Non deterministic path analysis on cFlow

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2021.9

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- Reason
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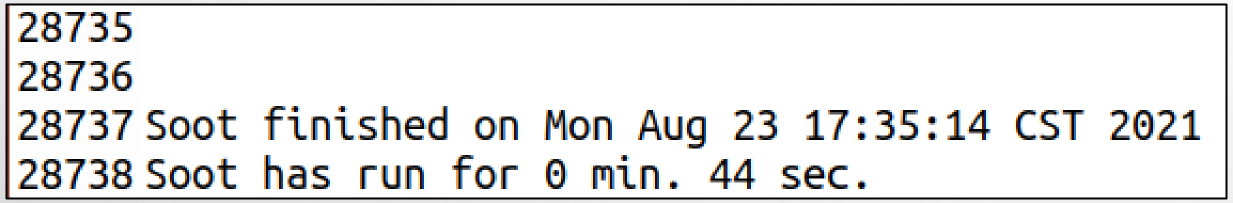
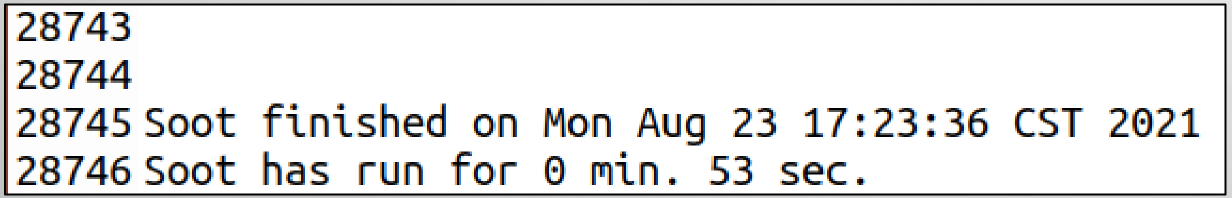
Problem

- Run cFlow on hadoop_common 3.3.0 several times,
- And I get two different outputs.



```
28735
28736
28737 Soot finished on Mon Aug 23 17:35:14 CST 2021
28738 Soot has run for 0 min. 44 sec.
```

a.txt: 28738 lines

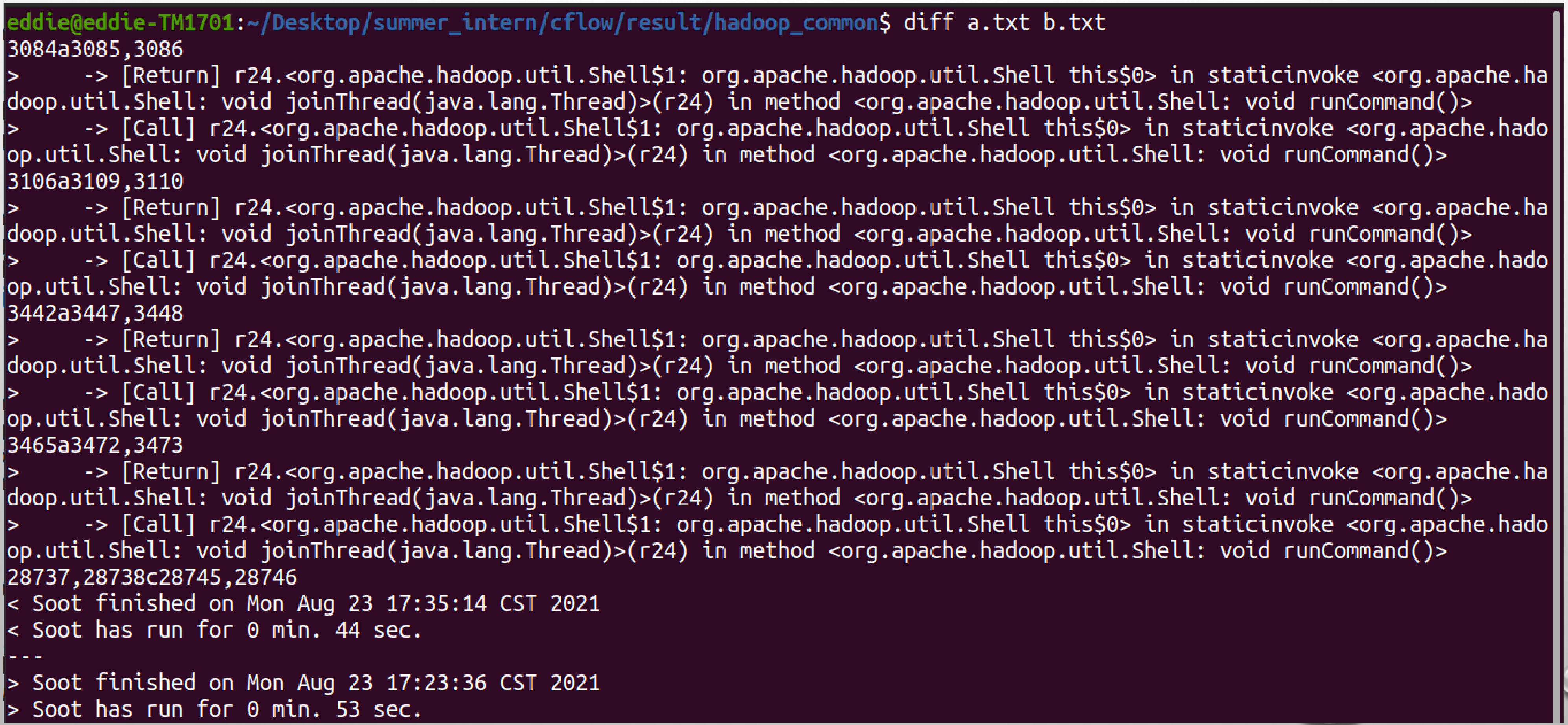


```
28743
28744
28745 Soot finished on Mon Aug 23 17:23:36 CST 2021
28746 Soot has run for 0 min. 53 sec.
```

b.txt: 28746 lines

Problem

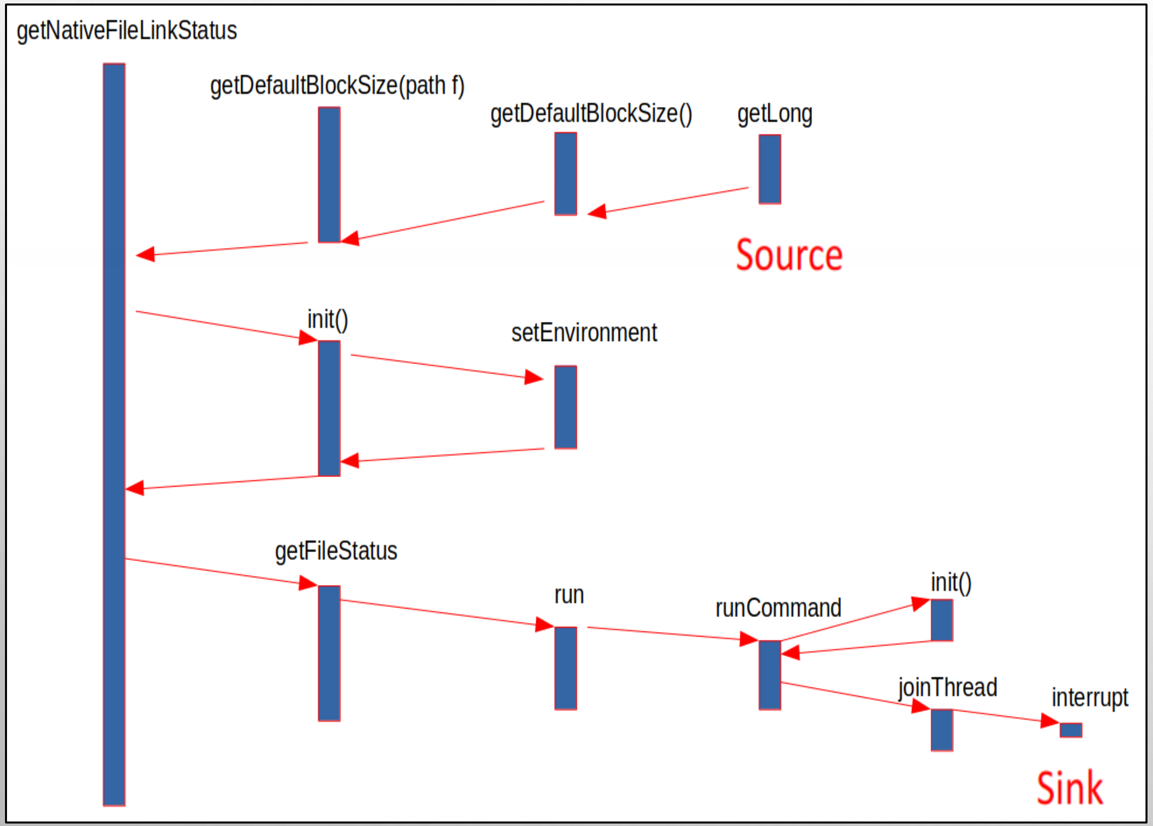
- b.txt has more taints about call and return on method joinThread().



