Using Clone Detection to Identify Bugs in Concurrent Software

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Concurrent Software

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Concurrent Software

- Concurrent software has multiple threads that can be interleaved in many different ways
- The different interleavings make concurrent software difficult to test and debug
  - **Data Races –** two or more threads access unprotected shared data, resulting in inconsistent access to the shared data
  - **Deadlock** – the order of lock acquisition prevents other threads from acquiring the needed lock

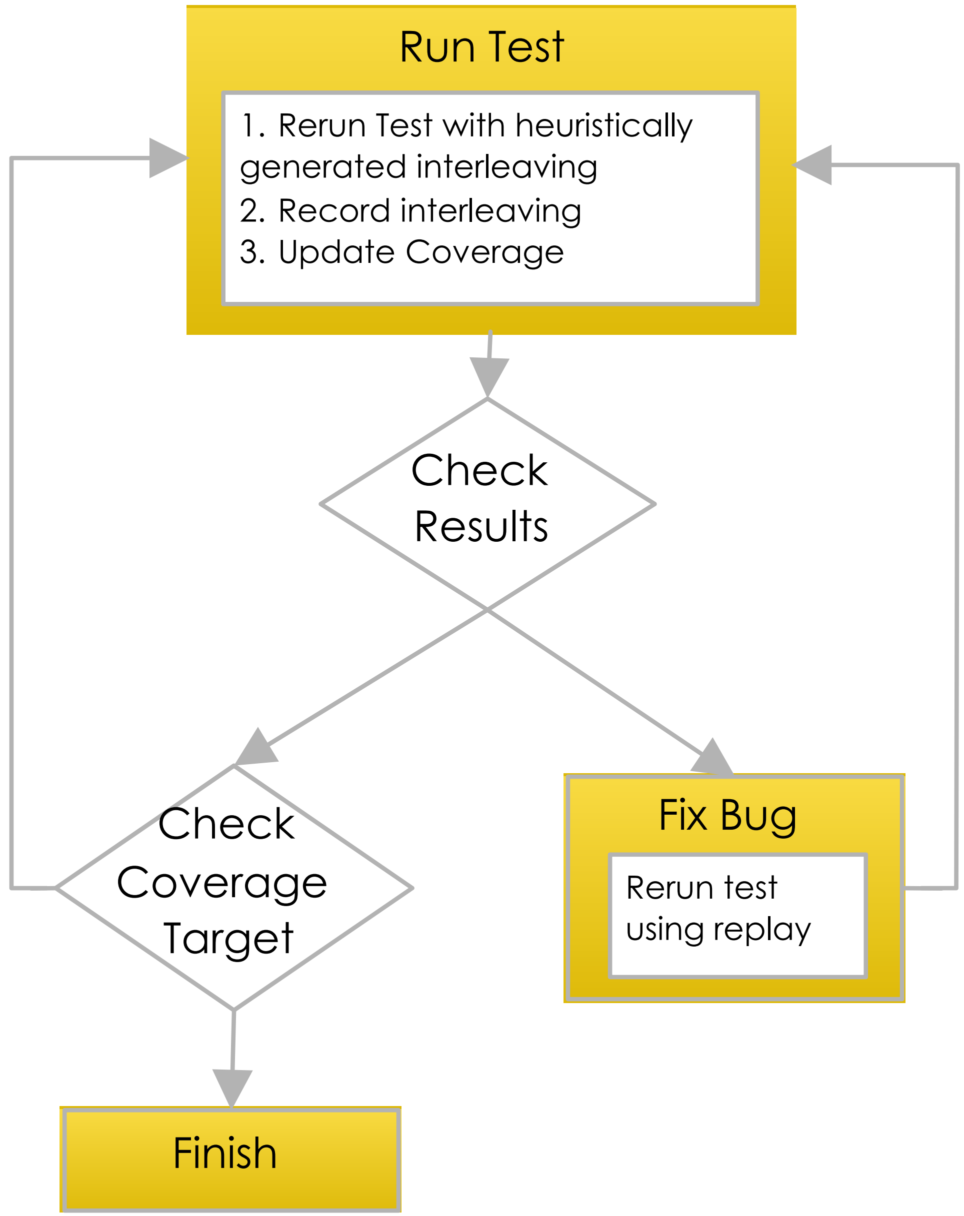
Concurrency Bug Detection

- Concurrency Testing
  - Costly dynamic analysis tools
  - Trade-off between effectiveness and efficiency

Example Testing Tools:
IBM ConTest
Microsoft CHESS
NASA Java Pathfinder
…

Concurrency Testing with IBM ConTest

- A typical testing process using ConTest [EFN+02]



[EFN+02] O. Edelstein, E. Farchi, Y. Nir, G.Ratsaby, and S. Ur. Multithreaded java program test generation. IBM Systems Journal, 41(1):111– 125, 2002.

Active Testing

"Active testing uses a randomized thread scheduler to verify if warnings reported by a predictive program analysis are real bugs."

- P. Joshi, M. Naik, C.-S. Park, and K. Sen [JNPS09]

Example: CalFuzzer

[JNPS09] P. Joshi, M. Naik, C.-S. Park, and K. Sen, "CalFuzzer:an extensible active testing framework for concurrent programs," in *Proc. of the 21st International Conference on Computer Aided Verification (CAV'09)*, 2009, pp. 675–681.

What kind of predictive program analysis can we use to improve testing with ConTest?

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Clone Detection

Clone Detection

- Ability to find similar code fragments within source code
- Able to find Type I-III clones
  I. Exact
  II. Near-exact
  III. Gapped

Goal

- Identify potential concurrency bugs in software using clone detection to localize testing effort

Key Tasks

1. Identification of concurrency bugs
2. Using clone detection of existing bugs (and bug patterns)
3. Localize testing efforts within the thread interleaving space

Identification of Concurrency Bugs

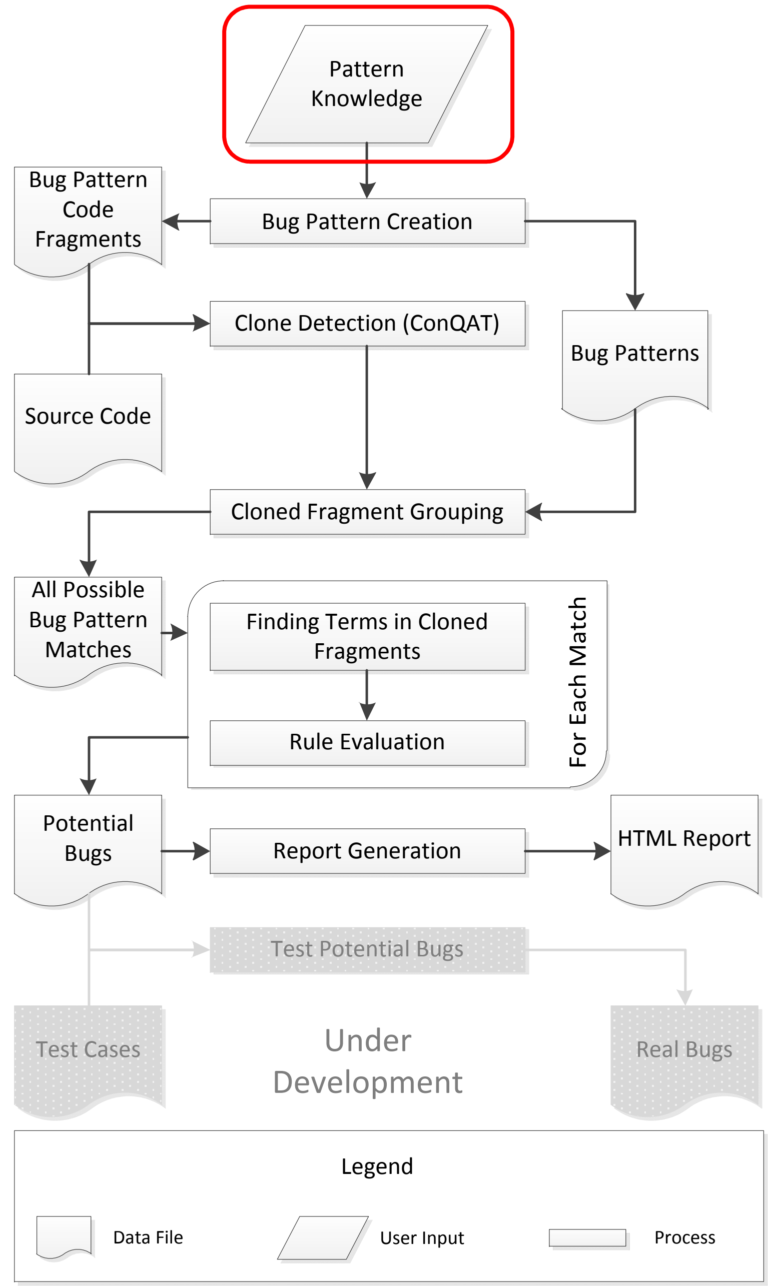
- An identified bug is abstracted to create a bug pattern
- Concurrency bug patterns require:
  - Code fragments involved in the bug
  - Interaction between the code fragments that causes the bug
    - Specifically, we are interested in the interaction between objects in the code fragments

Bug Patterns and Clone Detection

- Clone detection is used to identify clones of a bug pattern's code fragments
- The results of clone detection is a set of clones for each code fragment.
- We classify a set of clones that match a bug pattern's code fragments as either high- or low-potential for being an actual concurrency bug
  - (high-potential bug matches also satisfy rules that define the interactions between the code fragments of the bug pattern)

