Software Verification Witnesses

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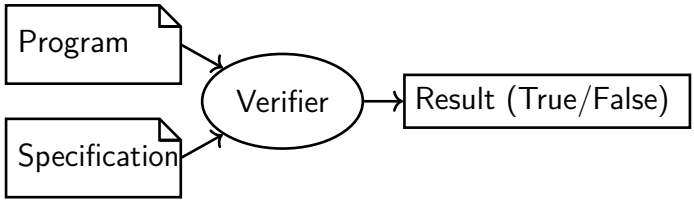
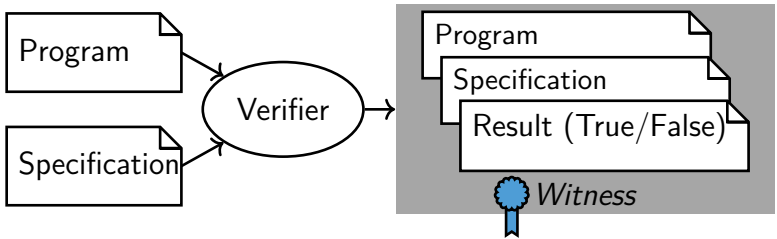
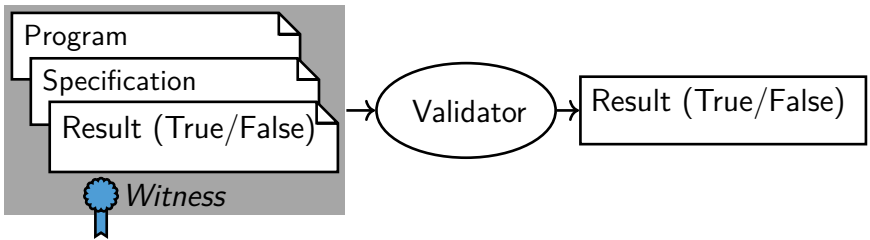
Software Verification



Software Verification with Witnesses



Witness Validation



- Validate untrusted results
- Easier than full verification

Purpose of Witnesses

- Validate verification results
- Provide insights into the verification process
- Exchange information between different tools

Software Verification Witnesses

Correctness Witnesses:

- Contains invariants
- Aids in reconstructing the proof

Violation Witnesses:

- Encode a set of paths
- At least one of the paths is a violation
- Aids in replaying a violation

Witnesses 2.0

- Contain a list of entries
  - **invariant_set**: part of a correctness witness
  - **violation_sequence**: part of a violation witness
- Metadata with information about the producer, program, and specification
- Content with the actual witness data

```
- entry_type: <...>
  metadata:
    format_version: "2.0"
    uuid: ""
    creation_time: ""
    producer:
      name: "CPAchecker"
      version: "2.3.1-svn"
      configuration: "svcomp24"
    task:
      input_files: <...>
      input_file_hashes: <...>
      specification: <...>
      data_model: "ILP32"
      language: "C"
  content: <...>
```

Correctness Witness 2.0

```
1  int main(void) {
2    short x = nondet();
3    int y = x;
4
5    while (x < 1024) {
6      x++;
7      y++;
8    }
9
10   assert(x == y);
11 }
```

```
1  <...>
2  content:
3  - invariant:
4      type: "loop_invariant"
5      location:
6        file_name: "example.c"
7        line: 5
8        column: 3
9        function: "main"
10     value: "( y == x )"
11     format: "c_expression"
```

Correctness Witnesses 2.0

- Contain a set of location and loop invariants
- **location invariant**: holds for every path through the given location
- **loop invariant**: holds for every path before the loop condition is evaluated

```
1  <...>
2  content:
3  - invariant:
4      type: "loop_invariant"
5      location:
6        file_name: "example.c"
7        line: 5
8        column: 3
9        function: "main"
10     value: "( y == x )"
11     format: "c_expression"
```

Witnesses With Function Contracts (WIP)

```c
int fib(int x) {
    if (x <= 1) {
        return 1;
    }
    return fib(x - 1) +
           fib(x - 2);
}

int main() {
    assert(fib(3) == 3);
}
```

```
<...>
content:
- invariant:
    type: "function_contract"
    location:
      file_name: "./example.c"
      line: 1
      column: 5
      function: "fib"
    requires: '0 <= x <= 3'
    ensures: "((0 <= x <= 1) ==> \result == 1)
          && (x == 2 ==> \result == 2)
          && (x == 3 ==> \result == 3)"
    format: "acsl_expression"
```

