Unit Test Generation Using Tree Mining Algorithms

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Introduction

- Identify bad practices and common mistakes in code
- Improve code quality
- Huge code data bases

Baseline Paper

- Mine patterns in CS1 student code
- Use Tree mining algorithm
- Small evaluation
- We want to go further

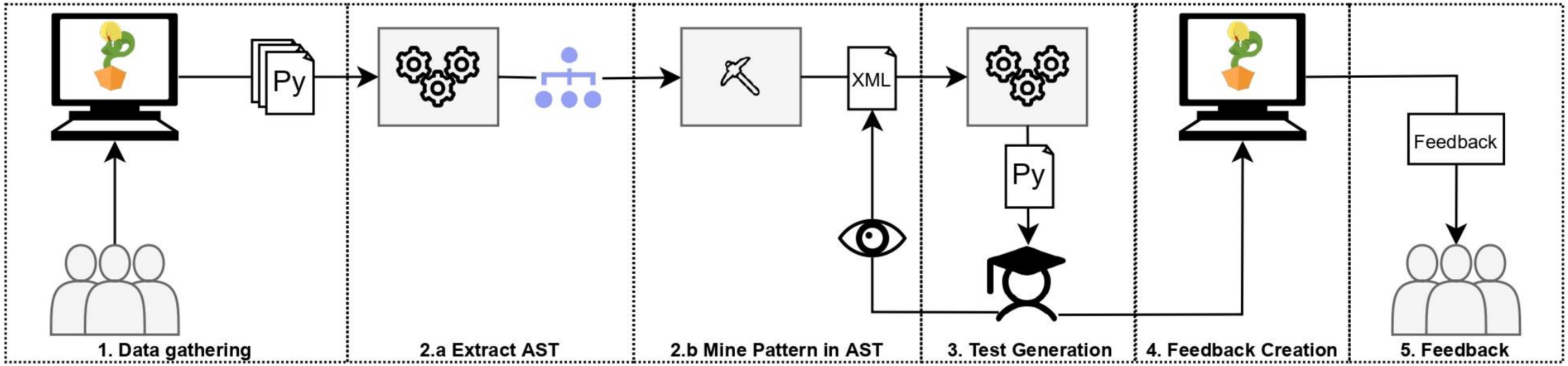
The Good, the Bad, and the Ugly: Mining for Patterns in Student Source Code

K. Mens, S. Nijssen, H.S. Pham

What do we add

- More systematic analysis but still manual
- Use of observed solutions for future students
- Automation of the detection of patterns of interest
- Creation of feedbacks to improve code quality

Methodology



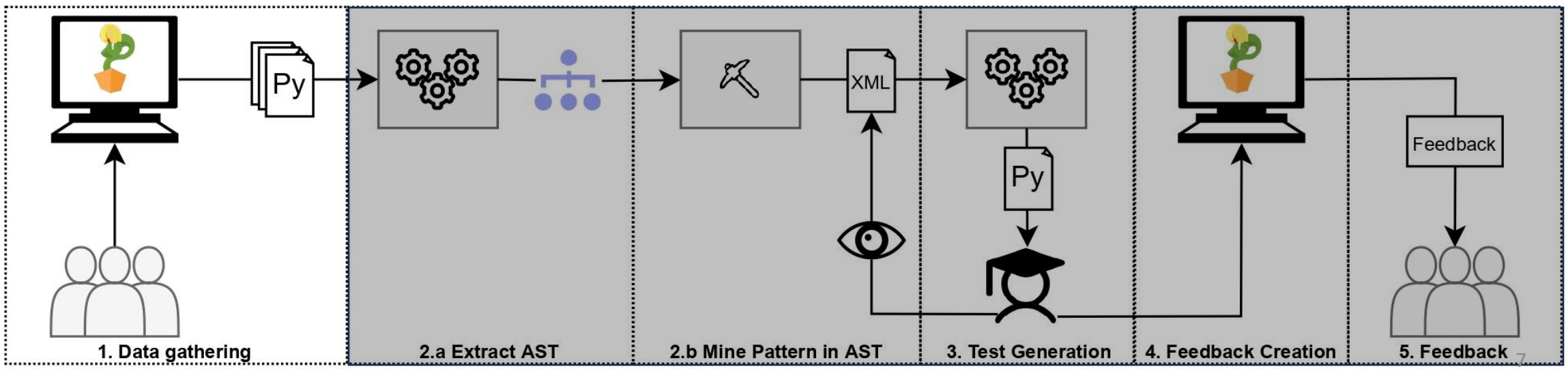
```python
def facteurs(n):
    assert isinstance(n,int),"please enter an integer"
    assert (n>0),"please enter a positive number"
    a=[2,3,5,7,11,13]
    count=0
    for i in a:
        while n%i==0:
            count+=1
            n=n//i
    if count==0 and n!=1:
        count=1
    return (count)
```

