Static Program Analyzer (SPA)
Project Iteration 2 Report

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Table of Contents

Project Background

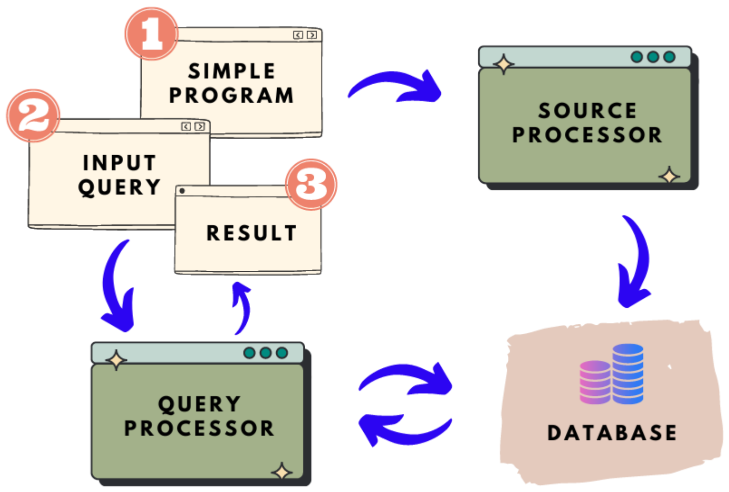
There is a high demand for IT experts in the modern digital era, particularly software developers. These professionals are in charge of developing, testing, and maintaining the software applications utilized by businesses and organizations all around the world.

One of the key tasks that software developers often have to deal with is understanding legacy code. This refers to code that has been written in the past and is still in use, but may not be well-documented or easy to understand.

To address this problem, there is a need for a tool that can help to break down large chunks of code into smaller, more manageable pieces of information. The goal of this tool is to improve the software maintenance process and make it more efficient, saving companies time and resources.

Static Program Analyzer (SPA)

For the SPA to respond to program queries, a source program must first be analyzed, with relevant program design entities extracted and stored in a database. The user is then given the ability to utilize Program Query Language (PQL) to inquire about the program using the SPA . These PQL queries are processed by the SPA and the results are displayed to the user based on the data held in the database.



Prototype Implementation

Iteration 1 implementation

All of these prototype features have been implemented in iteration 1 of the project. Additionally, we have fulfilled all of the prototype iteration 1's requirements.

1. Simplified Programming Language (SIMPLE)

a. Single Procedure
b. Statement
c. Read / Assign / Print / Call
d. Variable

2. Database (SQL)

a. Procedure
b. Variable
c. Statement
d. Constant

3. Program Query Language (PQL)

a. Declaration (single)
b. Select Cause (single)

Iteration 2 implementation

These are new prototype features that have been implemented on top of iteration 1 implementation