Violation Witness 2.0

```c
int main(void) {
  short x = nondet();
  int y = x + 1;

  while (x < 1024) {
    x++;
    y++;
  }

  assert(x == y);
}
```

```yaml
<...>
content:
- segment:
  - waypoint:
      type: assumption
      location:
        line: 3
        file_name: 'example.c'
      constraint:
        value: "x == 1024"
- segment:
  - waypoint:
      type: branching
      location:
        line: 5
        file_name: 'example.c'
      constraint:
        value: false
- segment:
  - waypoint:
      type: target
      location:
        line: 10
        file_name: 'example.c'
```

Violation Witnesses 2.0

- Contain a set of waypoints
- **follow**: the waypoint has to be passed as soon as the location is entered
- **avoid**: the run represented by the witness must not pass the waypoint (“sink node”)
- **target**: the property violation

```
1  <...>
2  content:
3  - segment:
4    - waypoint:
5        type: assumption
6        location:
7          line: 3
8          file_name: 'example.c'
9        constraint:
10         value: "x == 1024"
11 - segment:
12   - waypoint:
13       type: branching
14       location:
15         line: 5
16         file_name: 'example.c'
17       constraint:
18         value: false
19 - segment:
20   - waypoint:
21       type: target
22       location:
23         line: 10
24         file_name: 'example.c'
```

Violation Witnesses 2.0

Follow Waypoints

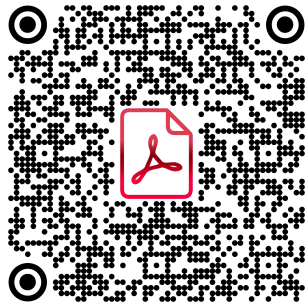
- **assumption**: the constraint must be valid before executing the statement
- **branching**: follow the given branch at the location
- **function_enter**: the function must be entered
- **function_return**: the value returned by the function

```
<...>
content:
- segment:
  - waypoint:
      type: assumption
      location:
        line: 3
        file_name: 'example.c'
      constraint:
        value: "x == 1024"
- segment:
  - waypoint:
      type: branching
      location:
        line: 5
        file_name: 'example.c'
      constraint:
        value: false
- segment:
  - waypoint:
      type: target
      location:
        line: 10
        file_name: 'example.c'
```

Conclusion

Witnesses contain machine-readable data to:

- Provide insights into the verification process
- Increase confidence in the verification results
- Allow for information exchange

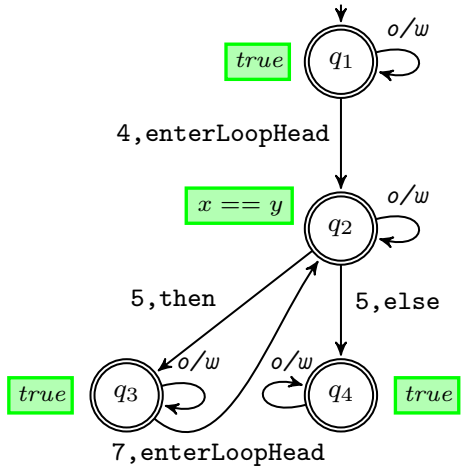


Witnesses version 2.0

Witnesses Version 1.0

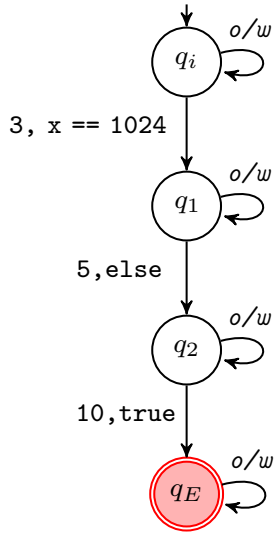
Correctness Witnesses 1.0

```
1  int main(void) {
2    short x = nondet();
3    int y = x;
4
5    while (x < 1024) {
6      x++;
7      y++;
8    }
9
10   assert(x == y);
11 }
```



Violation Witnesses 1.0

```
1  int main(void) {
2    short x = nondet();
3    int y = x + 1;
4
5    while (x < 1024) {
6      x++;
7      y++;
8    }
9
10   assert(x == y);
11 }
```



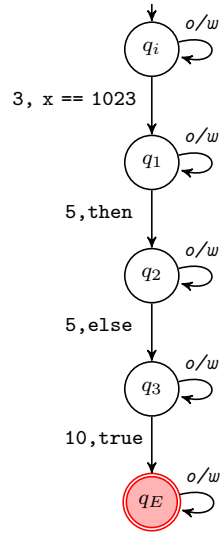
Why do we need Version 2.0?

