Automatic Testing and Fixing of Programs with Contracts

Yu Pei

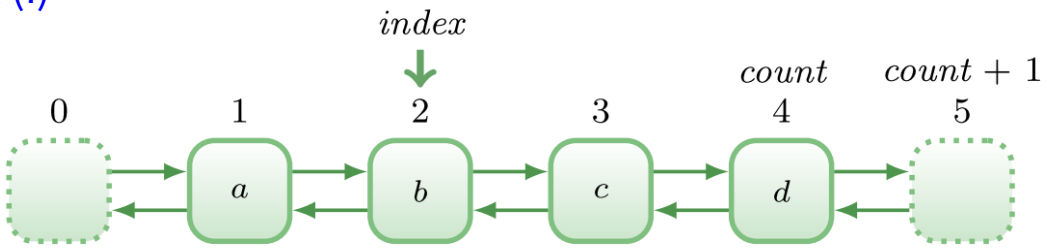
Chair of Software Engineering

Dec. 4, 2013

Design by contract

- Contracts in Eiffel

```
ARRAYED_CIRCULAR.go_i_th (i: INTEGER)
        -- Move cursor to `i'-th position.
    require
        valid_cursor_index (i)
    ensure
        index = i
```



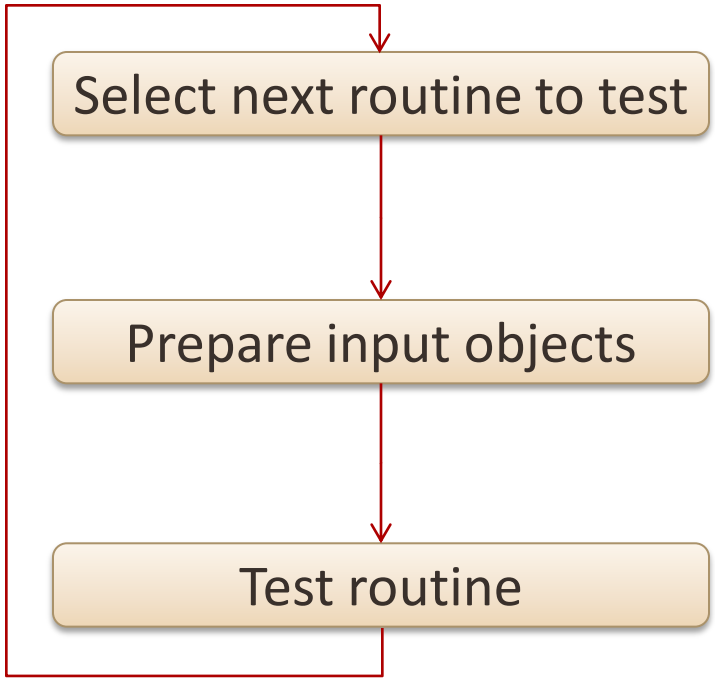
- Applications
  - Specification
  - Documentation
  - Testing & fixing

Automatic program testing

- Test case
  - Input
  - Oracle

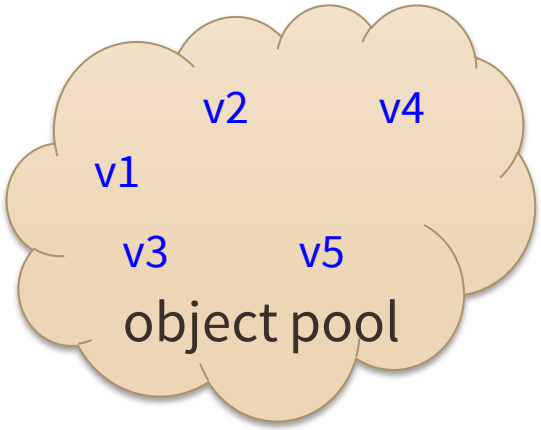
- **AutoTest**: Automatic testing programs with contracts
  - Precondition of the routine under test as the valid input filter
  - Postcondition of the routine as the oracle

The select-prepare-test cycle



Example testing process

```
create {ARRAYED_CIRCULAR [INTEGER]} v1.make
v2 := 1
v1.extend (v2)
v1.wipe_out
v3 := 125
v4 := v1.has (v3)
v5 := v1.count
```