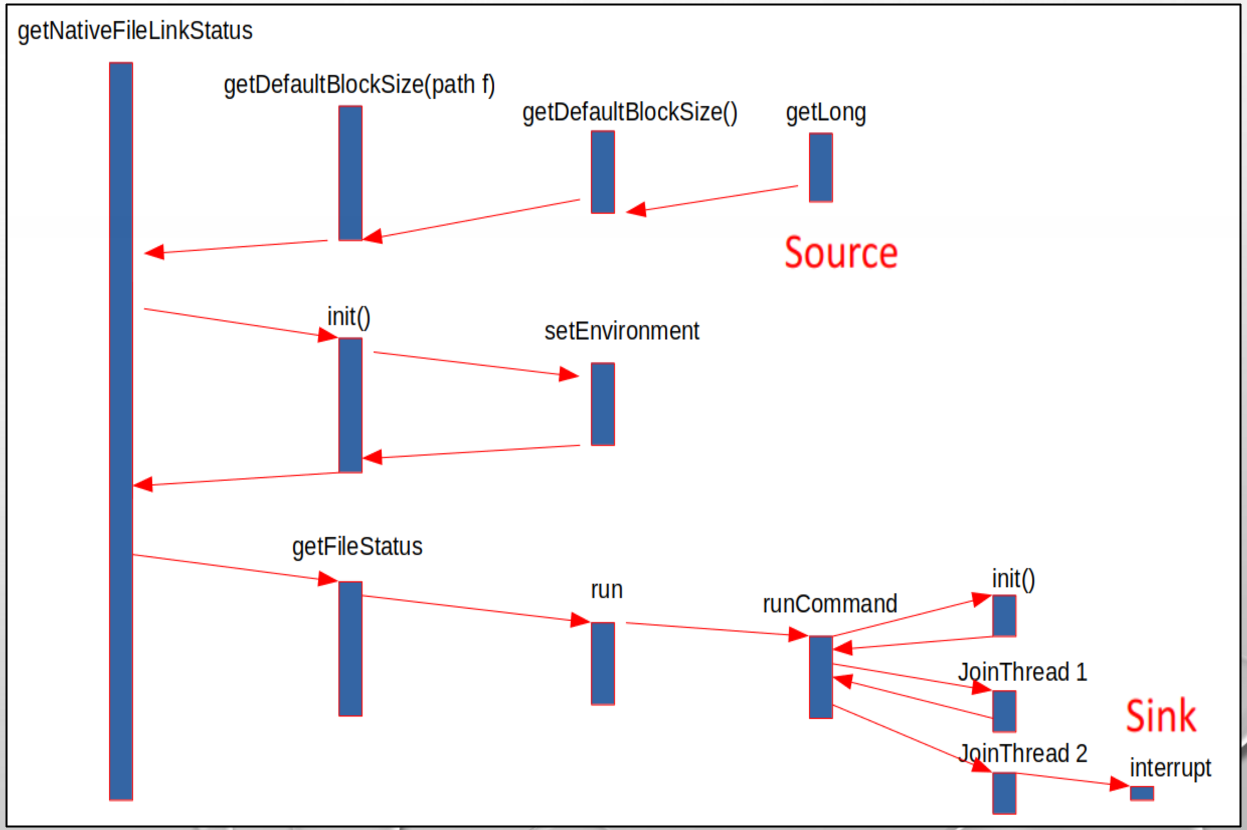
```
eddie@eddie-TM1701:~/Desktop/summer_intern/cflow/result/hadoop_common$ diff a.txt b.txt
3084a3085,3086
>     -> [Return] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24) in method <org.apache.hadoop.util.Shell: void runCommand()>
>     -> [Call] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24) in method <org.apache.hadoop.util.Shell: void runCommand()>
3106a3109,3110
>     -> [Return] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24) in method <org.apache.hadoop.util.Shell: void runCommand()>
>     -> [Call] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24) in method <org.apache.hadoop.util.Shell: void runCommand()>
3442a3447,3448
>     -> [Return] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24) in method <org.apache.hadoop.util.Shell: void runCommand()>
>     -> [Call] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24) in method <org.apache.hadoop.util.Shell: void runCommand()>
3465a3472,3473
>     -> [Return] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24) in method <org.apache.hadoop.util.Shell: void runCommand()>
>     -> [Call] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24) in method <org.apache.hadoop.util.Shell: void runCommand()>
28737,28738c28745,28746
< Soot finished on Mon Aug 23 17:35:14 CST 2021
< Soot has run for 0 min. 44 sec.
---
> Soot finished on Mon Aug 23 17:23:36 CST 2021
> Soot has run for 0 min. 53 sec.
```

Problem

- I trace the taint propagation path(at line 3084) that contains the difference above.



a.txt



b.txt

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Reason

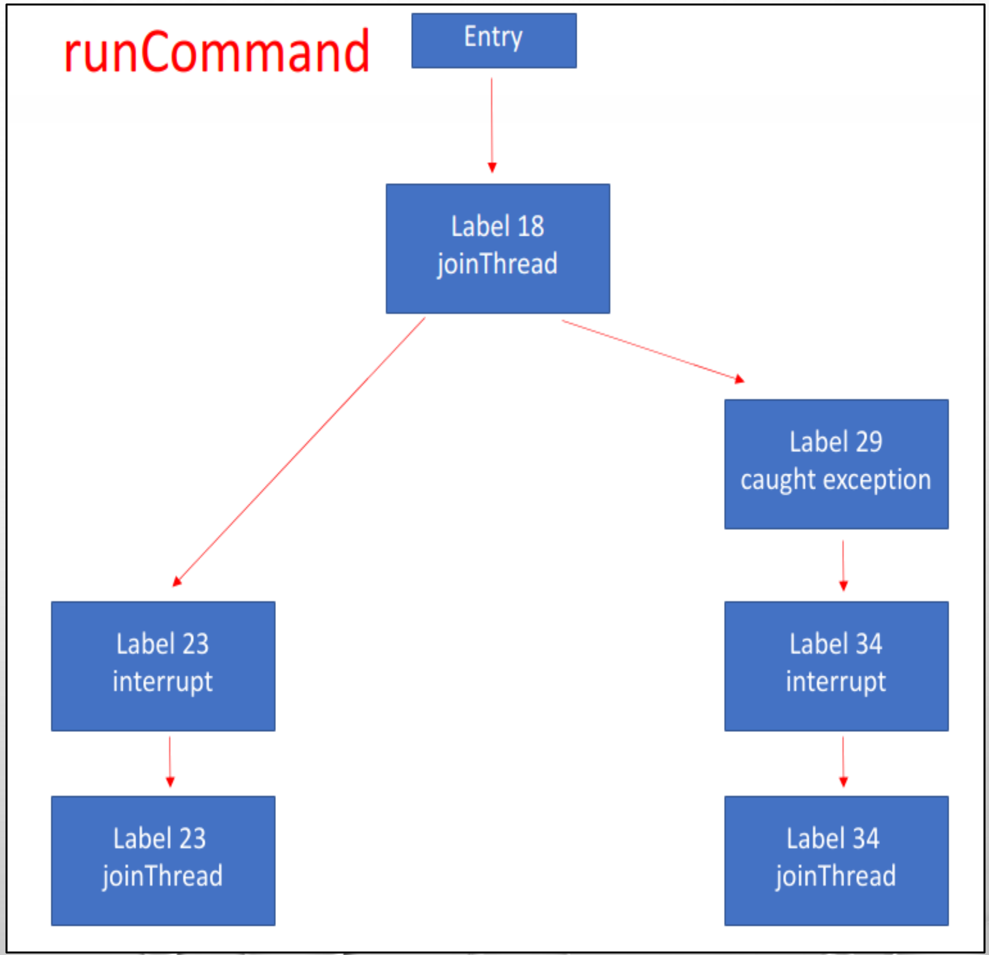
- For simplicity, I adjust cFlow by
  - Printing all taint propagation paths between each pair of source and sink.
  - Only detecting method getLong() as source and method interrupt() as sink.
  - Only Considering the taint propagation path after method runCommand().
- Also, I analyze the control flow graph of method runCommand() and joinThread().