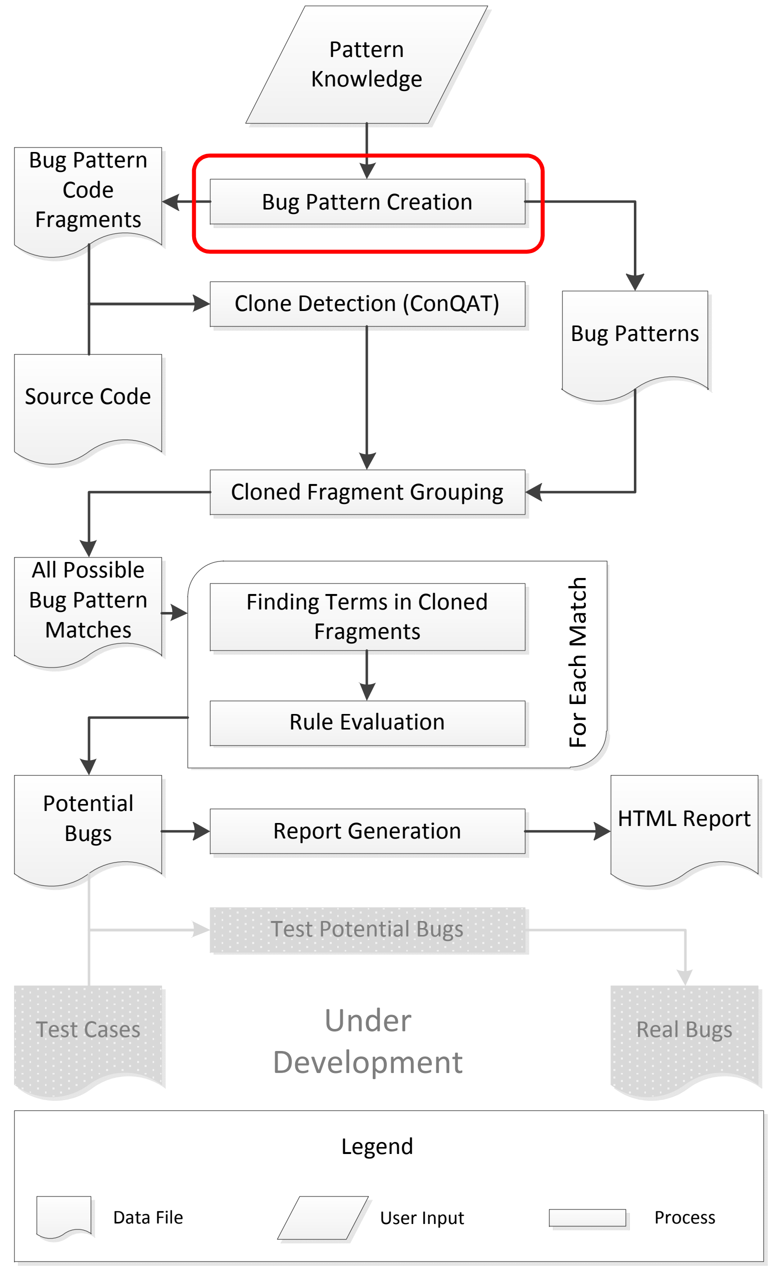
Walkthrough

- Pattern Knowledge
  - User knowledge
  - User experience



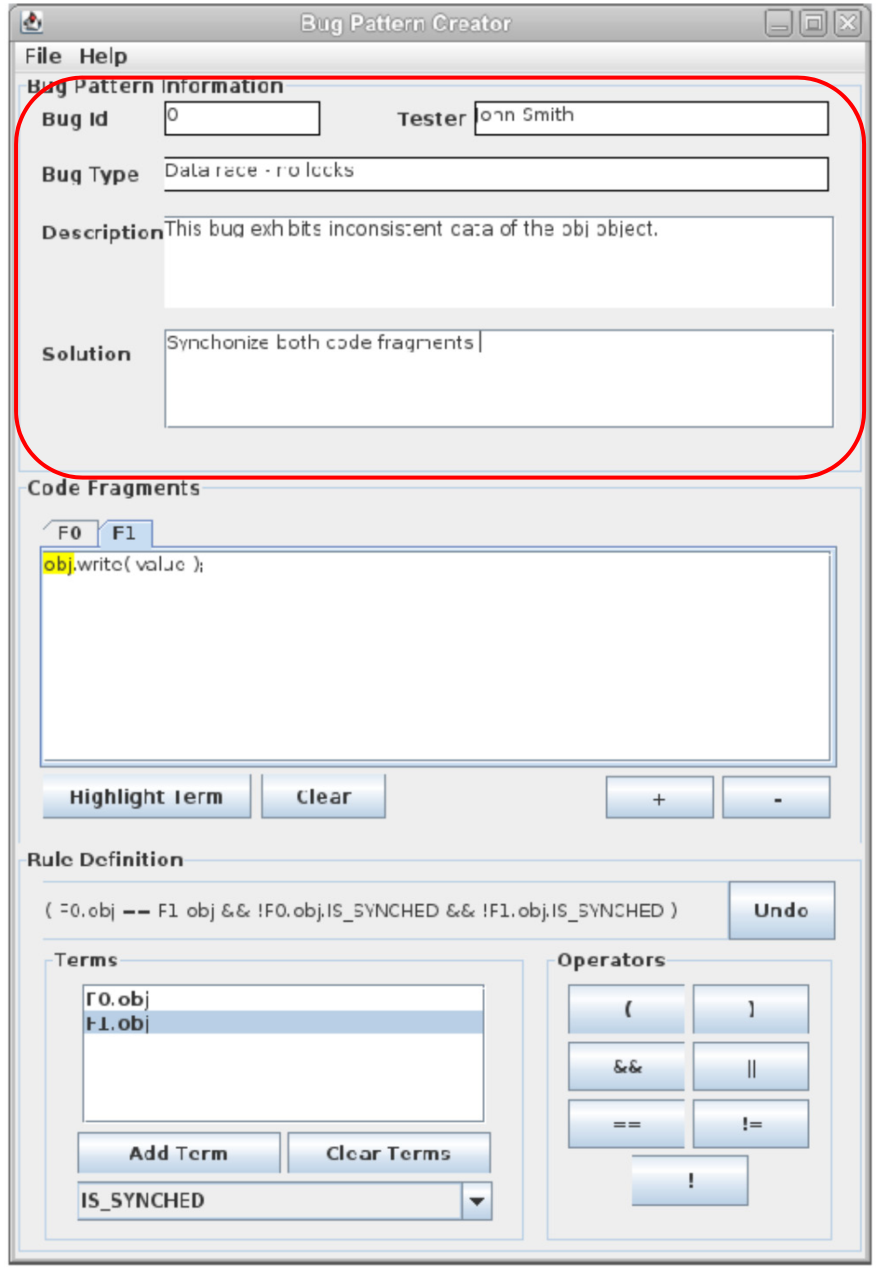
Walkthrough

- Bug Pattern Creation
  - Easy way to specify and maintain bug patterns using the Bug Pattern Creator



