Automatic **feedback** for student **mistakes** using **examples**

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Personalized Education

- CCC CAPE 2016 Workshop Vision:
  *"Personalization can meet the demands of **heterogeneous backgrounds** and different **learning styles**, and ensure **engagement** and **retention**."*
- Enabled by online learning platforms (MOOCs and on-campus blended classes) that allow tailoring **problem selection** and **feedback generation** to individual students' needs.

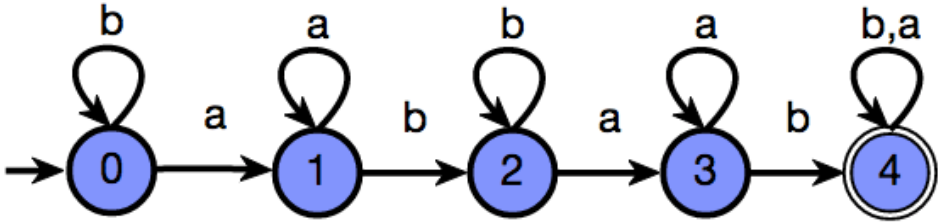
Example: Automata Tutor

(D'Antoni et al, TOCHI 2015; deployed at 20 universities)

Draw the DFA accepting the language:

{ *s* | '*ab*' appears in *s* exactly 2 times }

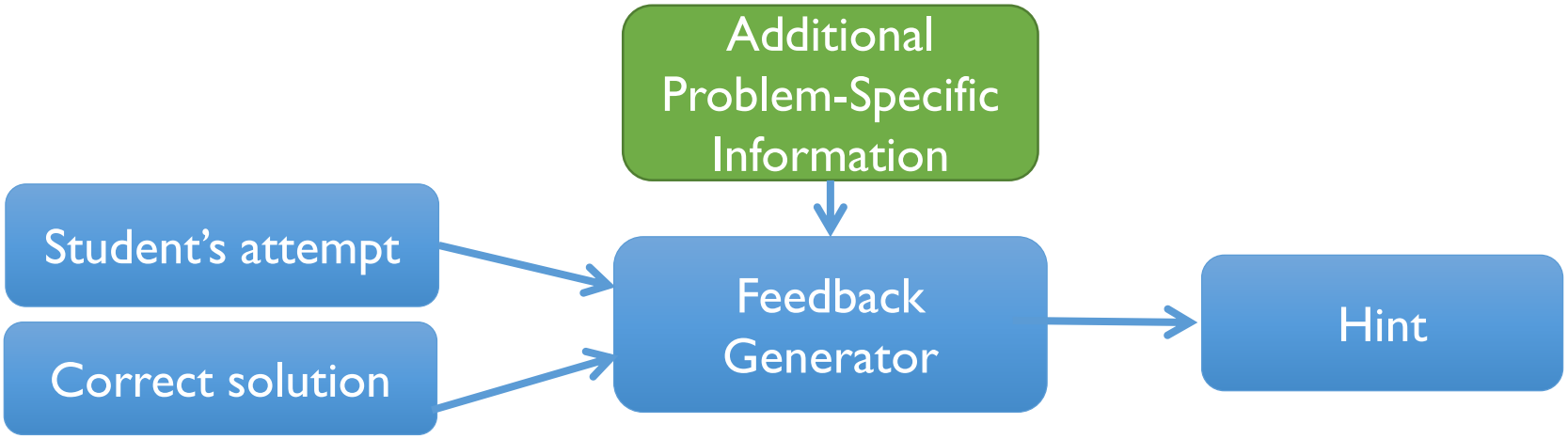
Student's Solution:



Feedback: Your DFA accepts the language

{ *s* | '*ab*' appears in *s* **at least** 2 times }

Generating Problem-Specific Hints



Challenge: How to include information about errors that are specific to the problem, but general enough to capture many different student instances of the error?

