Automating Generation of Programming Problems

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High Level Overview

- **Goal**: Create a system to automatically generate Python programming problems with characteristics specified by users

  - **Purpose**: Help teachers and students get personalized problems (classroom or MOOC setting)

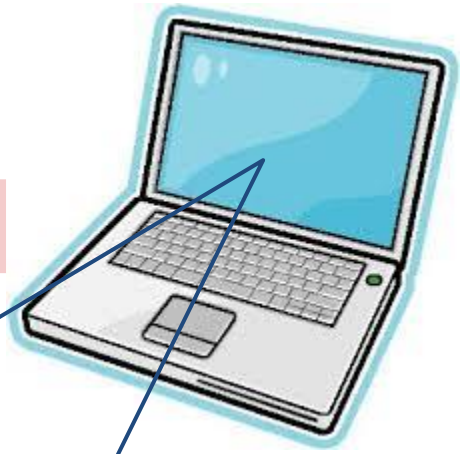
- **Strategy**: Synthesize a model of a Python AST (Abstract Syntax Tree) using Sketch

Example of a Programming Problem

Example of a Programming Problem

I want to practice these constructs:
arithmetic, recursion, if-then-else statements

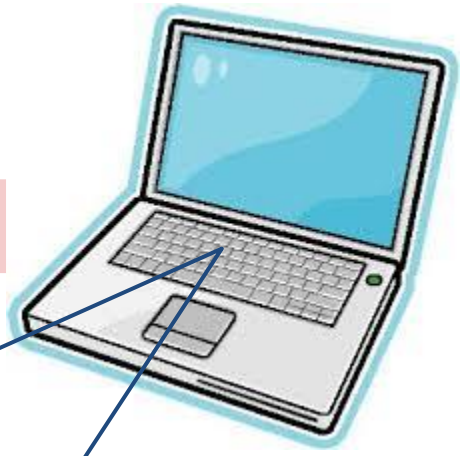
Example of a Programming Problem



Ok! Here is a problem for you. Fill in the blanks:

```
int sumDigits(int x){
            if(x/10 != 0){
            return ____ + sumDigits(___);
    }
    else return x;
}
```

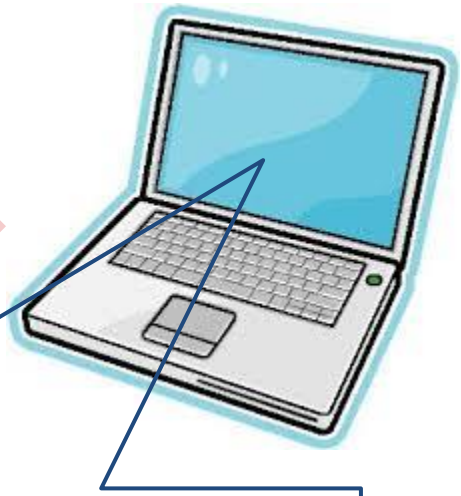
Example of a Programming Problem



I'll give you some hints.