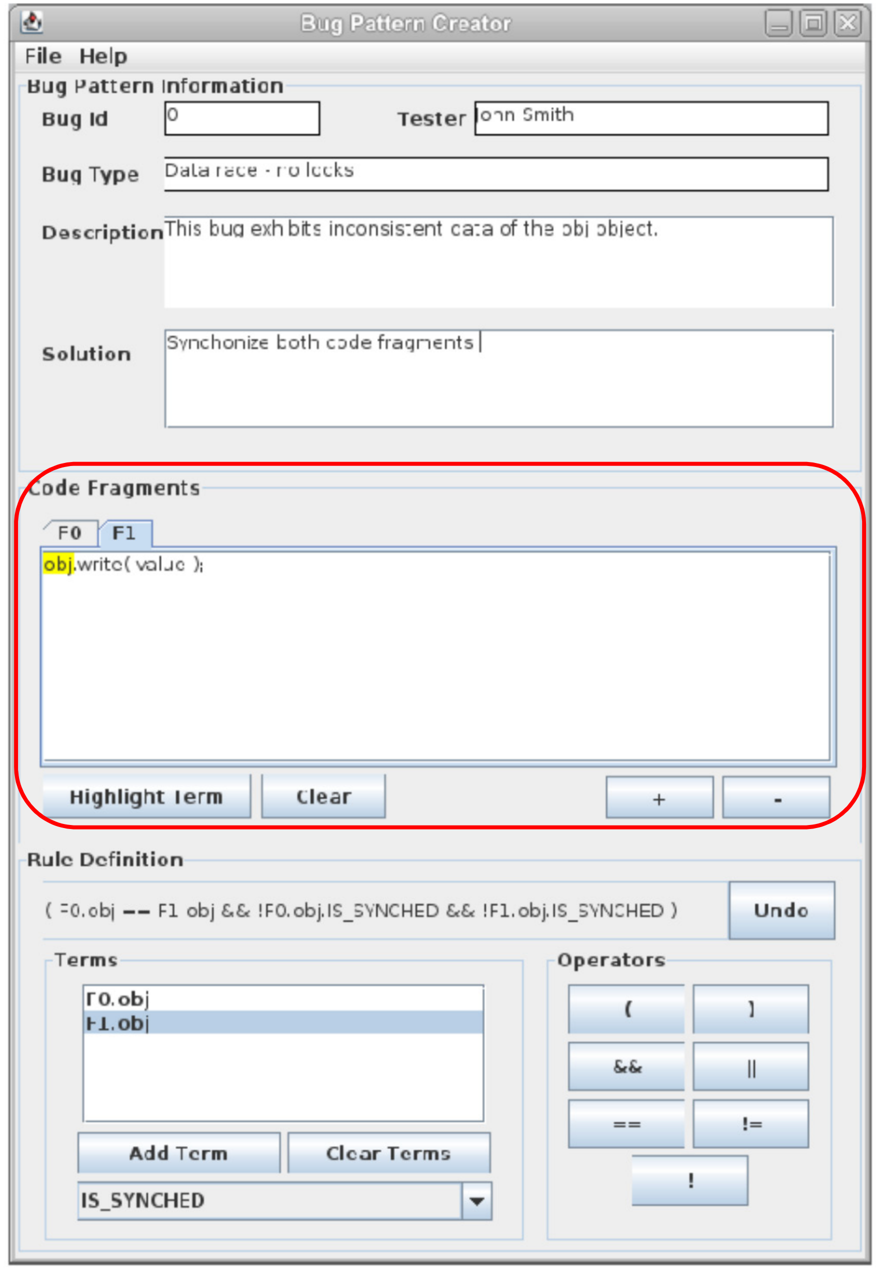
Bug Pattern Creator

- General bug pattern information



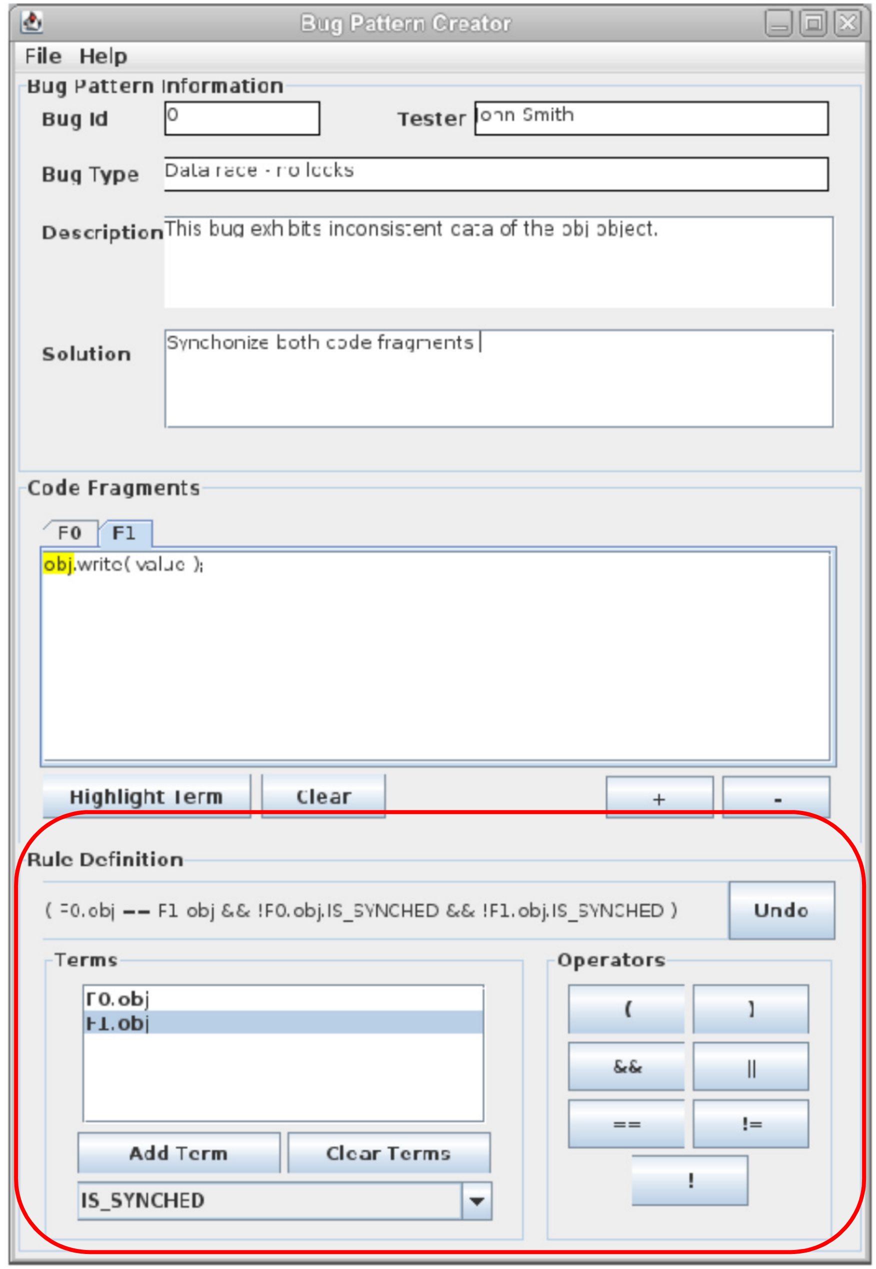
Bug Pattern Creator

- Code fragments required for this bug pattern
- Ability to highlight terms (objects that interact)



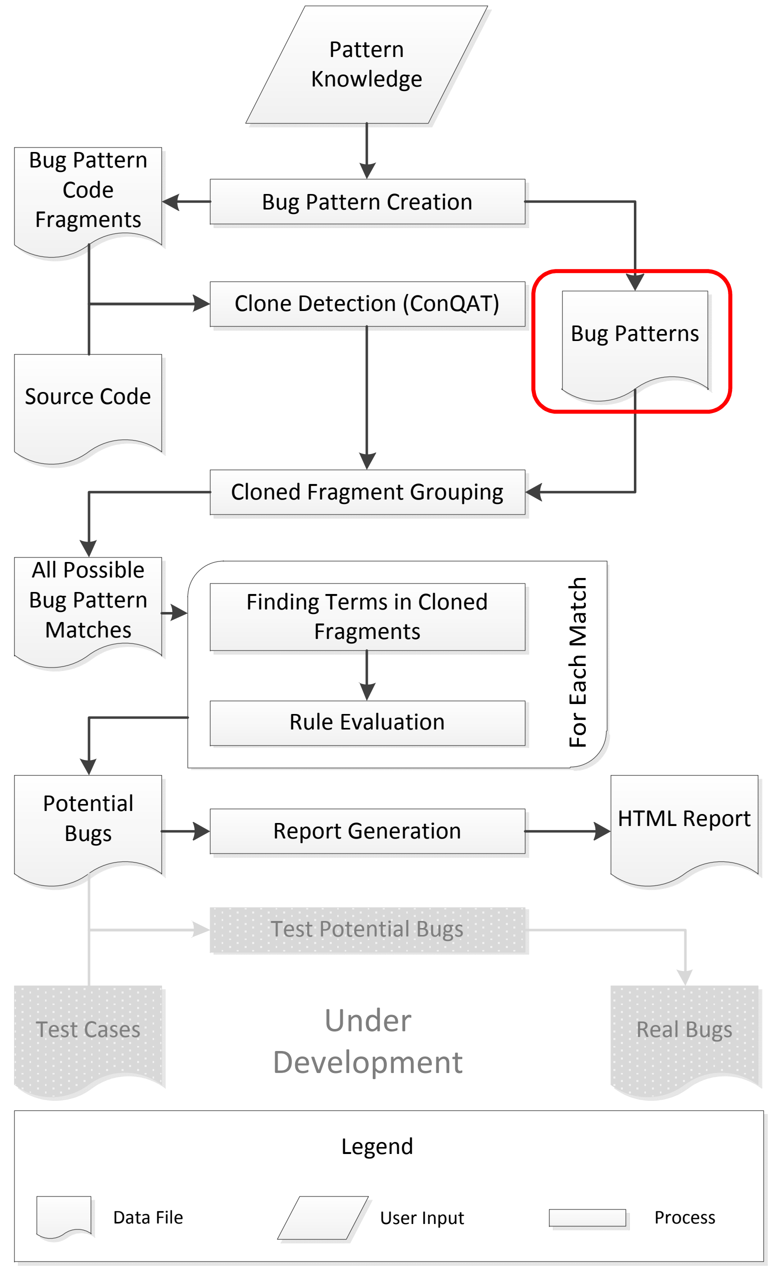
Bug Pattern Creator

- Terms from code fragments are combined into a rule
- Defines the interactions between code fragments
- Uses Boolean operators and properties



Walkthrough

- Bug Patterns
  - Contains bug pattern information that is represented in XML



Example Data Race Bug Pattern

```xml
<bugPattern id="0"    sourcePath="/bp/bug_pattern_0.xml">
  <type>Data race - no locks</type>
  <tester>John Smith</tester>
  <description>This bug exhibits inconsistent data of
      the obj object.</description>
  <solution>Synchronize both code
      fragments.</solution>
  <originalFragment sourcePath="/src/bp_code/
      bug_pattern_code_0_0.java" countLines="0“
      patternId="0" fragmentId="0">
    <term id="F0.obj" line="0" tokenPosition="3"/>
  </originalFragment>
  <originalFragment sourcePath="/src/bp_code/
      bug_pattern_code_0_1.java" countLines="0“
      patternId="0" fragmentId="1">
    <term id="F1.obj" line="0" tokenPosition="0"/>
  </originalFragment>
  <rule>(F0.obj == F1.obj && !F0.obj.IS_SYNCHED
      && !F1.obj.IS_SYNCHED)</rule>
</bugPattern>
```

