Automated Fixing

# of Programs with Contracts

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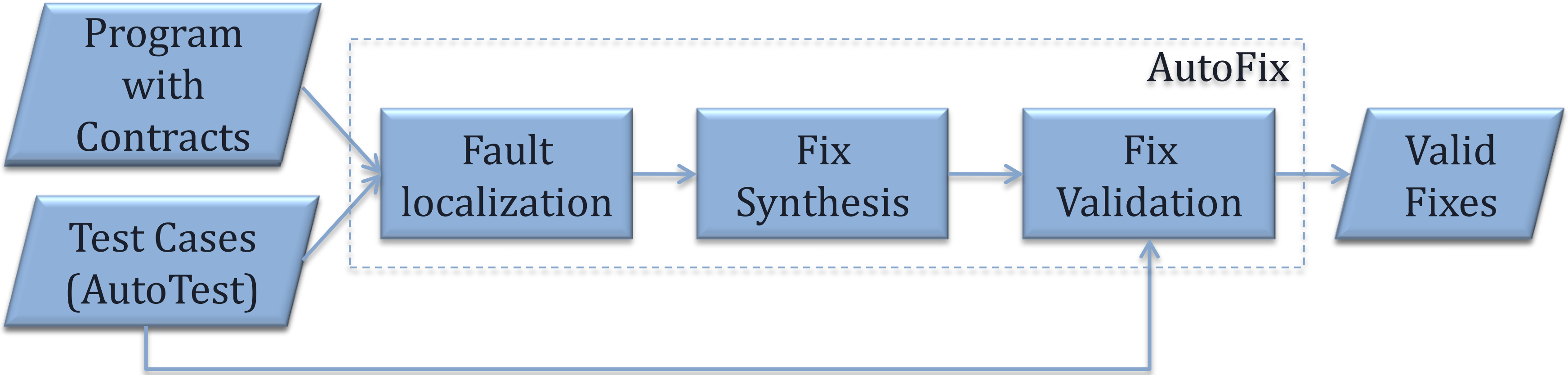
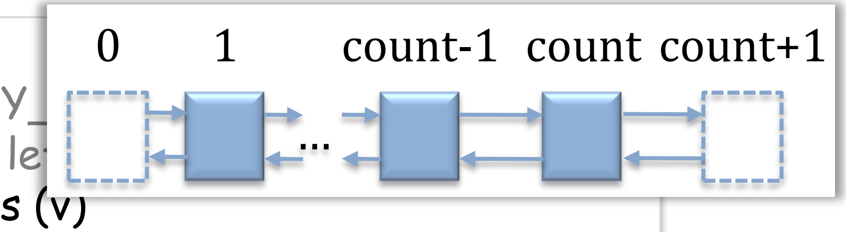
Overview


Program with Contracts
Test Cases (AutoTest)
AutoFix
Fault localization
Fix Synthesis
Fix Validation
Valid Fixes

Model-based Fault Localization

- Dynamic analysis
  - Difference between ***state invariants*** from passing and failing runs as the fault profile
  - State invariants in argument-less boolean queries

```
move_item (v: G)
        -- from TWO_WAY_
        -- Move `v' to the le
    require v /= Void ; has (v)
    local idx: INTEGER ; found: BOOLEAN
    do
        idx := index
        from start until found or after loop
            found := (v = item)
            if not found then forth end
        end
        remove
        go_i_th (idx)
        put_left (v)
    end
```



Invar. from passing

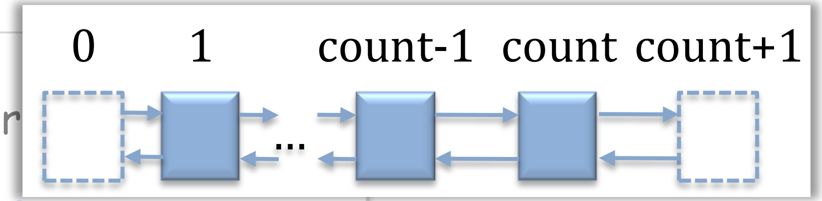
not is_empty
not before
not after
…

Invar. from failing

not is_empty
before
not after
…

Code-based Fault Localization

- Dynamic + Static Analysis
  - ***State components*** as candidate fault causes: <exp, loc, val>
  - Suspiciousness scores computed from
    - frequency of appearance in passing/failing runs
    - control dependence on the violation position
    - syntactical similarity with the failing assertion



```
1: move_item (v: G)
2:         -- Move `v' to the left of cursor
3:     require v /= Void ; has (v)
4:     local idx: INTEGER ; found: BOOLEAN
5:     do
6:         idx := index
7:         from start until found or after loop
8:             found := (v = item)
9:             if not found then forth end
10:        end
11:        remove
12:        go_i_th (idx)  -- <valid_index(idx), L-12, False>
13:        put_left (v)
14:    end
```

<index < idx, L-12, True> identified as a highly likely cause for fault.