Reason

- Here is the logic structure of method runCommand().

```
private void runCommand() throws IOException {
    ...
    try {
        ...
        joinThread(errThread);
        completed.set(true);
        ...
    } catch (InterruptedException ie) {
        ...
    } finally {
        ...
        if (!completed.get()) {
            errThread.interrupt();
            joinThread(errThread);
        }
        ...
    }
}
```

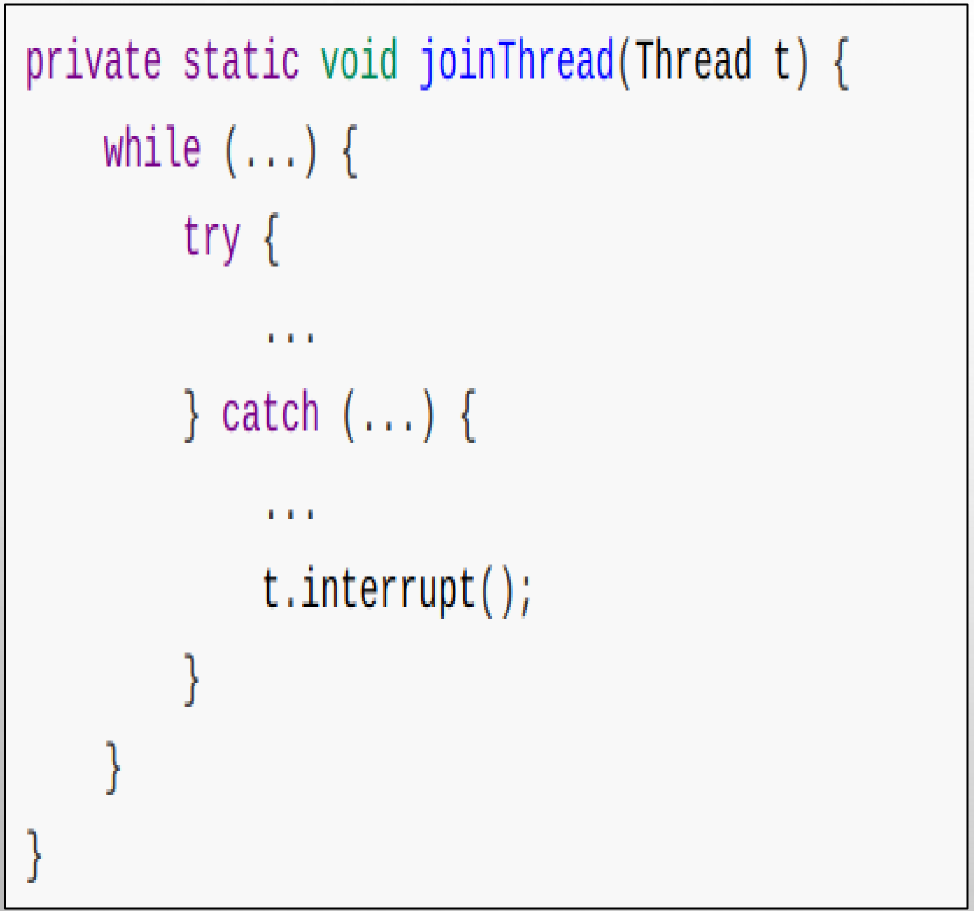
Source code



CFG

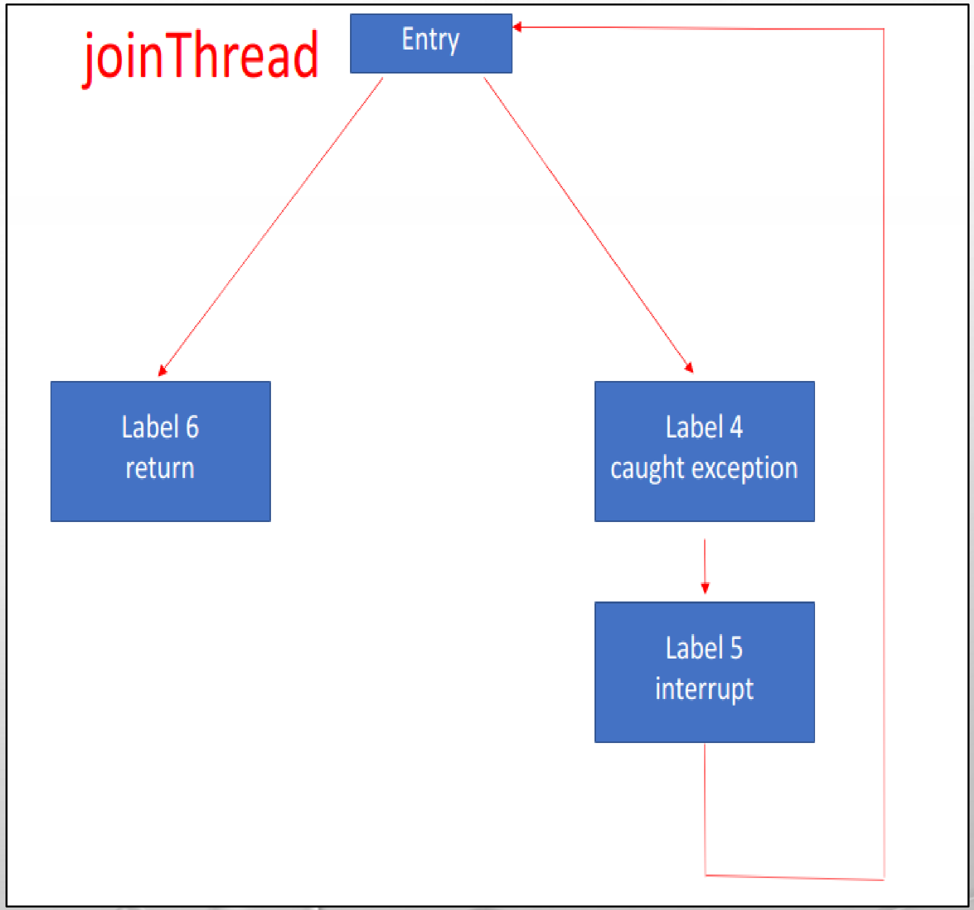
Reason

- Here is the logic structure of method joinThread().



```
private static void joinThread(Thread t) {
    while (...) {
        try {
            ...
        } catch (...) {
            ...
            t.interrupt();
        }
    }
}
```