1. Simplified Programming Language (SIMPLE)

a. While statement

b. If statement
c. Expression
d. Parent/Next/Use/Modify/Call/Pattern

2. Database (SQL)

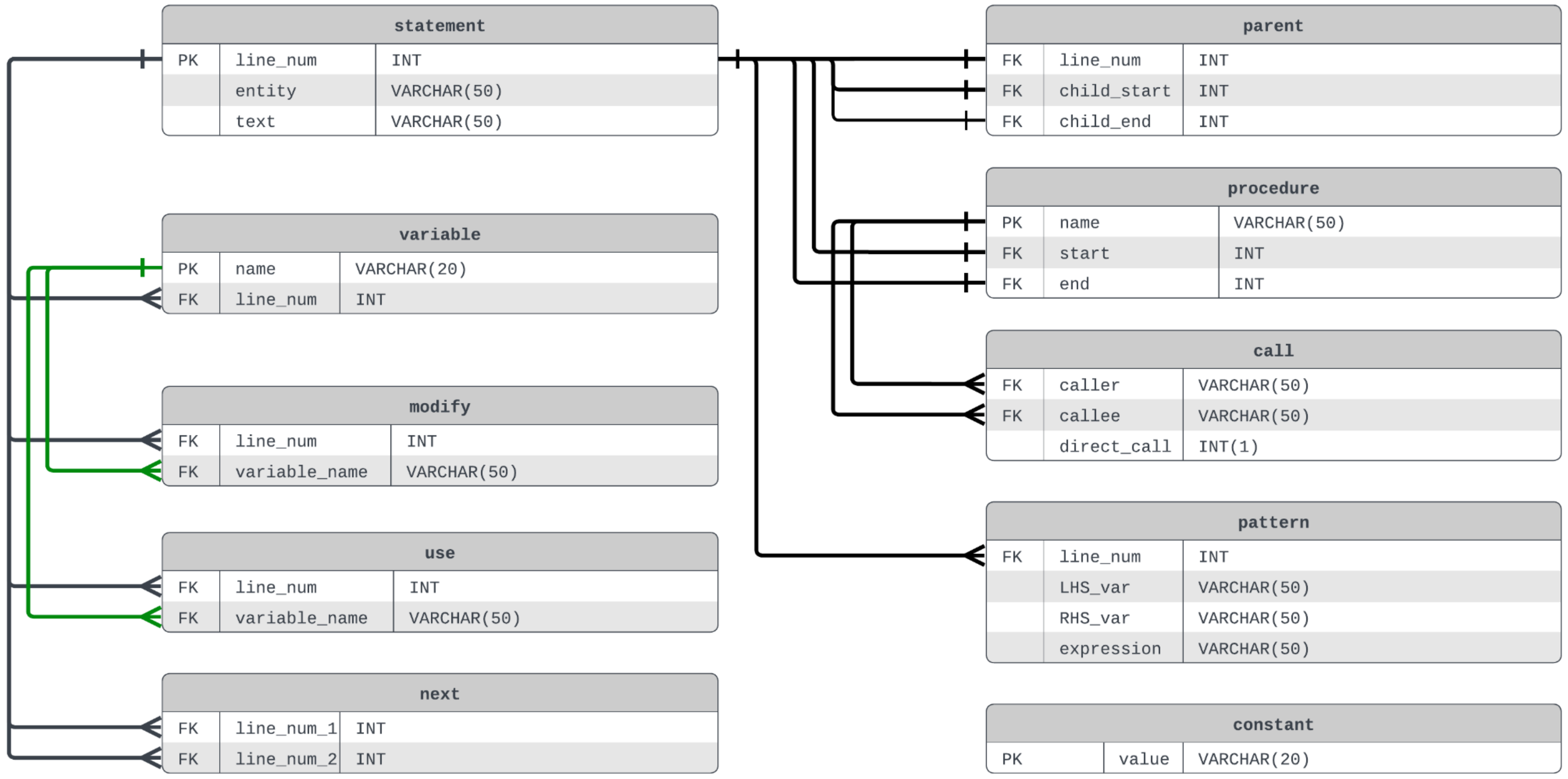
a. Modify
b. Use
c. Next
d. Parent
e. Call
f. Pattern

3. Program Query Language (PQL)

a. Declaration (Multiple Synonyms)
b. Such that (Single Cause)
    i. Parent
    ii. Modifies
    iii. Uses
c. Pattern (Single Cause)
    i. ("variable",_)
    ii. ("variable","_expression_")
    iii. (_,"_expression_")
    iv. (_,_)

Prototype Database Design

Database Diagram



statement		
PK	line_num	INT
	entity	VARCHAR(50)
	text	VARCHAR(50)

variable		
PK	name	VARCHAR(20)
FK	line_num	INT

modify		
FK	line_num	INT
FK	variable_name	VARCHAR(50)

use		
FK	line_num	INT
FK	variable_name	VARCHAR(50)

next		
FK	line_num_1	INT
FK	line_num_2	INT

parent		
FK	line_num	INT
FK	child_start	INT
FK	child_end	INT

procedure		
PK	name	VARCHAR(50)
FK	start	INT
FK	end	INT

call		
FK	caller	VARCHAR(50)
FK	callee	VARCHAR(50)
	direct_call	INT(1)

pattern		
FK	line_num	INT
	LHS_var	VARCHAR(50)
	RHS_var	VARCHAR(50)
	expression	VARCHAR(50)

constant		
PK	value	VARCHAR(20)

Table Description (Iteration 1)

Table	Column	Description
procedure	name	Stores the procedure name
statement	line_num	Stores the statement number
	procedure_name	Stores the procedure name that contains this statement
	entity	Stores the different types of statements such as print, read, assign, call, etc.
	text	Contains the content for the the statement to be used for pattern query
variable	name	Contains the variable name
	line_num	Contains the statement number that contains this variable
constant	value	Contains the constant value

Table Description (Iteration 2)

