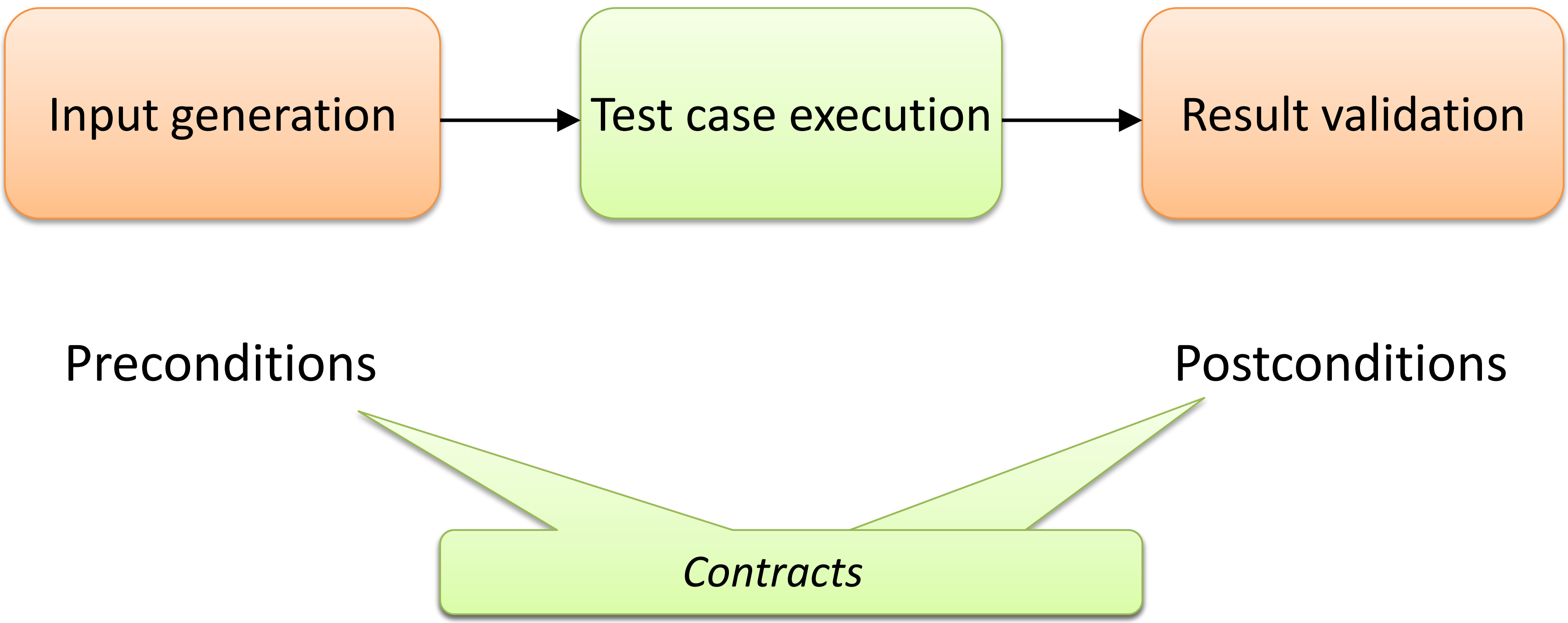
Satisfying Test Preconditions through Guided Object Selection

Yi Wei, Serge Gebhardt, Bertrand Meyer and Manuel Oriol

ETH Zürich

Automated unit testing



Design by Contract

```
put (v: G; i: INTEGER_32)
        -- From DS_ARRAYED_LIST
        -- Add `v' at `i'-th position.
    require
        extendible: extendible (1)
        valid_index: 1 <= i and i <= (count + 1)
        -- Implementation
    ensure
        one_more: count = old count + 1
        inserted: item (i) = v
```

Input filter

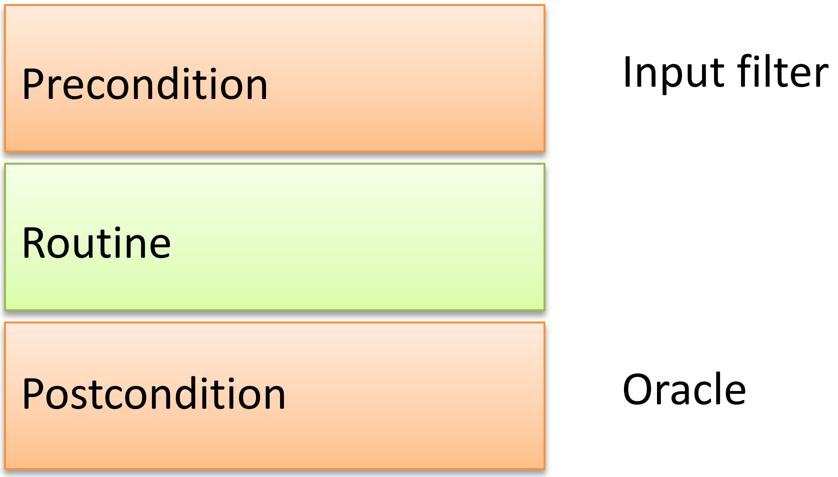
Oracle

Contract-based random testing

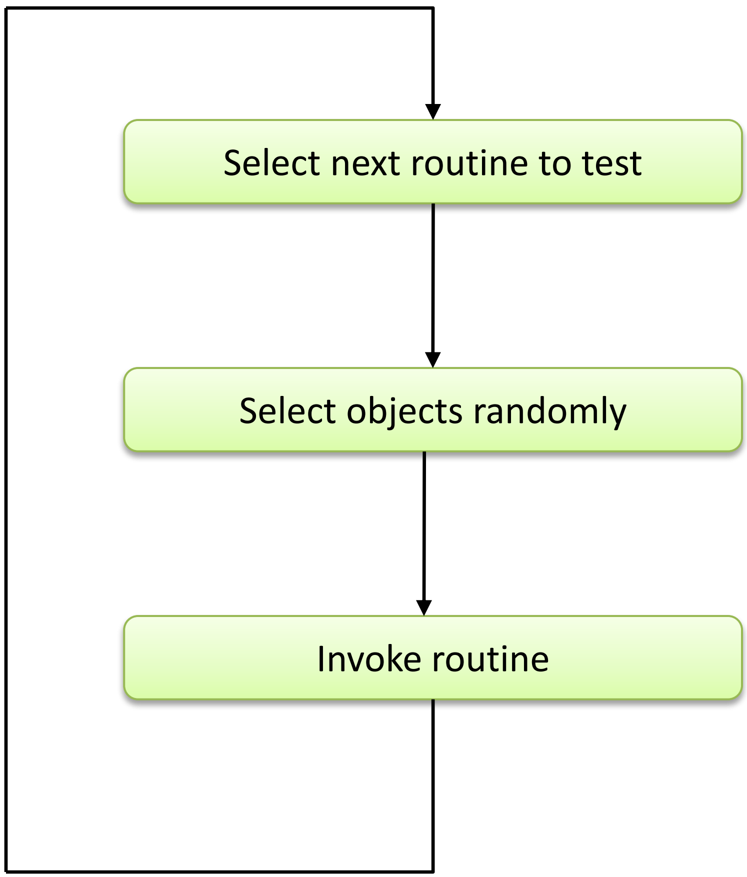
Random input generation:

- Primitive values: random selection

- Objects: constructor calls + other (state-changing) methods



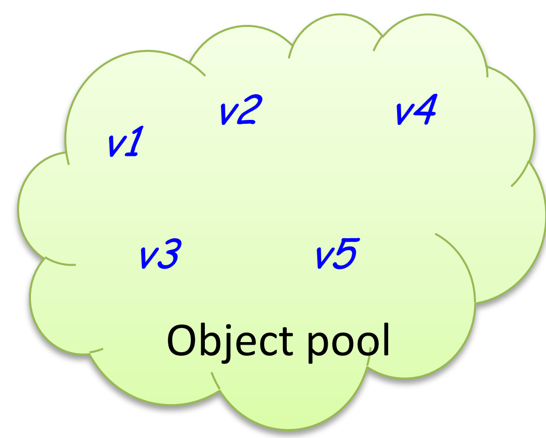
Original random testing strategy – the *or-strategy*



The or-strategy

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

Sample test cases



The issue of generating precondition satisfying tests

A random based testing tool implemented in such scheme has difficulty in generating valid test cases for precondition-equipped routines:

- Some routines are left untested.

- The testing tool may keep generating invalid test cases, instead of performing effective testing.