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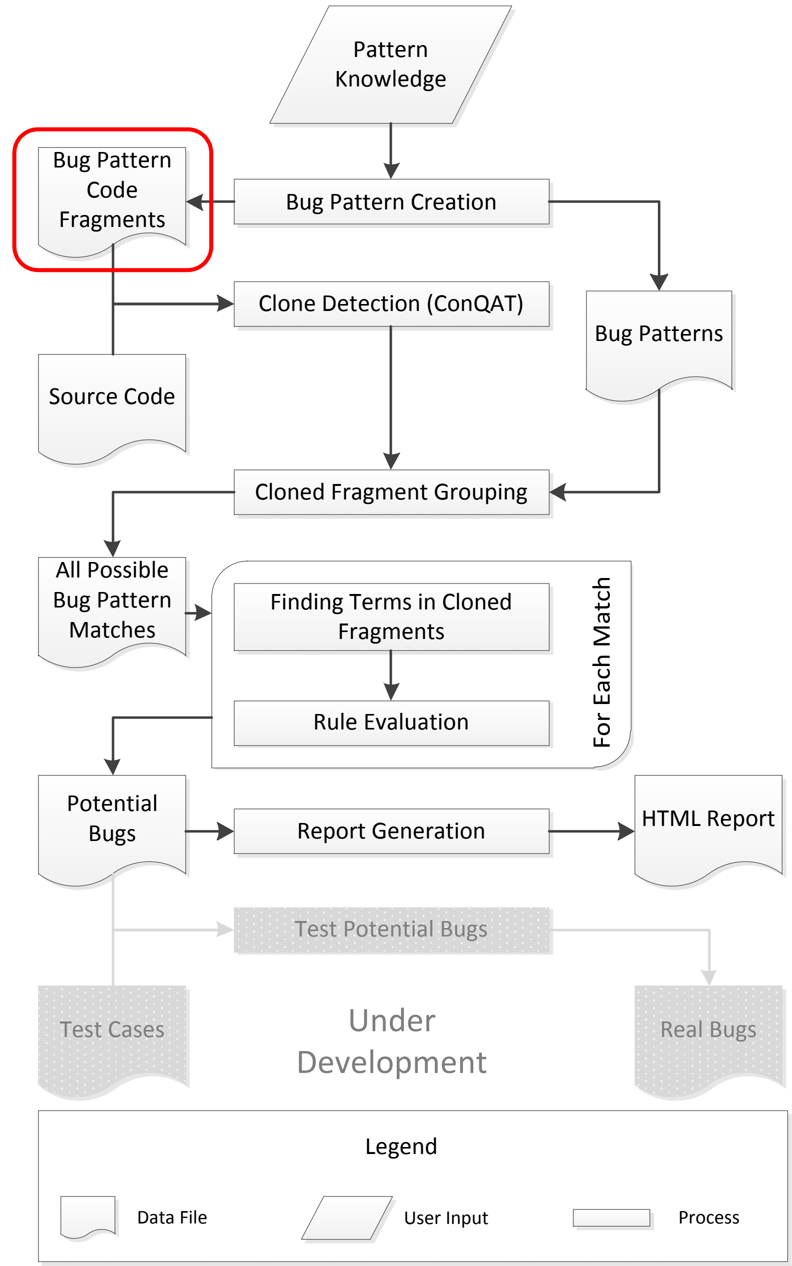
      && !F1.obj.IS_SYNCHED)</rule>
</bugPattern>
```

Example Deadlock Bug Pattern

```
<bugPattern id="1">
        ...
        <originalFragment fragmentId="0">
                <term id="F0.lock1"/>
                <term id="F0.lock2"/>
        </originalFragment>
        <originalFragment fragmentId="1">
                <term id="F1.lock2"/>
                <term id="F1.lock1"/>
        </originalFragment>
        <rule>(F0.lock1 == F1.lock1 && F0.lock2 == F1.lock2)</rule>
</bugPattern>
```

Walkthrough

- Bug Pattern Code Fragments
  - The actual code fragments that composes the bug pattern



Example Deadlock Code Fragments

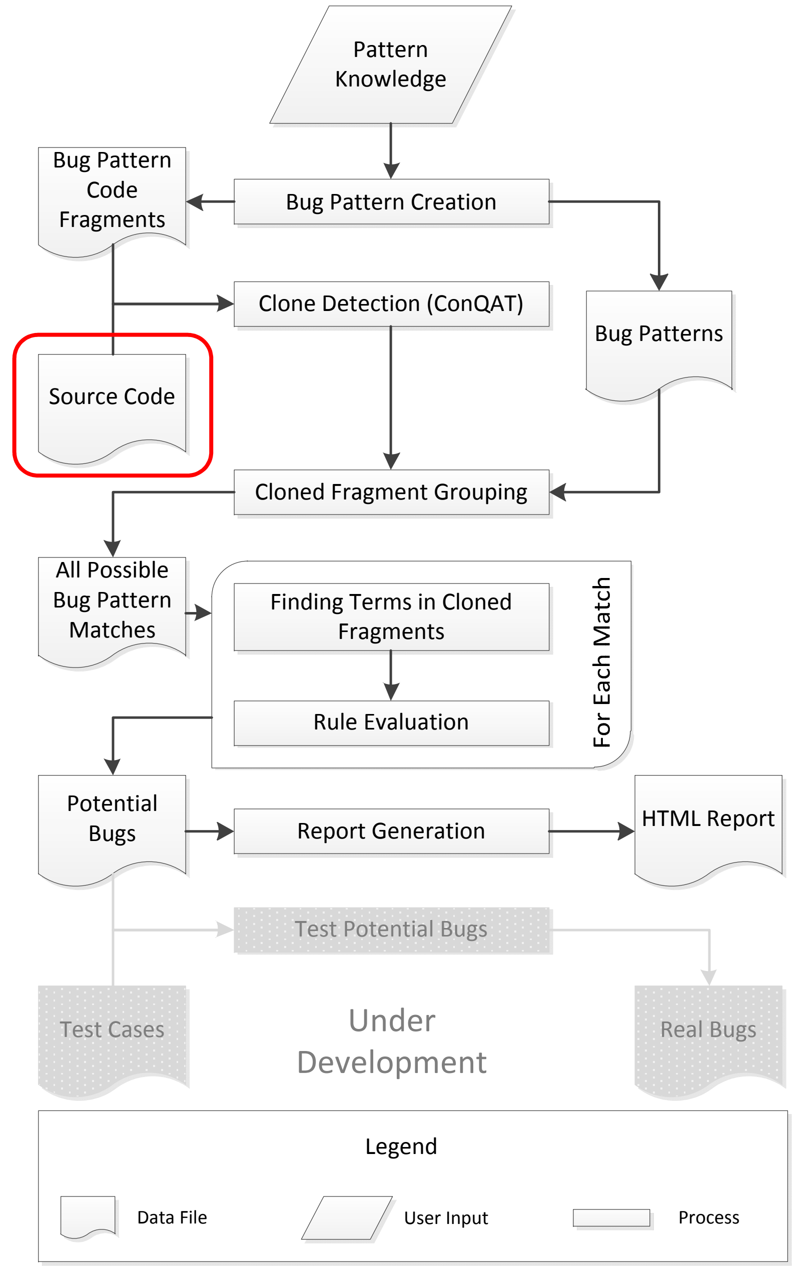
Bug Pattern

```
synchronized ( lock1 ){
   synchronized ( lock2 ){
     var1 = obj.read ( ) ;
   }
}
```

