Extracting Runtime Monitors from Tests: An Introduction

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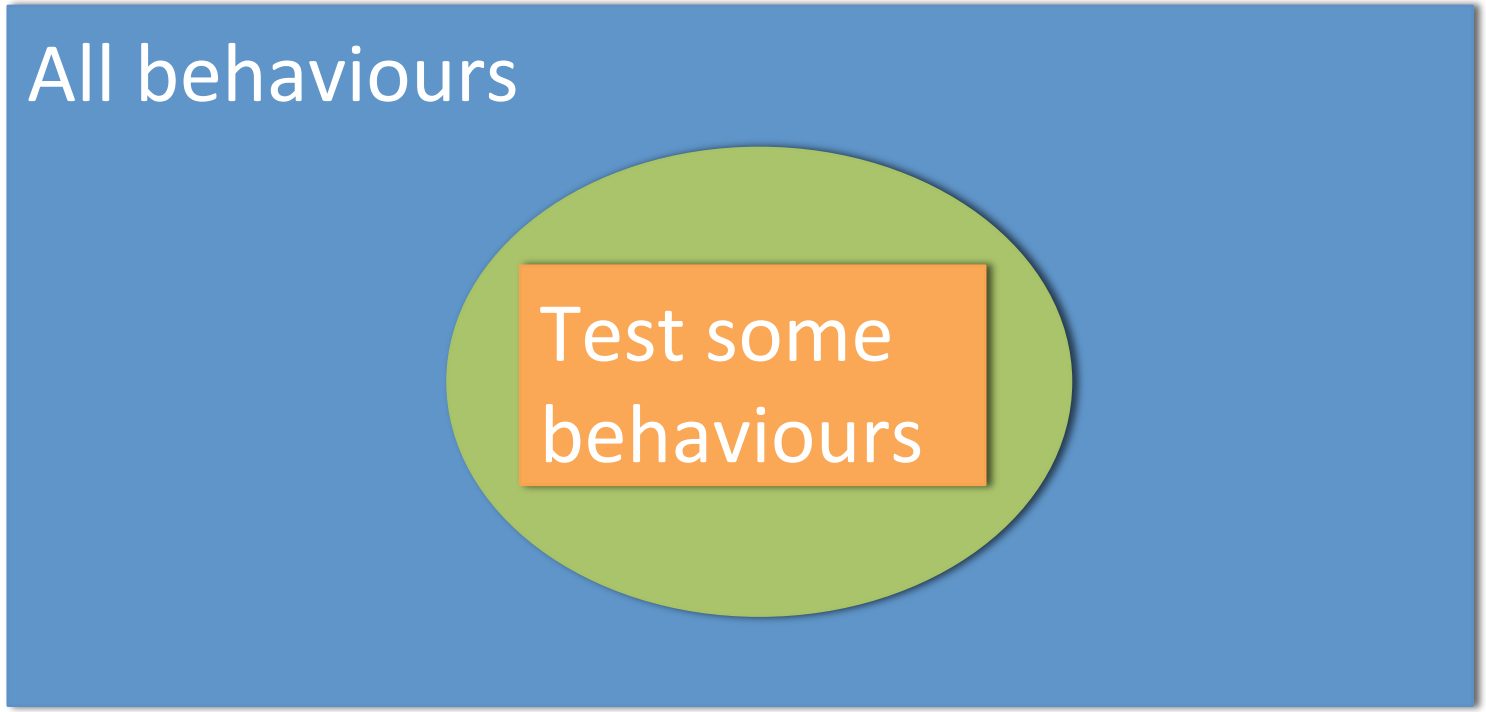
The Malta Council for Science & Technology

Why generate monitors from tests?

- Monitors can provide extra assurance at runtime
- Industry already invests a lot in testing
  (but little in runtime verification)
- Creating monitors after creating tests feels repetitive/waste