Table	Column	Description
parent	line_num	Stores the statement number of the container
	child_start	Stores the statement number of the first

		line in the container
	child_end	Stores the statement number of the last line in the container
modify	line_num	Stores the statement number where modifies(s,v) is tue
	variable_name	Stores the variable name where modifies(s,v) is true
use	line_num	Stores the statement number where uses(s,v) is true
	variable_name	Contains the variable name where uses(s,v) is true
call	line_num	Stores the statement number
	procedure_name	Stores the procedure name
	variable_name	Call variable in this procedure
	direct_call	Direct call within the procedure or indirect call via other procedure
pattern	line_num	Stores the statement number
	LHS_var	Store left hand side variable of assign
	RHS_var	Store right hand side variable of assign
	expression	Store postfix of RHS variable
next	line_num_1	Current line number of Control Flow Graph
	line_num_2	Next line number of Control Flow Graph

Table Relationship (Iteration 1)

Design Entity	Relationship	Design Entity
procedure	One to One	statement
variable	One to Many	statement
constant	-	-

Table Relationship (Iteration 2)

Design Abstraction	Relationship	Design Entity
modify	Many to One	statement
modify	Many to One	variable
use	Many to One	statement
use	Many to One	variable
parent	Many to One	statement
next	Many to One	statement
call	Many to One	procedure
pattern	Many to One	statement

Database Design Rational (Iteration 1)

The database is designed around the PQL. We analyzed the PQL, and determined that we're able to answer the Iteration 1 PQL queries using the database design shown above.

We created the Statement table for stmt, read, print, assign, while, if, call query. We store them in the same table as all of them return a Statement number. We identify the different entities via the entity field, and fulfill the pattern query via the text field.

Example of PQL to SQL

PQL	**SQL**
`print p; select p`	`SELECT line_num FROM statement WHERE entity = ‘print’`
`stmt s; select s`	`SELECT line_num FROM statement;`

We created the Variable, Procedure, and Constant table for variable, procedure, and constant query.

For the Constant table, we determined that there’s no Relationship query that uses constant. Hence, we don’t need to link it with the other tables.

For the Variable, and Procedure table, we determined that there are Relationship query that uses Variable, and Procedure. Hence, we separated them to simplify the SQL query, and linked them together via the Statement table using Foreign Keys.

Database Design Rational (Iteration 2)

For the design abstractions of “Uses” and “Modifies”, we decided to store all statements and variables that satisfy the indirect and direct relationships to the SQL table. By doing so, we aim to simplify the PQL to SQL conversion by eliminating the use of recursive query

For the design abstraction of “Parent”, we store the container statement number, and the child start and end statement number. This design allows us to fulfill the Parent and

Parent* PQL as we are able to determine whether a given Parent statement number is the direct or indirect Parent via SQL

For the pattern clause, we store the statement number, variables and expression of the "assign" to the SQL table. The expression stores the post-fix expression. This allows us to easily find the pattern of the expression.

Example of PQL to SQL

PQL	**SQL**
`assign t; while w;` `Select t such that Parent(w, t)`	`select 1 from statement s where s.line_num = x and ((select p.line_num from parent p join statement s2 on p.line_num = s2.line_num where s2.entity = 'while' and s.line_num between p.child_start and p.child_end order by p.line_num desc limit 1) = (select p.line_num from parent p where s.line_num between p.child_start and p.child_end order by p.line_num desc limit 1))`
`assign a; variable v;` `Select a such that Uses(a,v)`	`select 1 from use u where u.line_num in (select s.line_num from statement s where entity = 'assign');`

SPA Implementation

Source Processor (Iteration 1 and 2)

We utilized the given tokenizer to tokenize the SIMPLE code. Then, we iterated the tokens array, and used the SIMPLE grammar rules to process the code in the following order, and logic.