```
synchronized ( lock2 ){
   synchronized ( lock1){
      var1 = obj.read ( ) ;
   }
}
```

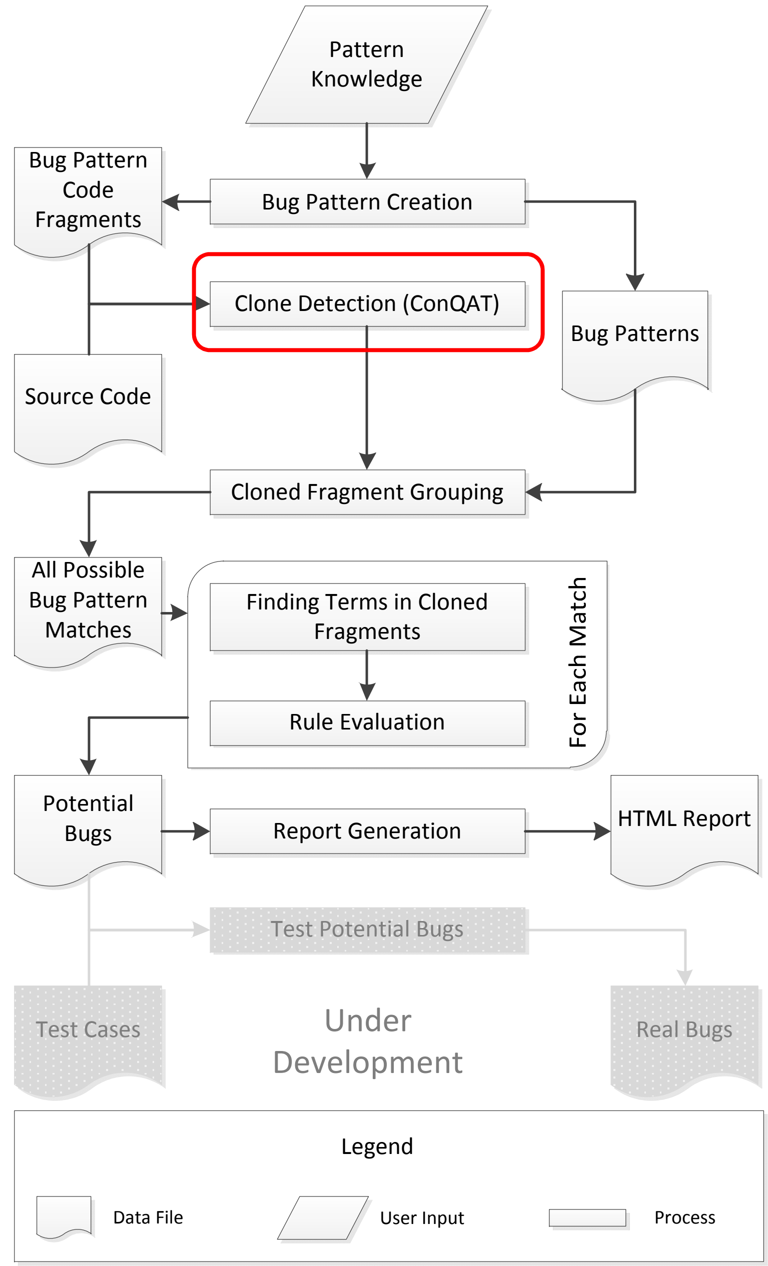
Walkthrough

- Source Code
  - The source code of the system under observation



Walkthrough

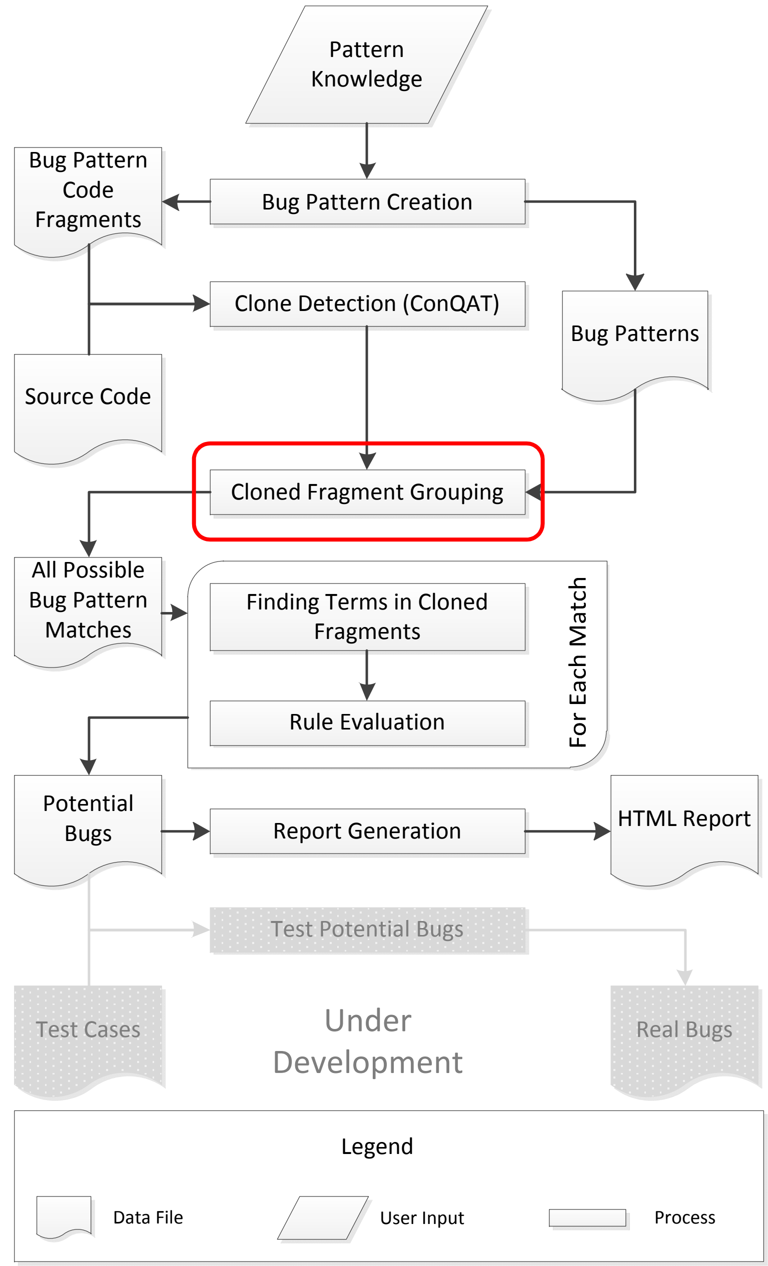
- Clone Detection (ConQAT[JDH09])
  - Designed for research
  - Detects type I-III clones between source code and bug pattern code fragments



[JDH09] E. Juergens, F. Deissenboeck, and B. Hummel, "CloneDetective – a workbench for clone detection research," in *Proc. of the 31st International Conference on Software Engineering (ICSE'09)*, 2009, pp. 603–606.

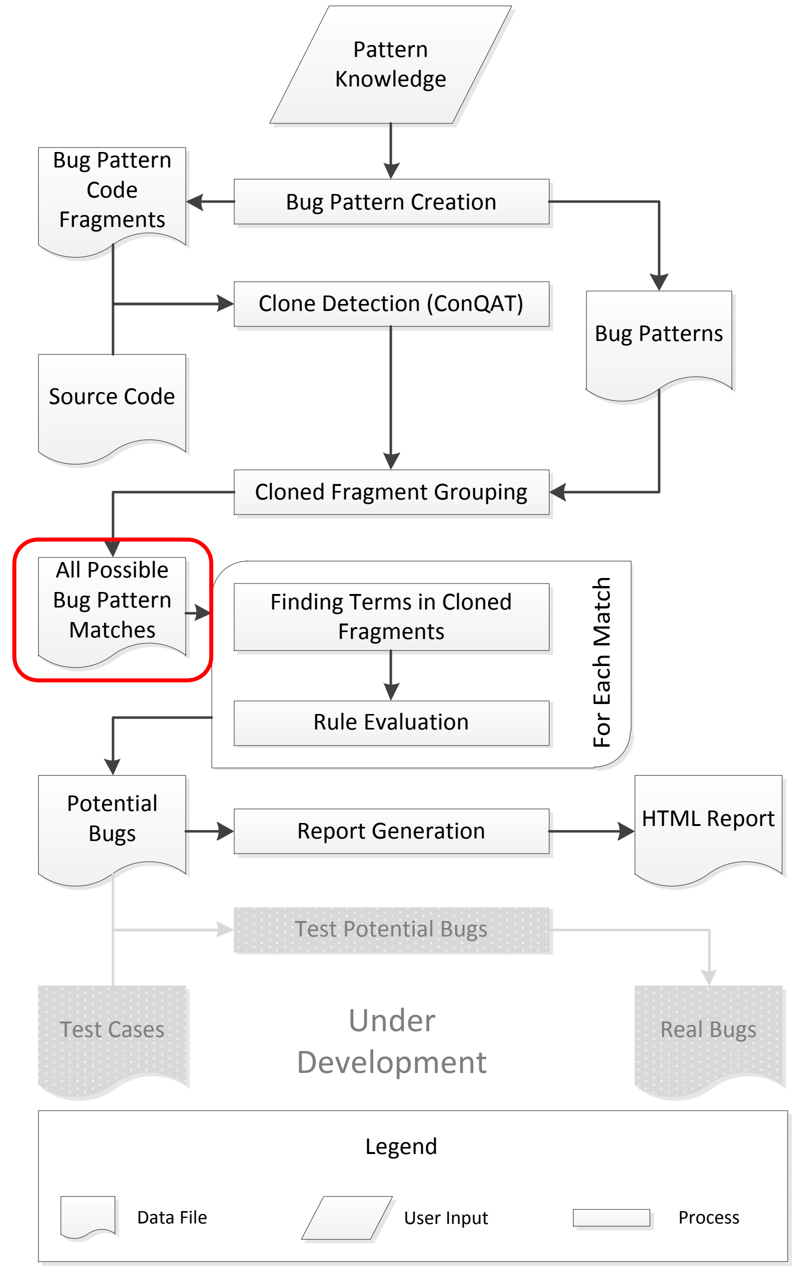
Walkthrough

- Cloned Fragment Grouping
  - Forms valid bug pattern combinations using found clones of bug patterns



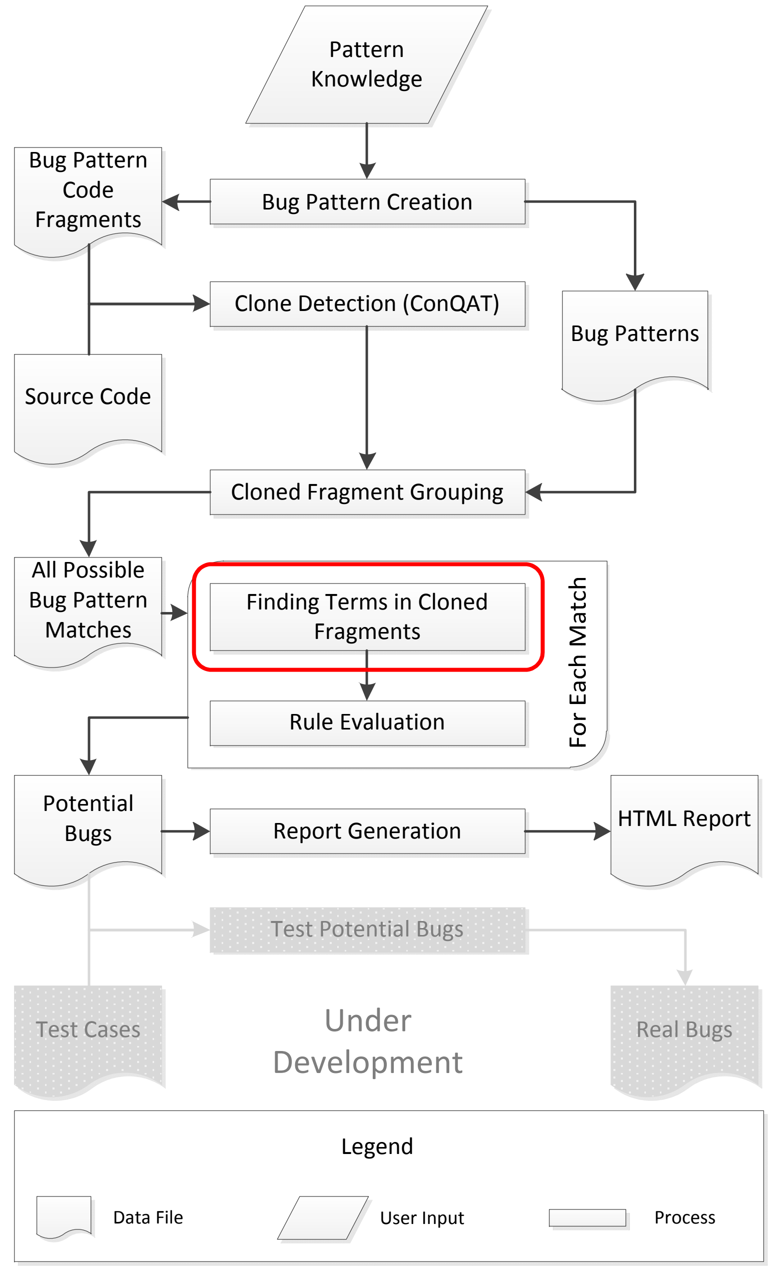
Walkthrough

- All Possible Bug Pattern Matches
  - Possible concurrency bugs



Walkthrough

- Finding Terms in Cloned Fragments
  - Type II and III clone's terms must be mapped to the appropriate terms



Finding Terms in Cloned Fragments