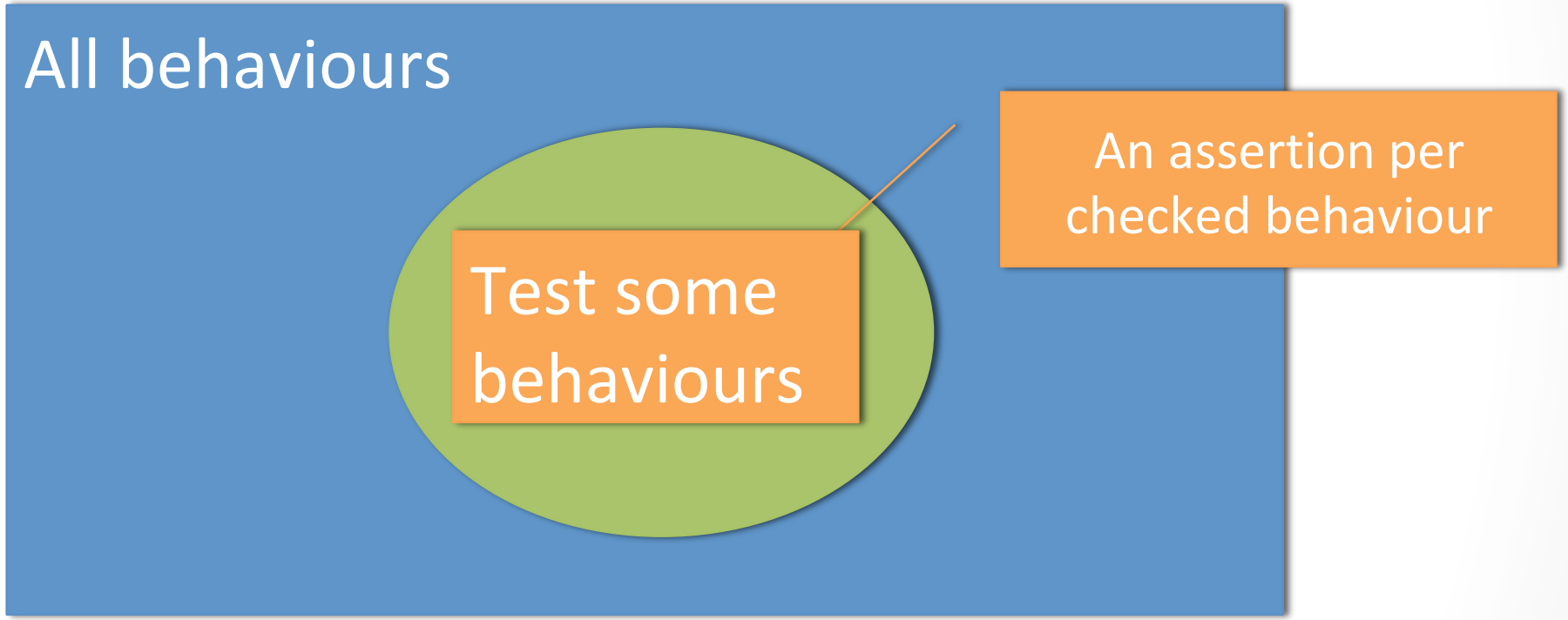
Verification – A language problem

Testing



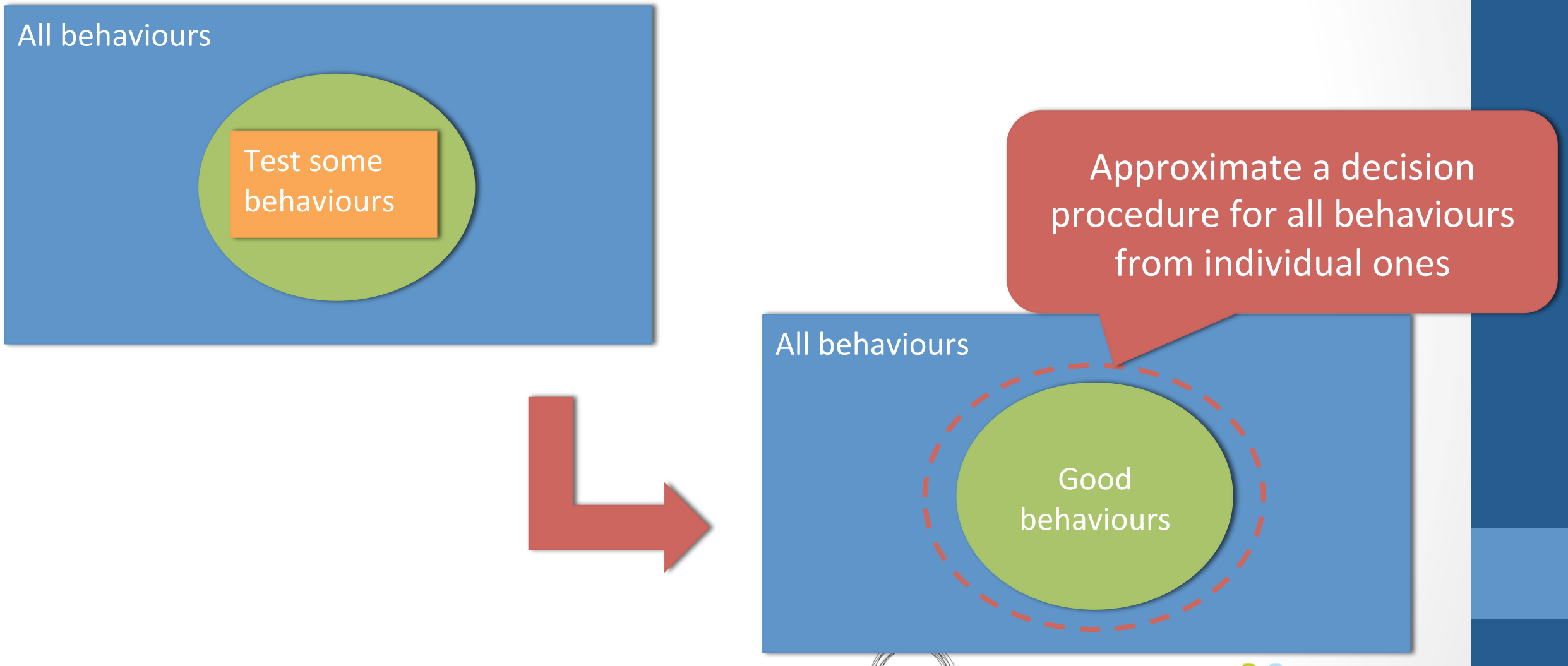
Runtime verification

Testing