Software Verification Witnesses 1.0: Unreadable Files

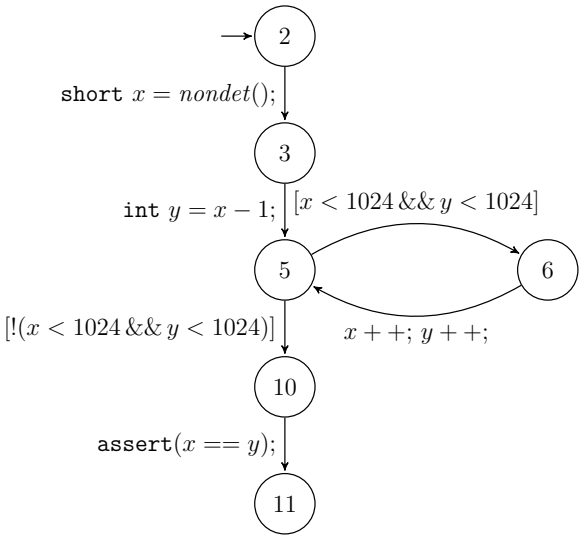
```
 1 <node id="A0">
 2 <data key="entry">true</data>
 3 </node>
 4 <node id="A2_3_1"/>
 5 <edge source="A0" target="A2_3_1">
 6 <data key="startline">4</data>
 7 <data key="endline">4</data>
 8 <data key="enterFunction">main</data>
 9 </edge>
10 <node id="A2"/>
11 <edge source="A2_3_1" target="A2">
12 <data key="enterLoopHead">true</data>
13 <data key="startline">6</data>
14 <data key="endline">6</data>
15 <data key="endoffset">130</data>
16 </edge>
```

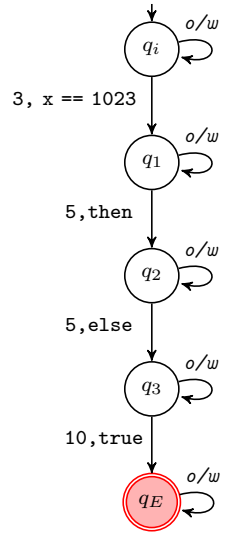
Software Verification Witnesses 1.0: Unclear semantics

```
1  int main(void) {
2    short x = nondet();
3    int y = x - 1;
4
5    while (x < 1024 && y < 1024) {
6      x++;
7      y++;
8    }
9
10   assert(x == y);
11 }
```

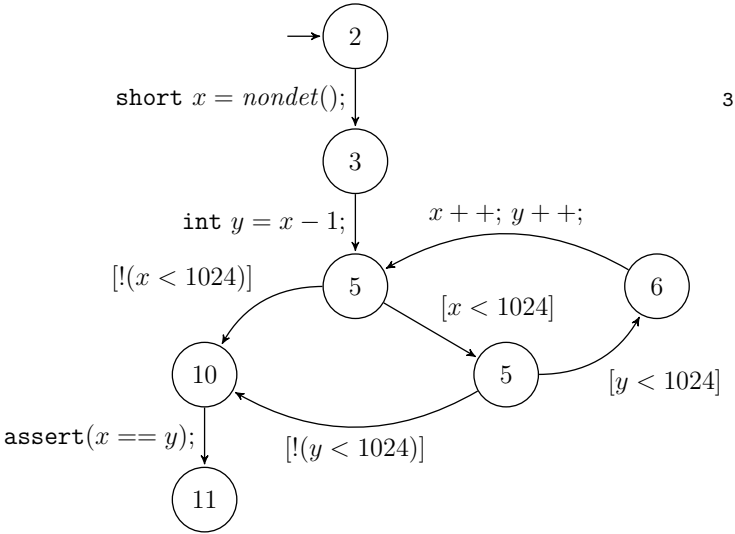


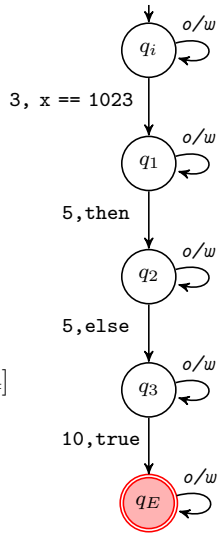
Software Verification Witnesses 1.0: Unclear semantics