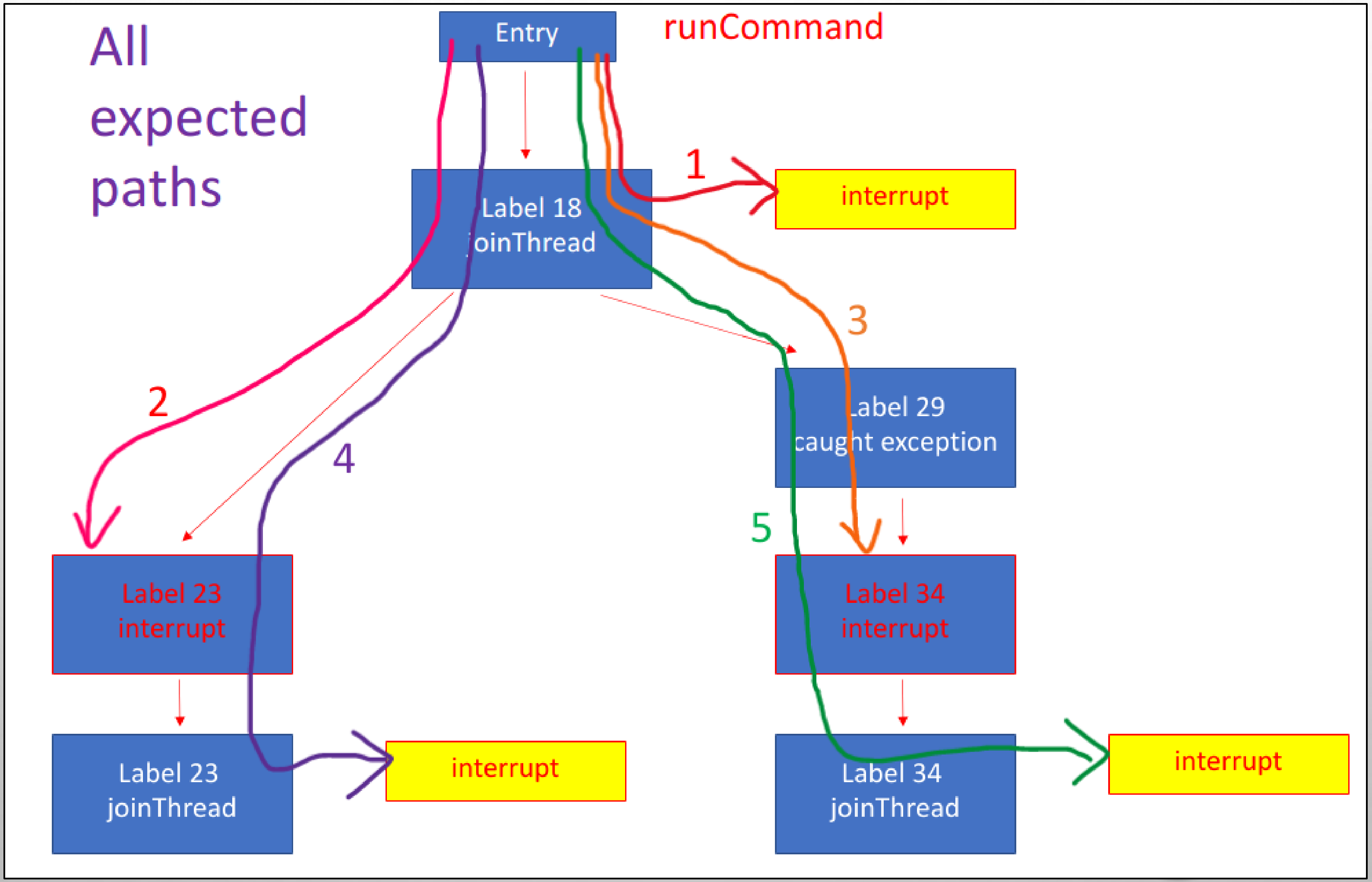
Source code



CFG

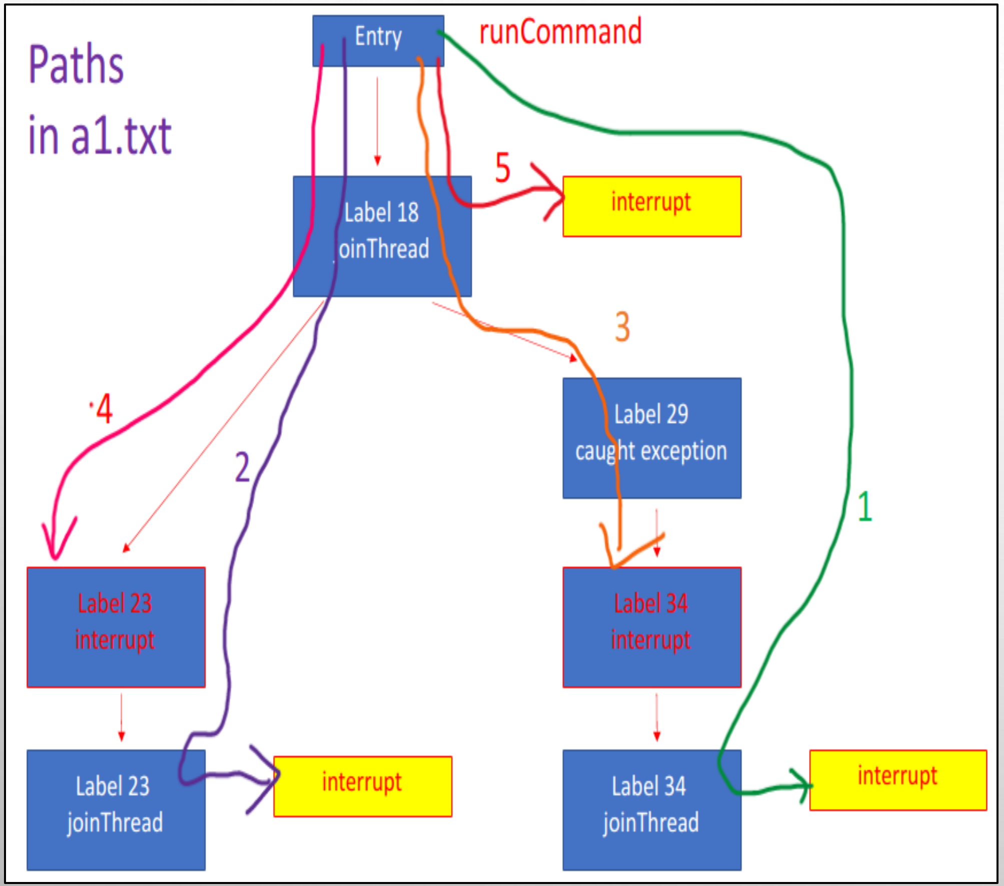
Reason

- Theoratically, there are five propagation paths to interrupt().

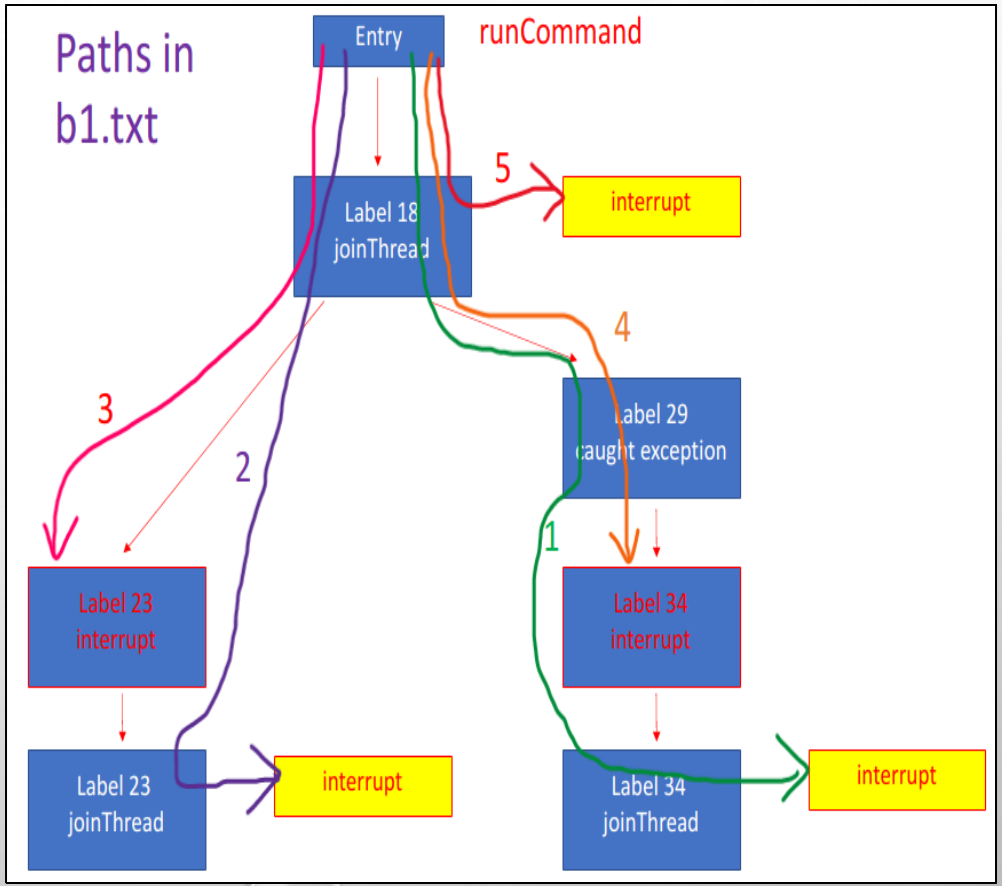


Reason

- However, I get two different outputs after this adjustment.