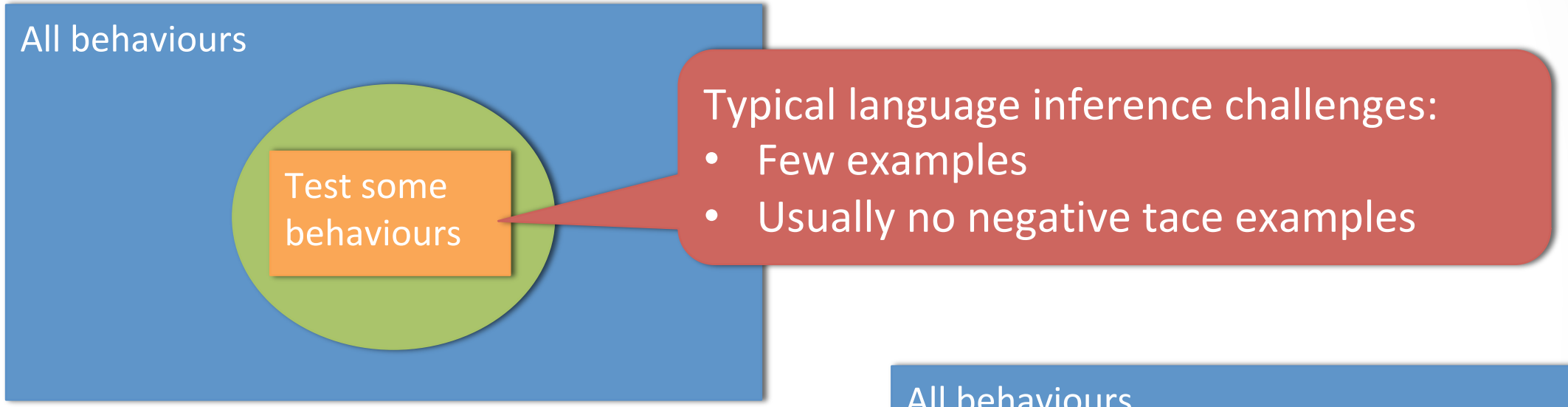


Runtime verification

Generating runtime verifiers from tests

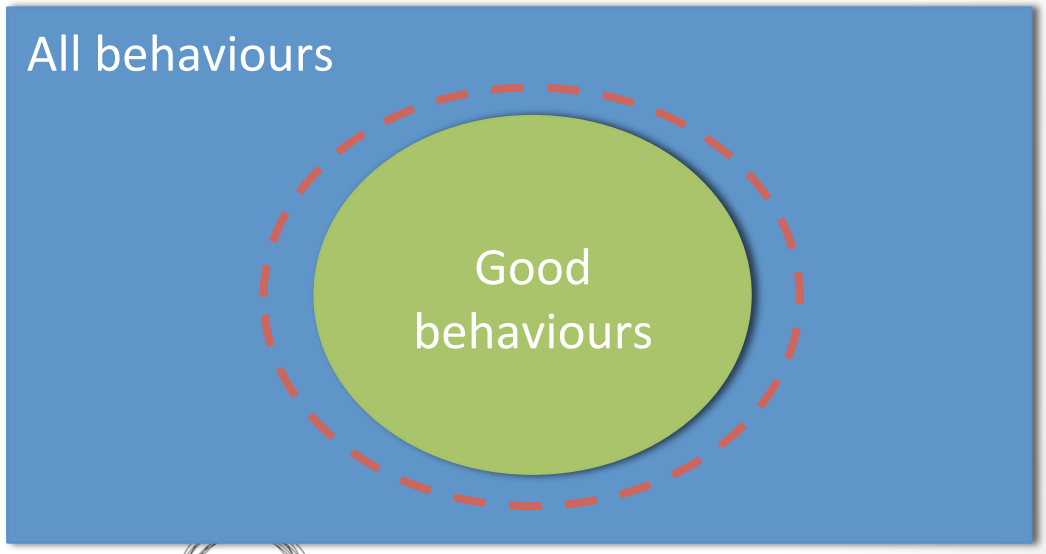


Why is it difficult?