What kinds of preconditions are difficult to satisfy?

```
remove_right_cursor (a_cursor: DS_ARRAYED_LIST_CURSOR )
        -- Remove item to right of `a_cursor' position.
        -- Move any cursors at this position forth.
    require
        not_empty: not is_empty
        cursor_not_void: a_cursor /= Void
        valid_cursor: valid_cursor (a_cursor )
        not_after: not a_cursor.after
        not_last: not a_cursor.is_last
```

At the beginning of the 50th minute, there are 356 list objects and 192 cursor objects, but only 5 out of 68,352 list-cursor combinations satisfied the precondition, the probability of a correct selection is 0.007% .

What kinds of preconditions are difficult to satisfy?

```
prune (n: INTEGER_32; i: INTEGER_32 )
        -- Remove `n' items at and after `i'-th position.
    require
        valid_index: 1 <= i and i <= count
        valid_n: 0 <= n and n <= (count - i + 1)
    ensure
        new_count: count = old count - n
```

This occurs often in preconditions

Guided object selection – the *ps-strategy*

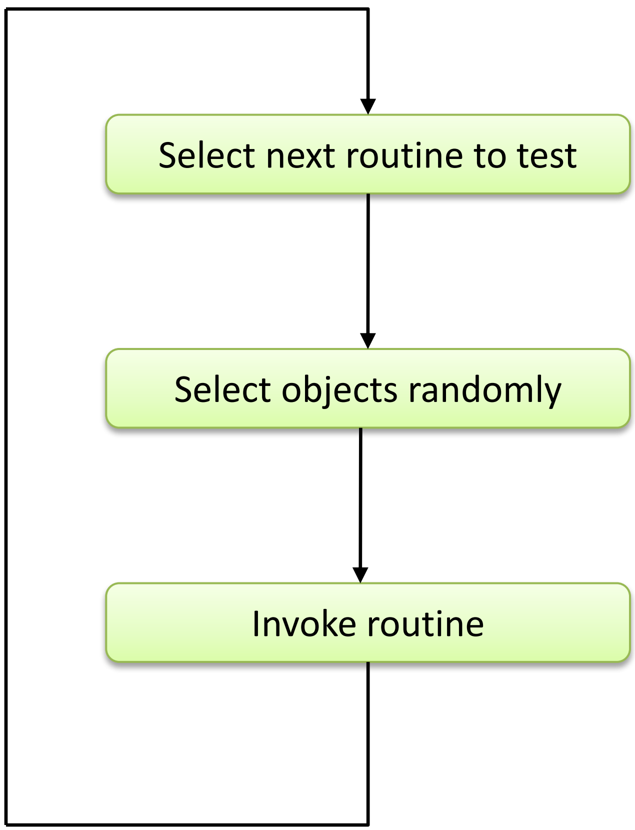
Observation

- The or-strategy can create objects satisfying many preconditions
- Needs to select those objects more effectively

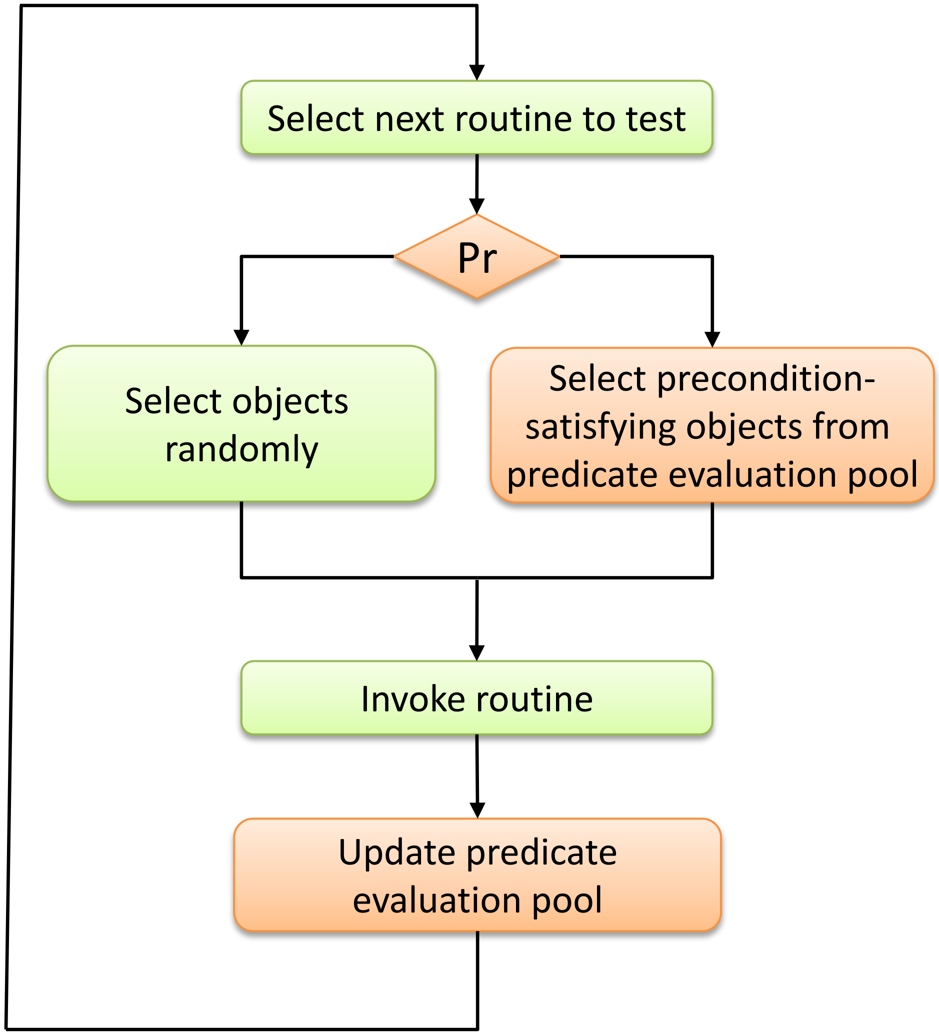
Solution: the precondition satisfaction strategy (ps-strategy)

- Keep track of which objects satisfy certain precondition predicates
- To test a routine, select precondition-satisfying objects with a higher probability
- Use linear constraint solver