Input: 123	Output: 6
Input: 444	Output: 12
Input: 12	Output: 3

Example of a Programming Problem



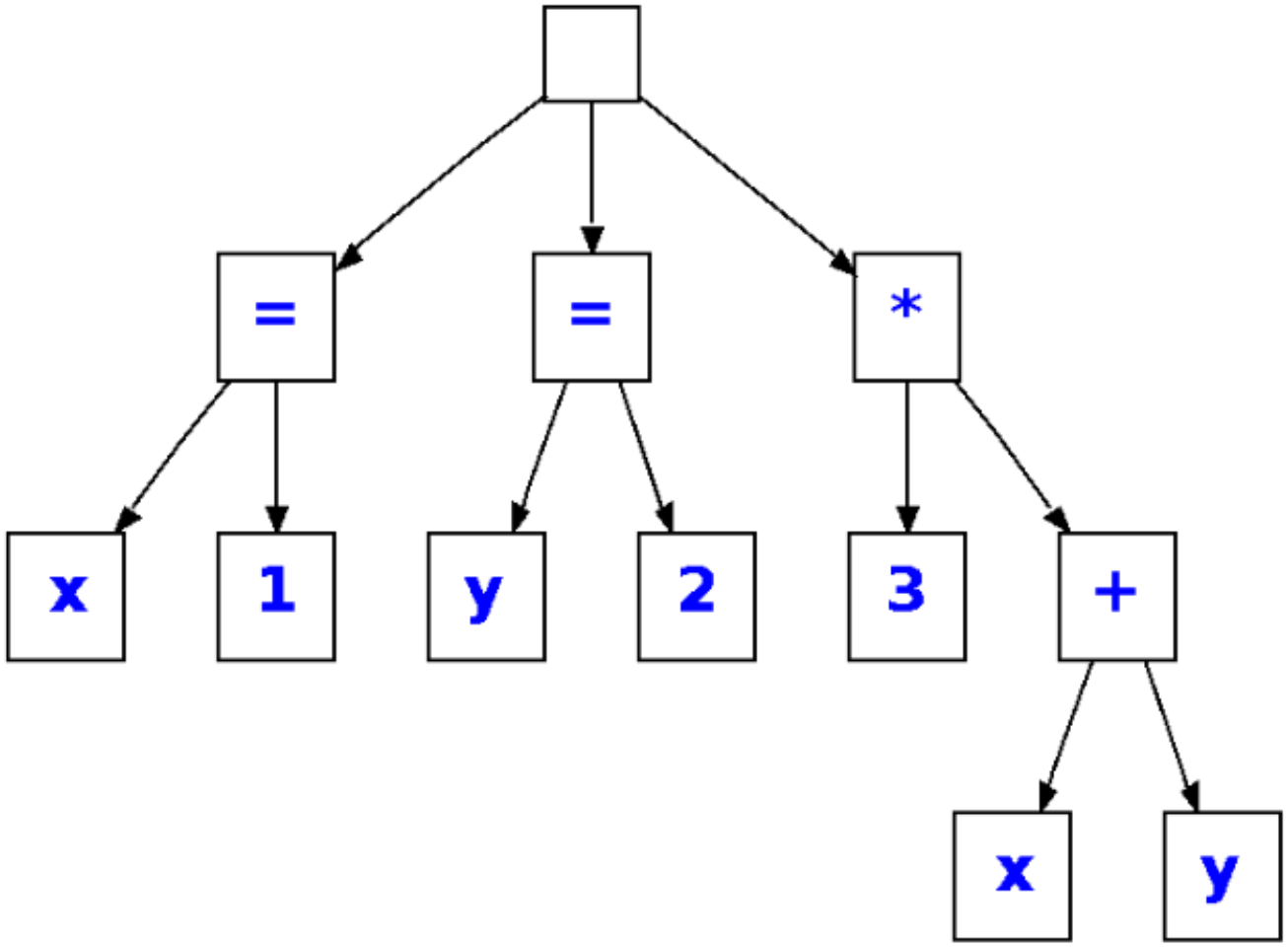
Here is my solution:

```
int sumDigits(int x){
            if(x/10 != 0){
            return x%10 + sumDigits(x/10);
    }
    else return x;
}
```

Preliminaries

Python Abstract Syntax Trees (ASTs)

```
x = 1
y = 2
3*(x+y)
```



Sketch Program Synthesis

Sketch Specification

```
harness void doublesketch(int x){
      int t = x * ??;
      assert t == x + x;
}
```

- **??** : arbitrary instances of expressions/statements
- Full fledged C++ code in the spec

Sketch Program Synthesis

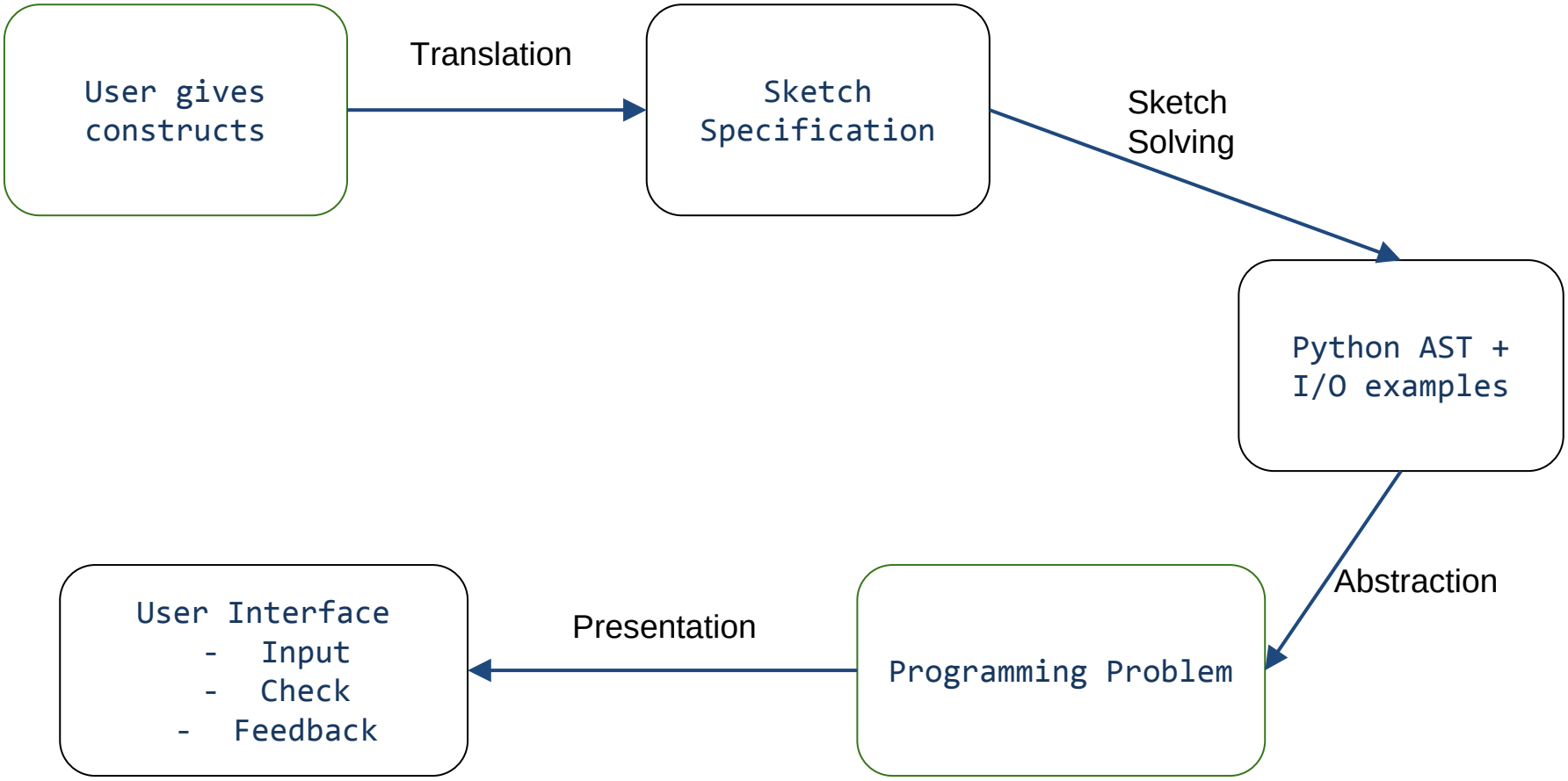
Sketch Solution

```
harness void doublesketch(int x){
      int t = x * 2;
      assert t == x + x;
}
```

