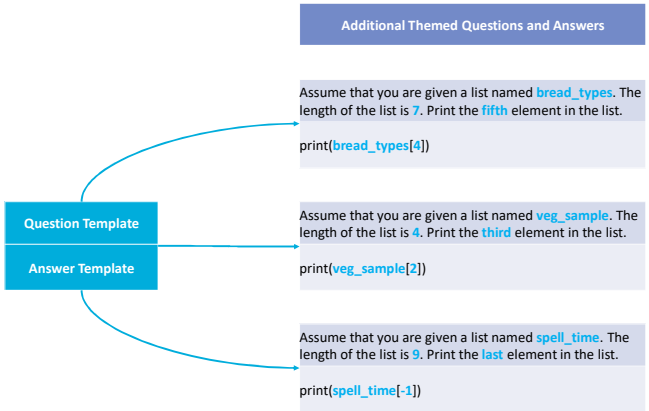
e. Our software then combines the templates with the list of meta-variable replacement values to create a new PWP with its corresponding answer and test cases.

Themed Question	Assume that you are given a list named baitNum. The length of the list is 6. Print the second element in the list.
Themed Answer	print(baitNum[1])
Themed Test	def test_1(): baitNum = [2, [1], 1.33, "0", (4, 5), {}] Student Code* assert baitNum[1] == Output from Student Code*

* Student answers are automatically extracted and inserted into the themed test cases to generate a grading script.

RESULTS

- We authored **52** templates, covering various CMPT 140/141 topics, and **4** sets of textual themes. Combining them we generated **208** new PWPs, each of which includes a question, a suggested solution, and several test cases.
- Our software is effective in generating new PWPs since given our approach:
  - The fixed template embodies the fundamental programming concepts.
  - The varied meta-variable replacement values support the different textual contexts we need for a new PWP.
- By substituting the meta-variables with different theme-specific values, we can easily synthesize various PWPs using a single template.
- For example, combining the template from the methods section with other theme-specific values, we generated the following different PWP questions and solutions. The accompanying test cases are omitted given their similarities to what is shown in the methods section.



FUTURE WORKS

- To the best of our knowledge, our research is the first attempt in automatic generation of PWPs using a template-based approach. Our software is effective, however, the fixed nature of the templates can lead to a limited number of variations and at times awkward phrasing.
- Pending approval from the Research Ethics Board, we intend to recruit first year computer science undergraduates to answer these machine-generated questions and explore the following questions based on their feedback:
  - Do machine-generated questions have the same variations in difficulty levels as manually-generated ones?
  - Do students find the machine-generated questions excessively confusing in terms of phrasing or other aspects?
  - How does student performance on the machine-generated questions differ from their performance on manually-generated ones?
  - Can the machine-generated questions can be effectively used as a pedagogical instrument?
- Related to PWPs' use in machine learning, we want to collect the variations in correct programming language answer to the same textual question.
- We use black-box testing for student answers, and we believe their answers will help to diversify our collection of PWP question-and-answer pairs.

DISCUSSION

- We encountered several pronounced challenges during our project.
- To balance complexity and flexibility of the templates we needed to systematically control the placement of meta-variables.
- We devised a grammar system to keep track of the meta-variables for their purposes and the kind of replacement values they are allowed to take.
- The templates for test cases were difficult to compose.
  - Both the flexibility incorporated in the question templates, and the specific values from different themes need to be accommodated by the test cases.
  - Problems including the use of membership and relational operators highlight this issue.
- Our test cases attempt to address potential opportunistic behaviour in assessment.
  - For example, extra testing is added by our software for recursion problems to ensure that recursion is used to execute the task.

ACKNOWLEDGEMENTS

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