Fixing Actions

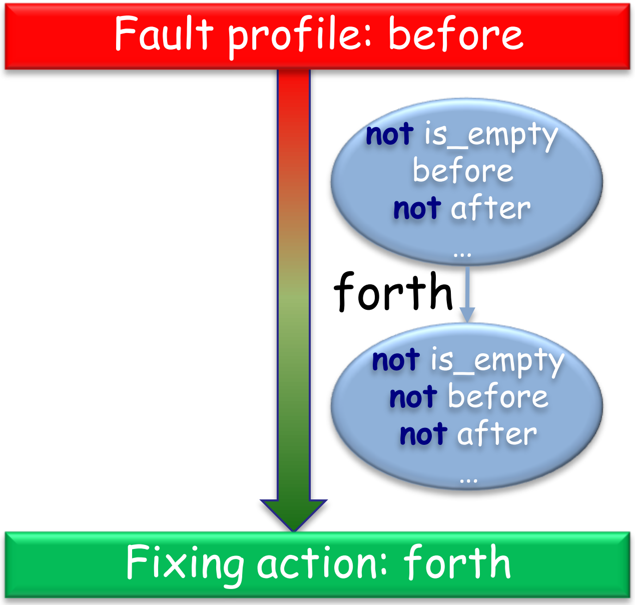
- Results of fault localization
  - Model-based: a list of <loc, inv>
  - Code-based: an ordered list of <exp, loc, val>
    - Order defined by the suspiciousness scores

- Fixing actions: code necessary for correcting the faulty state
  - Object behavioral model
  - Enumeration

Fixing Using Object Behavioral Model (OBM)

- Object behavioral model
  - Suggests how routines change object states
  - Contains a set of possible transitions
  - Can be learned from passing test executions

```
move_item (v: G)
        -- from TWO_WAY_SORTED_SET.
        -- Move `v' to the left of cursor.
    require v /= Void ; has (v)
    local idx: INTEGER ; found: BOOLEAN
    do
        idx := index
        from start until found or after loop
            found := (v = item)
            if not found then forth end
        end
        remove
        go_i_th (idx)
        put_left (v)
    end
```



Fixing by Enumeration

- Identify values that could be modified to affect the state
- Enumerate all applicable operations on the values
  - Fixing with state modification