Software Verification Witnesses 1.0: Unclear semantics





Version 1.0 vs. Version 2.0

Version 1.0 vs. Version 2.0

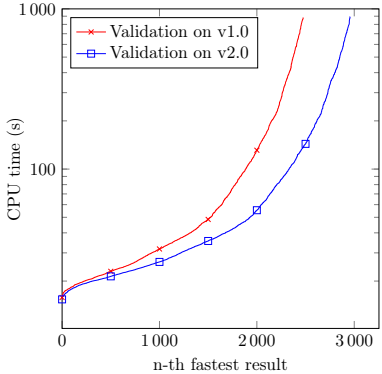
Version 1.0:

- ✗ Tied to the control-flow automaton
  - ⇒ Unclear semantics
  - ⇒ No underlying standard
  - ⇒ Harder to exchange information
- ✗ Difficult to read as file
- ✓ More complex
- ✓ Supports more properties
- ✗ Difficult to extend

Version 2.0:

- ✓ Tied to the program syntax
  - ⇒ Clear semantics
  - ⇒ Based on the C-Standard
  - ⇒ Easier to exchange information
- ✓ Human-readable
- ✗ Less complex
- ✗ Supports fewer properties
- ✓ Easy to extend

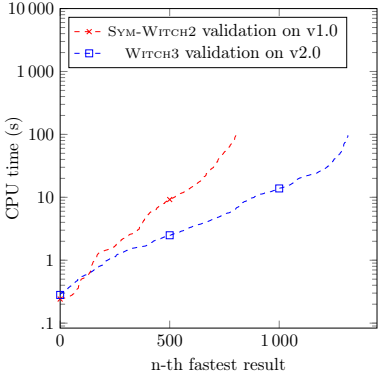
Version 1.0 vs. Version 2.0: Validation Correctness



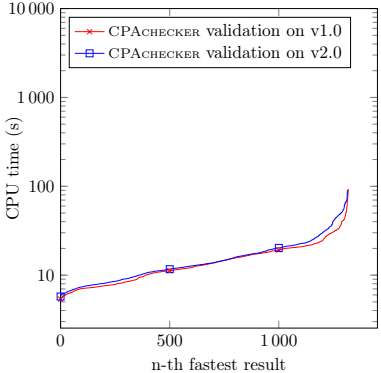
(a) Validation using UAutomizer

Correctness witnesses produced by CPAchecker: Quantile plots for the time taken for validation of the old and new witnesses for UAutomizer

Version 1.0 vs. Version 2.0: Validation Violation



(b) Validation of violation witnesses generated by CPAchecker



(c) Validation of violation witnesses generated by Symbiotic

Violation witnesses: Quantile plots for the time taken for validation of the old and the new witnesses generated by two different verifiers for two different validators

File Sizes Correctness Witnesses

	Witnesses v1.0			Witnesses v2.0		
Attribute	Min	Median	Max	Min	Median	Max
Length in Lines of Code	53	1 536	1 014 533	18	28	1 058
Size in kB	3	52	35 573	1	1	965
Number of Invariants	0	1	162	0	1	104

Different attributes of correctness witnesses in version 1.0 and 2.0 generated by CPAchecker

File Sizes Violation Witnesses

	Witnesses v1.0			Witnesses v2.0		
Attribute	Min	Median	Max	Min	Median	Max
Length in Lines of Code	12	372	258 730	27	171	114 460
Size in kB	2	14	9 098	1	6	3 071
Number of Nodes	1	38	28 304	-	-	-
Number of Waypoints	-	-	-	1	13	9 537

Different attributes of violation witnesses in version 1.0 and 2.0 generated by CPAchecker and Symbiotic