Comparison between the or-strategy and the ps-strategy



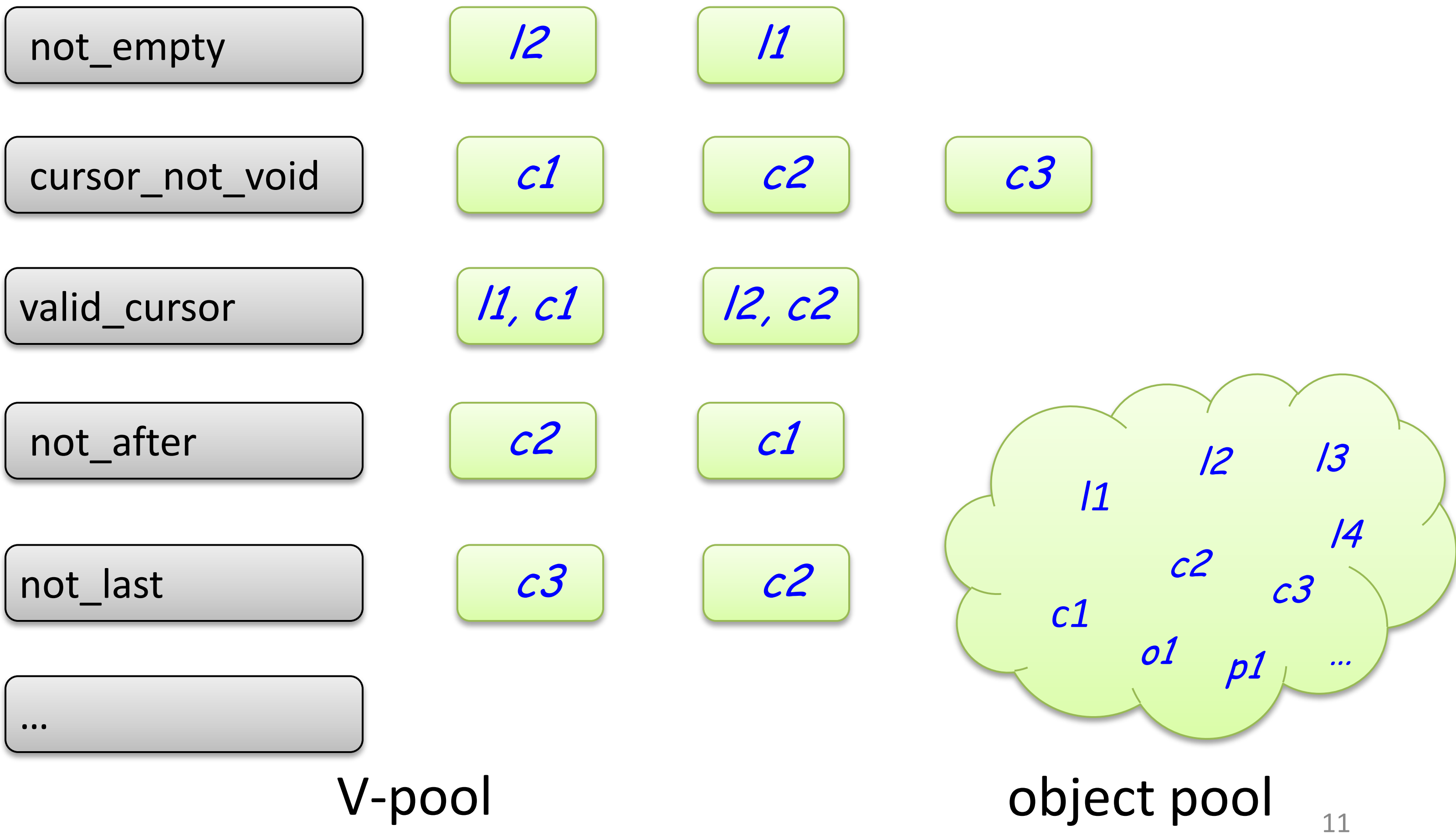
The or-strategy



The ps-strategy

Object selection guided by predicate evaluation pool (*V-pool*)

The V-pool keeps track of objects satisfying certain precondition predicates; those objects can be used to generate valid test cases.



Updating the predicate evaluation pool

After every *passing* test case

evaluate relevant predicates on ***last used objects***, and add precondition-satisfying object combinations to the V-pool.

Grow the V-pool as much as possible

After every *invalid* test case:

remove the object combination causing the precondition violation at the specific predicate from the V-pool.

Correct inconsistency lazily

After every passing test case…

```
replace_at_cursor (v: G; a_cursor: CURSOR)
        -- Replace item at `a_cursor' position by `v'.
    require
        cursor_not_void: a_cursor /= Void
        valid_cursor: valid_cursor (a_cursor)
```

> The V-pool contains *snapshots* of the relations among objects, this information may become inconsistent as testing proceeds.

```
l.force_last (v1)
c := l.new_cursor
c.go_i_th (1)
l.wipe_out
l.replace_at_cursor (v3, c)
```

cursor_not_void	c
valid_cu…	l, c
not_off	c
…	

After every invalid test case...

```
replace_at_cursor (v: G; a_cursor: CURSOR)
        -- Replace item at `a_cursor' position by `v'.
    require
        cursor_not_void: a_cursor /= Void
        valid_cursor: valid_cursor (a_cursor )
        not_off: not a_cursor.off
```

l.force_last (v1)

What is the success rate of test cases generated by the ps-strategy?

l.wipe_ou

l.replace_at_cursor (v3, c)

cursor_not_void	*c*
valid_cursor	*l, c*
not_off	*c*
...	

> 60% (cf. or-strategy: < 10%)

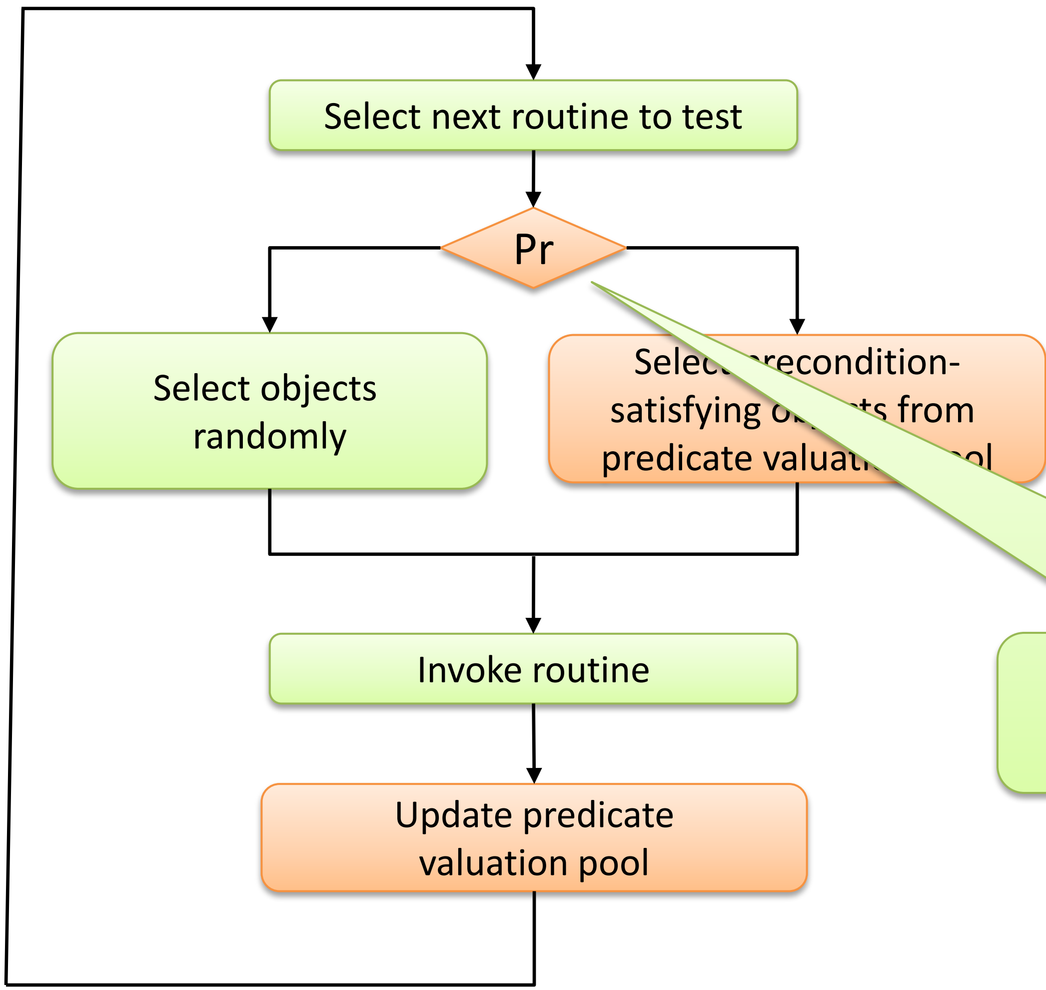
For linear constraints

```
prune (n: INTEGER_32; i: INTEGER_32 )
        -- Remove `n' items at and after `i'-th position.
    require
        valid_index: 1 <= i and i <= count
        valid_n: 0 <= n and n <= (count - i + 1)
    ensure
        new_count: count = old count - n
```

lpsolve is used to generate a minimal and a maximal solution

- Randomly select one value from the range
- Slightly biased on border values and potentially interesting values
- Solutions are cached

Optimization



Always enforcing precondition satisfaction slows down the test process *by (50~70%)*, without benefits:

- did not test more routines
- found much fewer faults

Turn precondition satisfaction on only from time to time

Evaluation

ps-strategy vs. or-strategy

Evaluation overview

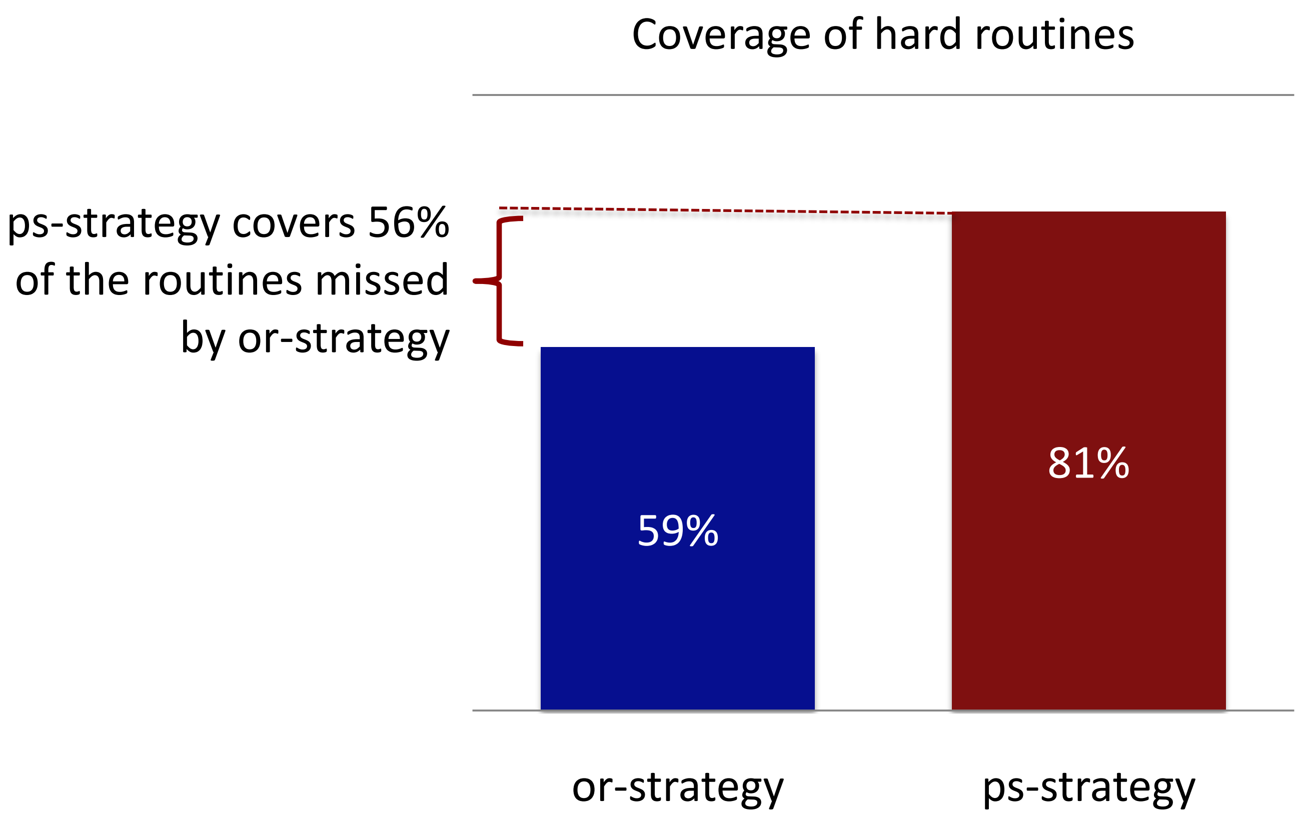
- How many more routines are tested by the ps-strategy?
- How often are routines tested by the ps-strategy?
- How many more faults are detected by the ps-strategy?
- How fast is the ps-strategy?

Experimental setup

- 92 classes of EiffelBase and Gobo libraries
  - widely used in production software
  - different data structures: lists, arrays, trees, stacks, and a regex lexer
- Arranged into 57 strongly-related test groups
  - based on dependency between classes
  - introduces more diversity in the object pool
- 30 test runs per group of 1 hour each, for both the or- and ps-strategies
- 3,420 hours of testing

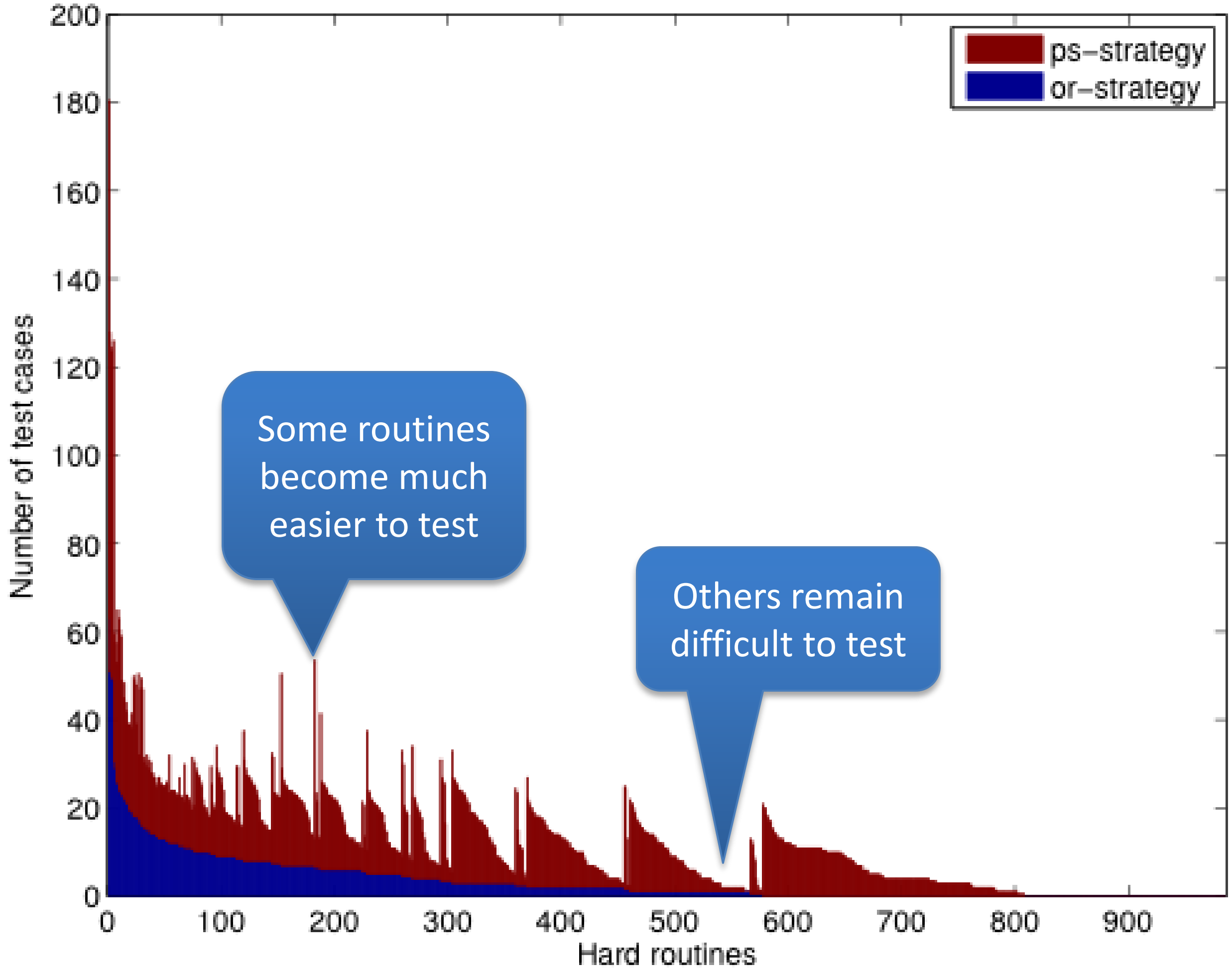
How many more routines are tested by the ps-strategy?

- A hard routine is one for which or-strategy failed to generate a valid test case for at least 90% of the time.