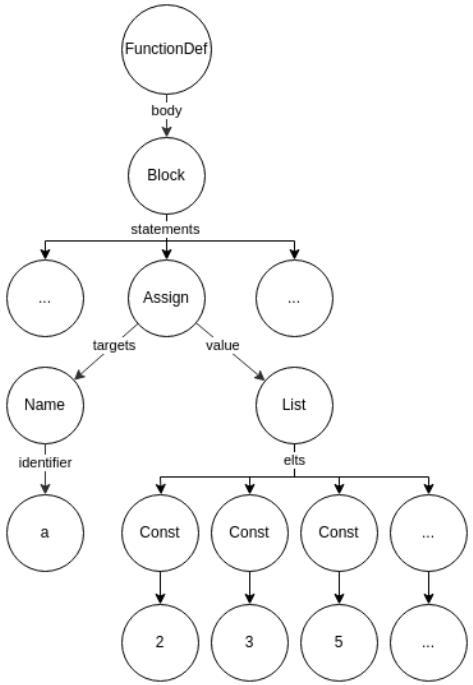
```python
def factors(n):
    l = [2,3,5,7,11,13,17,19] #list of primes
    i = 0
    t=[]
    for i in range(len(l)) :
        if n%l[i] == 0:
            t.append(l[i])
            i -= 1
    nbr = len(t)
    return (nbr)
```

```python
def facteurs(n):
    lst=[1,2,3,5,7,11,13,19]

    for i in range(1,8):
        for l in range(0,8):
            for k in range(0,8):
                for j in range(0,8):
                    if lst[i]*lst[j]*lst[k]*lst[l]==n:
                        if l==0:
                            return 2
                        elif k==0:
                            return 3
                        elif j==0:
                            return 4
                        else:
                            return 5
```

```python
def facteurs(n):
    l = [2,3,5,7,11,13,17,23,29,31]
    f = 0
    for i in range (2,n//2):
        f = 0
        if n == 1:
            None
        elif n%i == 0:
                for j in l:
                    while n%j == 0:
                        f += 1
                        n = n/j
                break
        else:
            f = 1
    return f
```