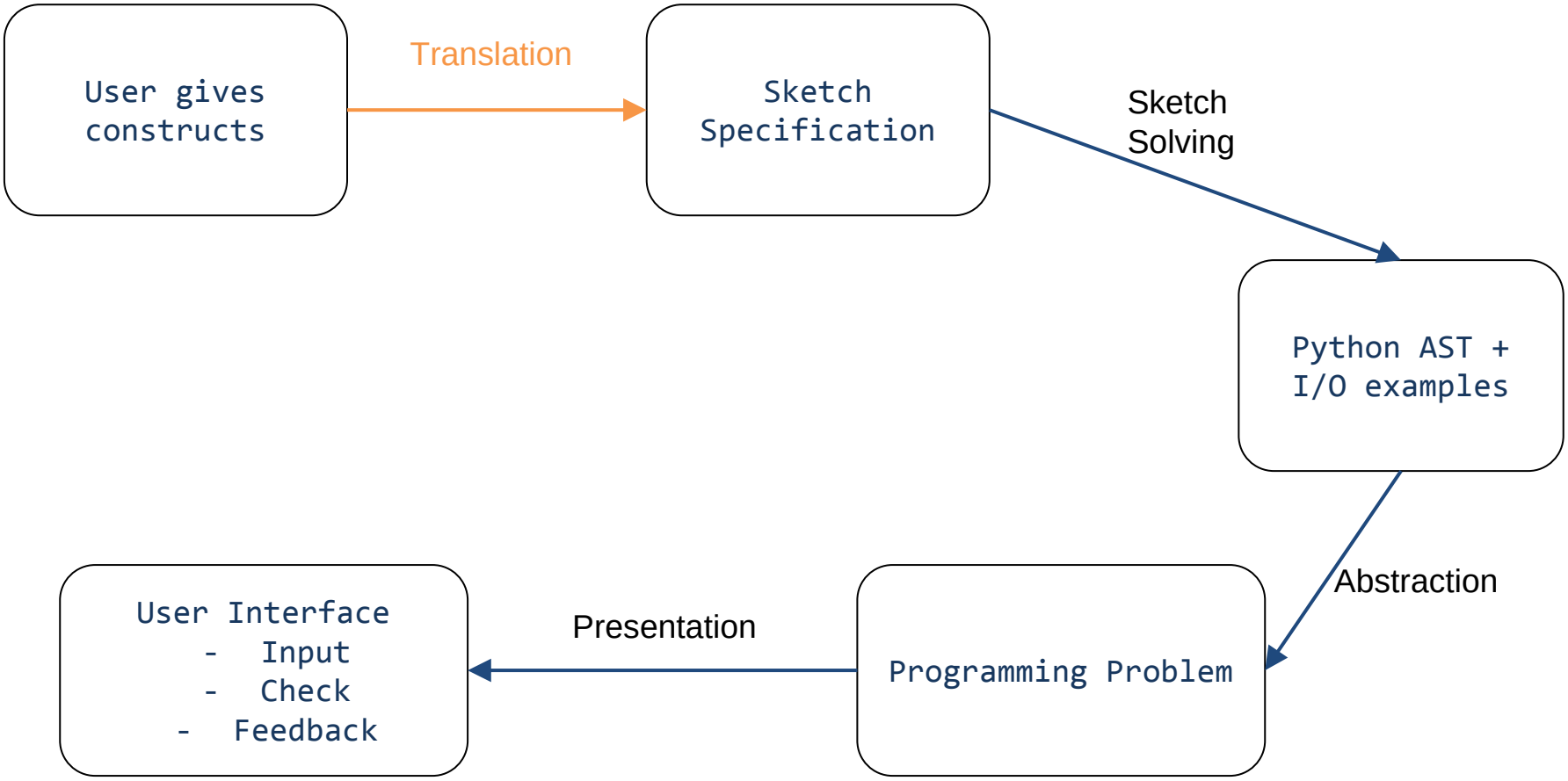
- **??** : arbitrary instances of expressions/statements
- Full fledged C++ code in the spec