```
synchronized ( lock1 ){
    synchronized ( lock2 ){
        var1 = obj.read ( ) ;
    }
}
```

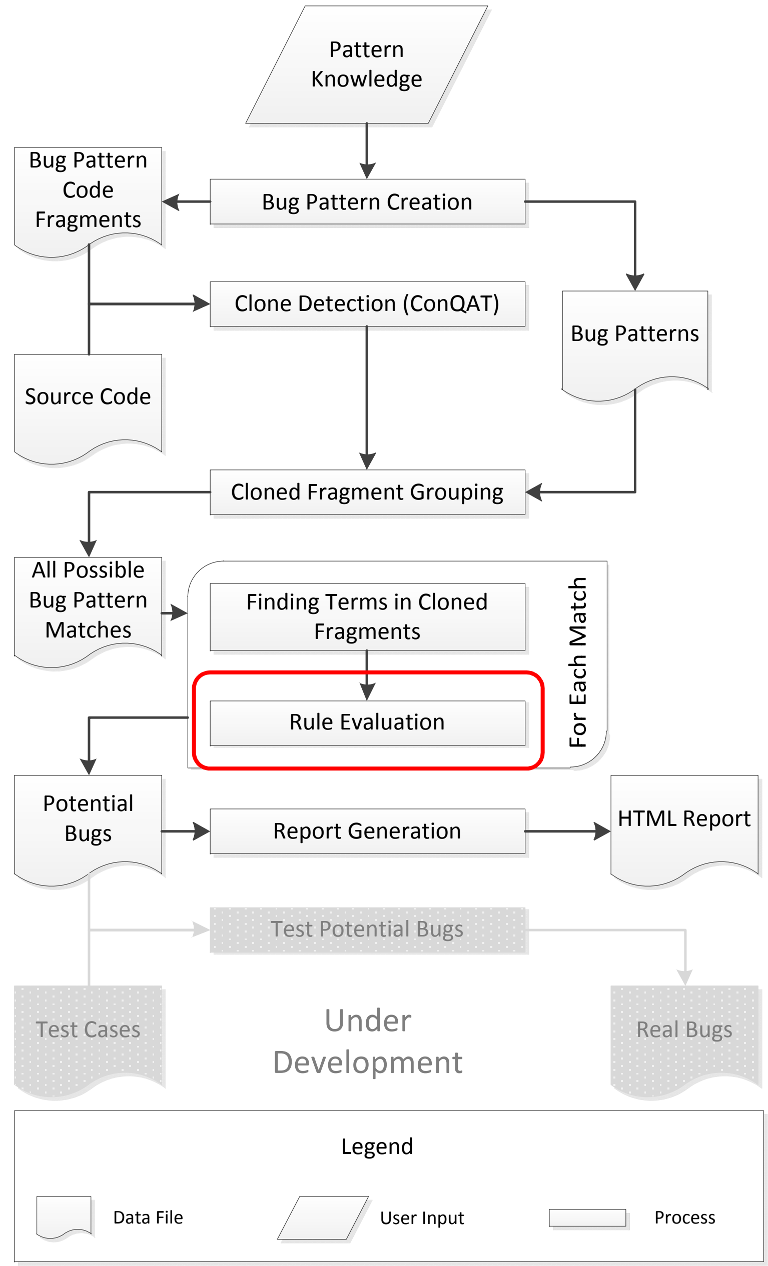
Original Bug Pattern Code Fragment