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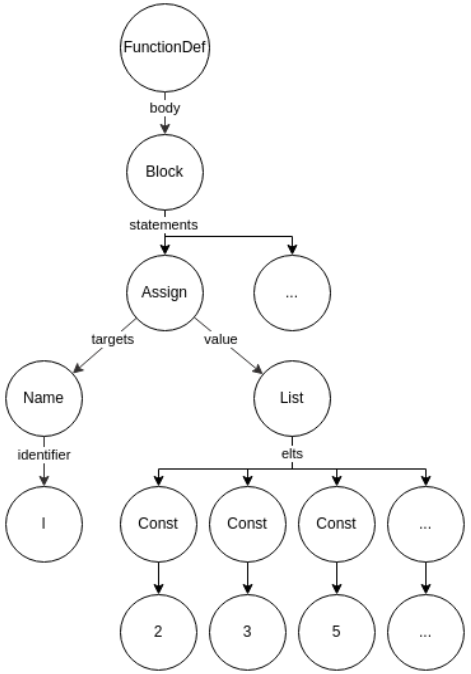
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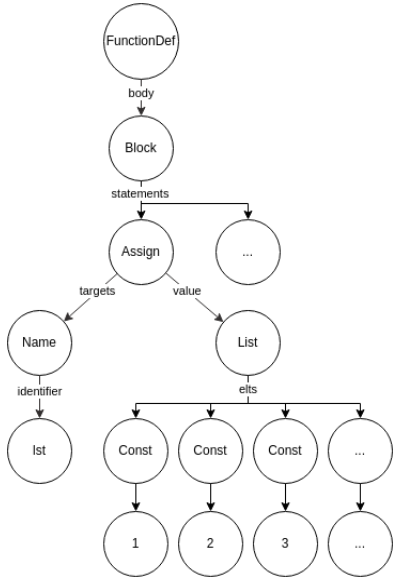
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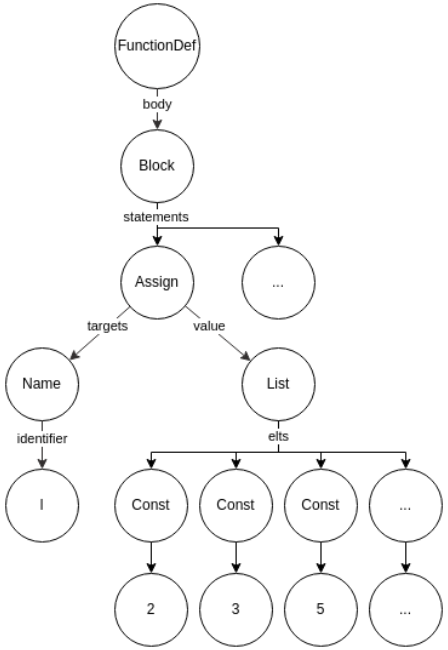
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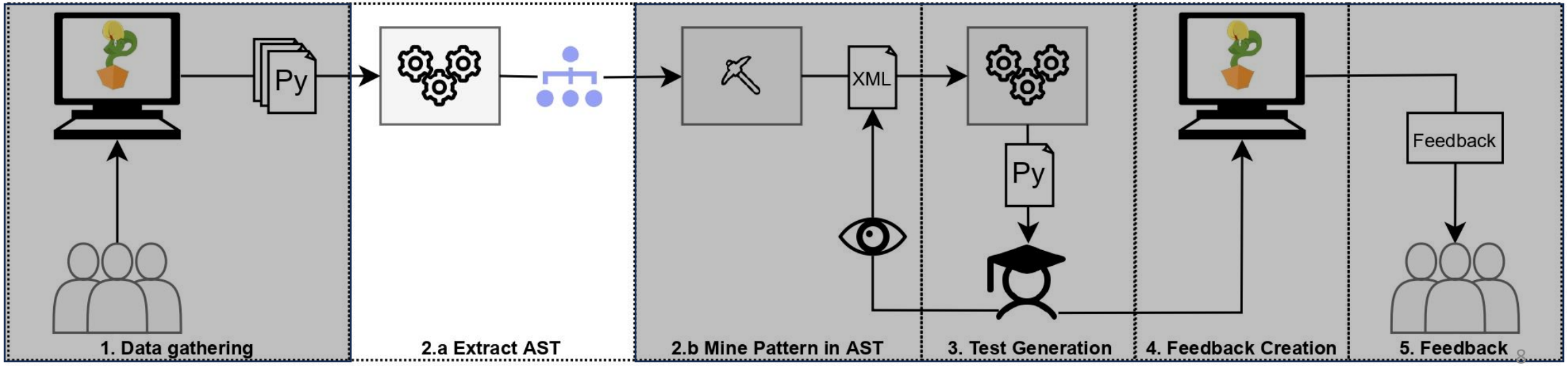
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XML
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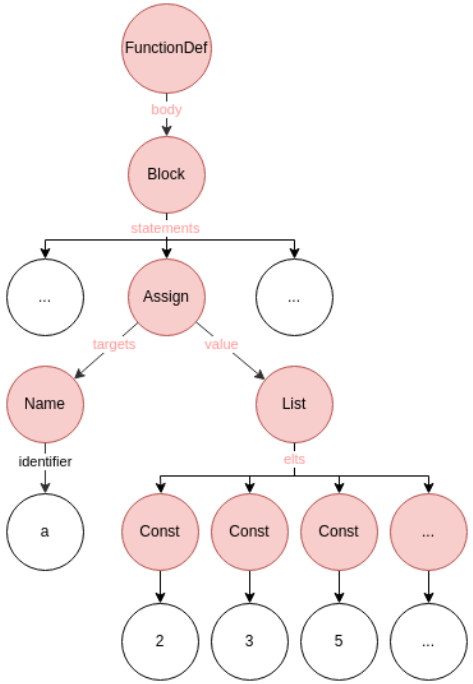
Feedback
1. Data gathering
2.a Extract AST
2.b Mine Pattern in AST
3. Test Generation
4. Feedback Creation
5. Feedback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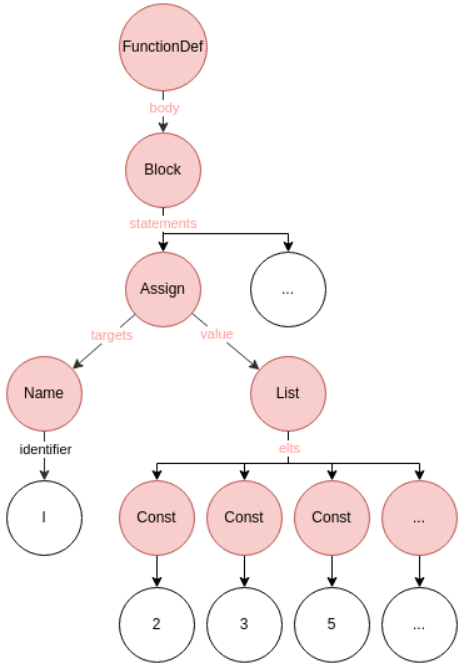
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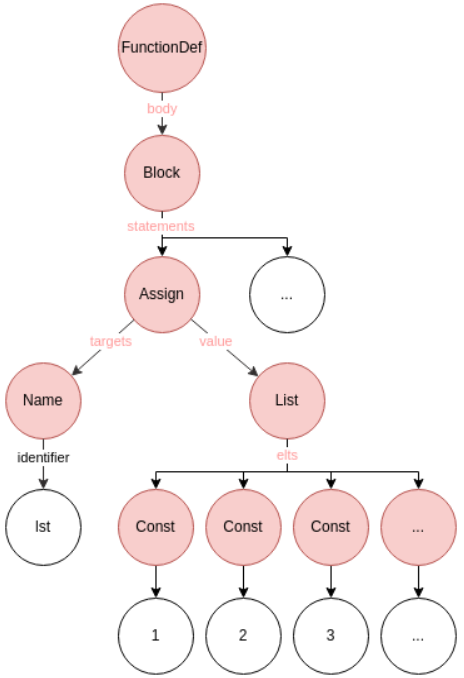
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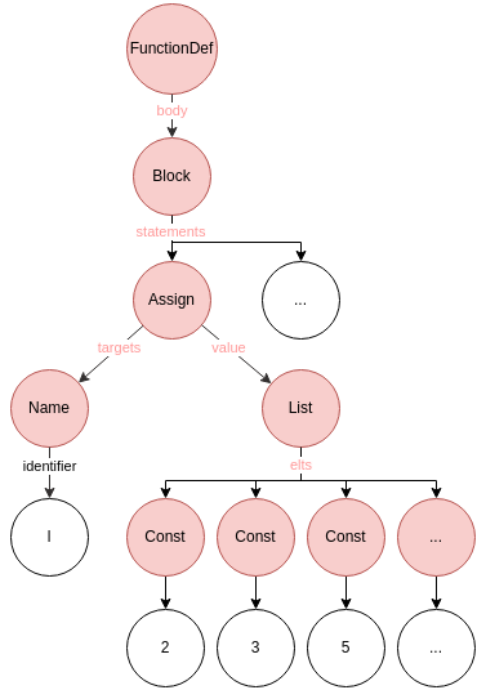
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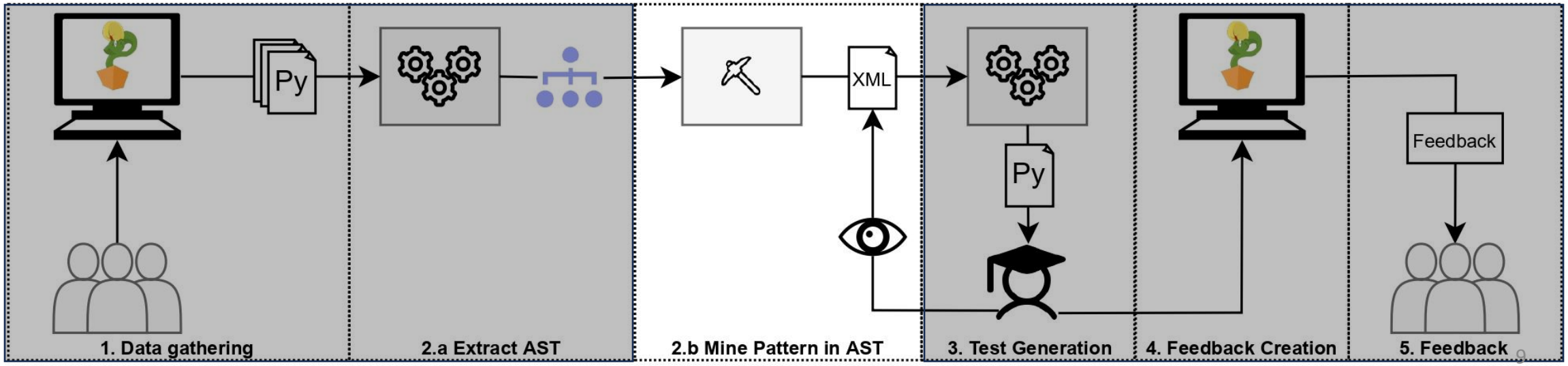
Py
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1. Data gathering
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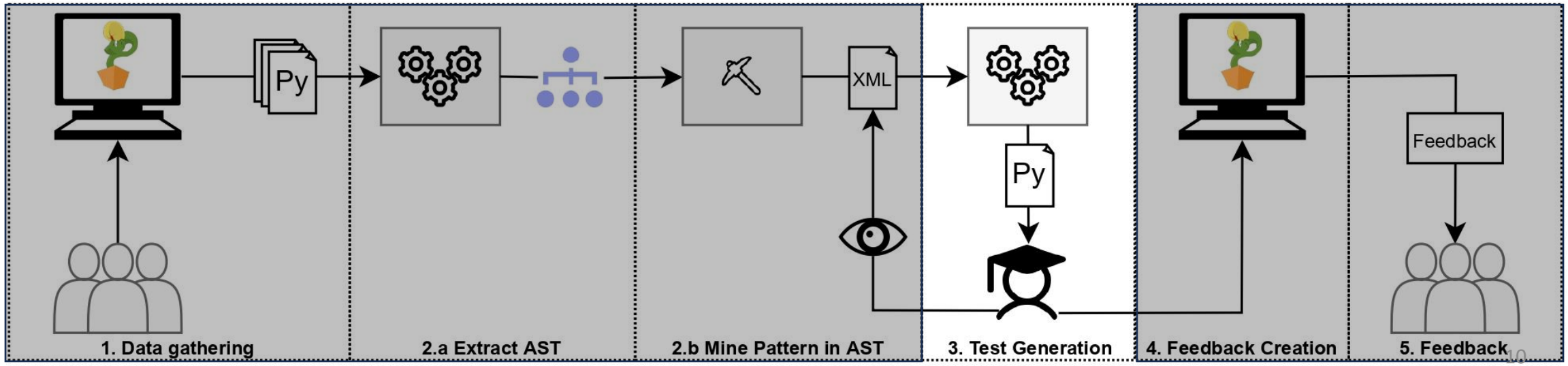
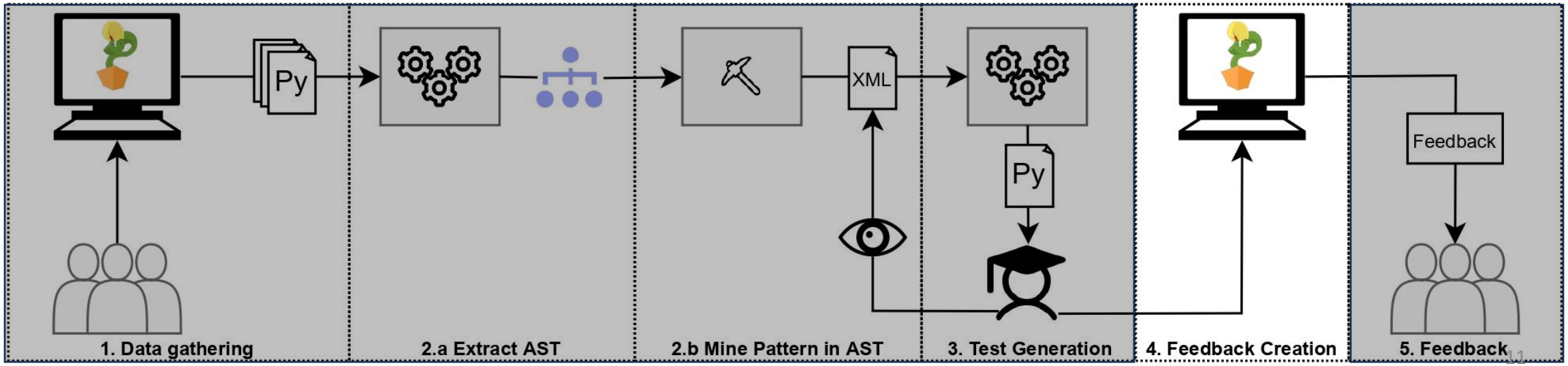
```python
def match_pattern_2(myast):
    ...
    for val in ast.iter_child_nodes(assign1) if isinstance(val, ast.Name)]
      if len(names1) < 1:
          continue
      lists1 = [val for val in ast.iter_child_nodes(assign1) if isinstance(val, ast.List)]
      if len(lists1) < 1:
          continue
      for list1 in lists1:
          constants1 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants1) < 1:
              continue
          constants2 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants2) < 2:
              continue
          constants3 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants3) < 3:
              continue
          constants4 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants4) < 4:
              continue
          constants5 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants5) < 5:
              continue
          constants6 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants6) < 6:
              continue
          return True
    return False
```



```
class TestQ(unittest.TestCase):
  def __init__(self,*args,**kwargs):
    super().__init__(*args, **kwargs)
    with open(str(q.__name__)+'.py','r') as f:
      self.ast = ast.parse(f.read())

  def test_hard_coded_list(self):
    if match_pattern_2(self.ast):
      self.fail("Feedback: Avoid using hard coded lists of precalculated numbers. Try to generalise your solution.")
```