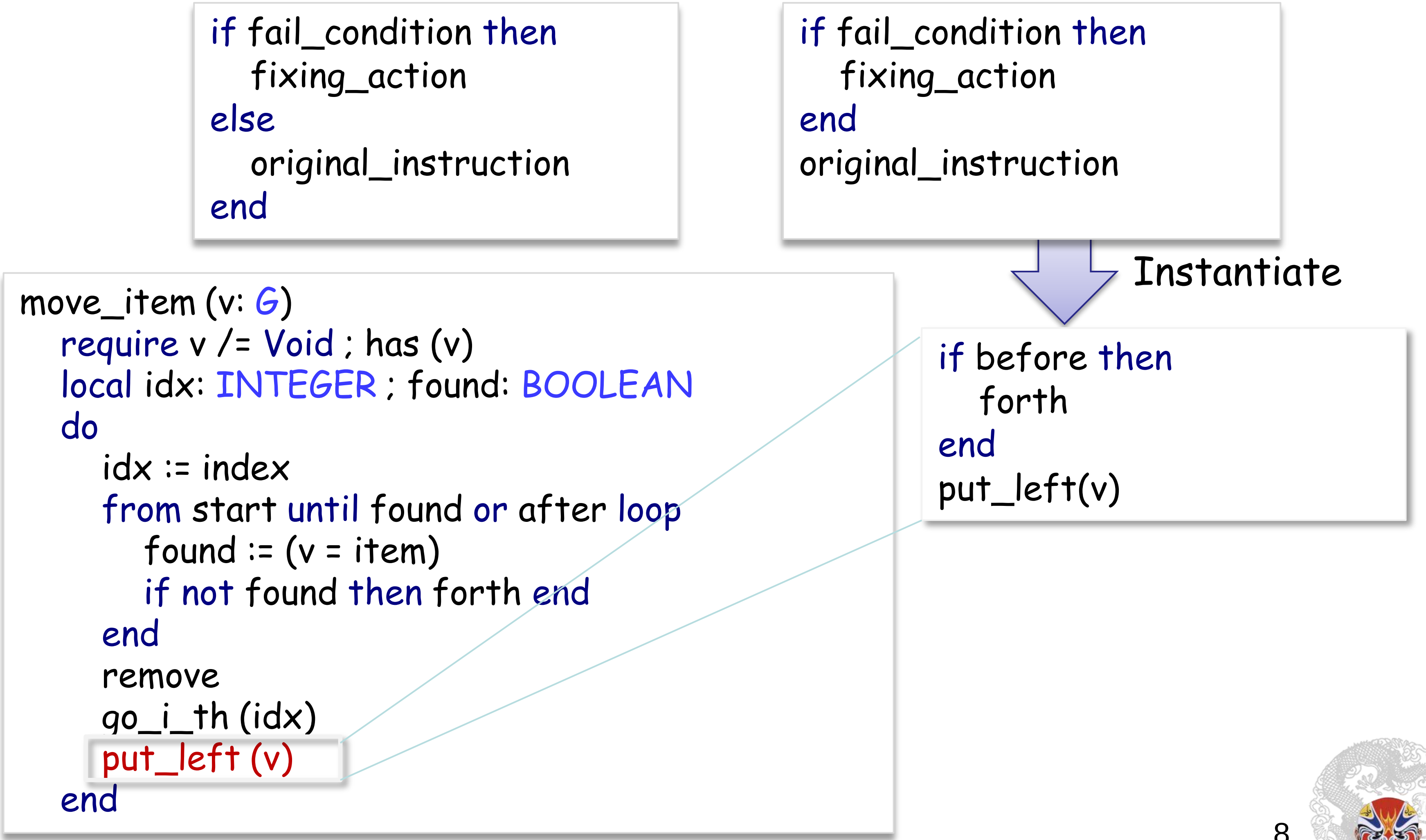
```
    -- <index<idx, L-12, True>
go_i_th (idx)          idx := idx – 1
```

  - Fixing with expression substitution

```
    -- <index<idx, L-12, True>
go_i_th (idx)          go_i_th (idx - 1)
```

Fix Synthesis

- Fix schemas capture common fixing styles.



```
if fail_condition then
    fixing_action
else
    original_instruction
end
```

```
if fail_condition then
    fixing_action
end
original_instruction
```

```
if before then
    forth
end
put_left(v)
```

```
move_item (v: G)
    require v /= Void ; has (v)
    local idx: INTEGER ; found: BOOLEAN
    do
        idx := index
        from start until found or after loop
            found := (v = item)
            if not found then forth end
        end
        remove
        go_i_th (idx)
        put_left (v)
    end
```

Validation and Ranking

- Validation
  - Run the patched program against all passing and failing tests, requiring
    - Passing tests still pass
    - Failing tests now pass
- Ranking
  - Static metrics favors
    - simple textual changes
    - changes close to the failing location
    - changes involving less original statements
  - Dynamic metric favors
    - behavioral preservation, i.e. passing tests should terminate in similar resulting states

Experimental Results

- Model-based fault localization + fixing actions from OBM
  - 42 faults from EiffelBase & Gobo: fixed 16 (38%)
  - In a small user study, 4 out of 6 of the selected fixes are the same as those from programmers
- Code-based fault localization + fixing actions by enumeration
  - 64 faults from EiffelBase & Gobo: fixed 14 (22%)
  - 9 faults from a student project: fixed 5 (55%)

❖Results considering only proper fixes.

❖Average fixing time is a few minutes per fault

Summary

- A fully automated approach to program fixing, which
  - works with program with contracts,
  - takes (passing and failing) test cases as inputs,
  - exploits dynamic and static analysis techniques,
  - validates candidate fixes through regression, and
  - succeeds in proposing proper fixes to real program faults.

- AutoFix

  http://se.inf.ethz.ch/research/autofix/

Questions