Problem-Specific Hints for Code

- **Autograder for Introductory Programming** (Singh, Gulwani, Solar-Lezama):
  Instructors must manually write down error model.
- **Our approach:**
  Assume many students are working on the same problem set. **Learn hints from student data.**

Setting: CS61a – Intro CS at UC Berkeley

- ~1500 students/semester
- Autograding infrastructure already in place: students submit problems to grading server (http://okpy.org), which runs a test suite, logs code and status, and returns feedback to student
- >200GB of plain-text python source code from last few semesters
- Next: DS8 Intro to Data Science – needs more instrumentation

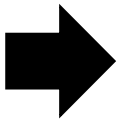
Approach

- Focus on code that runs but fails test suite.
- Capture (incorrect → correct) source pairs from students (cf. Hartmann et al., CHI 2010)
- Extract a reusable **transformation script** from each source pair using synthesis.
- If script succeeds to fix new program, turn template into conceptual hint.

Write a function product(n, term) that returns term(1) * ... * term(n)

```
def product(n, term):
    i = 1
    product = 1
    while i <= n:
        product *= i
        i += 1
    return product
```

FAILURE



```
def product(n, term)
    i = 1
    product = 1
    while i <= n:
        product *= term(i)
        i += 1
    return product
```

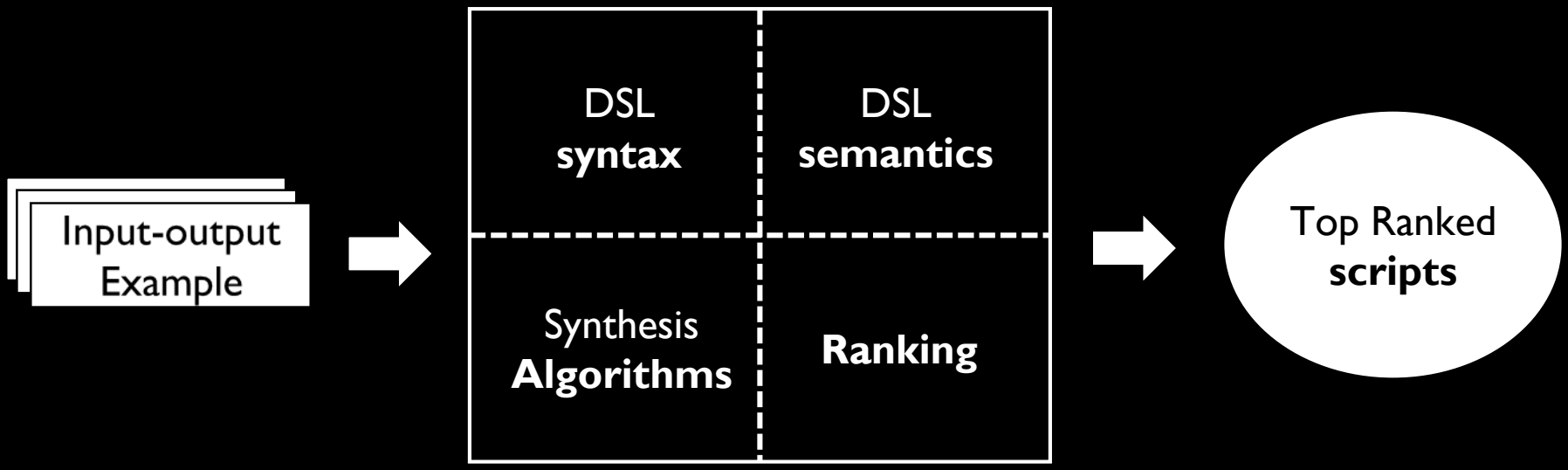
PASS

Input-output example specification

Program synthesis → $x \rightarrow \text{term}(x)$ → **Hint generation**

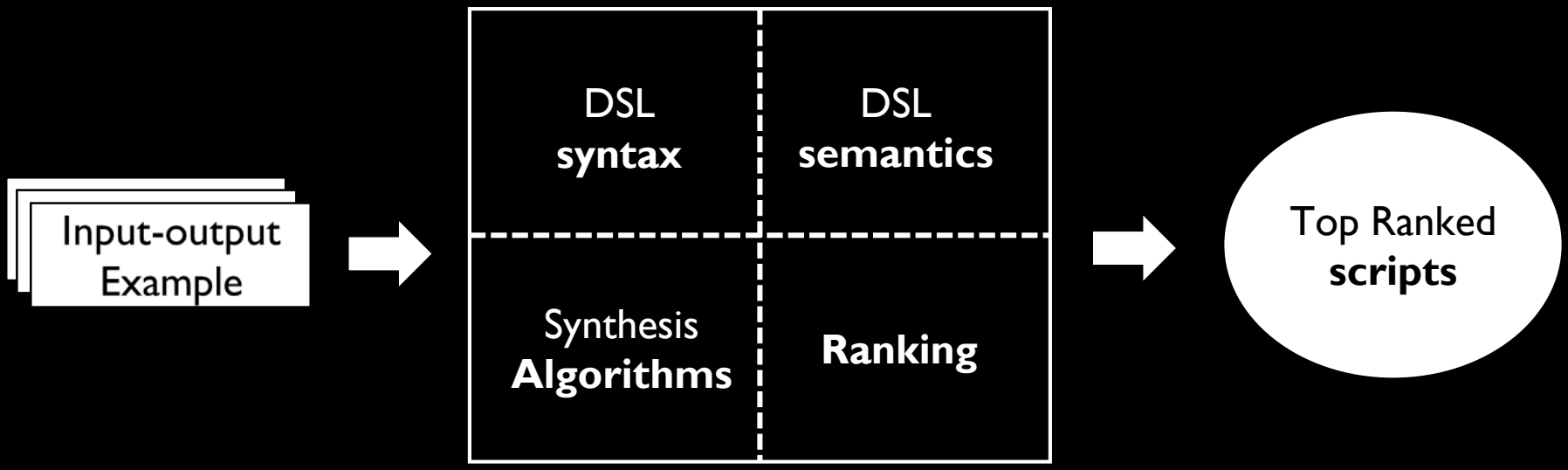
When should you call the passed-in function "term" in your while loop?

A technique for **learning transformations** using **examples**



Transformation script synthesis

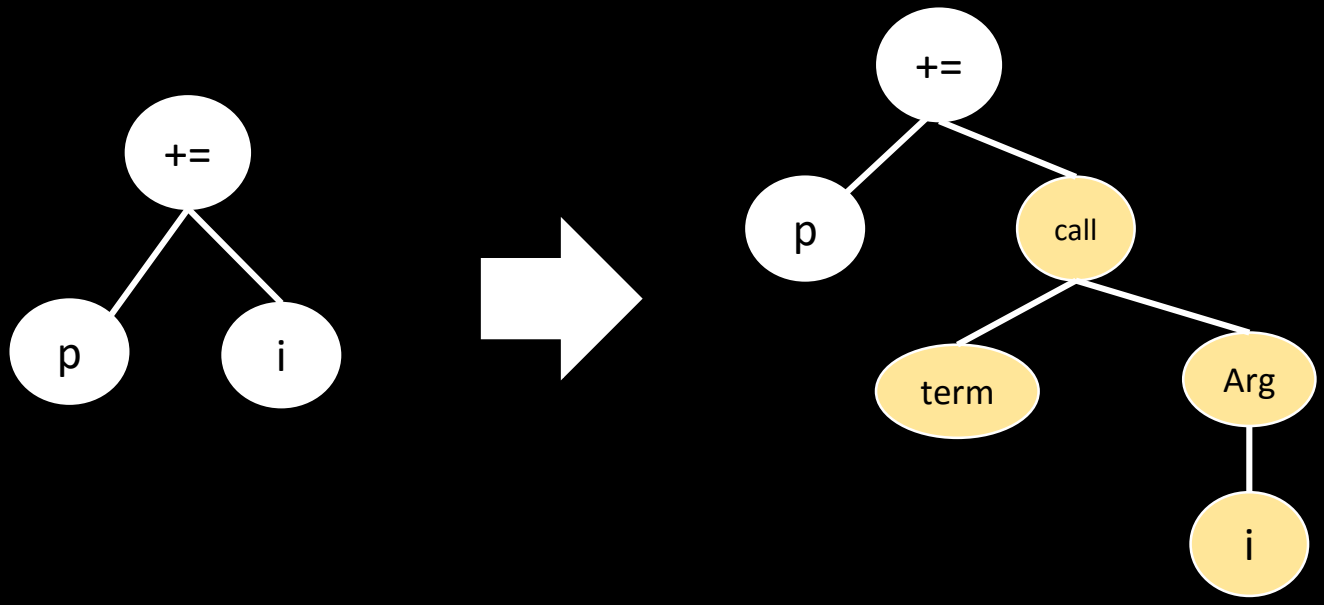
A technique for **learning transformations** using **examples**