```
synchronized ( lockB ){
    synchronized ( lockA ){
        a.add(a);
        newVar7 = a.read ( ) ;
    }
}
```

Source Code Clone Code Fragment

Walkthrough

- Rule Evaluation
  - The rule is evaluated to categories the possible bugs into high- and low-potential bugs



Rule Evaluation

1

- (F0.lock1 == F1.lock1 && F0.lock2 == F1.lock2)
  - Original bug pattern rule

2

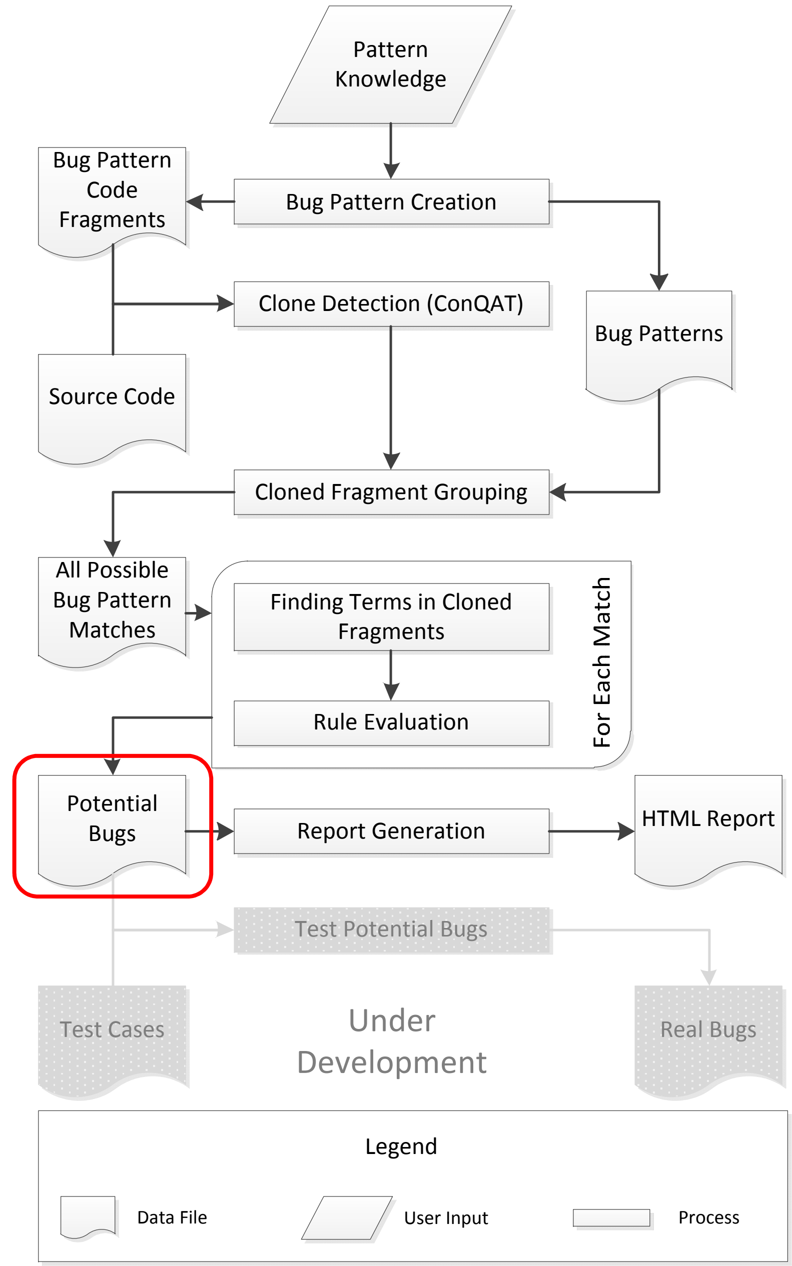
- (F0.lockB == F1.lockB && F0.lockA == F1.lockA)
  - Replace terms with source code clone match terms

3

- (true == true)
  - Evaluate

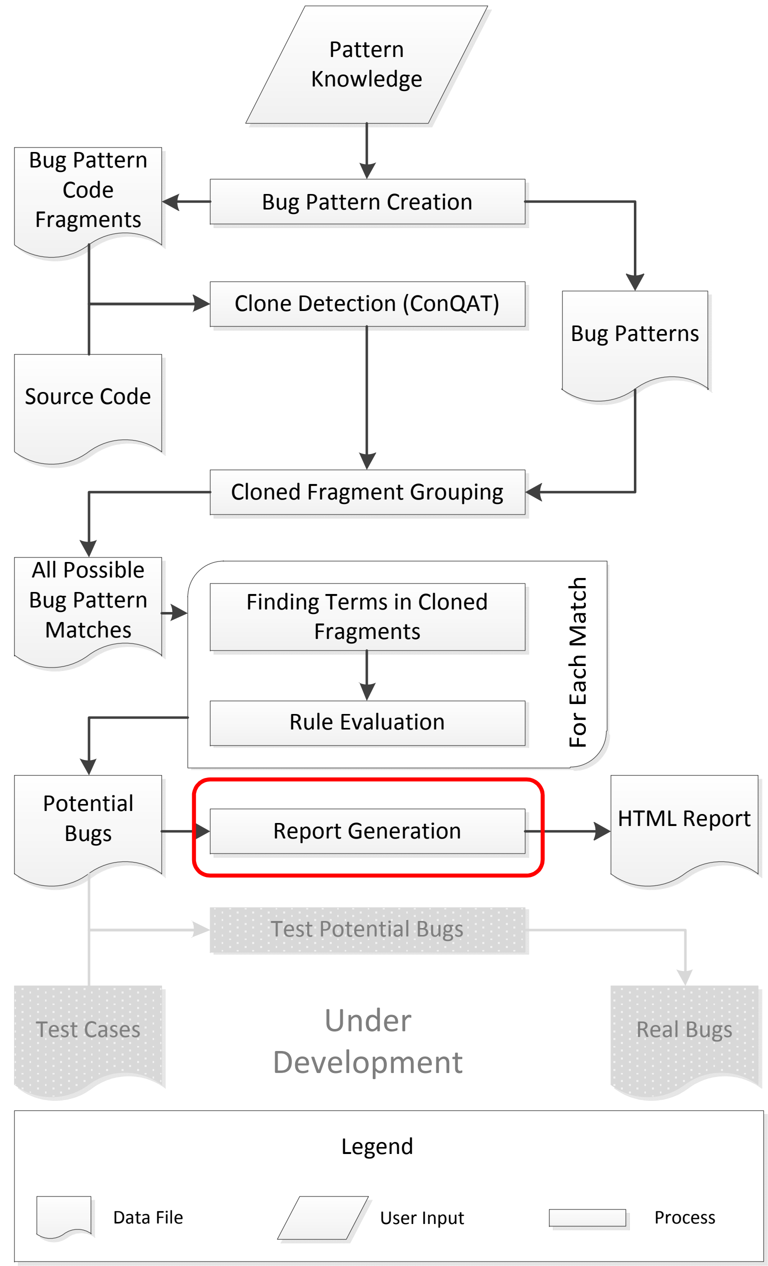
Walkthrough

- Potential Bugs
  - A XML list of high-potential bugs, along with source code location



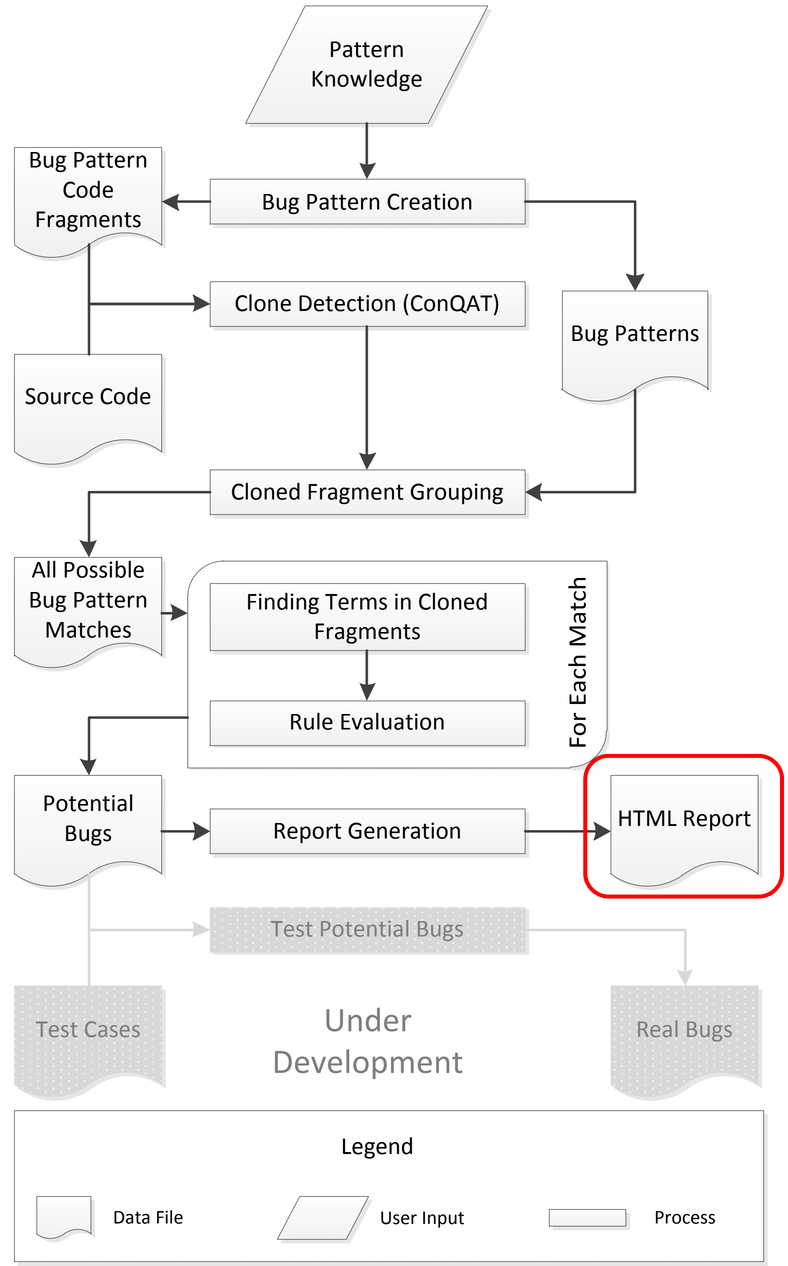
Walkthrough

- Report Generation
  - Process to transform XML list of potential bugs into an HTML report



Walkthrough

- HTML Report
  - A readable report of the potential bugs



HTML Report

- Summary statistics
- High-level view of potential bugs

HTML Report

Click the headings to expand for more details

High-Potential Bug Matches	**1/8.0** (12.5%)
Low-Potential Bug Matches	**7/8.0** (87.5%)

Bug Pattern 0

Id	0
Type	Deadlock - Wrong Locks
Tester	John Smith
Description	This bug exhibits the classic deadlocking situation that occurs with the wrong locks being used
Solution	Switch the locks to the right ones, exchanging the nested lock objects
Rule	(F0.lock1 == F1.lockA && F0.lock2 == F1.lockB)

High-Potential Bug Matches	**1/2.0** (50.0%)
Low-Potential Bug Matches	**1/2.0** (50.0%)

High-Potential Match 0

Evaluated Rule (F0.lockB == F1.lockB && F0.lockA == F1.lockA)