There are some errors in your answer. Your score is 84.0%. [Submission #646e0c6638185572f5c04455]

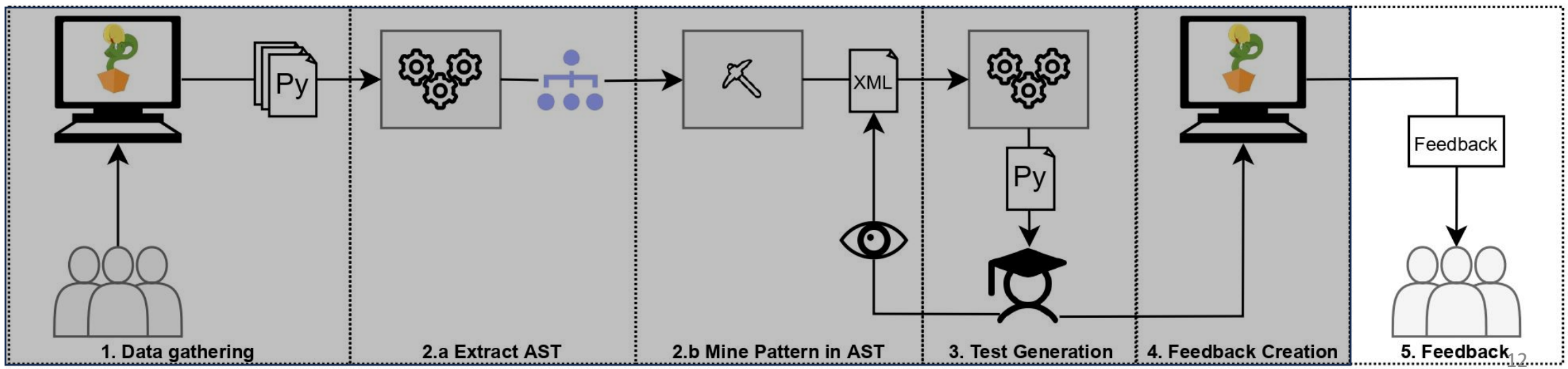
```
Suggestion:
Avoid using hard coded lists of precalculated numbers. Try to generalise your solution.

----------------------------------------------------------------------
Ran 9 tests in 0.007s

FAILED (failures=4)Failed test:
2 != 3 : Wrong value for factors(2022)

Failed test:
2 != 3 : Wrong value for factors(2022)

Failed test:
0 != 1 : Wrong value for factors(5)
```



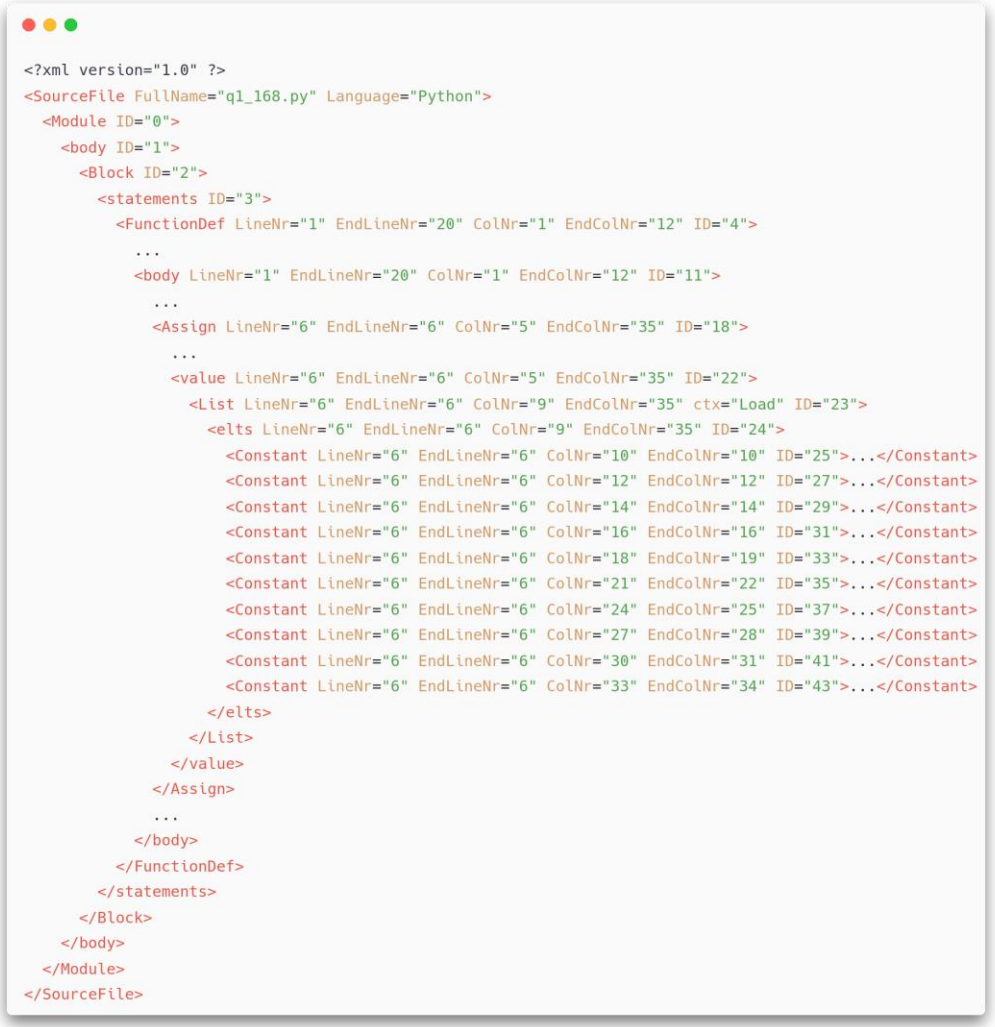
Step 1: Data gathering

- Student code submissions
- Exam question
- No feedback during the exam, ensuring unbiased patterns
- Similar exam conditions and individual responses of students
- Two groups: score ≥50% and <50%

```
def factors(n):
    l = [2,3,5,7,11,13,17,19] #list of primes
    i = 0
    t=[]
    for i in range(len(l)) :
        if n%l[i] == 0:
            t.append(l[i])
            i -= 1
    nbr = len(t)
    return (nbr)
```