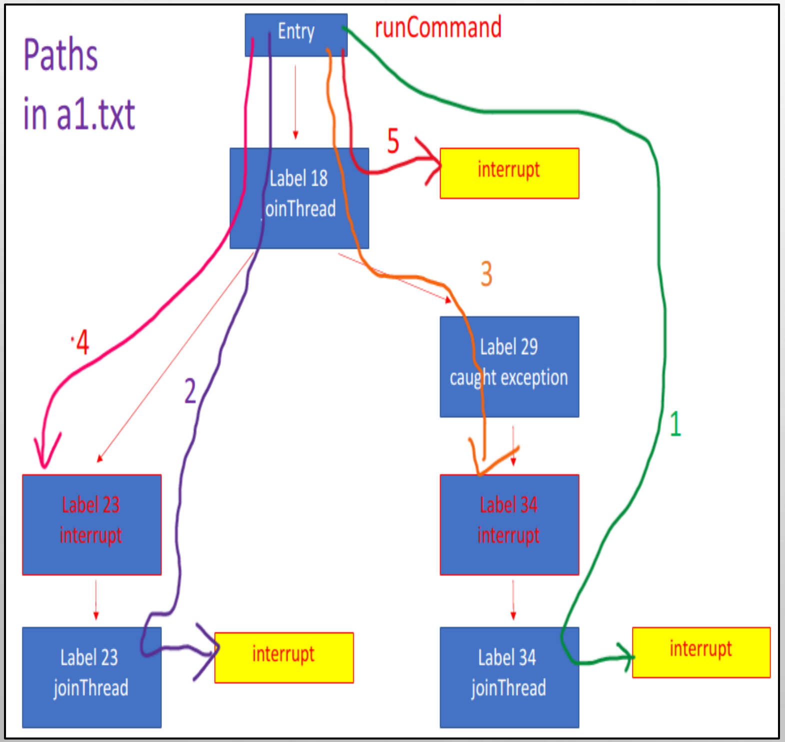
a1.txt



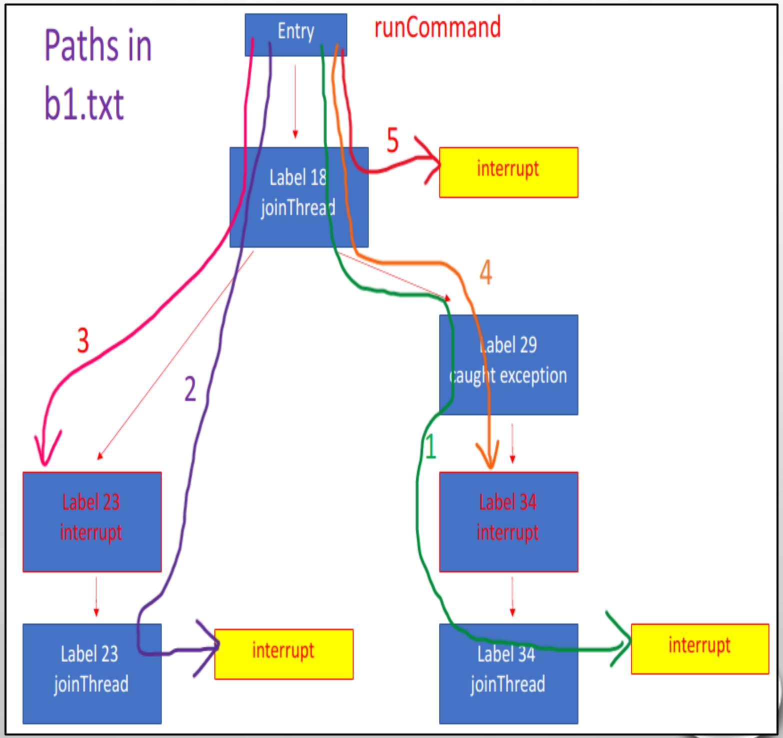
b1.txt

Reason

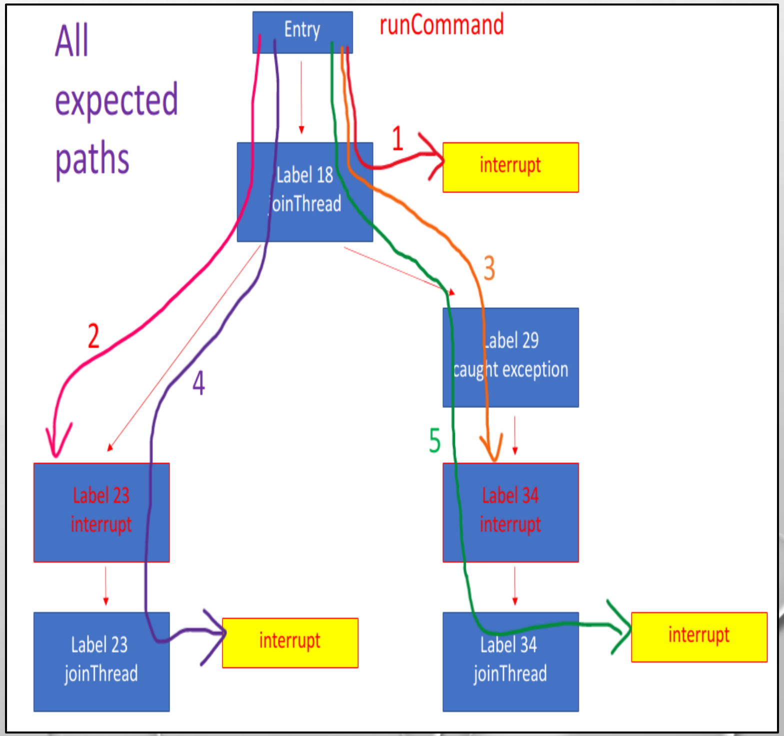
- From a1.txt and b1.txt, we can find that
  - joinThread() at Label 23 and Label 34 can be reached by skipping interrupt().
  - only path 1 in a1.txt and path 1 in b1.txt are different.



a1.txt



b1.txt



expected

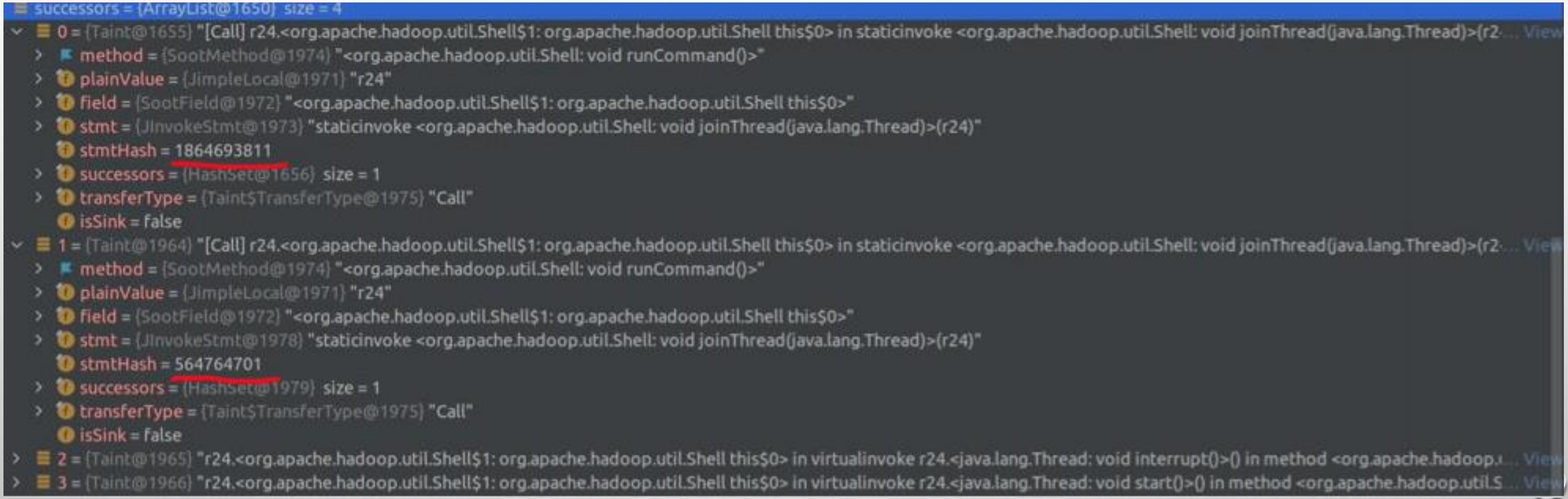
Reason

- I use IntelliJ IDEA to trace the path reconstruction step.
- Before the trace, I record the identityHashCode of each invoke statement of method joinThread() and interrupt().
- I have found a difference when current taint is

```
r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in r24
= $r87 in method <org.apache.hadoop.util.Shell: void runCommand()>
```

Reason

- In one case, the sorted list successors is

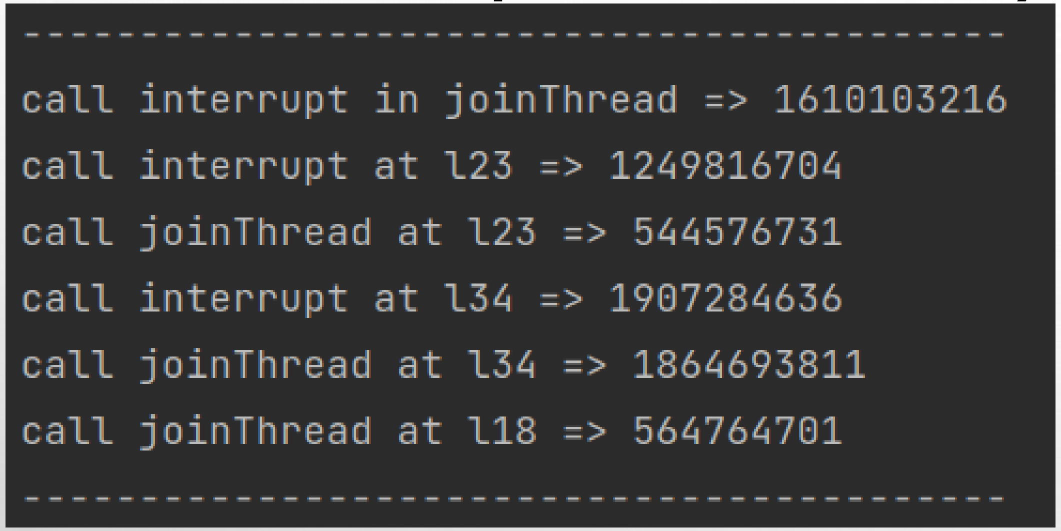


```
≡ successors = {ArrayList@1650}  size = 4
∨ ≡ 0 = {Taint@1655} "[Call] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r2... View
  > method = {SootMethod@1974} "<org.apache.hadoop.util.Shell: void runCommand()>"
  > plainValue = {JimpleLocal@1971} "r24"
  > field = {SootField@1972} "<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0>"
  > stmt = {JInvokeStmt@1973} "staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24)"
    stmtHash = 1864693811
  > successors = {HashSet@1656}  size = 1
  > transferType = {Taint$TransferType@1975} "Call"
    isSink = false
∨ ≡ 1 = {Taint@1964} "[Call] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r2... View
  > method = {SootMethod@1974} "<org.apache.hadoop.util.Shell: void runCommand()>"
  > plainValue = {JimpleLocal@1971} "r24"
  > field = {SootField@1972} "<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0>"
  > stmt = {JInvokeStmt@1978} "staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24)"
    stmtHash = 564764701
  > successors = {HashSet@1979}  size = 1
  > transferType = {Taint$TransferType@1975} "Call"
    isSink = false
> ≡ 2 = {Taint@1965} "r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in virtualinvoke r24.<java.lang.Thread: void interrupt()>() in method <org.apache.hadoop.... View
> ≡ 3 = {Taint@1966} "r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in virtualinvoke r24.<java.lang.Thread: void start()>() in method <org.apache.hadoop.util.S... View
```

{ Invoke joinThread 1864693811 | Invoke joinThread 564764701 | Invoke interrupt | Invoke start }