Code Fragment 0

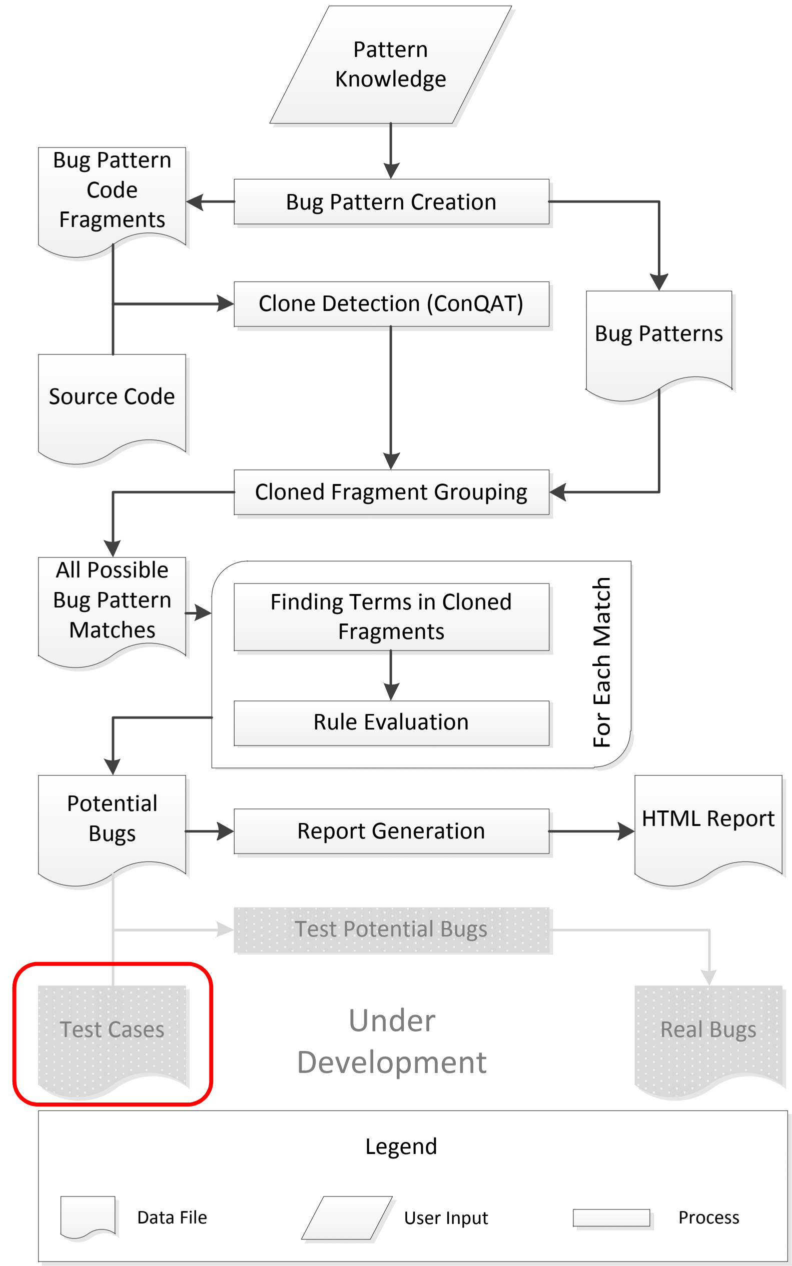
Source Path	/home/jalbert/workspace/conbpl/test-data/example/src/bug.java
Start Line	22
Line Count	12

Term Id	F0.lockB
Term Line Number	3
Term Token Position	0
Term Line Score	5
Term Score	5

Term Id	F0.lockA
Term Line Number	5

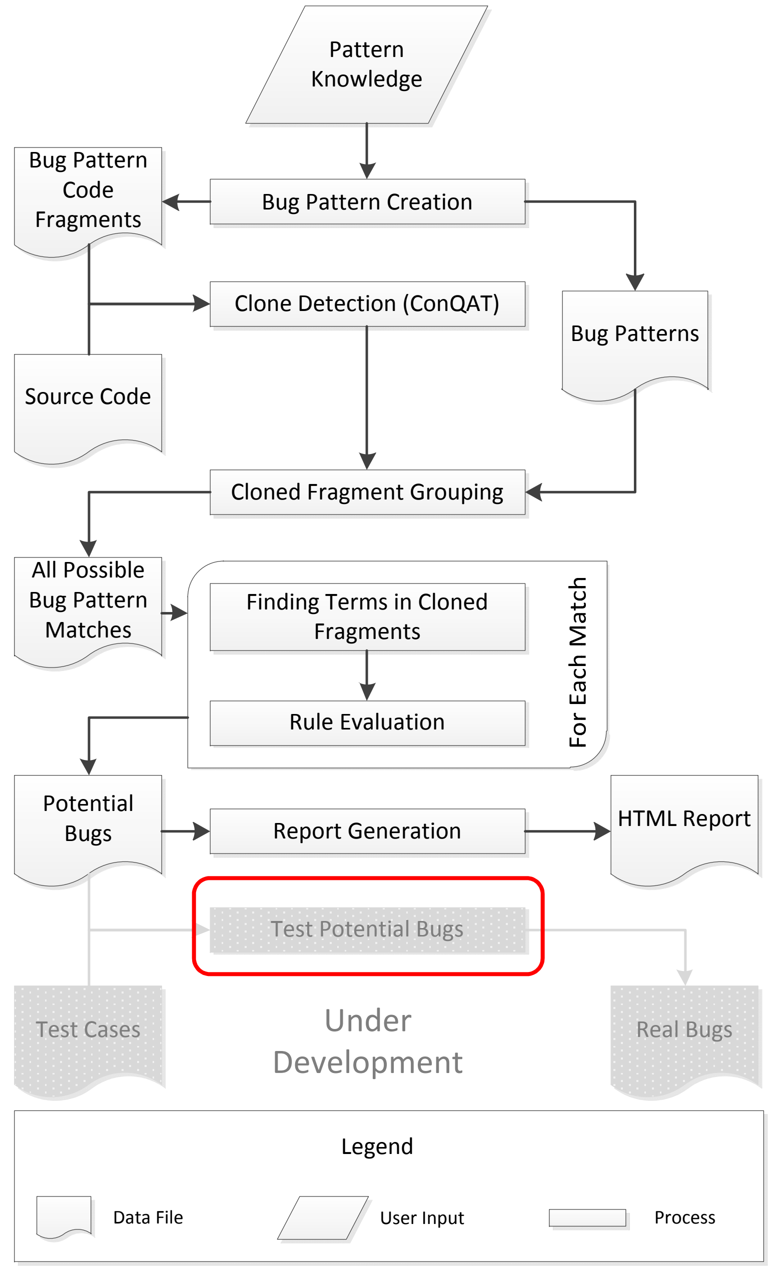
Walkthrough

- Test Cases
  - A testing suite that covers the area of the concurrency bug



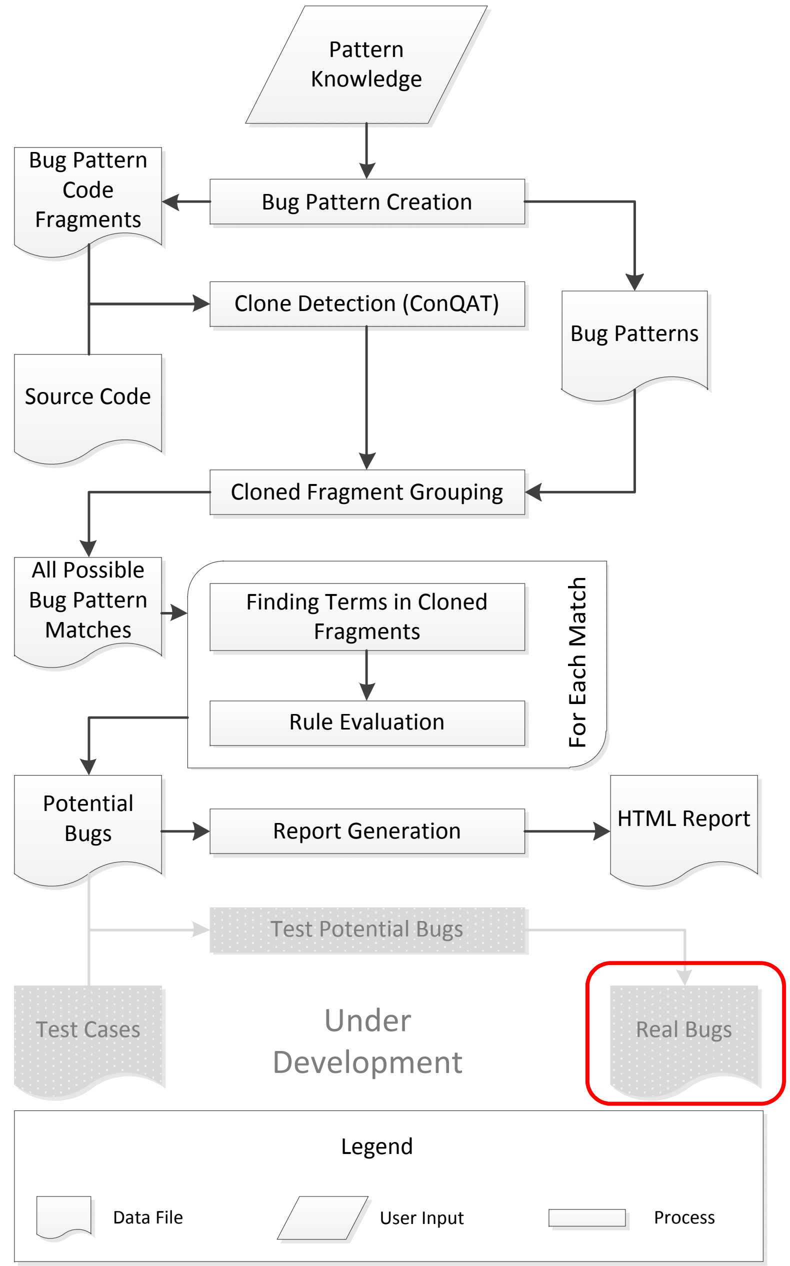
Walkthrough

- Test Potential Bugs
  - Using a dynamic testing technique like ConTest
  - Explore thread interleaving space to verify potential bugs



Walkthrough

- Real Bugs
  - A report of real found bugs is formulated



Proposed Experimental Evaluation

- In order to comprehensively evaluate our active testing research we need to satisfy the following three goals:
  - Ensure that our specification notation for concurrency bug patterns is expressive enough to handle many different types of concurrency bugs.
  - Assess our bug detection process and the use of clone detection with finding concurrency bugs.
  - Evaluate the benefits of using the high-potential bugs to localize testing effort.

Conclusion

- The use of clone detection and bug patterns should increase testing effectiveness by reducing the search space, even with the possibility of false positives.

Future Work

- Additional work is needed to finish the active testing process.
- Experimentation is needed to assess the benefits of our tool when compared to existing active testing tools such as CalFuzzer.

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