Details

System Overview



System Overview



ASTs in Sketch: Algebraic Data Types (ADTs)

Constructs:

Sketch Specification

```
adt expr{




}
int interpret(expr e, int[] context){
     switch(e){









}
...
```

ASTs in Sketch: Algebraic Data Types (ADTs)

Constructs:
integers

Sketch Specification

```
adt expr{
    Num {int val;}




}
int interpret(expr e, int[] context){
     switch(e){
          case Num: return e.val;




}
...
```

ASTs in Sketch: Algebraic Data Types (ADTs)

Constructs:
integers
variables

Sketch Specification

```
adt expr{
    Num {int val;}
    Var {int id;}




}
int interpret(expr e, int[] context){
     switch(e){
          case Num: return e.val;
          case Var: return context[var.id];




}
...
```

ASTs in Sketch: Algebraic Data Types (ADTs)

Constructs:
integers
variables
arithmetic

Sketch Specification

```
adt expr{
    Num {int val;}
    Var {int id;}
    Plus {expr left; expr right;}
    Mult {expr left; expr right;}

}
int interpret(expr e, int[] context){
     switch(e){
          case Num: return e.val;
          case Var: return context[var.id];
          case Plus: {
               int left = interpret(e.left, context);
               int right = interpret(e.right, context);
               return left + right;  }

}
...
```

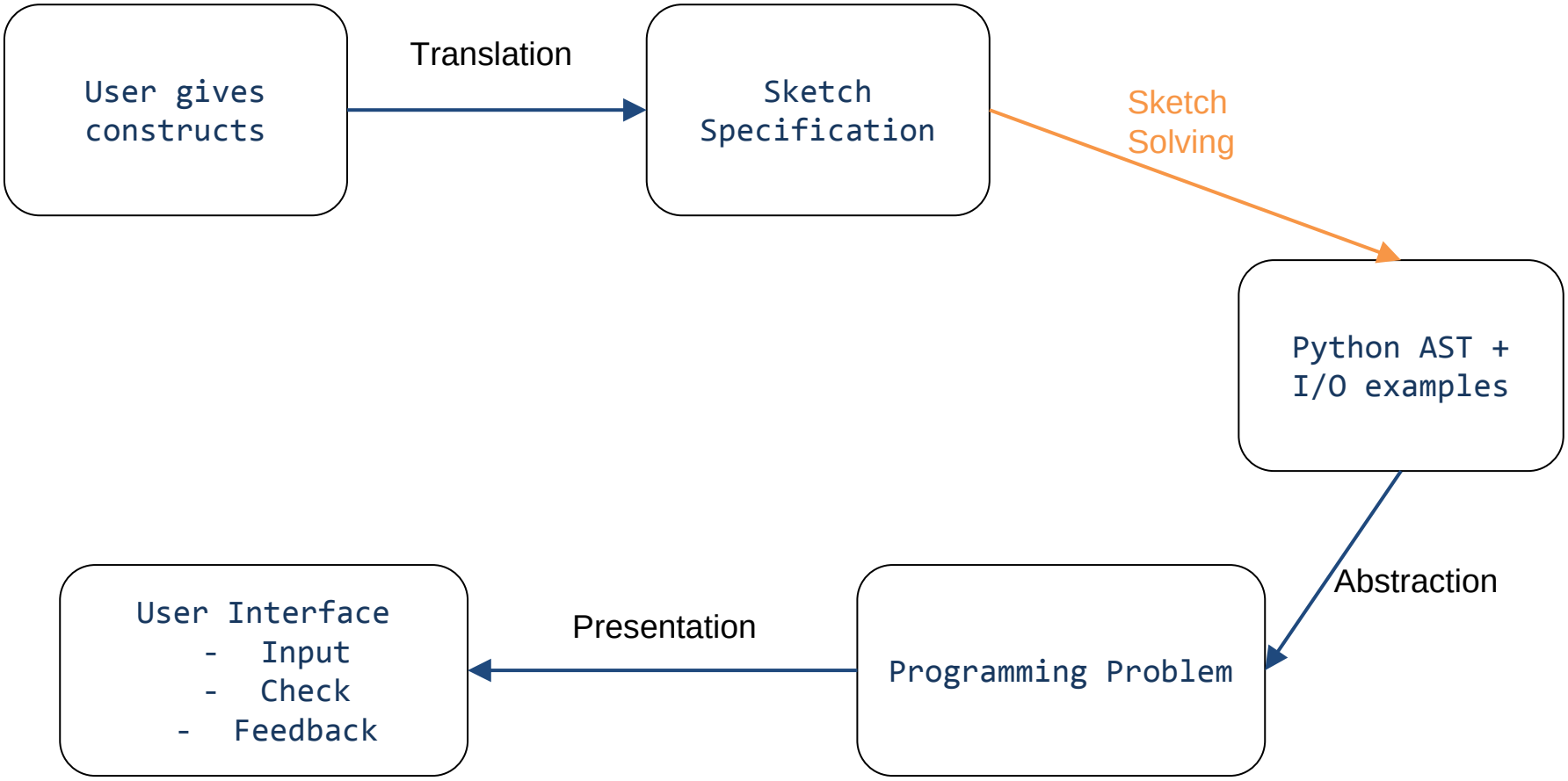
ASTs in Sketch: Algebraic Data Types (ADTs)