Microsoft PROSE (FlashMeta) as the framework for program synthesis

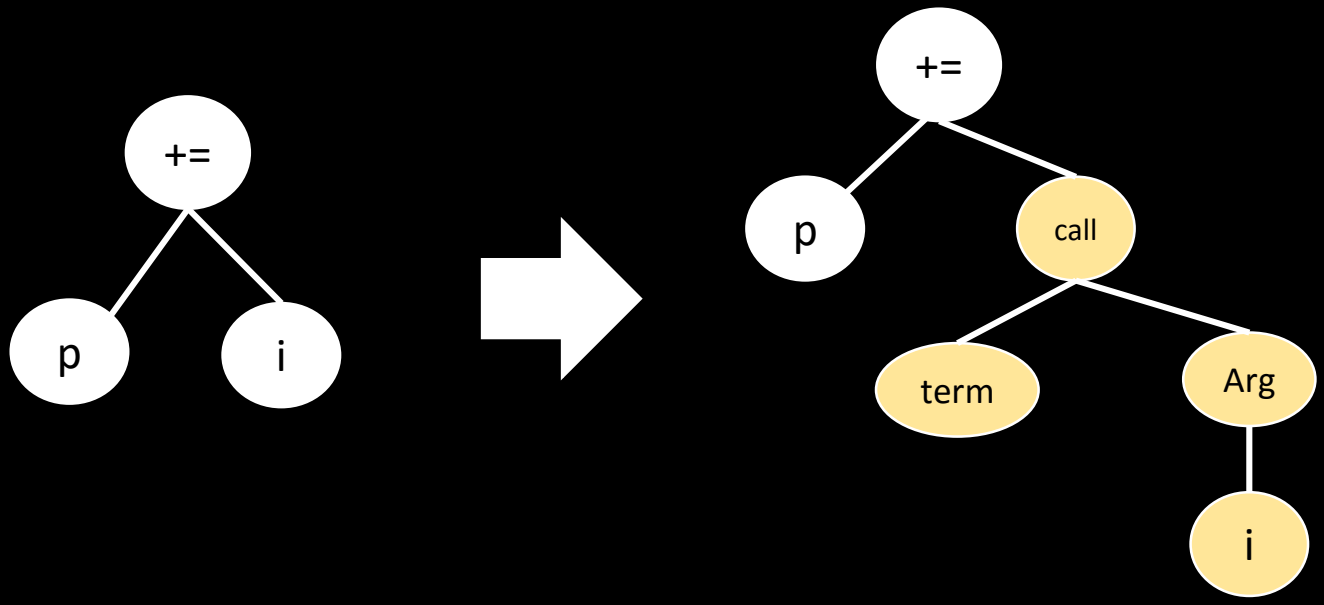
[Polozov and Gulwani, OOPSLA'15]

DSL example



DSL example

```
edit = Insert(node, ConstNode(CallExpression, Children(
LeafConstNode(NameExpression-term), SingleChild( ConstNode(Arg,
SingleChild(ReferenceNode(node, NameExpression("i")))))), 1)
```