Reason

- Since the Map from IdentityHashCode to Statement is



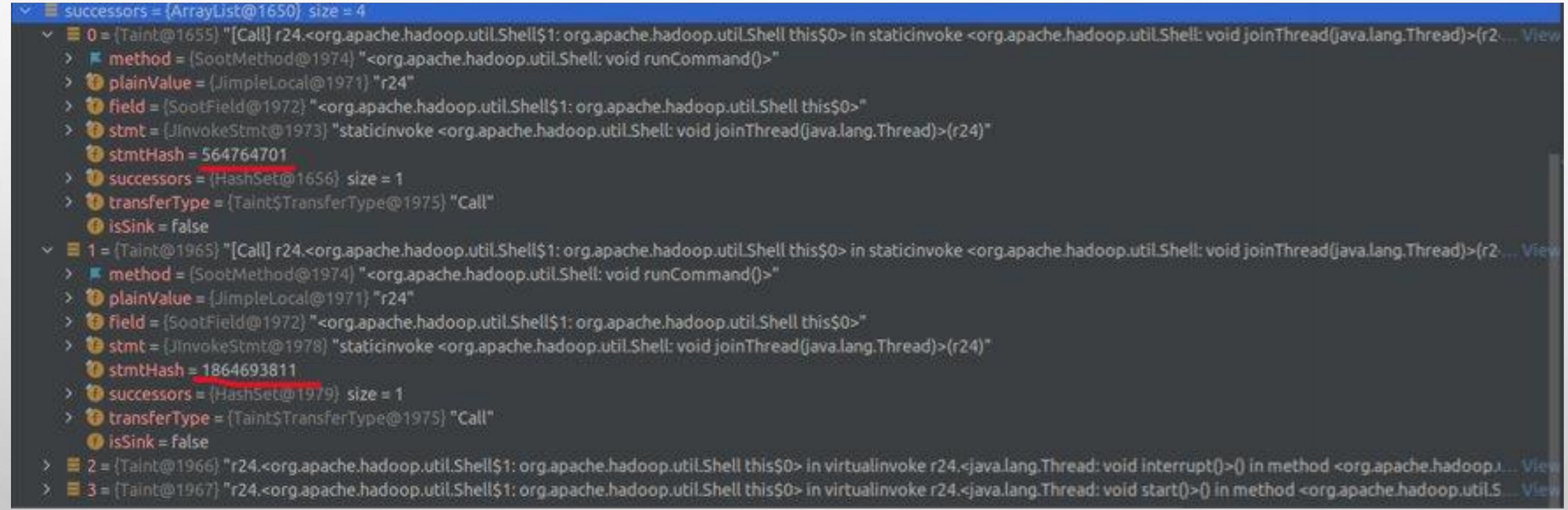
```
-----------------------------------------
call interrupt in joinThread => 1610103216
call interrupt at l23 => 1249816704
call joinThread at l23 => 544576731
call interrupt at l34 => 1907284636
call joinThread at l34 => 1864693811
call joinThread at l18 => 564764701
-----------------------------------------
```

- So successors is

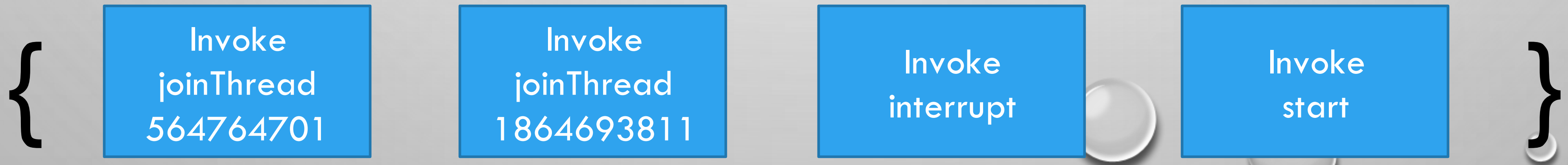
{ Invoke joinThread at Label 34 | Invoke joinThread at Label 18 | Invoke interrupt | Invoke start }

Reason

- In another case, the sorted list successors is

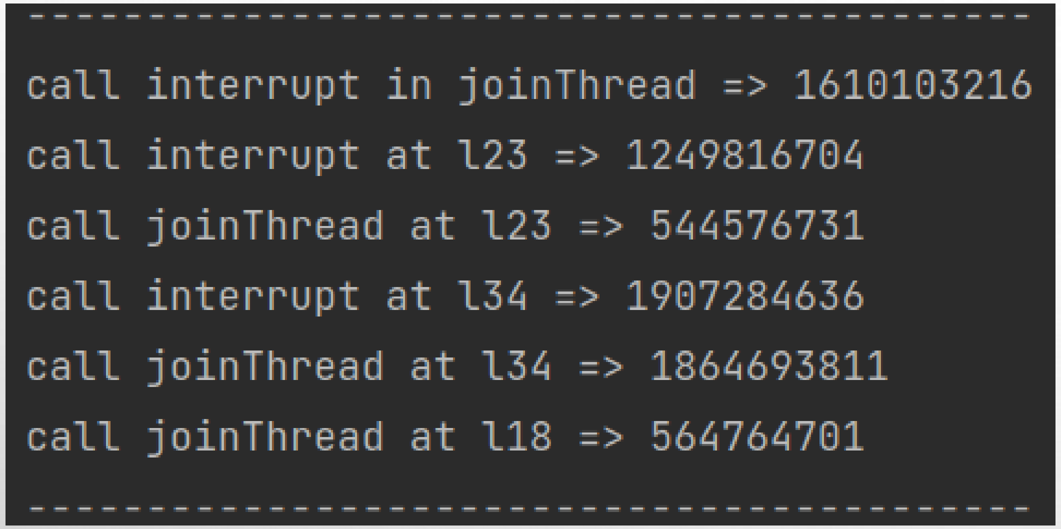


```
successors = {ArrayList@1650}  size = 4
  0 = {Taint@1655} "[Call] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r2... View
    method = {SootMethod@1974} "<org.apache.hadoop.util.Shell: void runCommand()>"
    plainValue = {JimpleLocal@1971} "r24"
    field = {SootField@1972} "<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0>"
    stmt = {JInvokeStmt@1973} "staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24)"
    stmtHash = 564764701
    successors = {HashSet@1656}  size = 1
    transferType = {Taint$TransferType@1975} "Call"
    isSink = false
  1 = {Taint@1965} "[Call] r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r2... View
    method = {SootMethod@1974} "<org.apache.hadoop.util.Shell: void runCommand()>"
    plainValue = {JimpleLocal@1971} "r24"
    field = {SootField@1972} "<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0>"
    stmt = {JInvokeStmt@1978} "staticinvoke <org.apache.hadoop.util.Shell: void joinThread(java.lang.Thread)>(r24)"
    stmtHash = 1864693811
    successors = {HashSet@1979}  size = 1
    transferType = {Taint$TransferType@1975} "Call"
    isSink = false
  2 = {Taint@1966} "r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in virtualinvoke r24.<java.lang.Thread: void interrupt()>() in method <org.apache.hadoop.... View
  3 = {Taint@1967} "r24.<org.apache.hadoop.util.Shell$1: org.apache.hadoop.util.Shell this$0> in virtualinvoke r24.<java.lang.Thread: void start()>() in method <org.apache.hadoop.util.S... View
```



Reason

- Since the Map from IdentityHashCode to Statement is



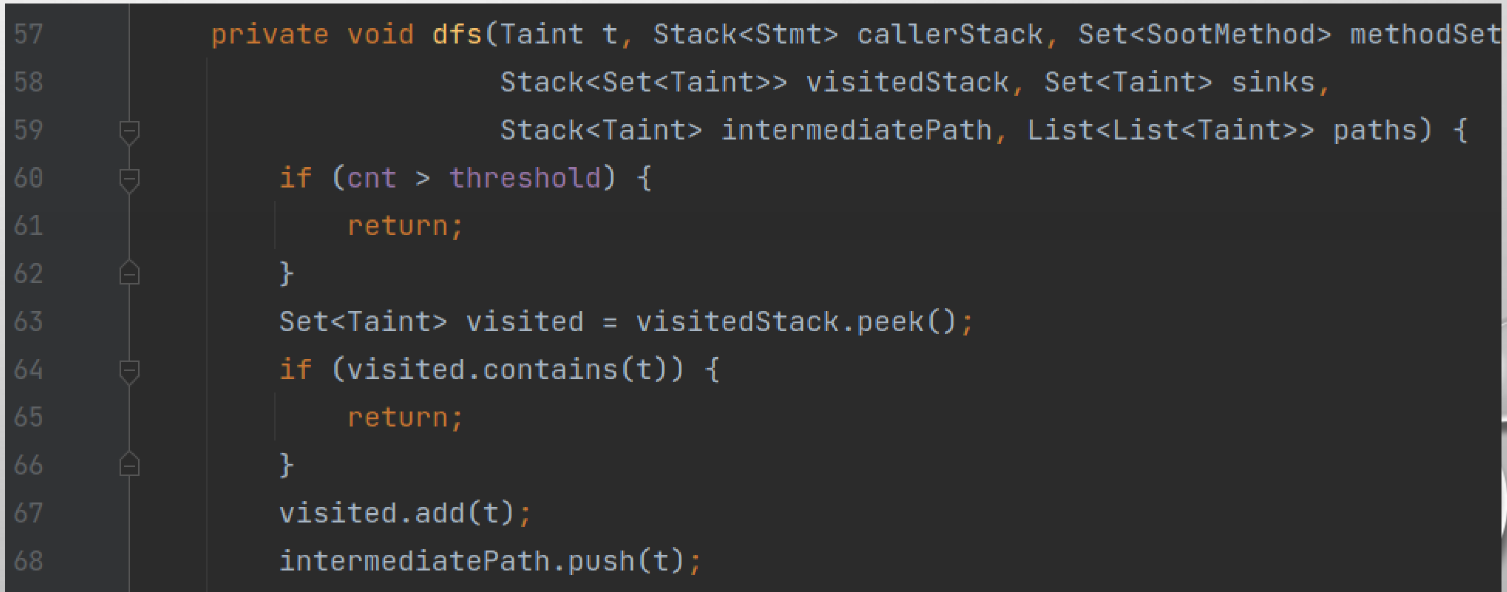
```
------------------------------------------

call interrupt in joinThread => 1610103216
call interrupt at l23 => 1249816704
call joinThread at l23 => 544576731
call interrupt at l34 => 1907284636
call joinThread at l34 => 1864693811
call joinThread at l18 => 564764701

------------------------------------------
```