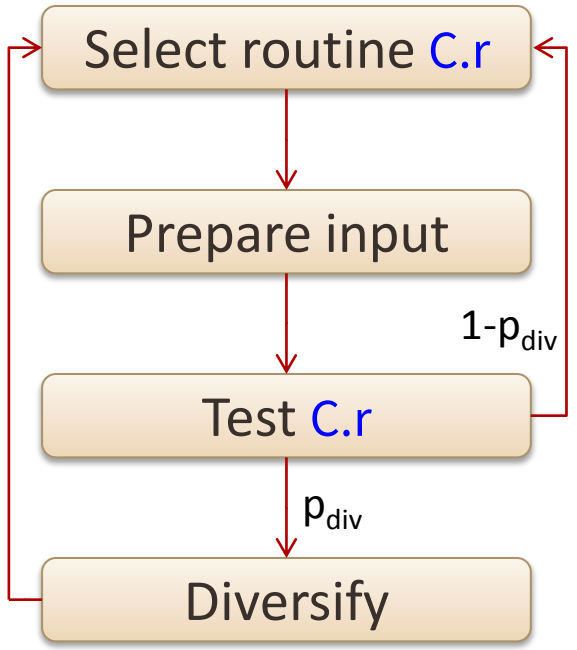
Performance evaluation

- Testing results
  - Precondition of the routine-under-test is violated
    - Invalid test case
  - Precondition of the routine-under-test is satisfied
    - Successful termination with postcondition satisfied
      - Passing test case
    - Premature termination or postcondition violation
      - Failing test case (detected fault)

- Evaluation criteria
  - Number of faults detected
  - Code coverage

Random+ testing

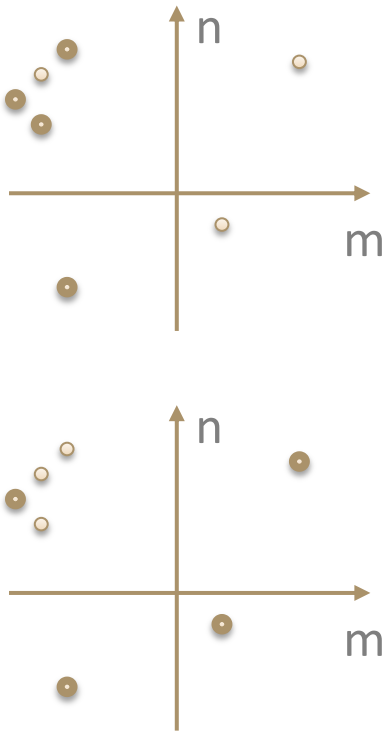
- Essentials
  - Input generation
    - Primitive types:
      random selection + boundary values
    - Reference types:
      random selection + constructor calls
  - Diversification
    - With probability p_{div} after each test



- Result
  - Find faults in widely used, industrial-grade code
  - High fault detection rate in the first a few minutes

Adaptive Random Testing (ART)

- Essentials
  - Maintain a list of objects O used in testing a routine r
  - Select the objects with the highest average *distance* to O for the next test of r

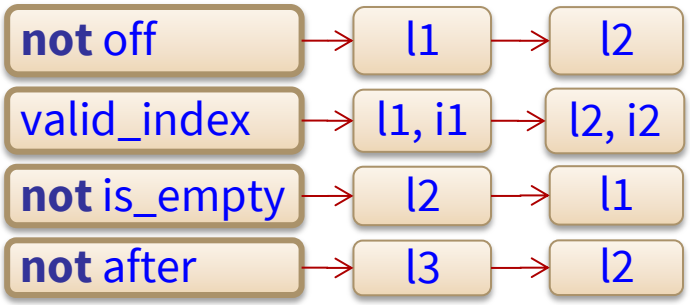


- Result
  - Takes less time and generated tests, on average by a factor of 5, to the first fault