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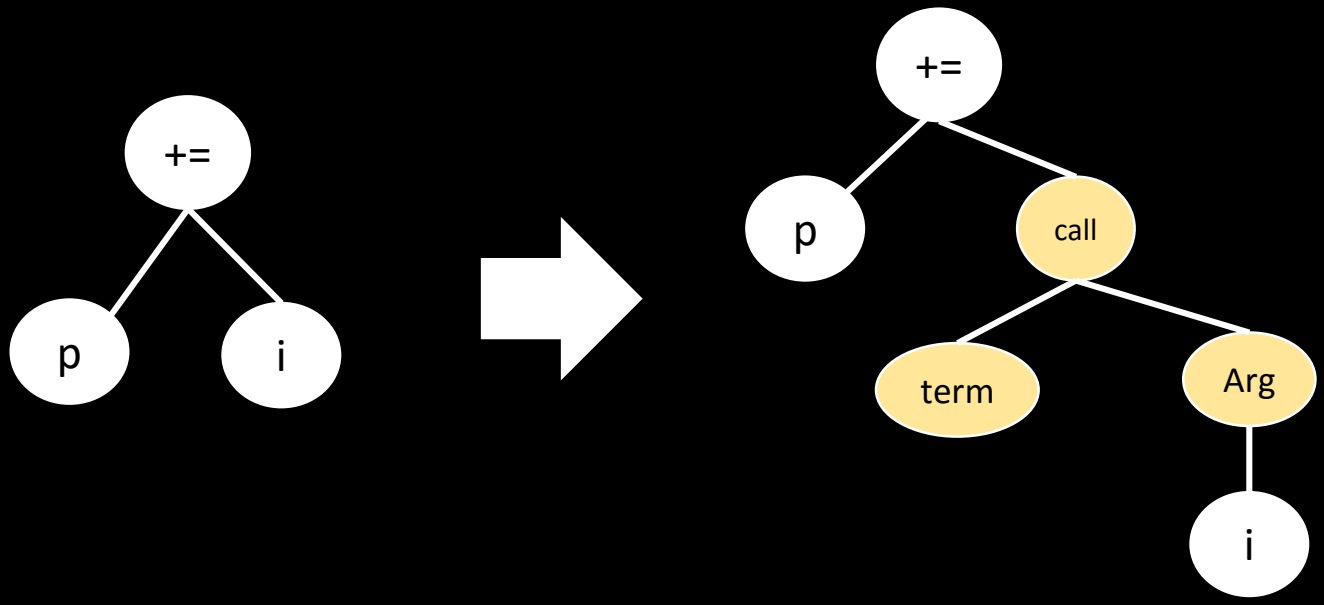
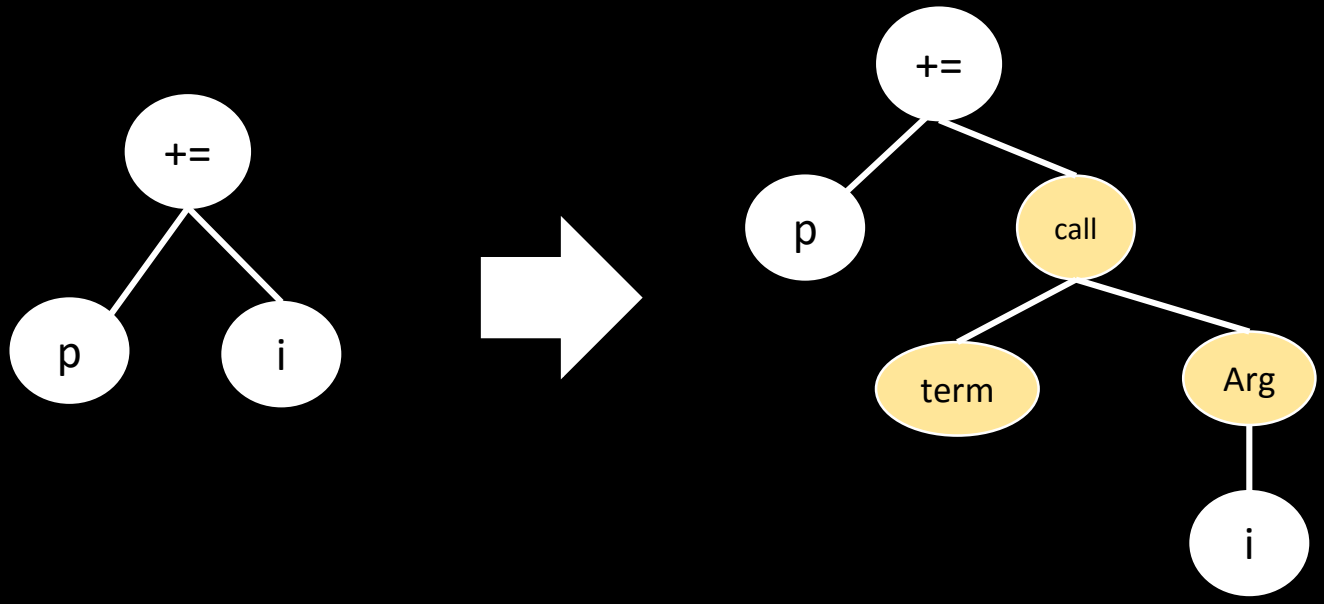