Step 2a: Extract AST

- Work on AST
- Tree-like structure
- Generate XML files representing the AST
- Applicable to other languages



```
<?xml version="1.0" ?>
<SourceFile FullName="q1_168.py" Language="Python">
  <Module ID="0">
    <body ID="1">
      <Block ID="2">
        <statements ID="3">
          <FunctionDef LineNr="1" EndLineNr="20" ColNr="1" EndColNr="12" ID="4">
            ...
            <body LineNr="1" EndLineNr="20" ColNr="1" EndColNr="12" ID="11">
              ...
              <Assign LineNr="6" EndLineNr="6" ColNr="5" EndColNr="35" ID="18">
                ...
                <value LineNr="6" EndLineNr="6" ColNr="5" EndColNr="35" ID="22">
                  <List LineNr="6" EndLineNr="6" ColNr="9" EndColNr="35" ctx="Load" ID="23">
                    <elts LineNr="6" EndLineNr="6" ColNr="9" EndColNr="35" ID="24">
                      <Constant LineNr="6" EndLineNr="6" ColNr="10" EndColNr="10" ID="25">...</Constant>
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                      <Constant LineNr="6" EndLineNr="6" ColNr="33" EndColNr="34" ID="43">...</Constant>
                    </elts>
                  </List>
                </value>
              </Assign>
              ...
            </body>
          </FunctionDef>
        </statements>
      </Block>
    </body>
  </Module>
</SourceFile>
```
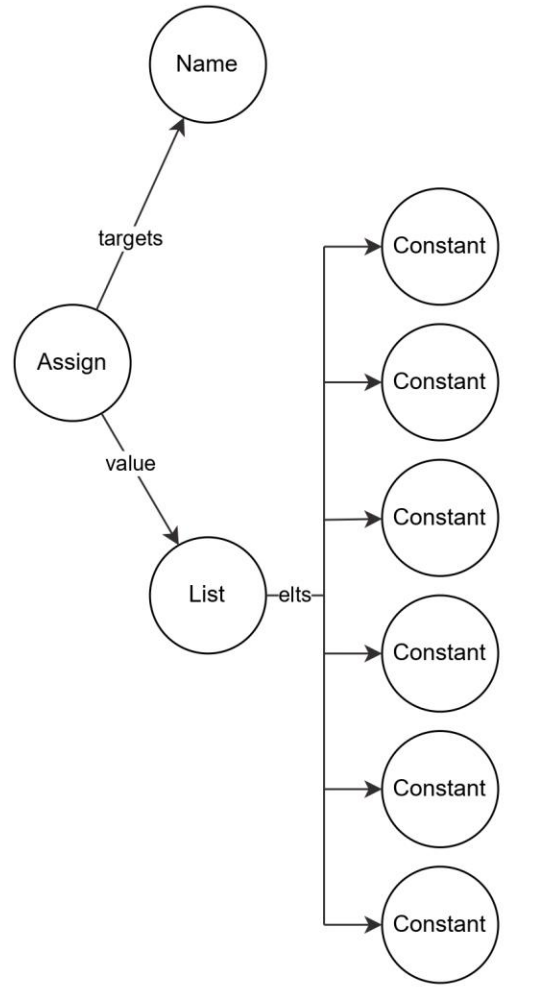

Step 2b: Mine pattern in AST

- FREQTALS is a tree mining algorithm for identifying frequent patterns in program ASTs.
- Configured with constraints like pattern size
- Searches for patterns based on structural characteristics and label frequencies.
- Discovers control flow, data structure, and algorithm patterns.
- Output patterns as tree-like structure

```
<Assign>
  <__directives>
    <match-sequence/>
  </__directives>
  <targets>
    <Name>
      <identifier>
        <Dummy>
          ...
        </Dummy>
      </identifier>
    </Name>
  </targets>
  <value>
    <List>
      <elts>
        <__directives>
          <match-sequence/>
        </__directives>
        <Constant>
          <identifier>
            <Dummy>
              ...
            </Dummy>
          </identifier>
        </Constant>
        ...
      </elts>
    </List>
  </value>
</Assign>
```



Step 3: Test generation

- Generate python function from the tree representation of the pattern
- Take an AST of student's code as input
- Return True if the AST matches the pattern
- Match a specific pattern
- Ensures equivalence with patterns