Constructs:
integers
variables
arithmetic
recursion
function calls
lists
assignments
if-then-else
while loops
for loops

Sketch Specification

```
adt expr{
    Num {int val;}
    Var {int id;}
    Plus {expr left; expr right;}
    Mult {expr left; expr right;}
    ...
}
int interpret(expr e, int[] context){
     switch(e){
          case Num: return e.val;
          case Var: return context[var.id];
          case Plus: {
               int left = interpret(e.left, context);
               int right = interpret(e.right, context);
               return left + right;  }
                    ...
}
...
```

System Overview



Synthesis Specification

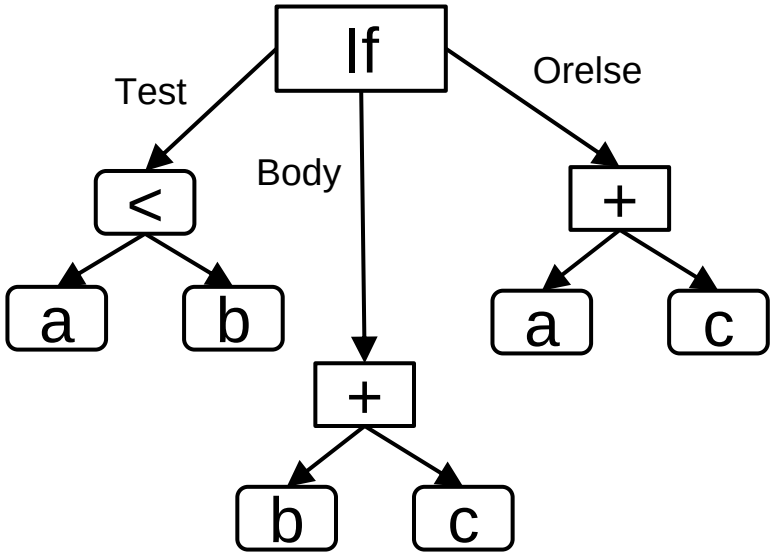
```
adt expr{
    Num {int val;}...
}
int interpret(expr e, int[] context){
     switch(e){
          case Num: return e.val;
          ...
}

//synthesis specification
harness synthesize(){
          expr e = ??(3); //AST of depth 3
          int[] inps = ??; int outp = ??; //input-output
example
          assert(interpret(e, inps)) == outp);
}
```

Synthesized AST with I/O Examples

Program

```
If (a<b):
   b + c
else:
   a + c
```



Input/Output Examples

(0, 0, 0) → (0)

(1, 2, 3) → (5)