DSL example

```
edit = Insert(node, ConstNode(CallExpression, Children(
LeafConstNode(NameExpression-term), SingleChild( ConstNode(Arg,
SingleChild(ReferenceNode(node, NameExpression("i")))))), 1)

selectedNodes = Selected(λx => Match(x,
AugmentedAssignStatement {NameExpression NameExpression}),
InOrderSort(ast))
```



DSL example

```
EditMap(λnode => edit, selectedNodes) Where

edit = Insert(node, ConstNode(CallExpression, Children(
LeafConstNode(NameExpression-term), SingleChild( ConstNode(Arg,
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selectedNodes = Selected(λx => Match(x,
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```
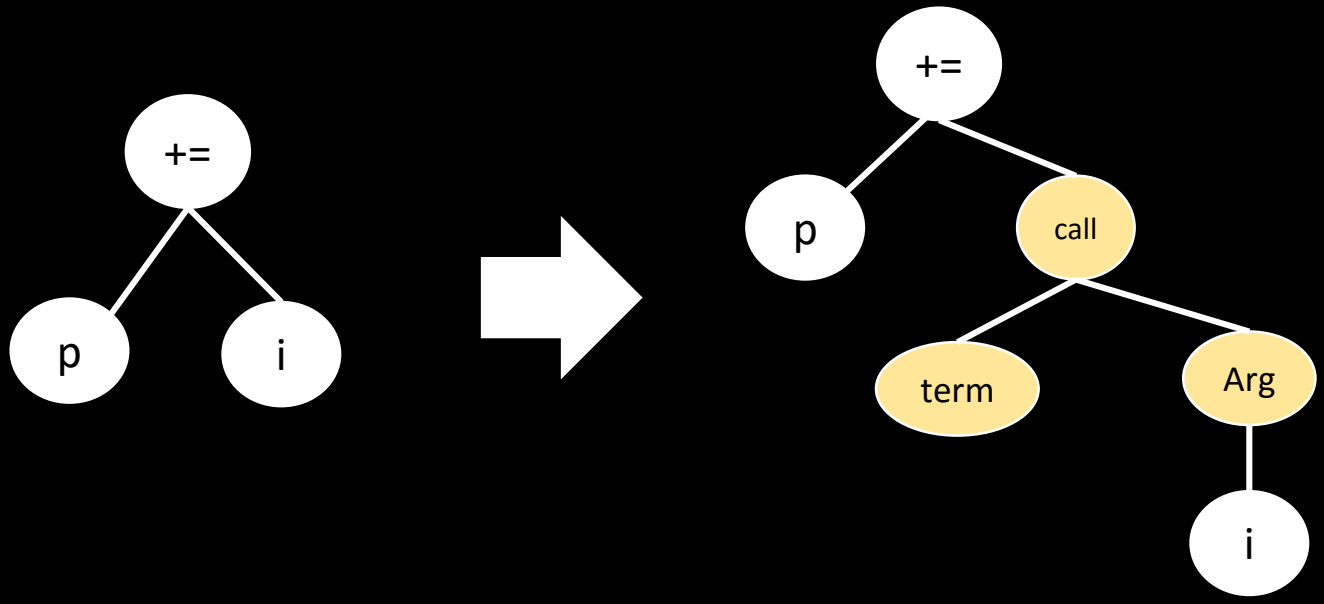



DSL **syntax**

```
@start IEnumerable<PythonAst> transformation := Apply(ast, patch);
Patch patch := Patch(editList) | ConcatPatch(editList, patch);
IEnumerable<Edit> editList := EditMap(edit, selectednodes) =
                Map(λnode : PythonNode => edit, selectednodes);
IEnumerable<PythonNode> selectednodes := Selected(match, nodes) =
                Filter(λx : PythonNode => match,nodes);
bool match := Match(x, template);
Edit edit := Update(node, n) | Insert(node, n, k) | Delete(node, r);
Node r := ReferenceNode(node, template);
Node n := LeafConstNode(info) | ConstNode(info, children) | r;
IEnumerable<Node> children := SingleChild(n) | Children(n, children);
IEnumerable<PythonNode> nodes := InOrderSort(ast);