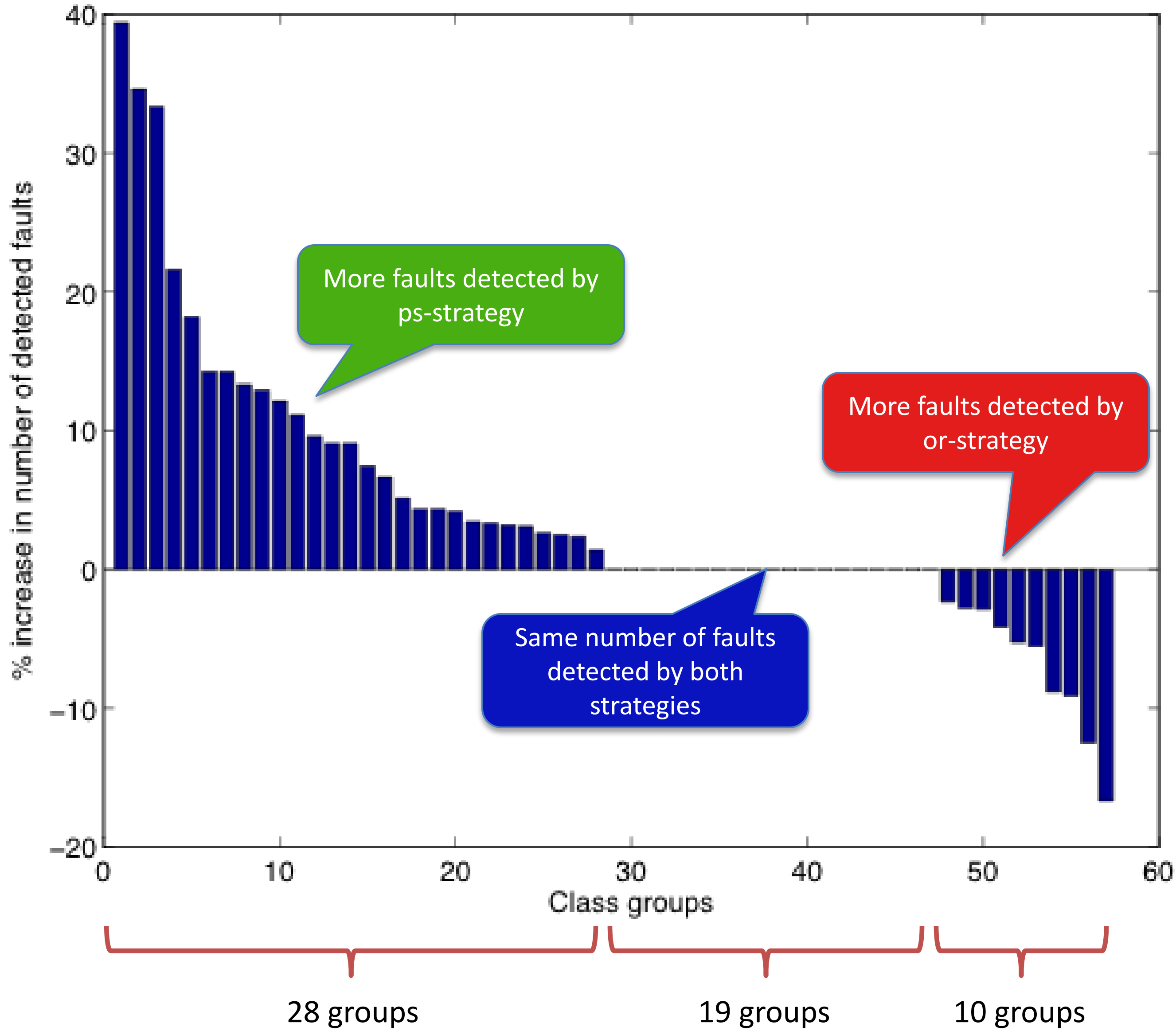
- But misses 1% of those tested by or-strategy.

How often are routines tested by the ps-strategy?

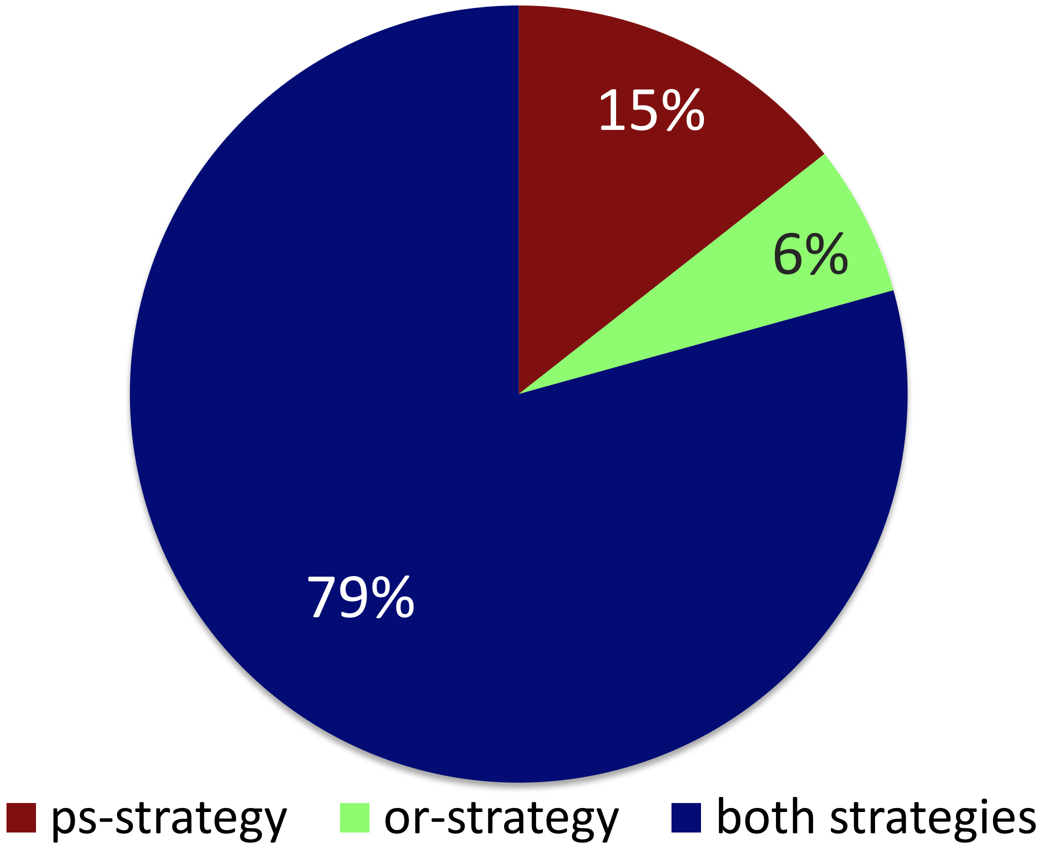


- Over 3.5 times as many valid test cases overall

How many more faults are detected by the ps-strategy?