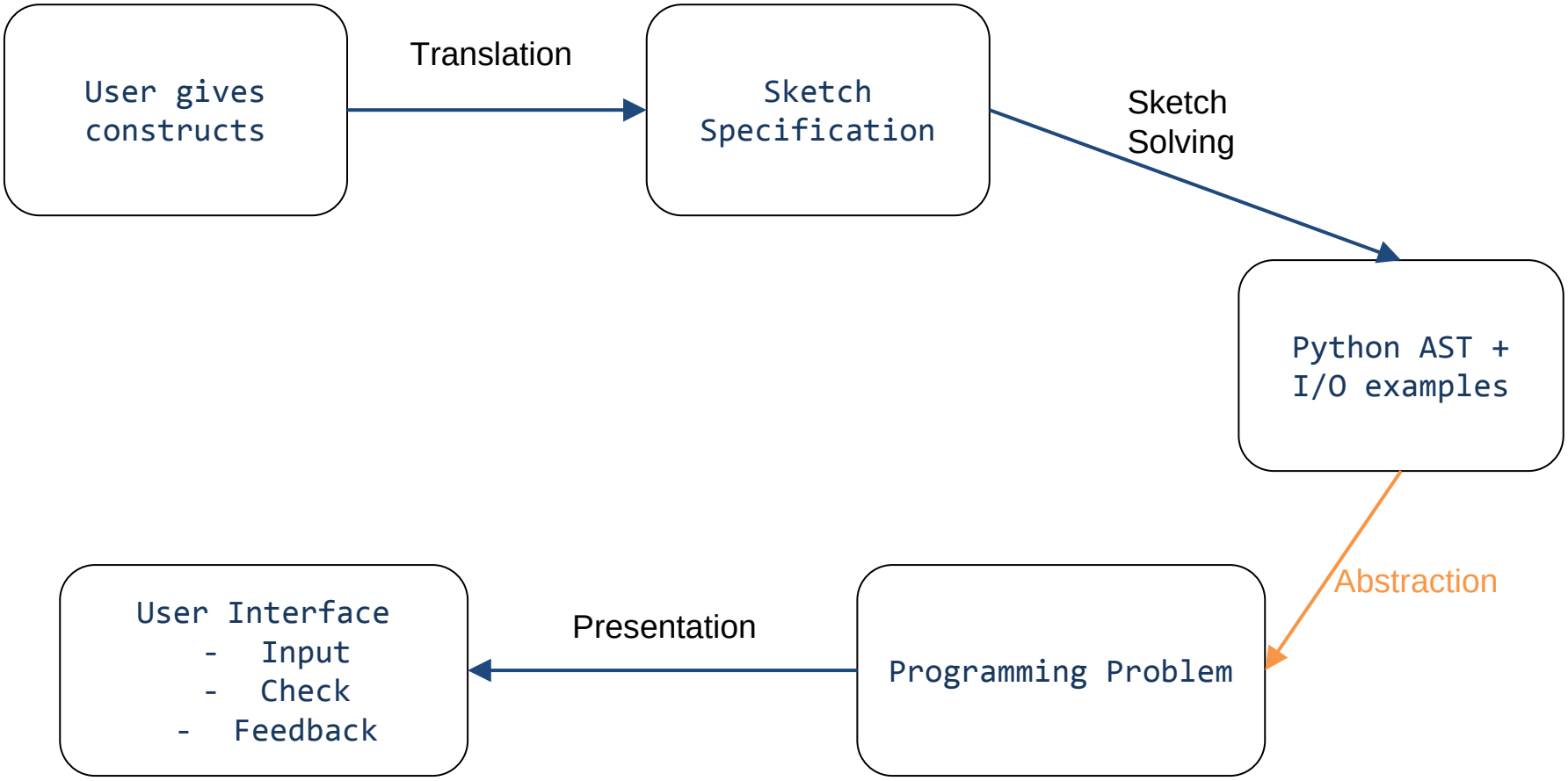
(-3, 2, -1) → (1)

(5, 3, -2) → (3)

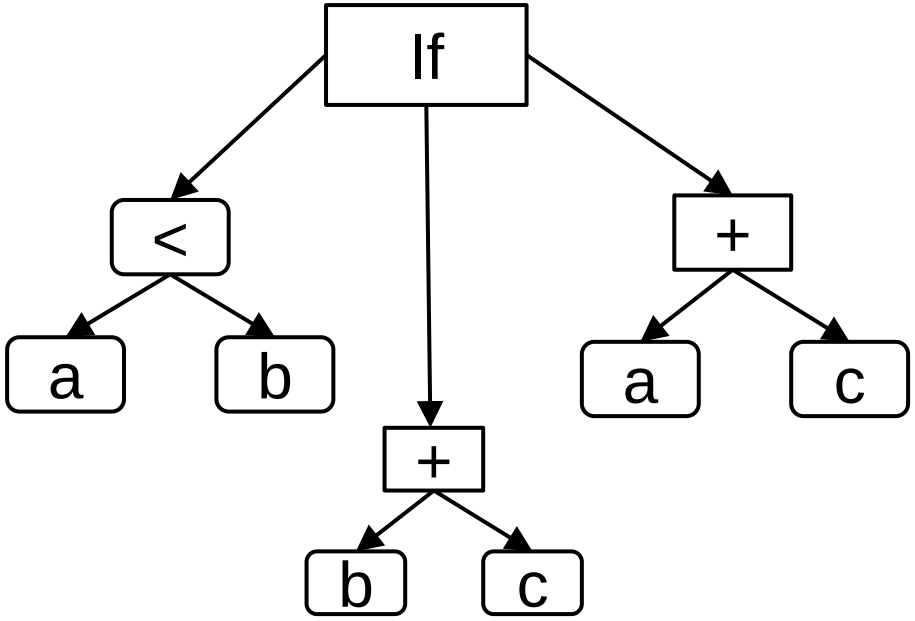
Synthesis: Challenges

- Finding ASTs that are **not trivially reducible**
  - e.g. (**a**+**0**) or (**a***1**) or if(**b**) then **a** else **a**
  - Adding “tainted” values to interpret function
    - Making sure that each top level node (input or constant) taints the output
  - Searching for many I/O examples (5 by default)
- **Scalability of Synthesis**
  - Parameters to control search space
    - Depth of AST
    - Number of each type of node to search for