- So successors is

{ Invoke joinThread at Label 18 | Invoke joinThread at Label 34 | Invoke interrupt | Invoke start }

Reason

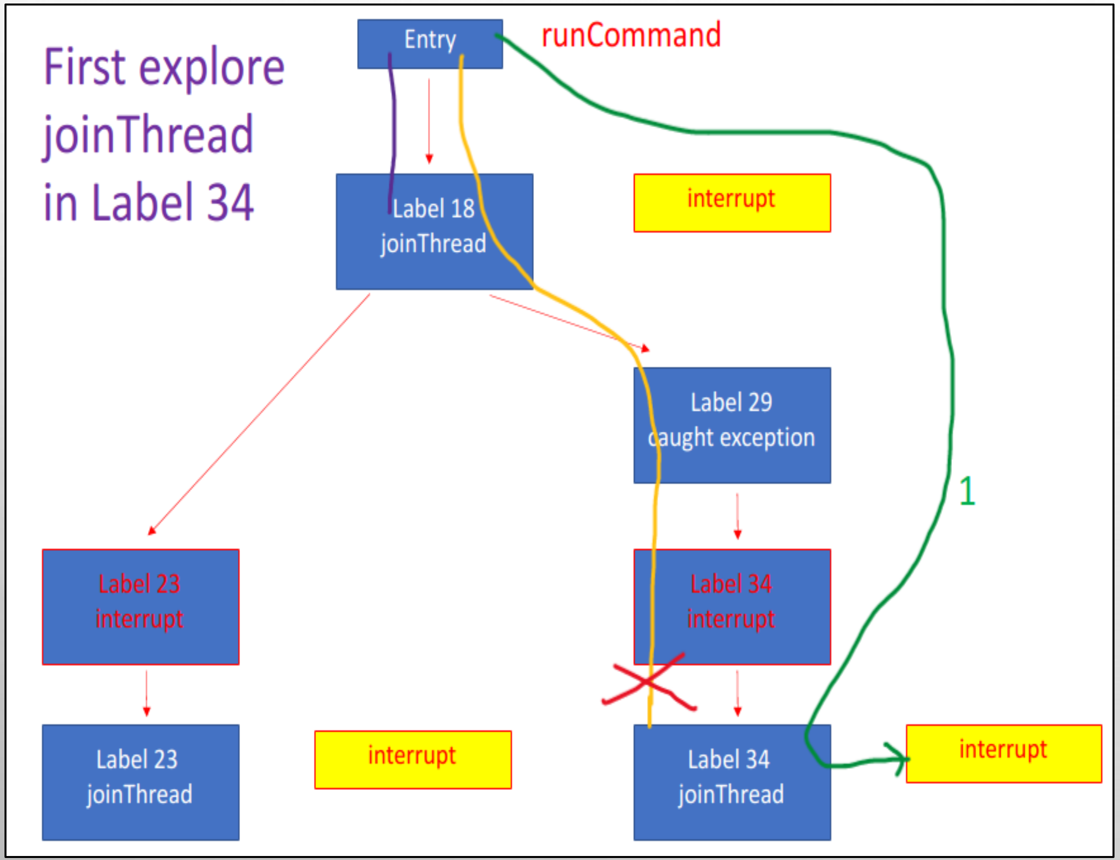
- Different sequence in successors(as an open list) can cause different sequence of DFS searching, which contributes to different paths due to visitedStack.
- VisitedStack can avoid repetitious visit to one taint in the same procedure.



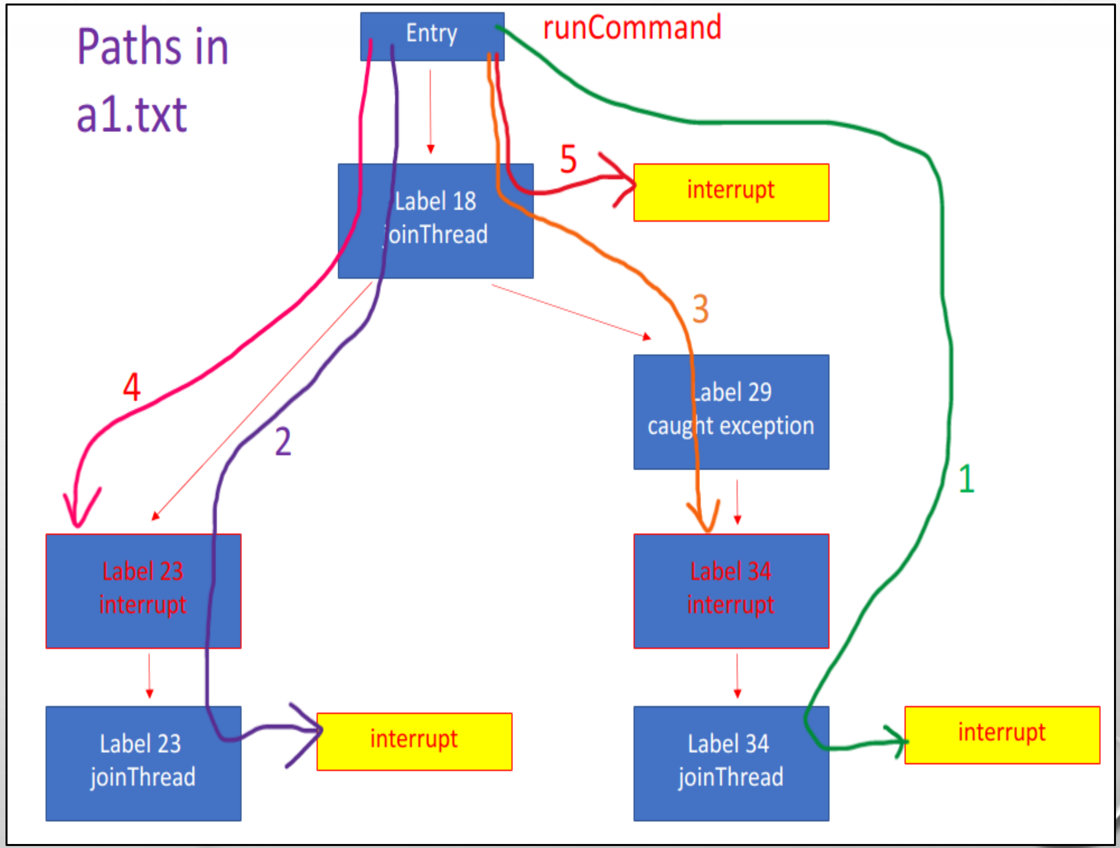
```
    private void dfs(Taint t, Stack<Stmt> callerStack, Set<SootMethod> methodSet
                     Stack<Set<Taint>> visitedStack, Set<Taint> sinks,
                     Stack<Taint> intermediatePath, List<List<Taint>> paths) {
        if (cnt > threshold) {
            return;
        }
        Set<Taint> visited = visitedStack.peek();
        if (visited.contains(t)) {
            return;
        }
        visited.add(t);
        intermediatePath.push(t);
```

Reason

- The first case causes the result of a1.txt.