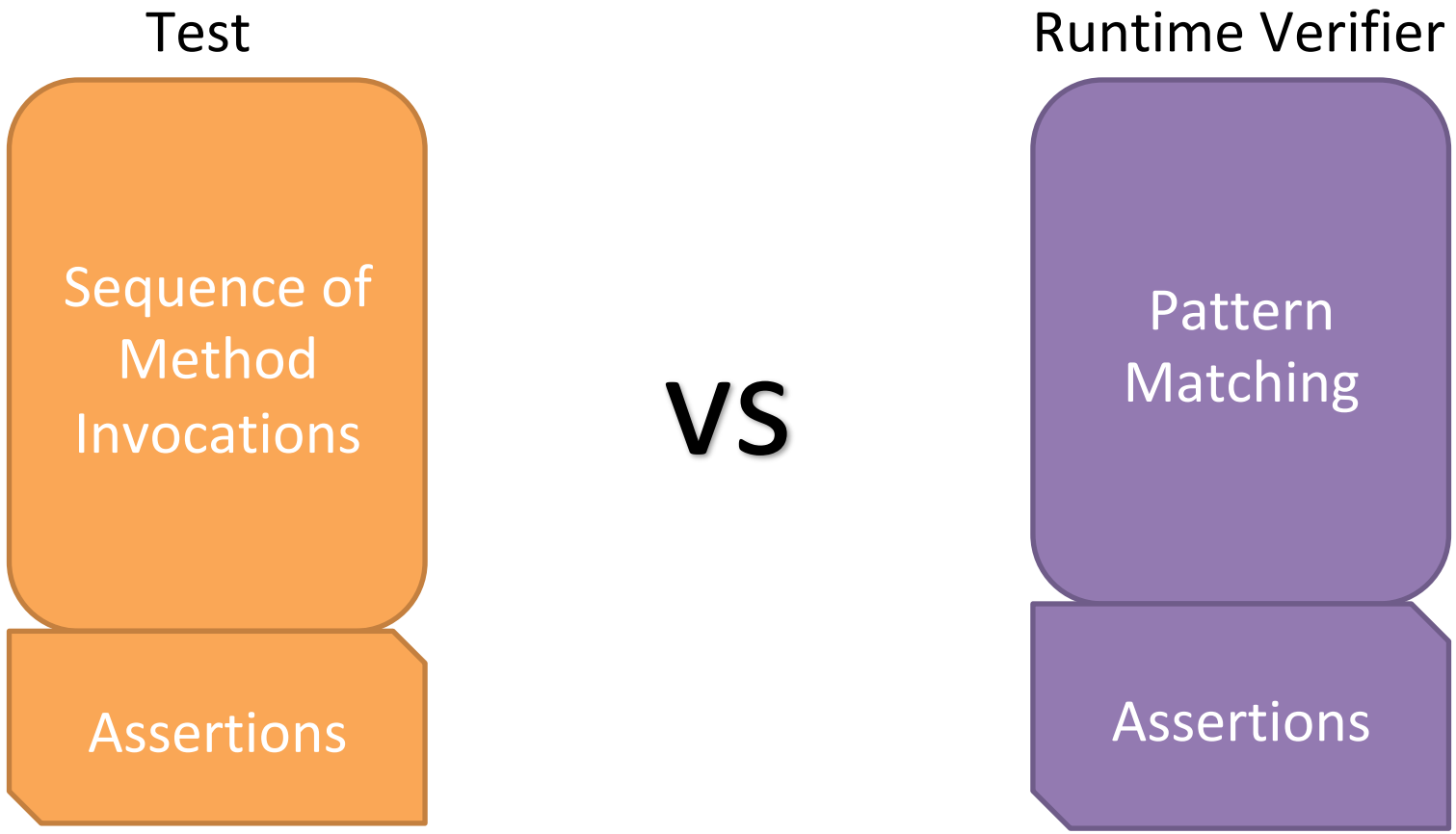


Typical language inference challenges:

- Few examples
- Usually no negative tace examples



Why not use test assertions directly?



Test assertions are typically very specific

```
@Test
public void testWithdraw(){
     Account a = new Account();
     a.setBalance(100);
     a.withdraw(60);
     assertEquals(a.getBalance(),40);
}
```

Idealistic test assertions

```
@Test
public void testWithdraw(){
     initialBalance = 100;
     withdrawAmount = 60;
     Account a = new Account();
     a.setBalance(initialBalance);
     a.withdraw(withdrawAmount );
assertEquals(a.getBalance(),initialBalance-withdrawAmount);
}
```

What if you insist on using assertions?

- There might be other hidden assumptions:
  - Assumptions on the global state (shared data structures, files, etc)
  - Assumptions on the control/data flow leading up to the assertion (test setup, method call sequence in test, etc)

Related approaches

Tests are generated and checked automatically using a model, e.g. automata with pre & post conditions

Testing to more “generalised” testing

1. EUnit → QuickCheck (Thomas Arts et al.)
2. Gherkin → QuickCheck (Christian Colombo et al.)

Model-based testing to RV

3. QuickCheck → Larva (Gordon Pace and Kevin Falzon)

Testing to Regression testing/Debugging

4. Invariant detection with Daikon (Pastore et al.)

1. EUnit → QuickCheck

- Generates QuickCheck automaton from sequences of method calls
- Uses algorithm to learn automata
- Uses learned automaton to improve testsuite

Points to consider

- Assumes the availability of negative traces
  - Not usually present in testsuites
- Suitable for testing, probably also for RV if negative traces are available

2. Gherkin → QuickCheck

- Similar to previous but state identification is easier as more explicit in Gherkin tests

Standard Business Specifications

```
Scenario: Model definition for myHealth - Doctors Section

Given I am on the "start state"
When I "login as a doctor"
Then I should go to the "doctors landing page"

Given I am on the "doctors landing page"
When I "click on Appointments"
Then I should go to the "appointments page"

Given I am on the "doctors landing page"
When I "click on Case Summaries"
Then I should go to the "case summaries page"

Given I am on the "doctors landing page"
When I "click on Laboratory Results"
Then I should go to the "lab results page"

Given I am on the "doctors landing page"
When I "click on Medical Image Reports"
Then I should go to the "medical image reports page"
```

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```

States

Standard Business Specifications

```
Scenario: Model definition for myHealth - Doctors Section

Given I [illegible] the "start state"
When I "login as [illegible]
Then I [illegible] to th "doctors landing page"

Given I am on the "doctors landing page"
When I "click on Appointments"
Then I should go to the "appointments page"

Given I am on the "doctors landing page"
When I "click on Case Summaries"
Then I [illegible] summaries page"

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Given I am on the "doctors landing page"
When I "click on Medical Image Reports"
Then I should go to the "medical image reports page"
```