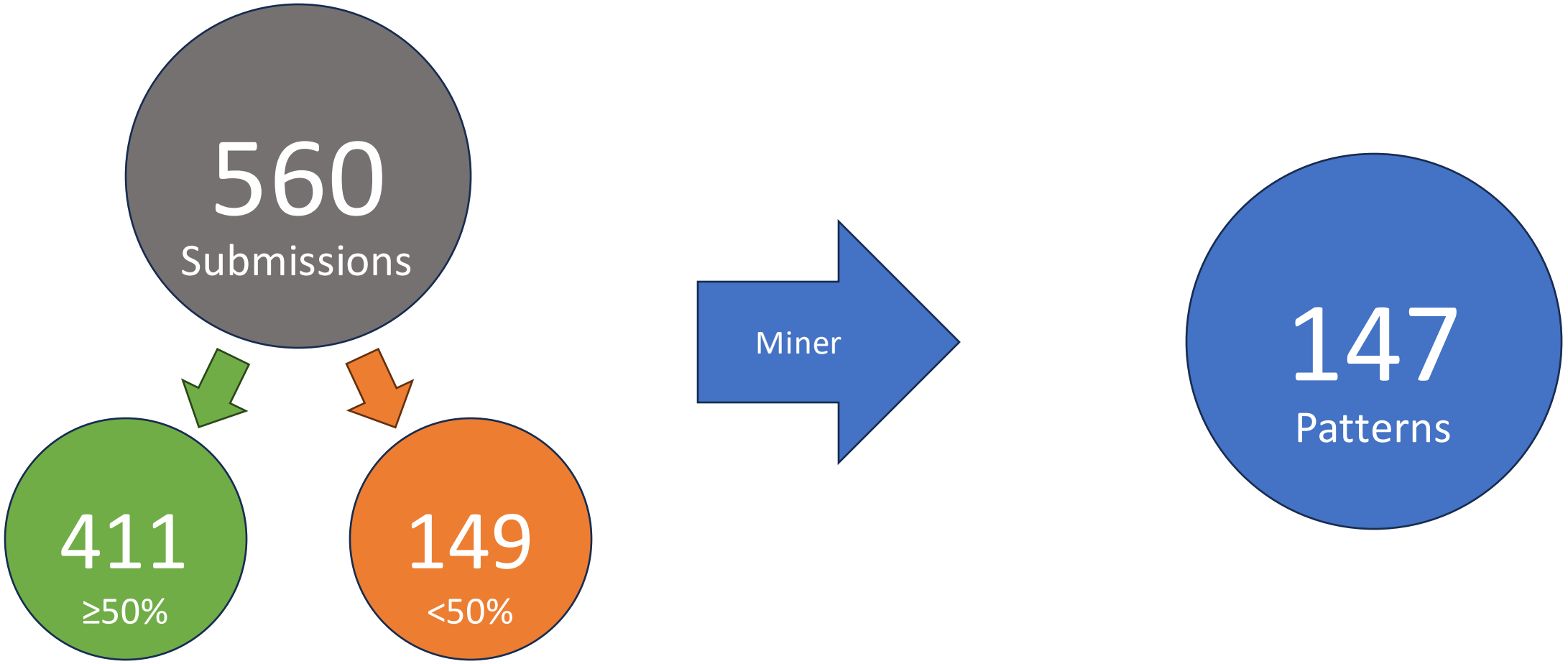
```
def match_pattern_2(myast):
    ...
    for val in ast.iter_child_nodes(assign1) if isinstance(val, ast.Name)]
      if len(names1) < 1:
          continue
      lists1 = [val for val in ast.iter_child_nodes(assign1) if isinstance(val, ast.List)]
      if len(lists1) < 1:
          continue
      for list1 in lists1:
          constants1 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants1) < 1:
              continue
          constants2 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants2) < 2:
              continue
          constants3 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants3) < 3:
              continue
          constants4 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants4) < 4:
              continue
          constants5 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants5) < 5:
              continue
          constants6 = [val for val in ast.iter_child_nodes(list1) if isinstance(val, ast.Constant)]
          if len(constants6) < 6:
              continue
          return True
    return False
```

Step 4: Feedback creation

- Improve feedbacks in auto graders
- Create simple unit test calling the generated function
- Include in our auto grader
- Easy to add test for other patterns

```
class TestQ(unittest.TestCase):
  def __init__(self,*args,**kwargs):
    super().__init__(*args, **kwargs)
    with open(str(q.__name__)+'.py','r') as f:
      self.ast = ast.parse(f.read())

  def test_hard_coded_list(self):
    if match_pattern_2(self.ast):
      self.fail("Feedback: Avoid using hard coded lists of precalculated numbers. Try to generalise your solution.")
```

Results



Good solution

- Compute prime factors
- Example of a good solution
- 3 main parts
  - Var initiation
  - **Loop** until n
  - **While** we can divide:
    - we divide our value
    - We **add 1** to our counter

```python
def facteurs(n):
    """
    Pre:  n est un entier strictement positif
    Post: retourne un entier représentant le nombre de facteurs premiers de n
    """
    nfact = 0
    val = n
    for i in range(2, n+1):
        while val % i == 0:
            val /= i
            nfact += 1
    return nfact
```