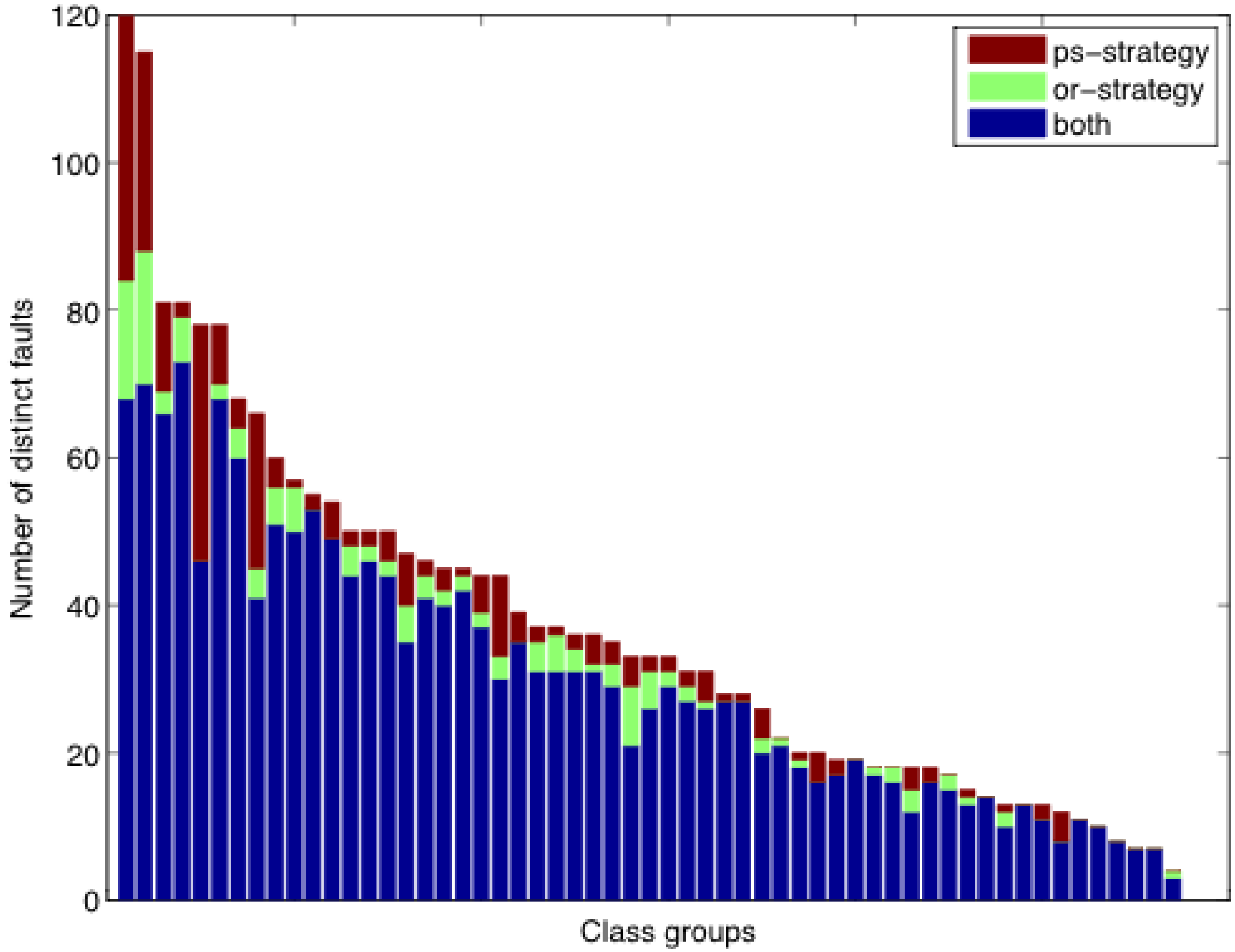


Fault coverage by each strategy



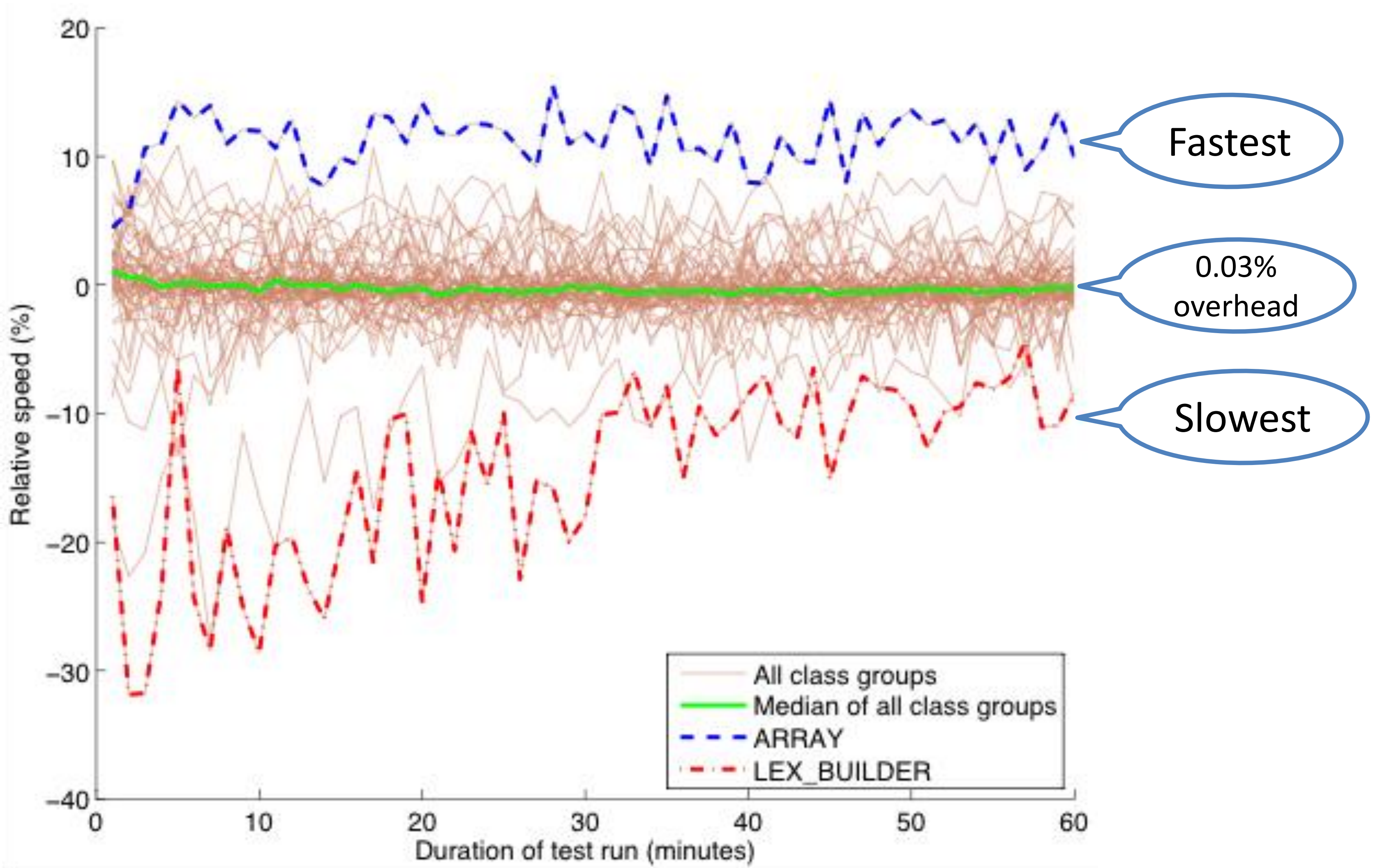
Almost 10% increase in the number of detected faults overall.

Fault coverage by each strategy



- Different class groups perform differently well

Test case generation speed



Routines still untested by the ps-strategy

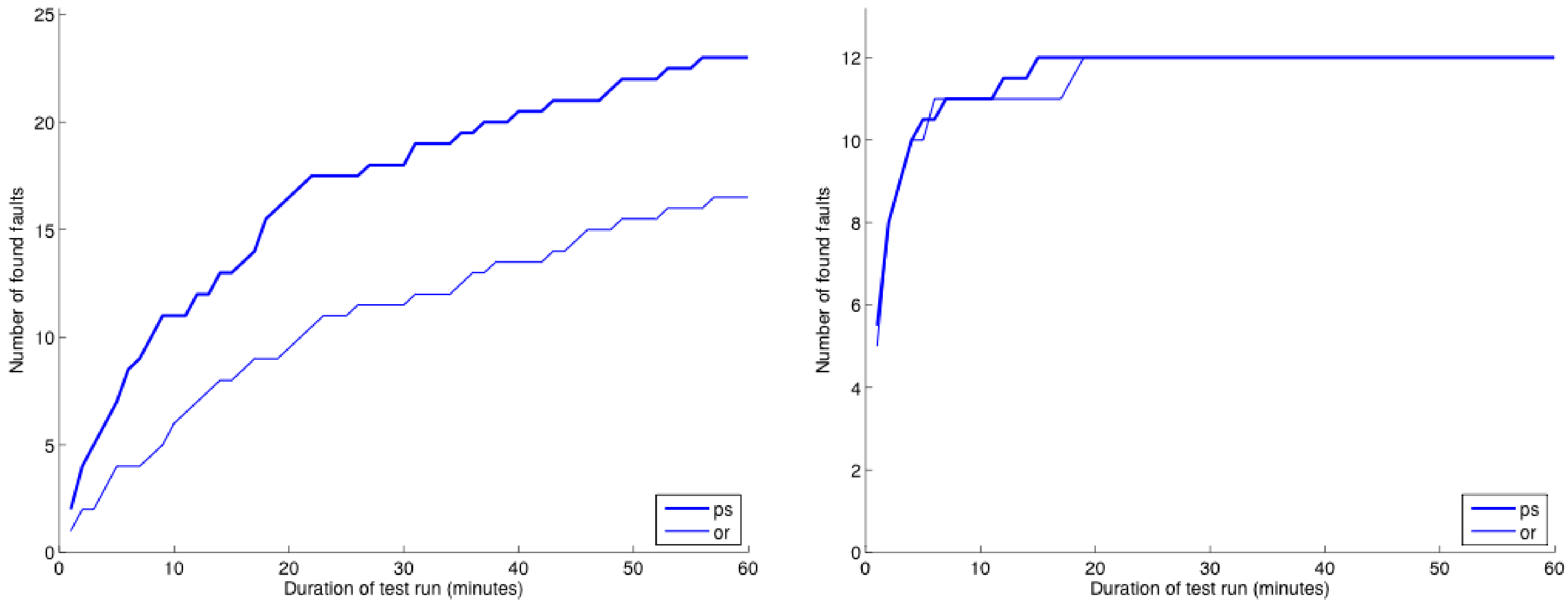
- Strategy-unrelated (51%)
  - Preconditions are hardcoded as unsatisfiable
  - Preconditions require a different environment (e.g. .NET)

- Strategy-related (49%)
  - Satisfying combinations are never created (bad luck)
  - Satisfying combinations are damaged before usage
  - Test runs are not long enough

Limitations to generalization

- The chosen classes are mostly data structures and might not be representative for all O-O programs.

- One-hour test runs might be too short, the number of faults does not reach a plateau.



Conclusion: ps-strategy vs. or-strategy

- How many more routines are tested by the ps-strategy?
  - The ps-strategy tests 56% of the routines missed by the or-strategy.