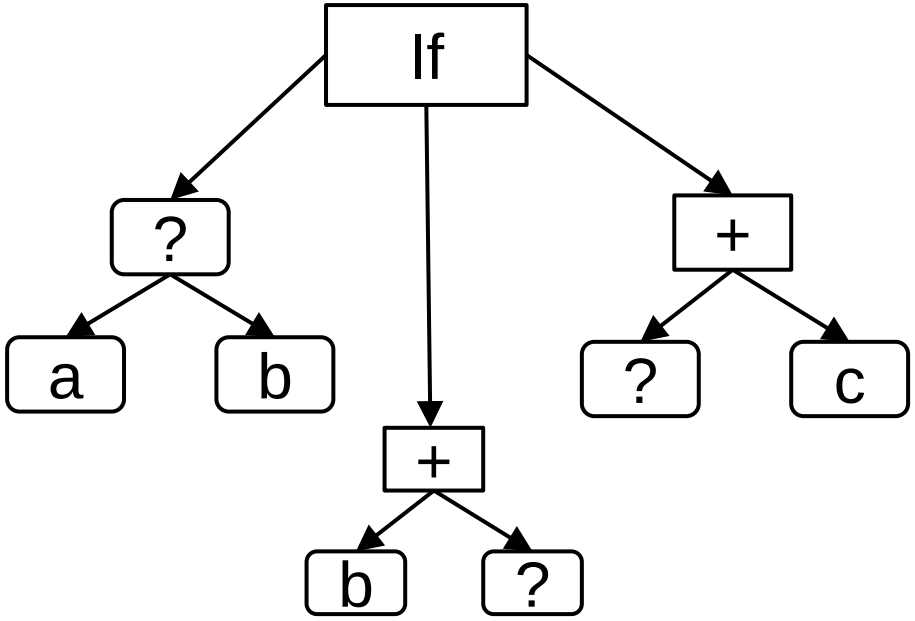
System Overview



Abstracted Programming Problem



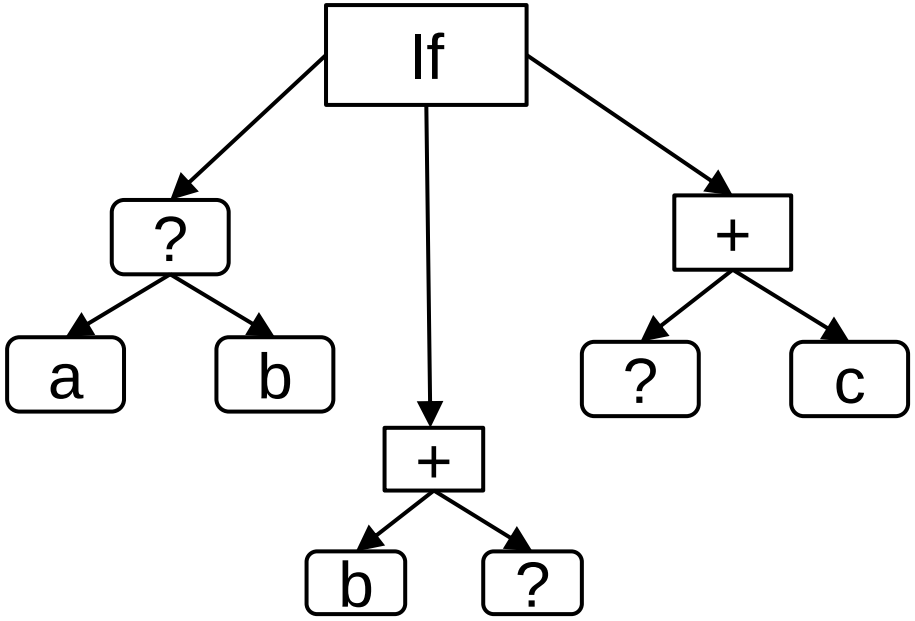
Abstracted Programming Problem



Abstracted Programming Problem

Programming Problem

```
If (a ?? b):
   b + ??
else:
   ?? + c
```



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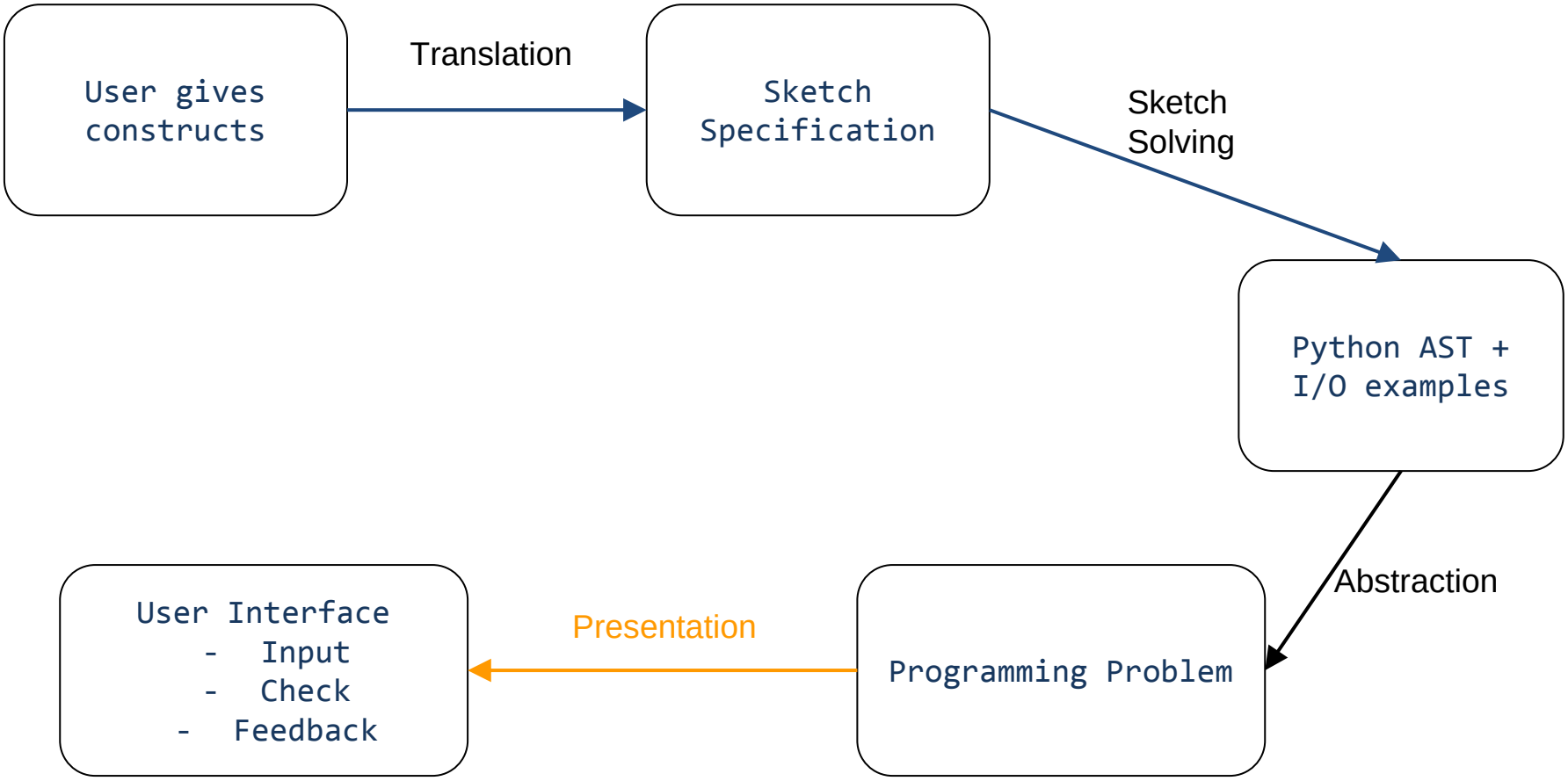

Problem Presentation

User sees:

```
If (a __ b):
   b + __
else:
   __ + c
```

Input/Output Examples

(0, 0, 0) → (0)

(1, 2, 3) → (5)

(-3, 2, -1) → (1)

(5, 3, -2) → (3)

Problem Presentation

User's attempt:

```
If (a != b):
   b + c
else:
   a + c
```

Input/Output Examples - Feedback

(0, 0, 0) → (0)

(1, 2, 3) → (5)

(-3, 2, -1) → (1)

(5, 3, -2) → (3)

Problem Presentation

User's second attempt:

```
If (a  <  b):
   b + c
else:
   a + c
```

Input/Output Examples - Satisfied!

(0, 0, 0) → (0)

(1, 2, 3) → (5)

(-3, 2, -1) → (1)

(5, 3, -2) → (3)

Results

ASTs/Programs generated by Sketch

Program:

```
If (c < b):
   b + b
else:
   a + b
```

Input/Output Examples

(0,2,1) → 4

(0,5,3) → 10

(30,1,2) → 31

(0,1,0) → 2

(7,5,3) → 10

ASTs/Programs generated by Sketch

Program:

```
If (c < b):
   a * a
else:
   b + a
```

Input/Output Examples

(2,1,5) → 6

(5,1,0) → 25