States

Actions

Standard Business Specifications

```
Given I am on the "doctors landing page"
When I "click on Laboratory Results"
Then I should go to the "lab results page"

Given I am on the "lab results page"
When I "search patient data"
Then I                    "lab results search result
and the result should be "true" when "no data found"
and th                    true" when "ok"

Given I am on the "lab results search results page"
When I "click on the myHealth logo"
Then I should go to the "doctors landing page"

G                         results search results page
and the result is "ok"
W                         results"
Then I should go to the "view lab results page"

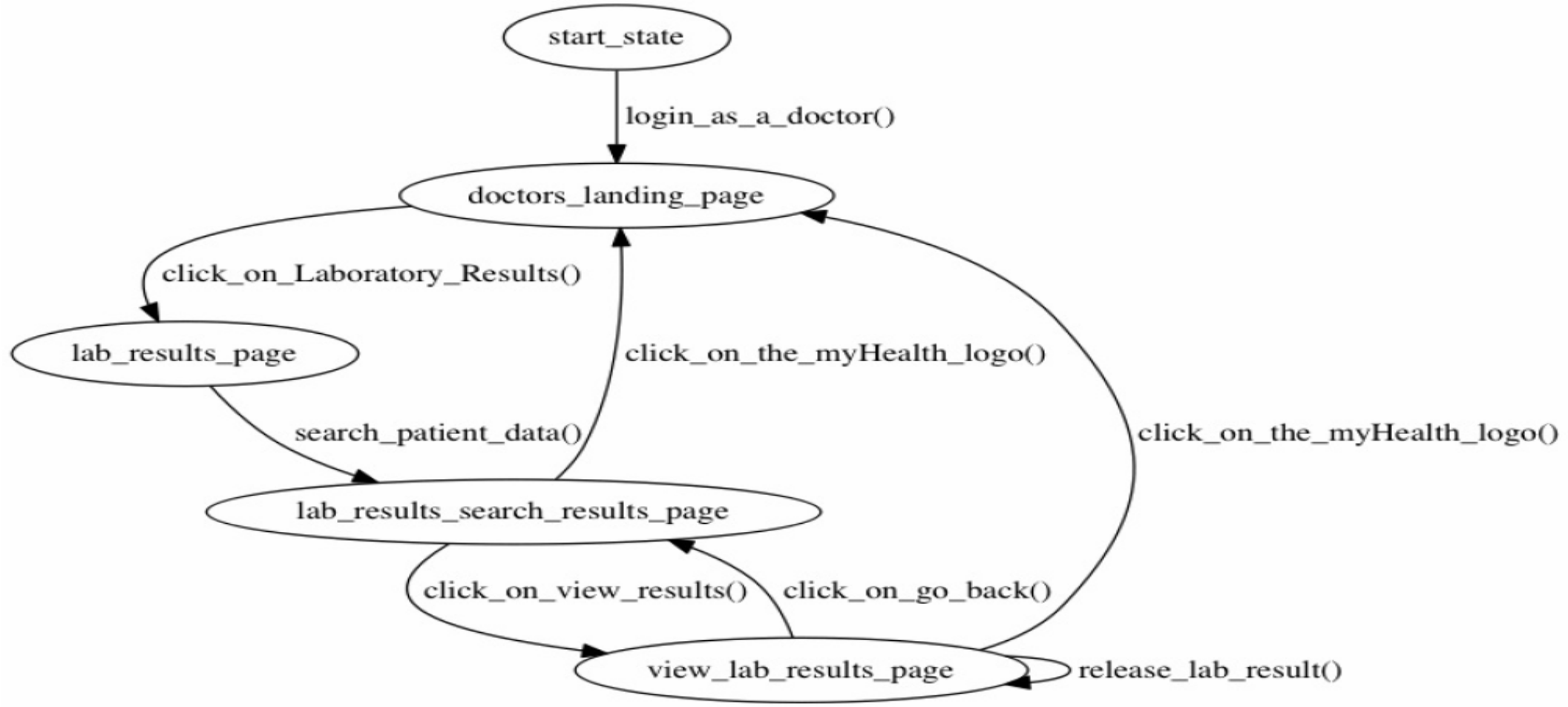
Given I am on the "view lab results page"
When I "release lab result"
Then I should remain on the "view lab results page"

Given I am on the "view lab results page"
When I "click on go back"
Then I should go to the "lab results search results page"
```

Post Condition

Pre Condition

Automatically Generated QC Model



Points to consider

- The higher the testing level, the more useful for RV

3. QuickCheck → Larva

- Translates QC automata into Larva script
- Main challenge is to make sure you match corresponding entry and exit points
  - recursiveMethod() -entry
    - recursiveMethod() -entry
    - recursiveMethod() -exit
  - recursiveMethod() -exit

Points to consider

- It is easy to go from Model-Based Testing to RV
- Model-Based Testing not very commonplace

4. Invariant detection with Daikon

- Detect invariants from running testsuite
- Filter out invariants which no longer hold on modified testsuite
- Use model checking to detect invariants which are violated in update