- How often are routines tested by the ps-strategy?
  - The ps-strategy tests routines over 3.5 times as often.

- How many more faults are detected by the ps-strategy?
  - The ps-strategy finds 10% more faults than the or-strategy.

- How fast is the ps-strategy?
  - The ps-strategy has negligible overhead (a mere 0.03%).

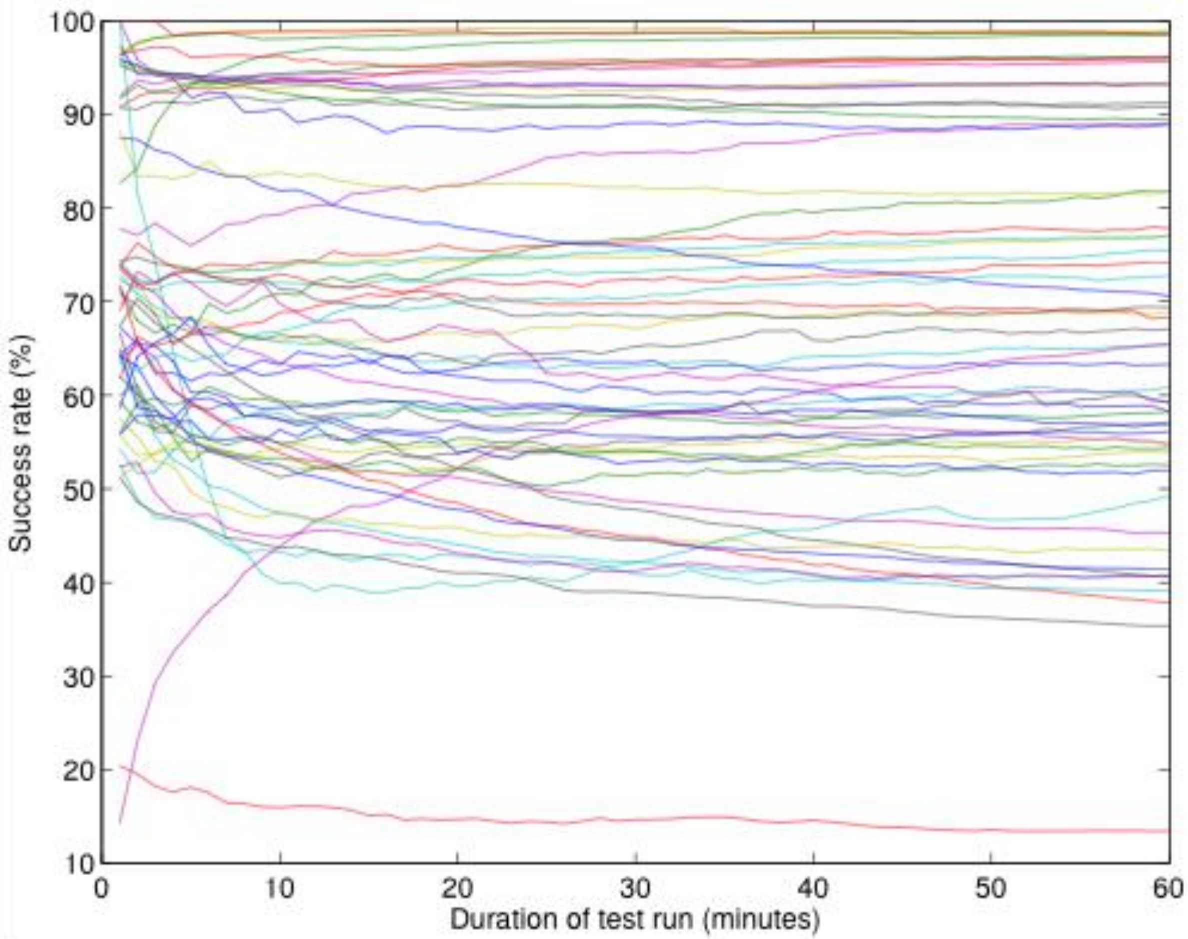
Questions

Importance of speed

- More valid test cases
  ⇒ more diversified object pool
  ⇒ greater chances of finding faults

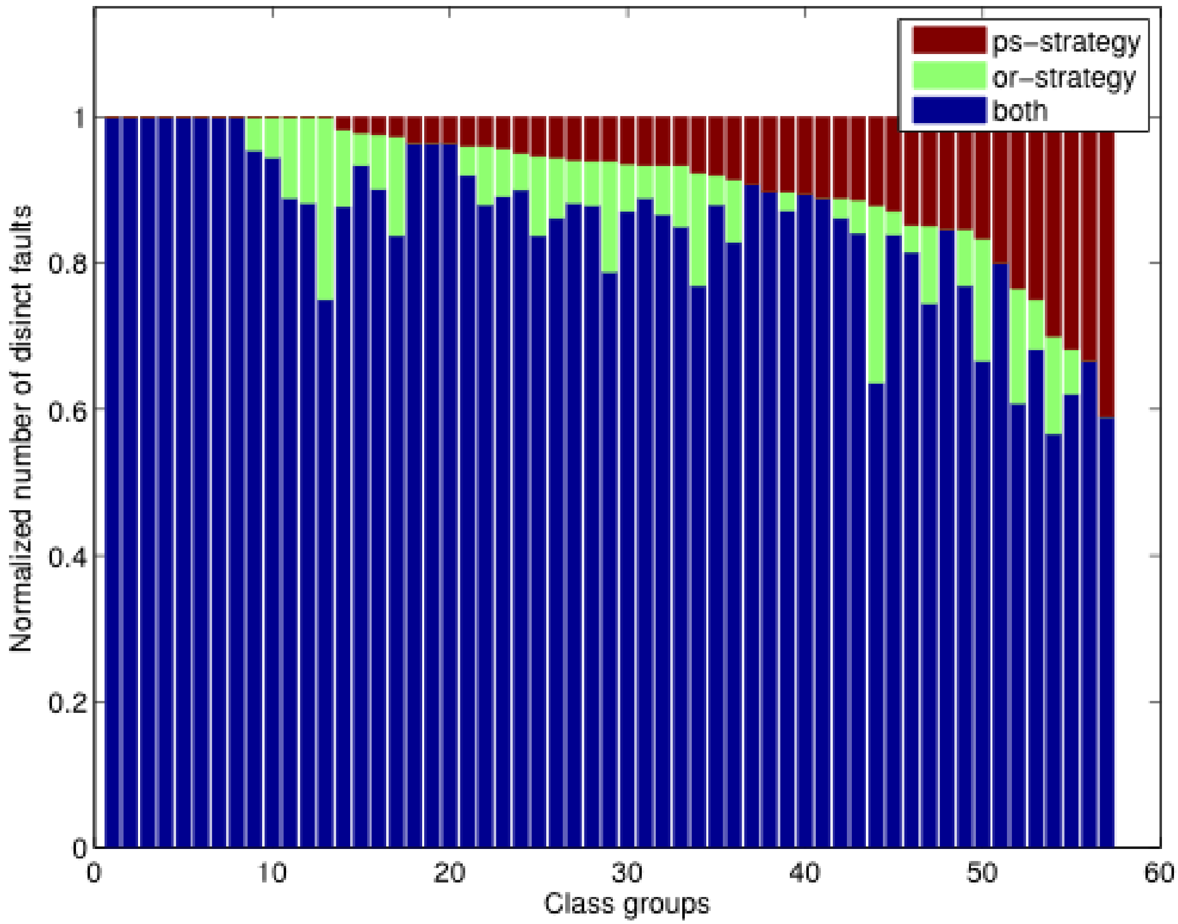
- Tried two other variations:
  - Iterating through all objects in the pool, overhead >50% (even with optimizations)
  - Always enforcing precondition satisfaction, big overhead

Success rate of the ps-strategy



- varies from as low as 20% to as high as 99%
- mostly over 40%
- generally decreasing because hard routines are favored

Distribution of fault detection



Optimization

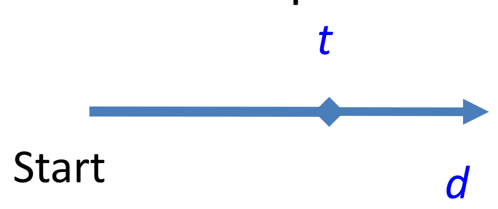
As a tradeoff, the precondition satisfaction is only turned on for routine *r* from time to time:

$$P_r(t,d) = \left(1 - \frac{t}{d}\right) \times C$$

t: time relative to the starting of the test run when *r* is last tested.

d: duration of the test run until now.