Testing with guided object selection

- Essentials
  - Keep track of precondition-satisfying objects
  - Use them with higher probability

```
ARRAYED_CIRCULAR.swap (i: INTEGER)
      -- Exchange item at `i'-th position
      -- with item at cursor position.
   require
      not off
      valid_index (i)
```



v-pool

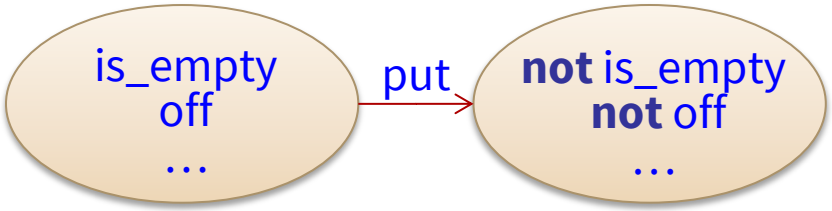
- Results
  - 56% of the routines that cannot be tested before are now tested
  - 10% more faults detected in the same time
  - Routines tested 3.6 times more often

Stateful testing

- Essentials
  - Input space and object states in Boolean expressions

    ARRAYED_CIRCULAR.swap (i: INTEGER)

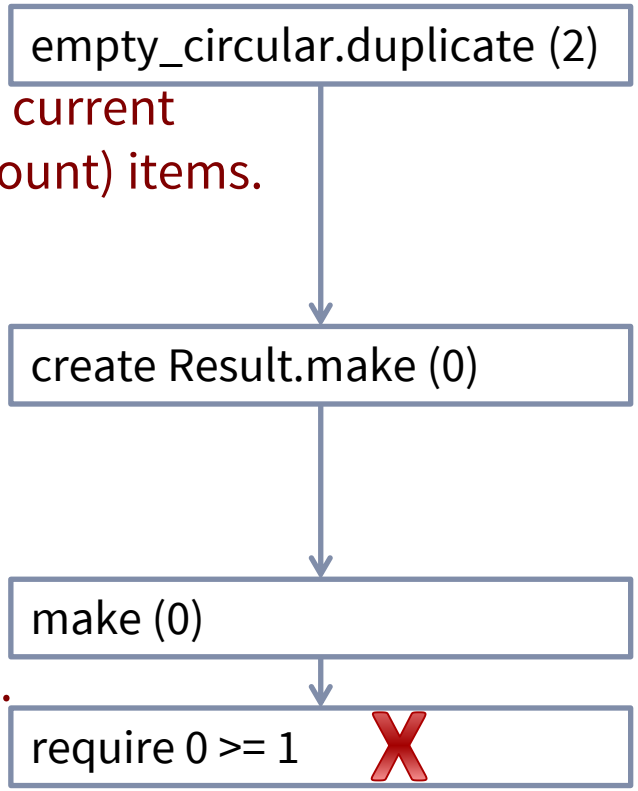
    - before, after, is_empty, i > 0, …
  - Infer preconditions from existing tests
    - Boolean expressions that always hold
  - Prepare inputs violating the inferred preconditions
    - Select objects in the object pool
    - Transit objects using *object behavioral model*