Points to consider

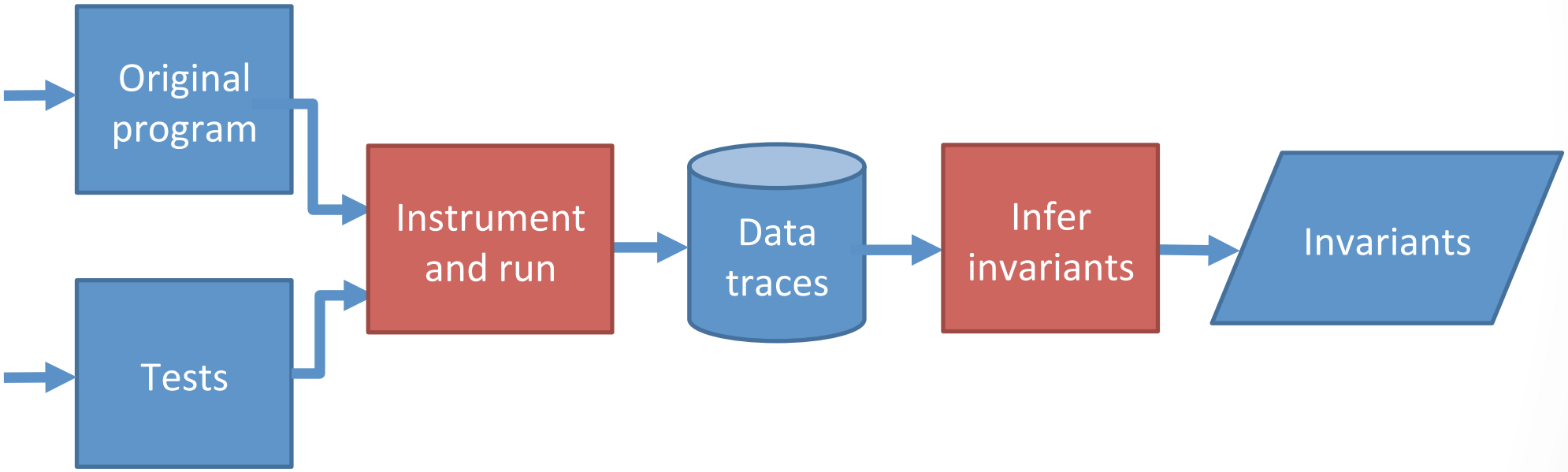
- How can we adapt it to RV?

Approach 1: Gherkin → QC → Larva

- We know how to go from Gherkin to QC
- We know how to go from QC to Larva
- Go from Gherkin to Larva

Approach 2: Infer invariants

- Daikon – an invariant generation tool

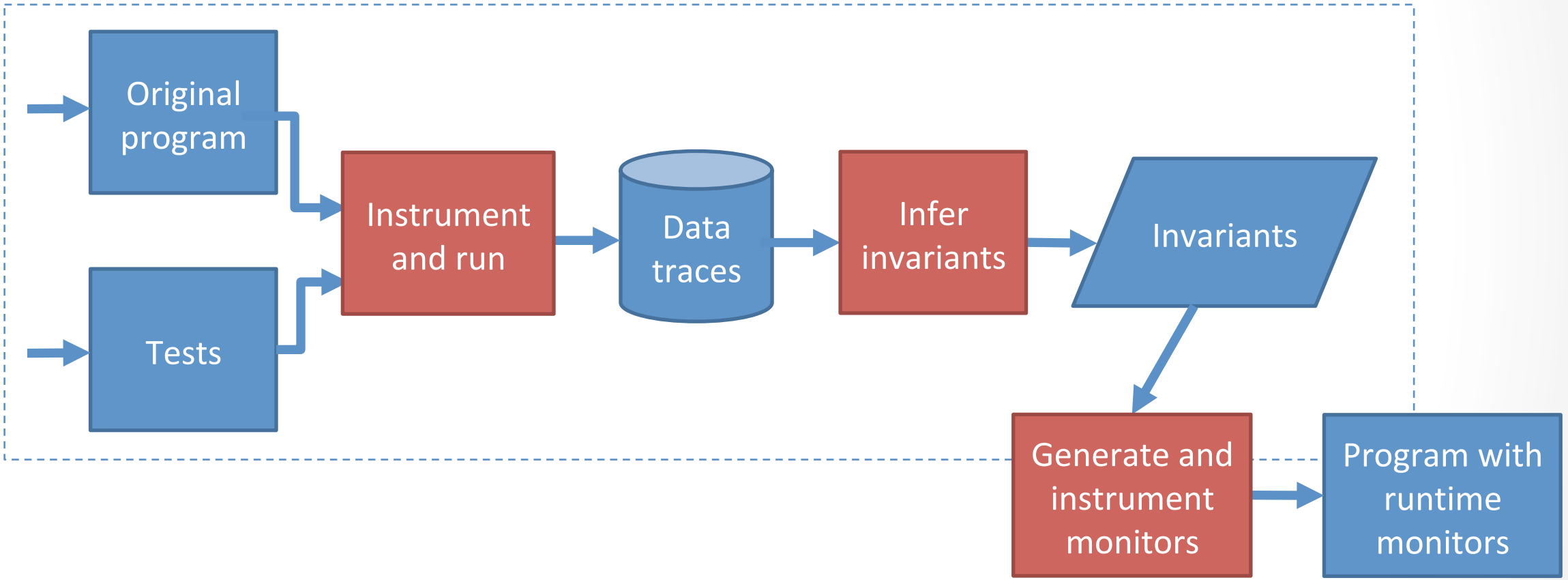


Approach 2: Infer invariants

- Daikon – an invariant generation tool

```
===========================================================================
transactionsystem.UserAccount.deposit(double):::ENTER
this.opened == true
amount one of { 100.0, 500.0, 1000.0 }
===========================================================================
transactionsystem.UserAccount.deposit(double):::EXIT
this.opened == orig(this.opened)
this.account_number == orig(this.account_number)
this.owner == orig(this.owner)
this.opened == true
this.account_number.toString == orig(this.account_number.toString)
this.balance > orig(this.balance)
this.balance >= orig(amount)
this.balance - orig(this.balance) - orig(amount) == 0
===========================================================================
```

Approach 2: Infer invariants



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this.balance >= orig(amount)
this.balance - orig(this.balance) - orig(amount) == 0
================================================================================
```

Pattern match on deposit
+
Check postconditions if preconditions hold

Two main challenges

- Make monitors useful
  - Weaken preconditions
  - Tighten postconditions

- Avoid false negatives

Challenge – Weaken preconditions

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Is this deliberate?

Challenge – Weaken preconditions

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================================================================================
```

Is this deliberate?

