

# Exploring the Design Space of Automatically Synthesized Hints for Introductory Programming Assignments

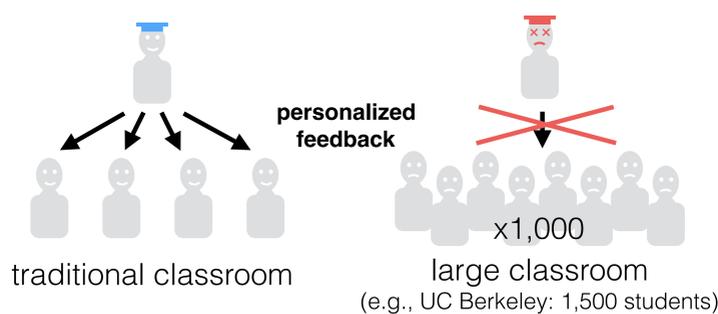
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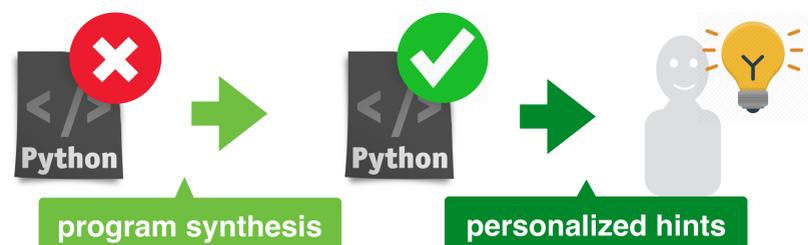
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## Background

For massive programming courses, **personalized feedback does not scale.**



**Program synthesis** techniques can enable personalized feedback at scale. It **automatically find fix** of students code and then **turn this fix into a sequence of hints.** (e.g., AutoGrader [Singh 2013], Refazer [Rolim 2017])



**example**

```
def accumulate(combl
- total = 0
+ total = base
  if n==0:
    return combl
  else:
    while n>0:
      total :
```

**example**

Hint 1:  
Look at **line 2**

Hint 2:  
In total = 0 at line 2, **replace the value 0 with base.**

## Problem

However, **currently generated hints** are

e.g., at line 2 in "total = 0", replace the value 0 with base

**different from teachers' hint-giving strategy.**

### Findings from an Interview



**We don't want to give away the solution** because it cuts off the learning opportunity. Students also do not like to have just an answer. (Interview with an intro CS course TA at UC Berkeley)

### Observations of Q&A posts in Piazza



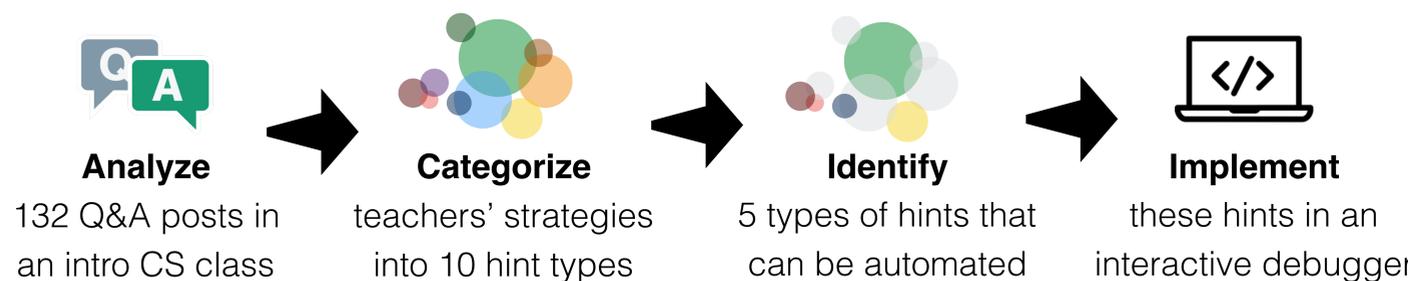
**Teachers illustrate why the code fails:** e.g.) Check the value of total and count. The correct behavior looks like this.  
total = 1 2 3 4 5 6 [7] 6 5  
count = 1 2 3 4 5 6 7 8 9

**Teachers encourage students to explore their code with interactive debuggers** e.g.) Try to examine the code in Python Tutor. What happens when you call accumulate? Is the combiner function that you're passing correct?

## Challenges

A key challenge in **automatic programming feedback** is **how to design pedagogically-useful hints** as effective as manual teachers feedback.

## Design Space of Synthesized Hints



- location hints:** point out locations that need to be fixed.
- data hints:** suggest the expected type or value of a variable at a code trace.
- behavior hints:** highlight how the incorrect behavior diverges from the nearest solution.
- example hints:** provide an example of input and output that a program must satisfy.
- transformation hints:** suggest abstract or concrete fixes to apply to incorrect code.

**Location Hint**  
Check the value of total in line 2

```
1 def accumulate(combiner, base, n, term):
2   total = 0
3   if n==0:
4     return combiner(base, 0)
5   else:
6     while n>0:
7       total = combiner(term(n), total)
8       n -= 1
9   return combiner(base, total)
```

**Data Hint**  
Running accumulate(mul, 2, 3, square)  
Expected 72 but got 0

```
1 def accumulate(combiner, base, n, term): # acc
2   total = 0 # total = 0 should be total = 2
3   if n==0:
4     return combiner(base, 0)
5   else:
```

**Behavioral Hint**  
Running accumulate(add, 11, 5, identity)  
Expected 26 but got 16

```
1 def accumulate(combiner, base, n, term): # combine
2   i = 1
3   total = 1
4   while i <= n:
5     total = combiner(total, term(i))
```

**Behavioral Hint**  
Running accumulate(add, 11, 5, identity)  
Expected 26 but got 16

```
1 def accumulate(combiner, base, n, term): # combine
2   i = 1
3   total = 1
4   while i <= n:
5     total = combiner(total, term(i))
```

**Example Hint**  
Running accumulate(add, 11, 5, identity)  
Expected 11 | 12 | 14 | 17 | 21 | 26  
Result 1 | 1 | 2 | 4 | 7 | 11 | 16

**Transformation Hint**  
Running accumulate(add, 11, 5, identity)  
Expected 11 | 12 | 14 | 17 | 21 | 26  
Result 1 | 1 | 2 | 4 | 7 | 11 | 16

## Contributions

- a characterization of five types of hints** that can be generated by state-of-the-art synthesis techniques, informed by a formative study
- the implementation of these hints in an interactive debugging interface** appropriate for deployment and evaluation in a large programming classroom.