- Result
  - 68% more faults detected with 7% time overhead

An example fault

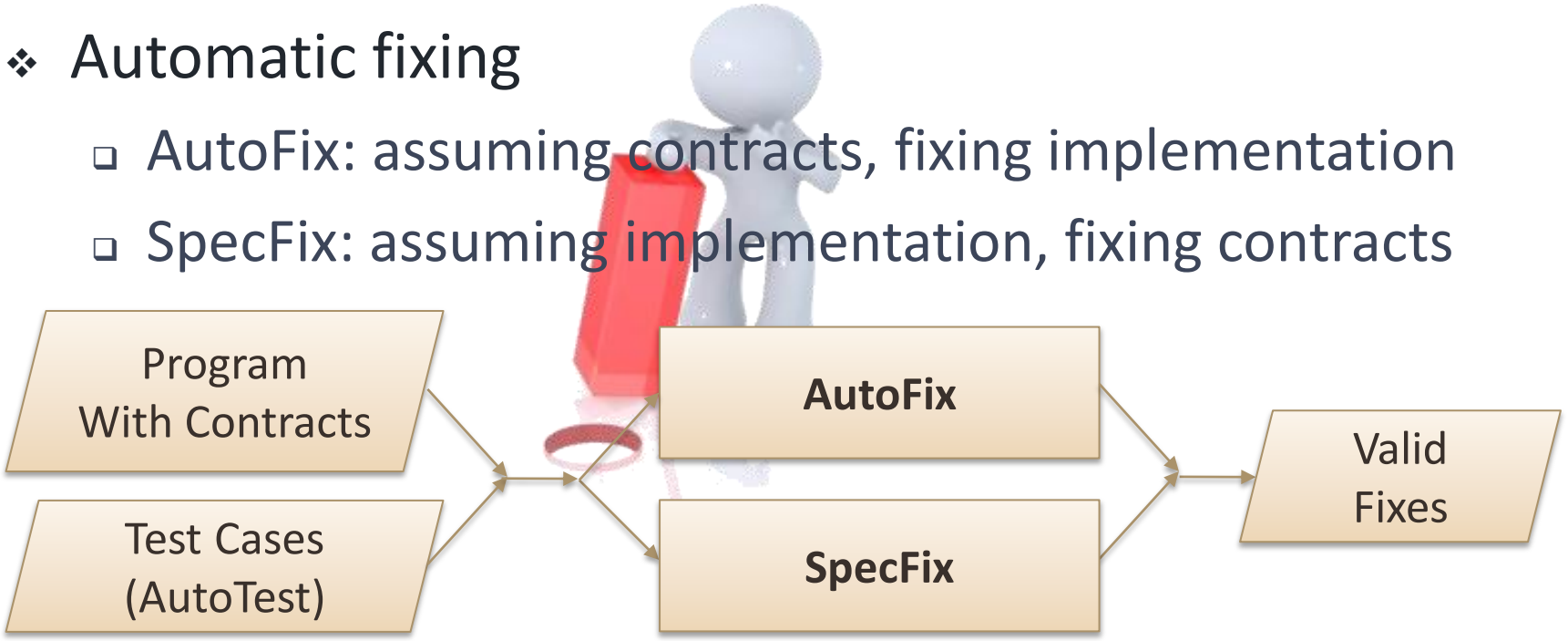
```
class ARRAYED_CIRCULAR
  duplicate (n: INTEGER): like Current
      -- Copy of sub-chain beginning at current
      -- position and having min (`n', count) items.
    require  n >= 0
    do
      create Result.make (count)
      …
    end

  make (n: INTEGER)
      -- Create a circular with `n' items.
    require  n >= 1
    do
      create list.make (n)
    end

  ….
```



Program faults and automatic fixing

- Program faults are discrepancies between the contracts (specification) and the implementation

- Automatic fixing
  - AutoFix: assuming contracts, fixing implementation
  - SpecFix: assuming implementation, fixing contracts



AutoFix: fault localization

- State snapshots as candidate fault causes:
  <expression, location, value>

  - Compute suspiciousness scores based on heuristics:
    A state snapshot is more suspicious, if it
    - Appears more often in failing runs than in passing runs
    - Is closer to the violation position in the control flow graph
    - Is syntactically more similar to the failing assertion

```
<count = 0, loc, True>
<is_empty, loc, True>
…
```

AutoFix: fix synthesis

- Fix actions: code necessary for changing the faulty state snapshot
  - Identify relevant objects and generate actions to either modify them or replace them with others objects

```
replace `count' with `count + 1'
```