C: a constant, set to 0.8 in our experiments



Benefits:

- Routines are tested often
- Routines are tested throughout the whole testing run

Fault detection probability

- What is the probability of a strategy to detect a given fault in a single test run?

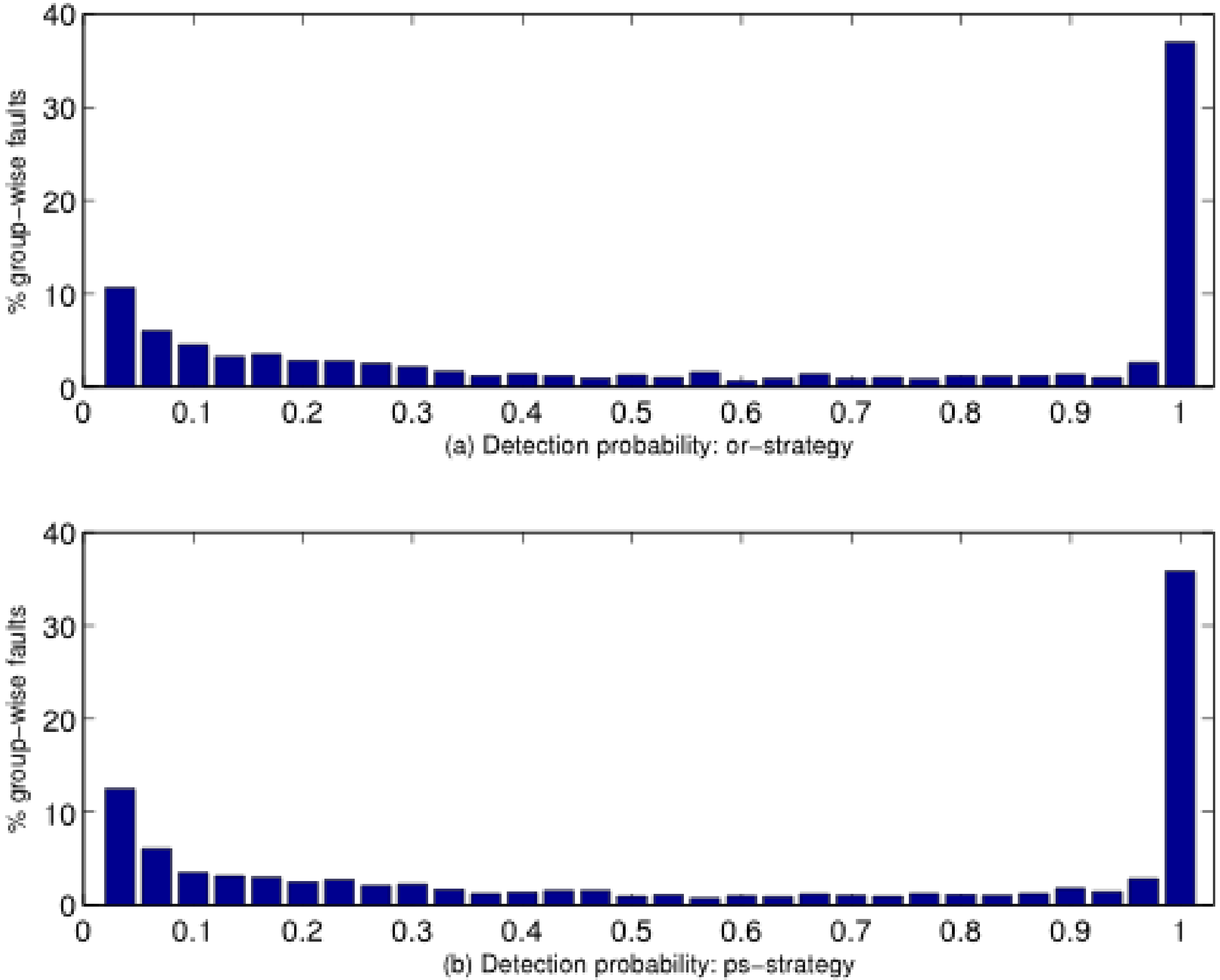
- The higher the probability, the less runs are needed to detect that fault.

- Fault Detection Probability of fault *f* using strategy *s*:

$$D(f,s) = \frac{N(f,s)}{R}$$

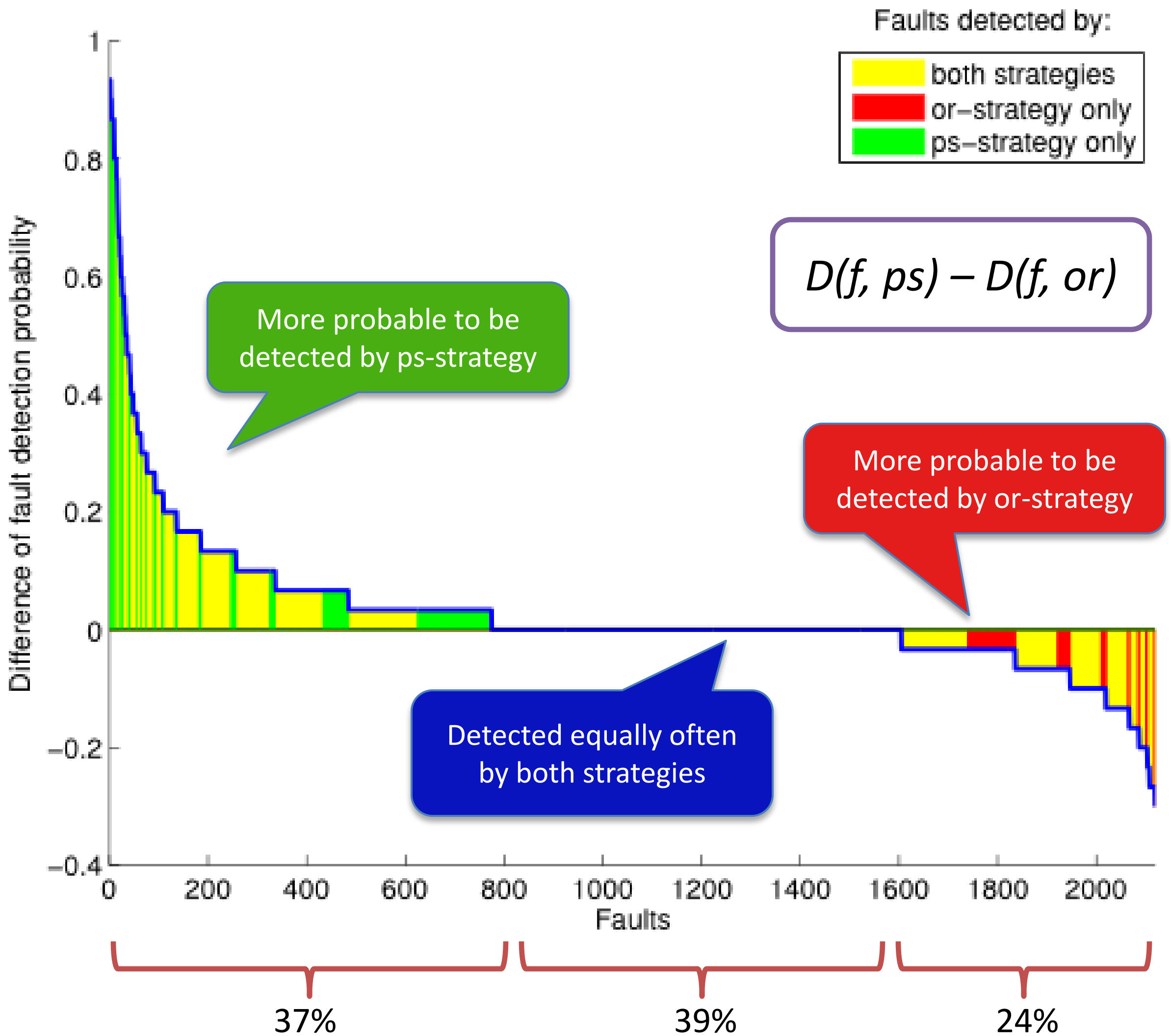
  - *N(f, s):* number of test runs in which *f* was detected under strategy *s*
  - *R:* number of test run per class group

Fault detection probability: behavior of both strategies



- Very similar behavior between both strategies
- But does not mean that the probability is the same under both strategies

Fault detection probability: ps-strategy vs. or-strategy



- ps-strategy does a better job at finding faults systematically