(3,2,0) → 9

(3,8,0) → 9

(1,4,6) → 10

ASTs/Programs generated by Sketch

Program:

```
If (b < c):
   a * c
else:
   a * b
```

Input/Output Examples

(2,1,3) → 6

(3,3,2) → 9

(6,4,5) → 30

(4,1,7) → 28

(10,2,1) → 20

ASTs/Programs generated by Sketch

Program:

```
If (c < a):
   2*c + b
else:
   2*c
```

Input/Output Examples

(4,26,0) → 26

(7,11,10) → 20

(0,11,15) → 30

(8,16,12) → 24

(30,28,1) → 30

ASTs/Programs generated by Sketch

Program:

```
If (c > 3):
   2
else:
   a+c
```

Input/Output Examples

(0,24,4) → 2

(0,0,4) → 2

(0,8,6) → 2

(8,16,8) → 2

(8,0,1) → 9

ASTs/Programs generated by Sketch

Program:

```
If (c < 4):
   a+b
else:
   a+c
```

Input/Output Examples

$(4,2,3) \rightarrow 6$

$(2,3,0) \rightarrow 5$

$(4,0,8) \rightarrow 12$

$(3,3,0) \rightarrow 6$

$(1,0,10) \rightarrow 11$

Current Status and Future Work

- Current Status
  - Parts of the pipeline Independently tested
    - Python ASTs
    - Sketch Synthesis
  - Working on putting them together
- Future work/Improvements
  - Automating different processes
    - Abstraction with heuristics
    - Generation of Sketch Specifications
    - Generating optimal problems
  - UI (input, verify, feedback)

Acknowledgements

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