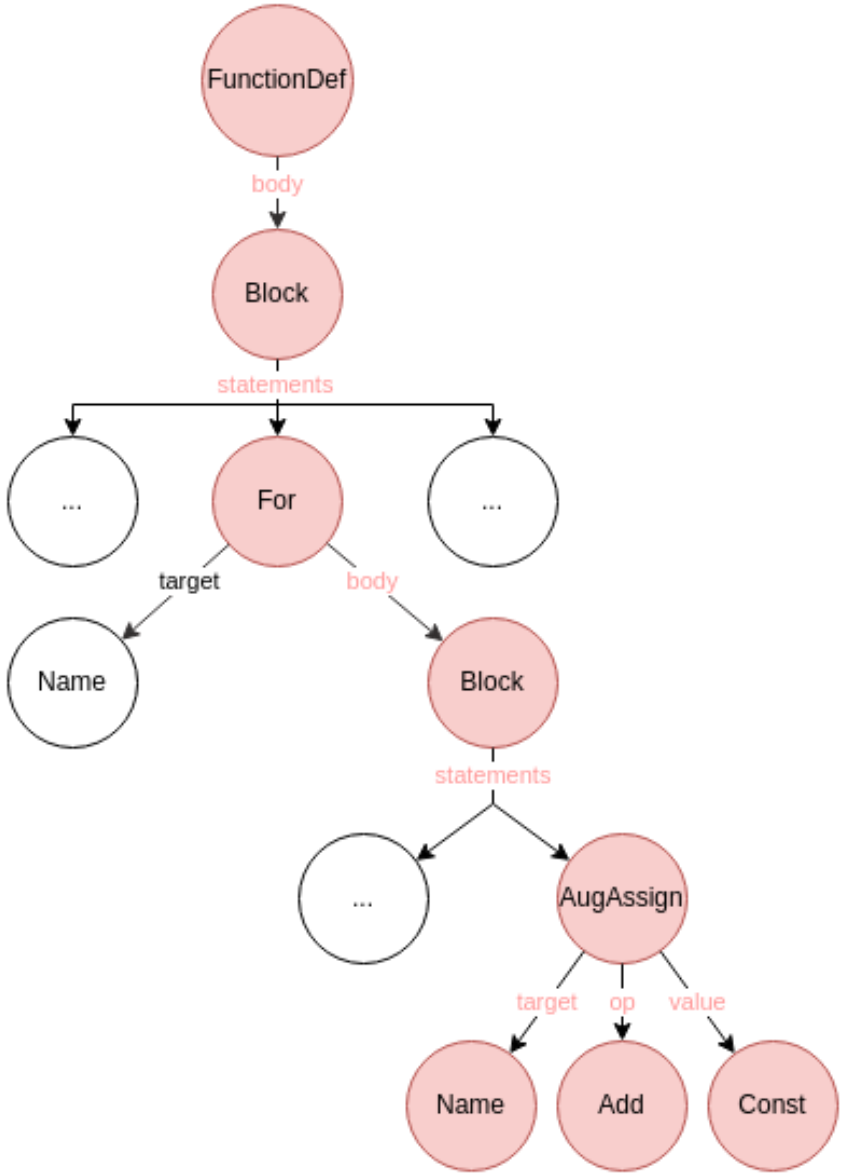
Examples of a mistake

```
def factors(n):
    for i in range(2,n):
        if n%i!=0:
            i+=1
            return 1
        elif n==1:
            return 0
    count = 0
    for f in range(2,n):
        while n%f==0:
            count+=1
            n=n/f
            return n
        f+=1
    return count
```

```
def factors(n):
    fac = 0
    if n == 1:
        fac = 0
    for i in range(2,n+1):
        sum = n/i
        sum2 = sum/i
        fac +=1
    return fac
```

```
def factors(n):
    count = 0
    if n == 1:
        return 0
    for i in range (2,n+1):
        if n % i == 0:
            n = n//i
        count += 1
    return count
```

Pattern found



Python test

```python
def match_pattern_79(myast):
    ...
    fors1 = [val for val in ast.iter_child_nodes(block1) if isinstance(val, ast.For)]
    if len(fors1) < 1:
        continue
    for for1 in fors1:
        ...
        augassigns1 = [val for val in ast.iter_child_nodes(for1) if isinstance(val, ast.AugAssign)]
        if len(augassigns1) < 1:
            continue
        for augassign1 in augassigns1:
            names3 = [val for val in ast.iter_child_nodes(augassign1) if isinstance(val, ast.Name)]
            if len(names3) < 1:
                continue
            adds1 = [val for val in ast.iter_child_nodes(augassign1) if isinstance(val, ast.Add)]
            if len(adds1) < 1:
                continue
            constants2 = [val for val in ast.iter_child_nodes(augassign1) if isinstance(val, ast.Constant)]
            if len(constants2) < 1:
                continue
            return True
    return False
```

Unit Test with feedback

```
class TestQ(unittest.TestCase):

  def __init__(self,*args,**kwargs):
    super().__init__(*args, **kwargs)
    with open(str(q.__name__)+'.py','r') as f:
      self.ast = ast.parse(f.read())

  def test_incr_in_for(self):
    if match_pattern_79(self.ast):
      self.fail("Feedback: Incrementing the factor counter inside your For loop might give you too high
numbers. Maybe you should update your counter only in certain cases?")
```

Conclusion

- Bad practices and common mistakes can be found in students' code
- Manual identification of interesting patterns is hard and time consuming
- Possibilities for advanced feedback creation
- Test are too technical to modify

Future work

- Further validation with more data, students, and teachers.
- The goal is to study how teachers use the tool and improve it based on their needs.
- Validation is also aimed at determining if students benefit from the improved feedback provided by the generated test suites.
- Automation of bad pattern detection
- Make it easier to modify unit tests

What's next?

- Language to describe pattern
- Build over Python
- Easy to learn and use
- Inspired by regex
- Backtracking approach
- ANTLR for Python with added grammar

```
def ?(foo):
  ?*
  ? = [?, ?, ?, ?, ?, ?, ?*]
  ?*
  return ?
```

Pattern language

Wildcard	Description
?	Match exactly 1 element
?*	Match 0 or more elements
?{name}	Match 1 element and bind it to {name}
?:	Match 1 element with a body
?*:	Match 0 or more element with bodies

Some examples

```
def ?(bar):
    ?:
        for ? in ?:
            ?*
    return ?
```

```
def ?(?*):
    ?*
    ?var1 = ?
    ?*
    return ?var1
```

```
def foo(bar):
    ?*
    ?*:
      ?*
      ?var1+=1
      ?*
    ?*
    return ?var1
```

```
def ?(foo):
  ?*
  ? = [?, ?, ?, ?, ?, ?, ?*]
  ?*
  return ?
```

Questions?

Bonus

FREQTALS

- Tree mining algorithm for frequent pattern identification.
- Uses XML tree format.
- Generates and prunes patterns iteratively.
- Configurable with minimum pattern size, etc.
- Allows to find specific syntactic constructs.

PHAM, Hoang Son, NIJSSEN, Siegfried, MENS, Kim, *et al.* Mining patterns in source code using tree mining algorithms.