@input PythonNode ast;
@feature[Score=TemplateScore] PythonNode template;
@feature[Score=InfoScore] NodeInfo info;
@feature[Score=KScore] int k;
```

Program **synthesis**

Example

Input `p += i`
Output `p += term(i)`

Apply(**patch**)

`Insert(term(i)), 0, 1)`

`Insert(term(i)), 0, 1)`

Insert(node, **n**)

`term(i)`

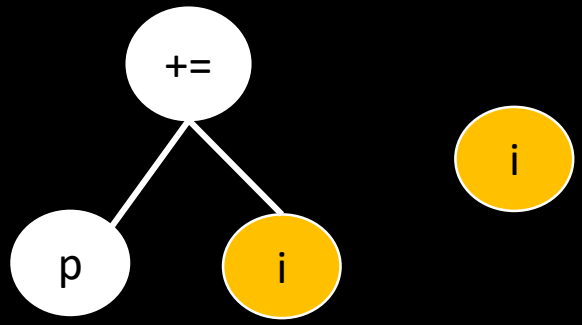
`i`

LeafConstNode(**type**, value)

`NameExpression`

`i`

ReferenceNode(value, **template**)



Ranking

- Prefer ReferenceNode to ConstNode
- Prefer abstract templates to concrete templates

Can our technique generate fixes for student submissions based on previous data?

Preliminary Evaluation

CS 61a

Leave-one-out cross validation

- Mistake is a pair of submissions of a single student containing her correct submission and her last incorrect submission
- Mistakes were taken from a sample of submissions clustered by test cases

Question	Mistakes
Product	215
Repeated	108

Our technique fixed 81% of the submissions

Question	Mistakes	Fixed mistakes	Scripts
Product	215	190 (88%)	8
Repeated	108	73 (68%)	10

Examples

General

Update($literal$, 1)
Update($literal$, 0)
Delete($arg, n-1$), Insert(n, arg, 0)
Insert($arg, n+1$)
Update($binaryExp$, $<$)
Update($nameExp$, j), Update($nameExp$, j), Update($literal$, 0)

Question Specific

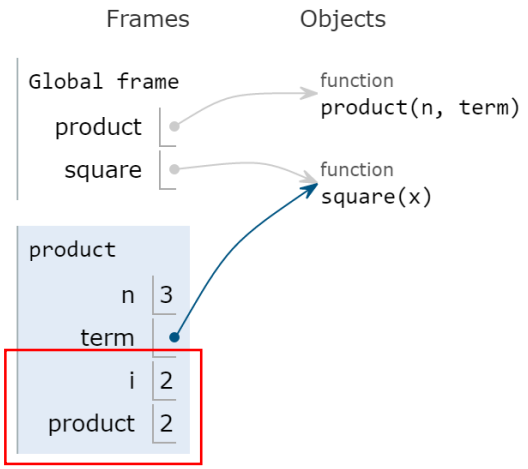
Insert(b$inaryExp$, term(x), 1)
Insert($assignStmt$, term(x), 1)
Insert($returnStmt$, $term(x)$, 1)
Update($literal$, n), Insert($returnStmt$, term(n), 1)
Update($nameExp$, Identity)
Update($literal$, Identity)
Insert(if ($n == 0$) return identity, ifStmt, 0)
Update($expStmt$, return $expStmt$)
Insert(return $nameExp$, $SuiteStmt$, 0)

Next steps

Data-centric hints

```
1. def product(n, term):
2.     i = 1
3.     product = 1
4.     while i <= n:
5.         product *= i
6.         i += 1
7.     return product
```

Actual

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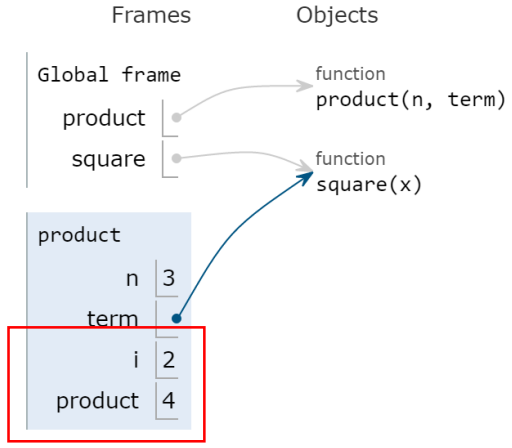
Expected



Further studies

First deployment in CS61a summer or fall 2016

User study: controlled experiment of different hints

Comparison to Autograder

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