1. We created the following variables to store the information that we need.
    a. `vector<Procedure*> procedure;`
        i. It stores all the Procedures that were parsed.
        ii. The SourceProcessor will insert the statements that satisfy the Uses(s,v), Modifies(s,v), and Calls(p,q) to the `_uses`, `_modifies`, `_calls` vector respectively.
        iii. When the parse completes, we'll iterate through each Procedure, performs some processing on the `_uses`, `_modifies`, `_calls` to insert the statements and variables that satisfy the indirect and direct Uses(s,v), Modifies(s,v) and Calls(p,q) relationship into their respective table.
        iv. When the parse completes, we iterate through each Procedure, and insert the Procedure names into the "procedure" table.
    b. `stack<Container*> parentStack;`
        i. It stores all the Containers (if/else/while/procedure) that were parsed. We treat the "else" keyword as Containers also.
        ii. The purpose is to help us to create a tree representation of the code for constructing the Control Flow Graph, and the Parent(s,v) relationship
        iii. The SourceProcessor will create a new Container object when it encounters `if`, `else`, `while`, and `procedure` keywords, and push it onto the stack.
        iv. The SourceProcessor will pop the Container object from the stack when it encounters a closing curly brackets "}".

        v. The SourceProcessor will create a Statement object, and insert it into `_statements` vector when it encounters a statement.
        vi. The SourceProcessor will create a Container object, and insert it into `_childContainers` vector when it encounters a Container.
    c. `vector<Statement*> callStatements;`
        i. It stores all the `call` Statement that were parsed
        ii. The purpose is to assist us in populating the indirect and direct Uses(s,v) and Modify(s,v).
    d. `int stmtNumSubtract = 0;`
        i. It stores the extra incremented statement number due to the `else` keyword.
        ii. Our method to construct the Control Flow Graph requires us to treat `else` as a separate Container instead of a statement under an `if` Container. Hence, we treat it as a statement, and assign a statement number to it. Thus, we need to account for the extra incremented statement number so that we can get the correct statement number as defined in the project
    e. `int stmtNum = 0;`
        i. It stores the current statement number
    f. `int nestedLevel = 0;`
        i. It stores the current nested level for each statement.
        ii. The purpose is to assist us in constructing the Control Flow Graph
2. We iterate through the tokens, and parse it as follows
3. If the word is “procedure”
    a. Get the procedure name at index + 1, and insert it into the procedure table.
    a. Create a Procedure object, populate it with the correct data, and push it onto the `procedure` vector, and `parentStack`
    b. Increment the `nestedLevel`
4. If the word is “while”

    a. Increment the `stmtNum` and `nestedLevel`
    b. Create a Container object, fill it with the correct data, and push it onto the `parentStack`.
    c. Create a new Statement object, fill it with the correct data, and insert it into the created Container object `_statements` vector attribute.
    d. Perform a while loop to process the condition portion. The terminating condition is when we encounter “}”.
    e. Within the while loop, we use regex match to insert the correct tokens into the Constant or Variable table.
    f. At the end, we insert this While statement into the Statement table as a “while” statement type.

5. If the word is “if”
    a. Increment the `stmtNum` and `nestedLevel`
    b. Create a Container object, populate it with the correct data, and push it onto the `parentStack`.
    c. Create a new Statement object, fill it with the correct data, and insert it into the created Container object `_statements vector` attribute.
    d. Perform a while loop to process the condition portion. The terminating condition is when we encounter the keyword “then”.
    e. Within the while loop, we use regex match to insert the correct tokens into the Constant or Variable table
    f. At the end, we insert this “if” statement to the Statement table as an “if” statement type.
6. If the word is “else”
    a. Increment the `stmtNum`, `nestedLevel`, and `stmtNumSubtract`
    b. Create a Container object, populate it with the correct data, and push it onto the `parentStack`.
    c. Create a new Statement object, fill it with the correct data, and insert it into the created Container object `_statements vector` attribute.
7. If the word is “=”

    a. Create a Statement object, fill it with the correct data, and insert it into the Container object `_statements` vector attribute via `parentStack.top()`
    b. Insert the Left Hand Side variable into the Variable, and Modifies table
    c. Perform a while loop to process the Right Hand Side assign statement. The terminating condition is “;”.
    d. Within the while loop, we use regex match to insert the correct tokens into the Constant or Variable table
    e. The right hand side values are converted to postfix expression and inserted into the pattern table.
    f. At the end, we insert this statement into the Statement table as an “assign” type.