Missing test cases?

Challenge – Weaken preconditions

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Remove such invariants

Challenge – Weaken preconditions

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================================================================================
```
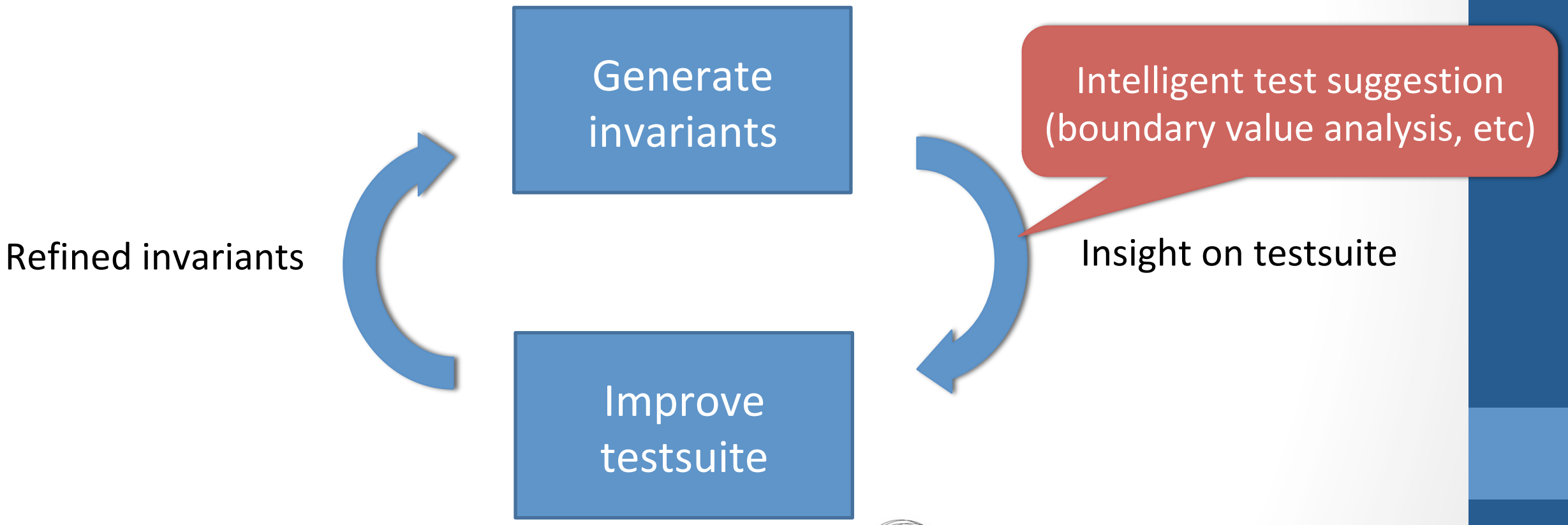
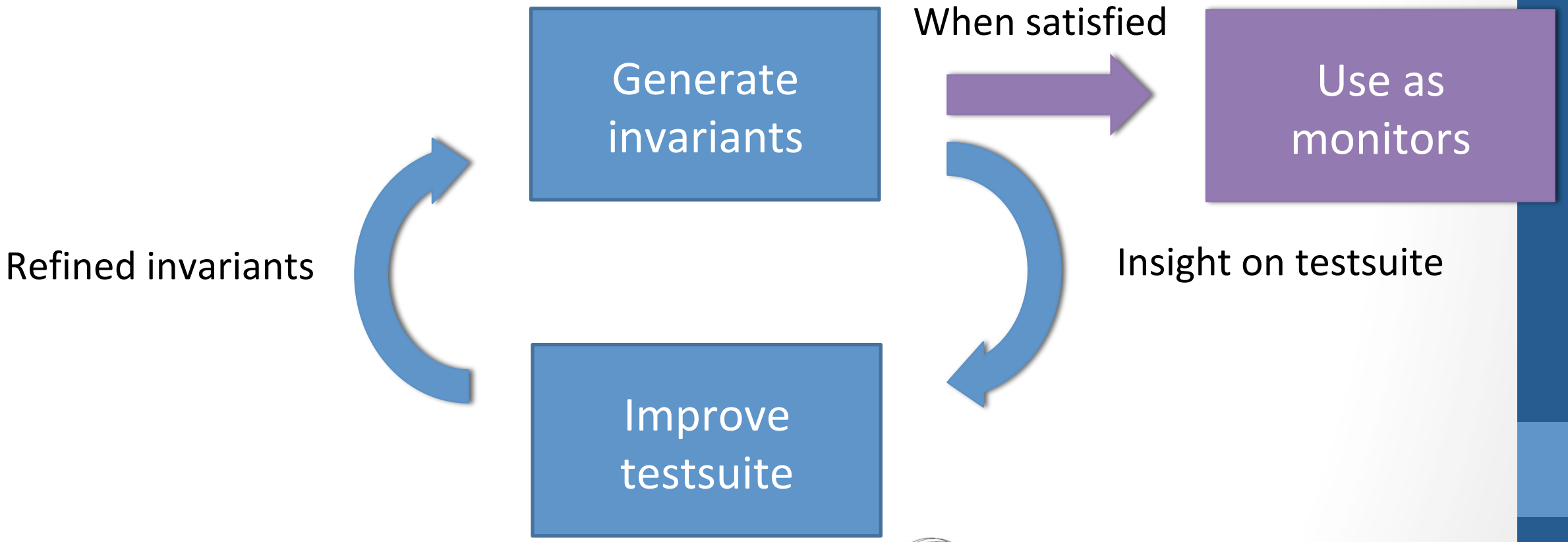

Remove such invariants

Set appropriate threshold

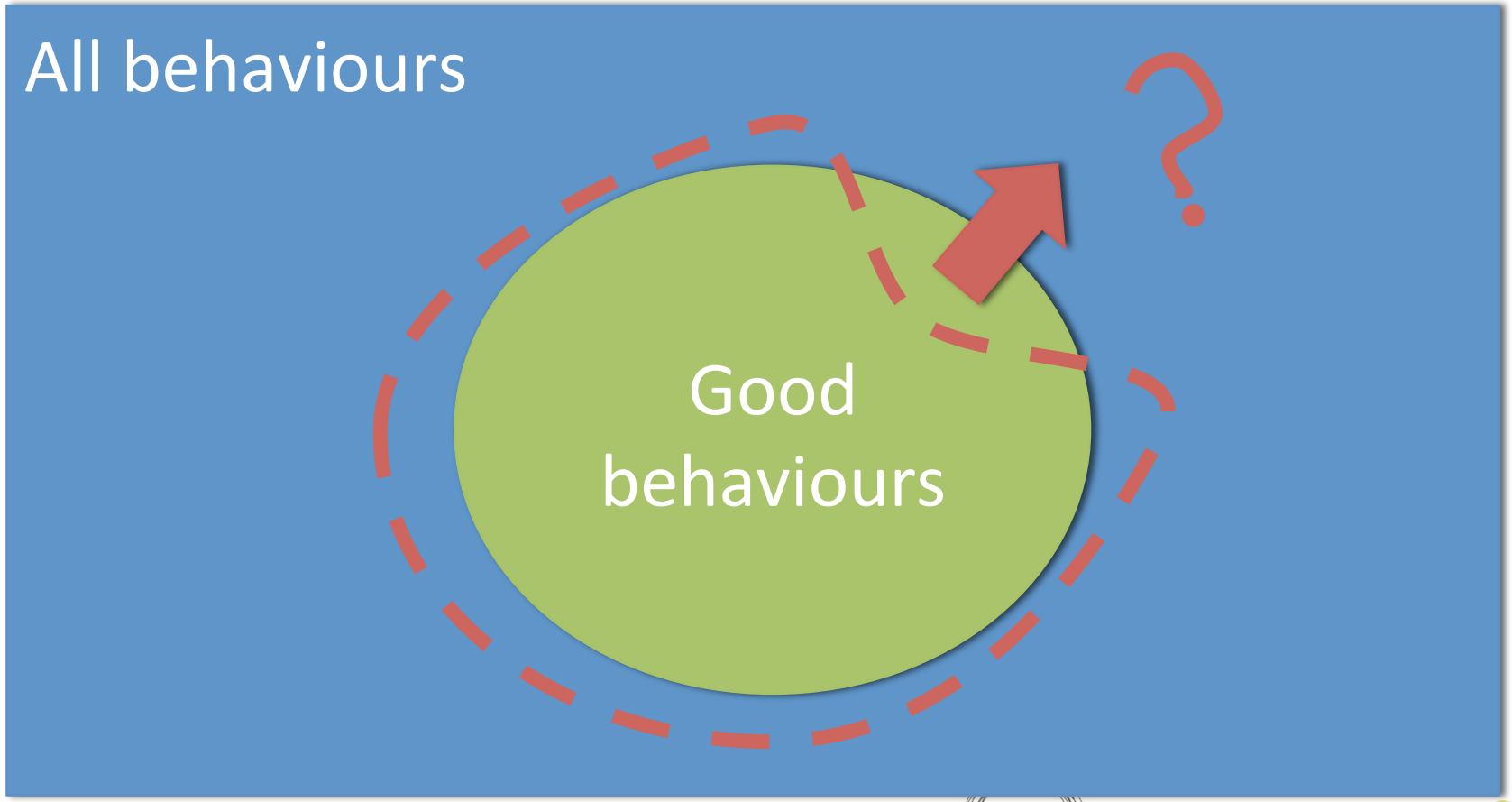
A test case improvement problem



A test case improvement problem



Challenge – Avoiding false negatives



Approach 3: Combine testing and RV by design

- Specification of tests and monitors in a single language

  (like property-based testing but allowing some properties to be specified by examples)

  - If a precise specification is available, generate test cases automatically
  - If not, have test cases and specifications specified separately

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- Specification of tests and monitors in a single la

  (like property-based testing but allowing so properties to be specified by examples)

  - If a precise specification is available, generate test cases automatically
  - If not, have test cases and specifications specified separately

E.g., balance'=balance + deposit
Automatically generates
200 = 150 + 50
350 = 290 + 60

E.g., balance' >= 0

Conclusion

- Generating monitors from tests is hard!
- Following presentations:
  - What we learned so far from the case study at Ixaris
  - The next challenge along the way: filtering out unuseful monitors