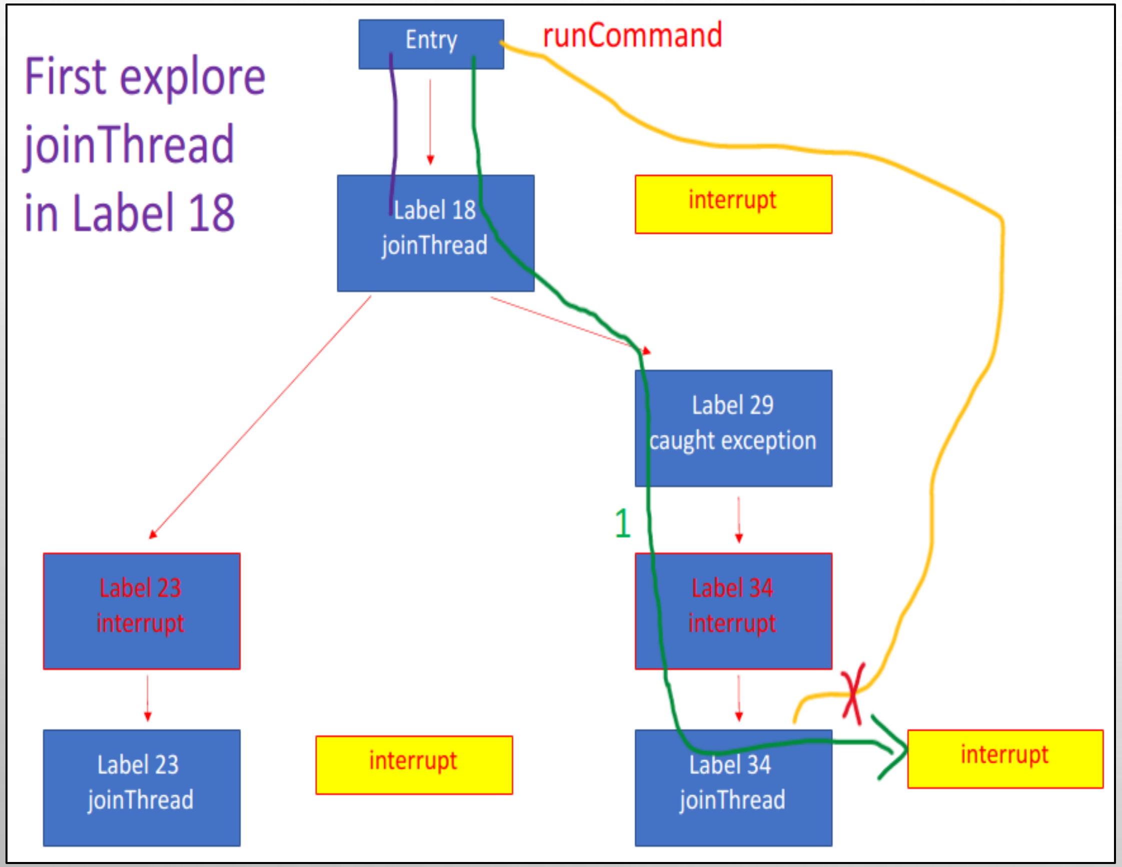
Searching case 1



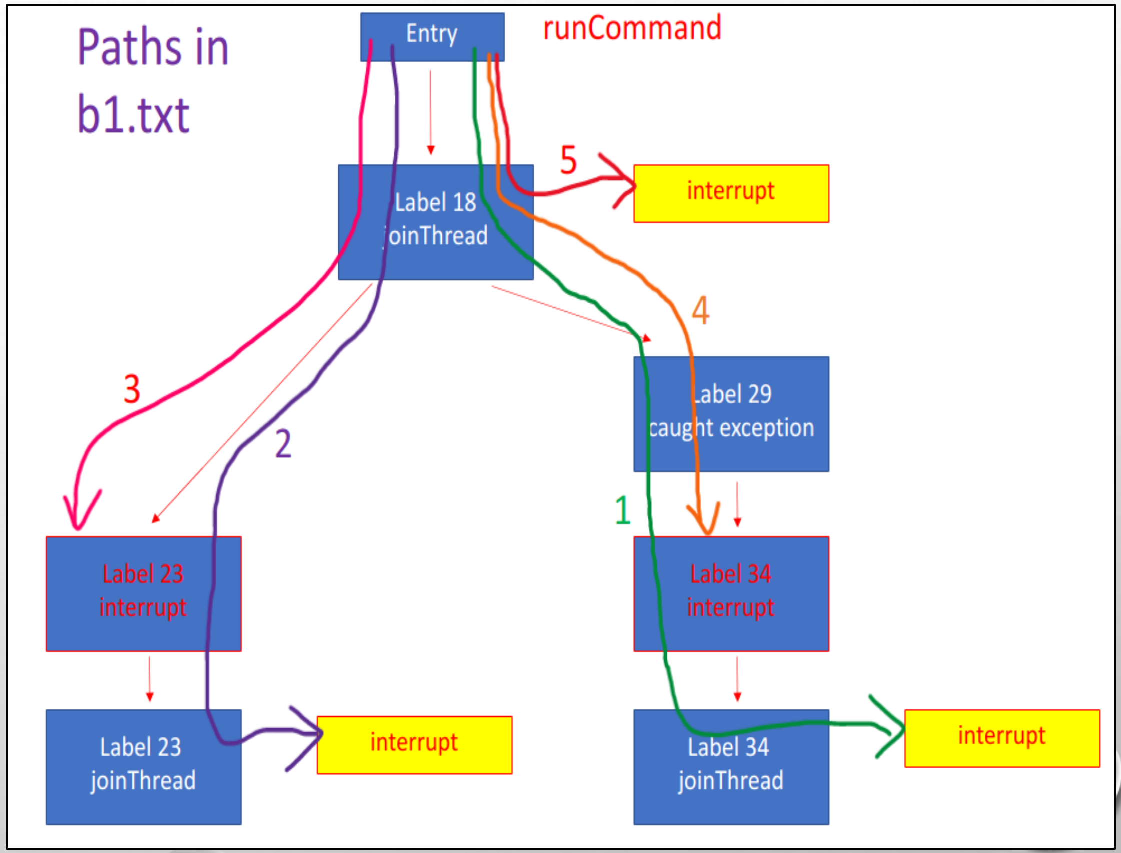
a1.txt

Reason

- Another case causes the result of b1.txt.



Searching case 2



b1.txt

Reason

- Why successors is not deterministically sorted after the sort?
  - Originally, the sequence of taints appended into successors is not deterministic(Soot???)
  - The sort is stable and it is based on the comparison on the string representation of taint. However, Two taints on invoke statement of joinThread() has the same string representation

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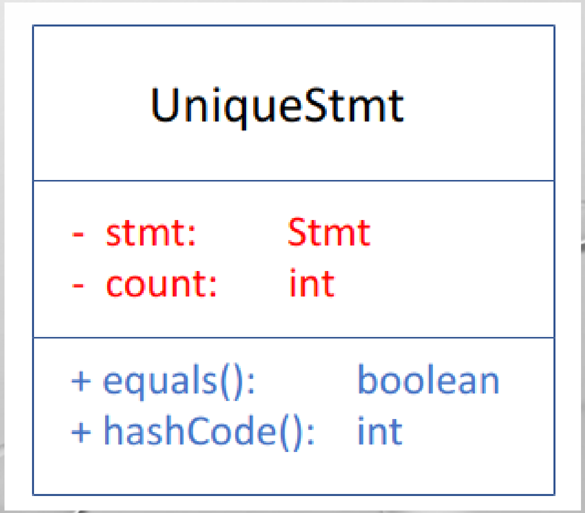
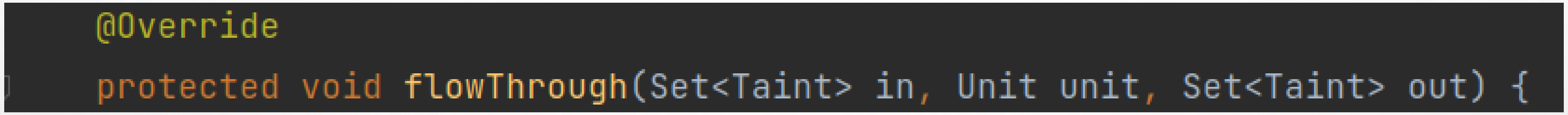
Solution

- Since it is not easy to change the feature of Soot , I try to add more information to each statement for comparison.
- Here, I encapsulate each statement with its sequence number(count) as UniqueStmt, so those statements are distinct in comparison.



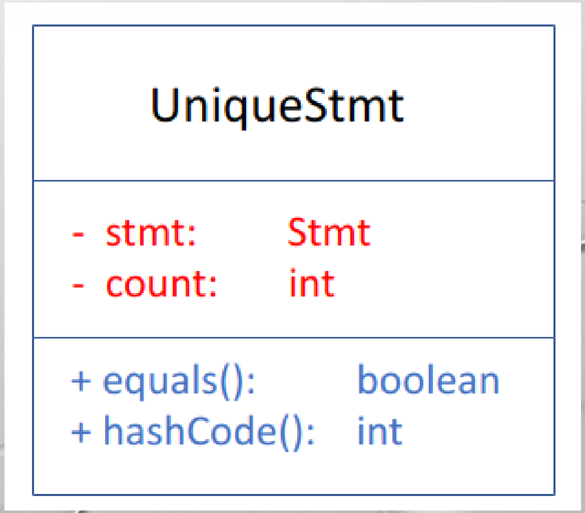
Solution

- I get UniqueStmt for each statement in method flowThrough()



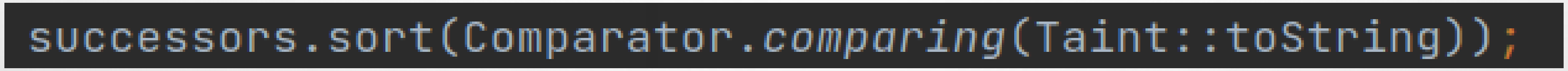
```
    @Override
    protected void flowThrough(Set<Taint> in, Unit unit, Set<Taint> out) {
```

- To save memory, I use some HashMaps to maintain a cache for UniqueStmts that have been created. And It requires some time for caching.



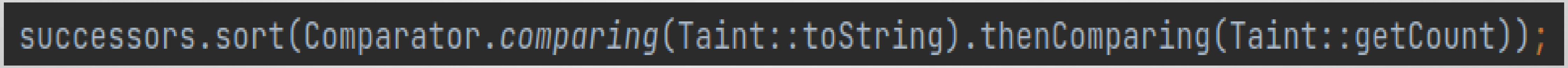
Solution

- Then I only need to add the info of statement count for comparison. That is, I change the comparison from



```
successors.sort(Comparator.comparing(Taint::toString));
```

to



```
successors.sort(Comparator.comparing(Taint::toString).thenComparing(Taint::getCount));
```

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Result

- I test the revised cFlow on hadoop_common 3.3.0 for 10 times and check the outputs.
- All output files contain 28746 lines and they only differ in execution time.

deterministic

- Both versions have 29 iterations to build taint propagation graph. However, the original one requires 50s, but the revised one requires 3min 20s.

Sacrifices performance

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Next step

- Test cFlow on more applications
- Consider implicit taint propagation
- Consider Alias Analysis