8. If the word is “read”, “print” or “call”
    a. Create a Statement object, fill it with the correct data, and insert it into the Container object `_statements` vector attribute via `parentStack.top()`
    b. We insert the statement into the Statement table as the respective type.
    c. If the word is “read” or “print”.
        i. We insert the variable into the Variable table
        ii. We insert the Statement object into Uses or Modifies table depending on whether the word is “print” or “read”
    d. If the word is “call”
        i. We insert the Statement object into the `callStatements` vector
9. When all the tokens has been parsed, we iterate through the `procedure` vector to do the following
    a. Do additional processing to insert all direct and indirect Uses(s,v) and Modifies(s,v) statements and variables into the Uses and Modifies table1
    b. Construct Control Flow Graph, and insert each Control Flow Graph nodes into the Next table
    c. Get all the Containers, and insert them into the Parent table

The regex pattern for Variable is as follows.

```
^((?!(procedure|while|if|then|else|call|read|print)+$)[A-Za-z][
A-Za-z0-9]*)
```

It does the following

1. If the word matches “procedure”, “while”, “if”, “then”, “else”, “call”, “read”, “print”, skip
2. If (1) isn’t skipped, match only if the word starts with an alphabet, followed by 0 or more alphanumeric. It follows the SIMPLE grammar for Variables

The regex pattern for Constants is as follows. It matches a series of digits

```
^[0-9]+$
```

Using the above logic, we’re able to parse the SIMPLE grammar, extract, and insert the correct data into the various tables

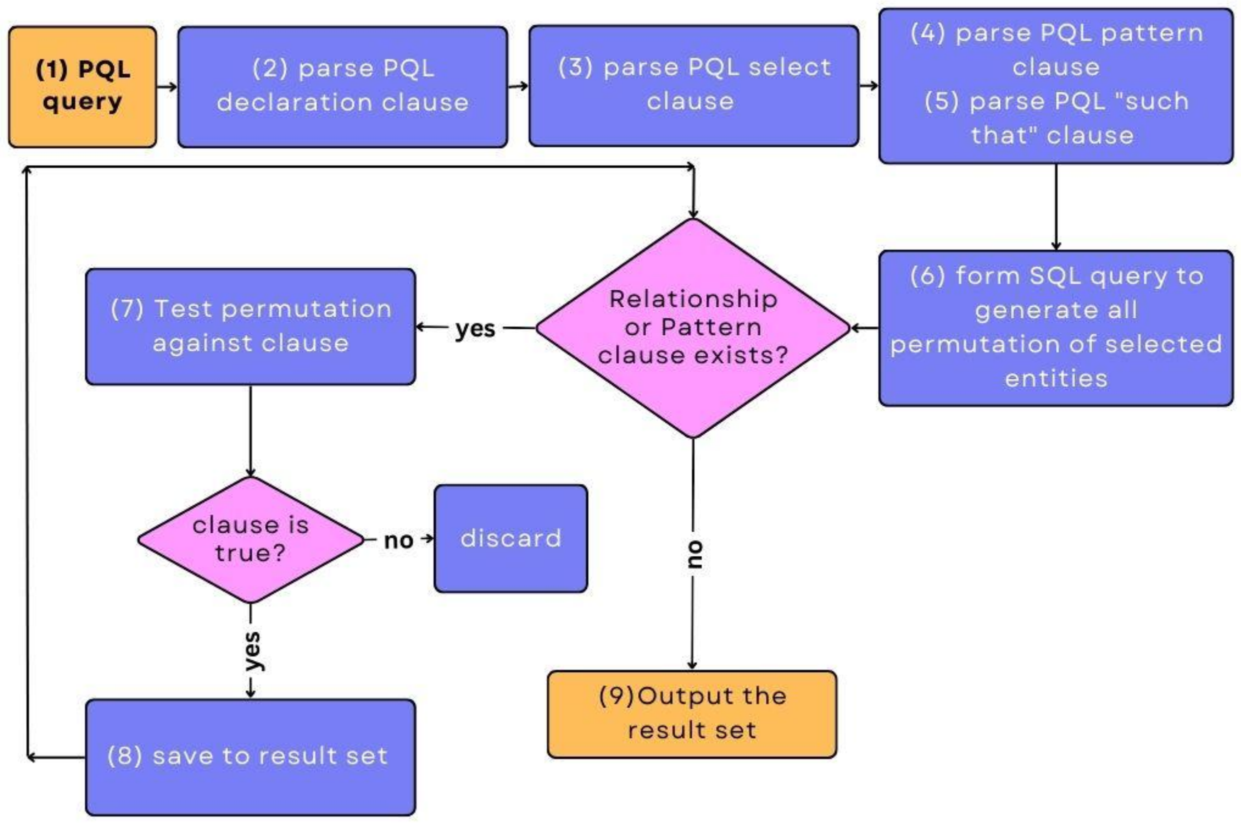
Query Processor

Design

We designed the query processor such that it’s able to

- Return the correct output for different entity synonyms
- Handle any number of “such that” and “pattern” clause

The diagram shows an illustration of the query processor flowchart below.