- Fix schemas: common styles of wiring the fix actions into the feature body

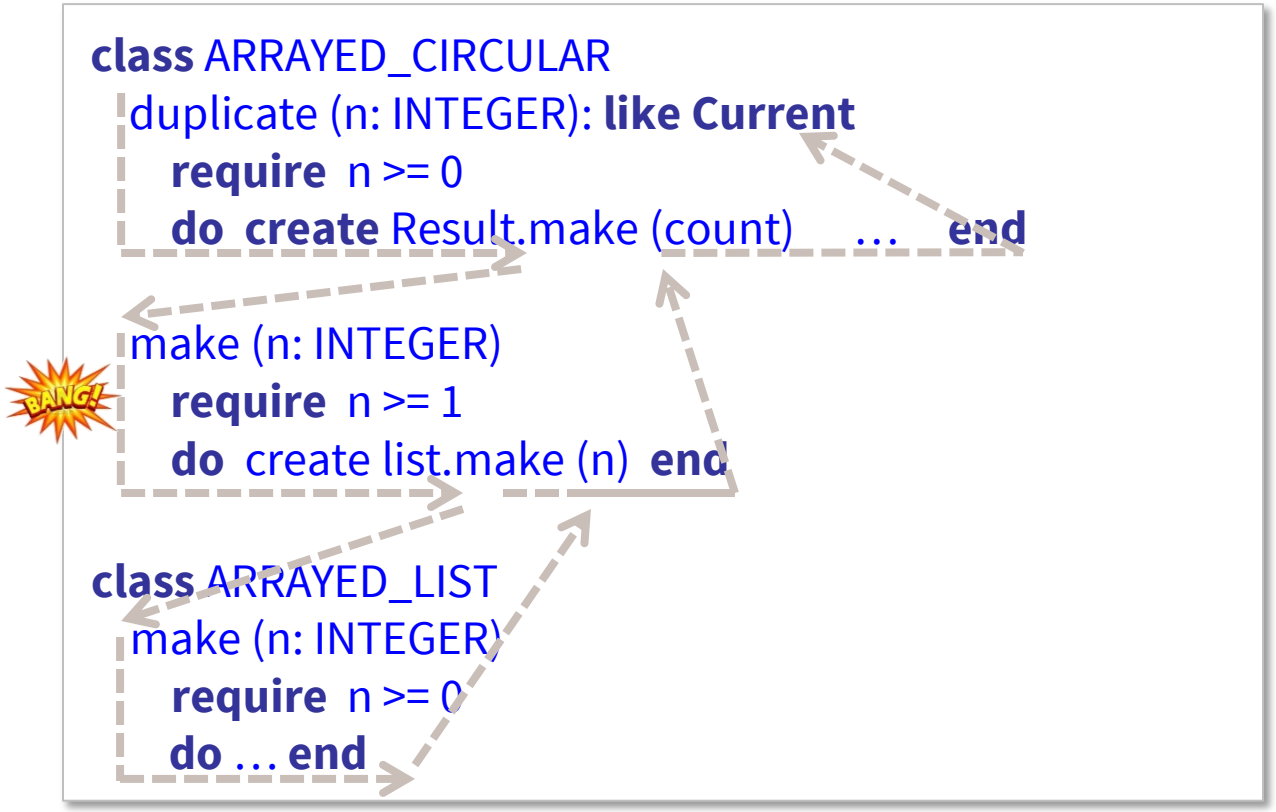
```
if count = 0 then
    create Result.make (count + 1)
else
    create Result.make (count)
end
```

AutoFix: fix validation and ranking

- Validation
  - Run the patched program against all passing and failing tests, requiring
    - Failing tests now pass
    - Passing tests still pass
- Ranking
  - Static metrics, favoring
    - Simple textual changes
    - Changes close to the failing location
    - Changes involving less original statements
  - Dynamic metric, favoring
    - Behavioral preservation

SpecFix: fix generation

- Possible contract faults



  - $make_{pre}$ being too strong ⇨ contract weakening
  - Preconditions of all open features on the stack being too weak ⇨ contract strengthening

SpecFix: fix validation and ranking

- Validation
  - Valid fixes should
    - Turn originally failing tests to either passing or invalid tests
    - Leave originally passing tests as still passing
  - Use more tests for validation than for fix generation to overcome overfitting

- Ranking
  - Prefers fixes resulting in more passing tests, or with weaker contracts

Experimental evaluation

- AutoFix: **204** randomly detected faults in various programs were used for evaluation
  - 86 (or **42%**) faults got valid fixes
  - 51 (or **25%**) faults got proper fixes

- SpecFix: 44 faults from real-life Eiffel libraries
  - 11 (or **25%**) faults got proper fixes
  - Most of them are preferred by programmers to fixes that change the implementation

Summary

- Contracts are specifications in the form of executable code
  - AutoTest
    - Detects discrepancies between the implementation and the contracts
  - AutoFix
    - Corrects the implementation according to the contracts
  - SpecFix
    - Adjusts the contracts to reflect the implementation

To find out more

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

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

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

THANKS