(1) PQL query
(2) parse PQL declaration clause
(3) parse PQL select clause
(4) parse PQL pattern clause
(5) parse PQL "such that" clause
(6) form SQL query to generate all permutation of selected entities
Relationship or Pattern clause exists?
yes
no
(7) Test permutation against clause
clause is true?
no
discard
yes
(8) save to result set
(9)Output the result set

We illustrate the flowchart using the following PQL query

```
while w; variable v;
Select <w,v> such that Parent(w,v)
```

1. In step (2), we process the declared entity and its synonym. This step is necessary for step (3) as the entity type determines the returned output. For example, “while”, “if”, “call”, etc return statement numbers, and “variable”, “procedure” return names.
2. In step (3), we process the selected synonym, and construct the SQL statement to obtain the selected synonyms’ permutations.
    a. In this example, the SQL statement would be

    ```
    select  s.line_num,  v.name  from  statement  s  where
    s.entity = “while” join variable v
    ```

3. In step (4) and (5), we process the “such that” and “pattern” clauses to store the relationship inputs, and add them to a stack.
4. In step (6), we execute the SQL statement constructed in step (2) to get the full data set.
5. In step (7), we test each permutation in the data set against all the “such that” and “pattern” clauses. We created database functions to cater for all relationships and entities. The database functions would form and execute the SQL query based on the input. Then, the function returns true if there's a result, and false if there’s none. Using the returned boolean, we would determine whether the “such that” and “pattern” clause is true for the given permutation
    a. In this example, we’ll call the Parent function, and pass the “while” statement number, and variable names as input.
6. If there’s no more clauses to test, we return the output.

Testing

Approach (Iteration 1)

Our approach is as follows

1. We tested the base case by having a single procedure, un-nested condition statements, and all the various entities such as call, read, print, etc.
2. We increased complexity by
    - Adding multiple nested conditions.
    - Adding equations to the If and While condition, and Assignment statement.
3. We test the pattern matching rule by
    - Adding variation of Variable names from the SIMPLE keywords.
4. We produce the final test cases by combining (2), and (3)

The Source Processor is correct if it passes all the above. Examples as follows

Examples

Nested Conditions

```
 if(...) then{
    while(...){
        if(...) then{
            while(...){
            }
        }
        else{
            while(...){
            }
        }
    }
}
else{
    while(...){    }
    if(...) then{
    }
    else{
        while(...){
        }
    }
}
```

Complex Conditions and Equations

```
If == ((WHilE4) + ((CaLLg)) * ((1224 - AssiGn)/(pRINT * 2212))
```

```
pRINT = ((rEAD) * 2) - ((PRinT + 1) * (WHile / PRinT) / PRINT /
(ReAd)
```

Variation of Variable names from SIMPLE keywords

```
Read, Print, Assign, While, If, Call, rEAD, pRINT, aSSIGN, wHILE,
If, cALL, ReaD, PriNt, AssiGn, WhilE, iF, CalL, READ, PRINT,
ASSIGN, WHILE, IF, CALL, ififif, callcallcall
```

Approach (Iteration 2)

We identified that the input to the “such that” and “pattern” clauses can be classified into generic or specific input.

The input is generic if

- It’s a declared synonym and the synonym is not present in the select clause.

The input is specific if

- It’s a declared synonym and the synonym is present in the select clause.
- It’s not a declared synonym

Hence, there are four cases to test

1. (Generic , Generic)
2. (Generic , Specific)
3. (Specific, Generic)
4. (Specific, Specific)

Examples

PQL query for (Generic, Generic) inputs

```
variable v; procedure p; statement s;
Select s such that Uses(p, v)
```

PQL query for (Generic, Specific) inputs

```
variable v; procedure p
Select v such that Uses(p, v)

procedure p;
Select p such that Uses(p, “myVar”)
```

PQL query for (Specific, Generic) inputs

```
variable v; procedure p
Select p such that Uses(p, v)

variable v;
Select p such that Uses(p, “myVar”)
```

PQL query for (Specific, Specific) inputs

```
variable s;
Select s such that Uses(“main”, “myVar”)
```