Precise Program Repair

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Background of Yingfei Xiong

- 2006~2009， The University of Tokyo, Ph.D.
  - Advisor: Zhenjiang Hu, Masato Takeichi
- 2009~2011， University of Waterloo, PostDoc
  - Supervisor： Krzysztof Czarnecki
- 2012~， Peking University, Assistant Professor under Young Talents Plan
- Research Interests
  - Software Analysis, Program Language Design

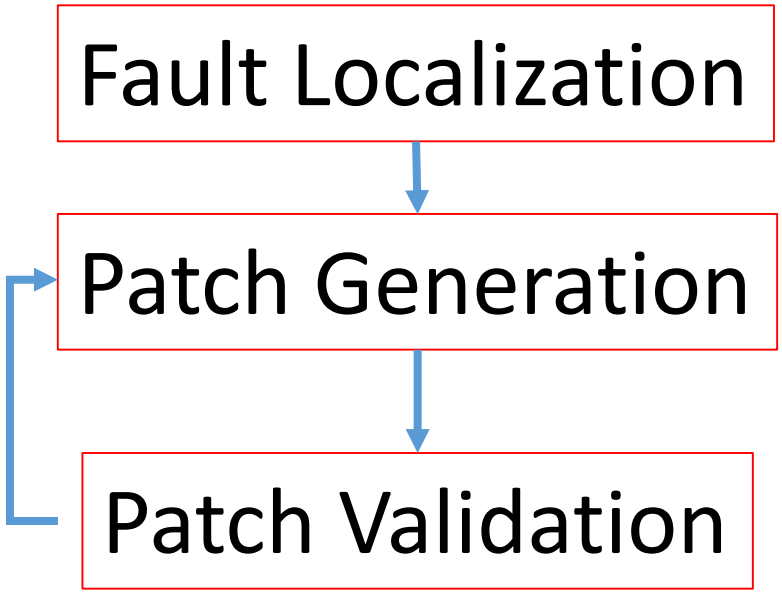
Origin

- “War. War never changes” – Fallout series
  - The war between developers and bugs never changes
- Fault Detection: Is there a bug?
  - Since 60s
  - Example Techniques： Testing, Verification
- Fault Localization: Where is the bug?
  - Since 90s
  - Example Techniques： Spectrum-based fault localization
- Fault Repair: How to fix the program?
  - Since 00s
  - Example Techniques： Test-based Program Repair

“Generate-Validate” Program Repair

Input: a program and a set of tests, where the program fails at least one test

Output: a patch that makes the program pass all the tests



Existing Work

- GenProg
  - [Weimer et al.: ICSE'09, GECCO'09, CACM'10, ICSE'12]
  - Approach
    - Replace the potentially faulty code with code pieces elsewhere
    - Use search algorithm to find an optimal combination
  - Results: 55/105，8$/bug
- Inspired a wave of program repair research
  - AutoFix, Nopol, RSRepair, MintHint, AutoRepair, SemFix, DirectFix, SPR…

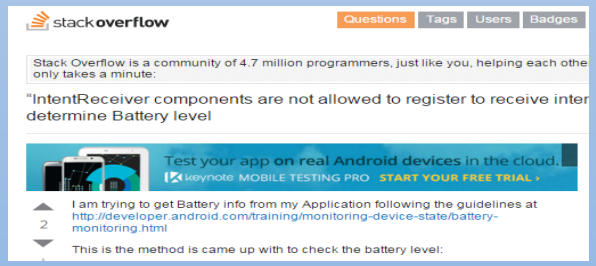
A Turning Point

- [Qi-ISSTA'15]
  - Only 2 among the 55 defects were correctly fixed by GenProg
  - Reason: passing the test does not guarantee correctness
- [Le Goues-FSE'15]
  - Extensive experiments on more methods, datasets, test suites
  - The finding still holds
- Other work
  - Prophet, Angelix
  - The precision (proportion of correct patches) is lower than 40%

Our Work

High Precision Defect Repair

Learn from QA sites [ASE15]



Precise Condition Repair [ICSE17]

Filtering out wrong patches [ICSE18]

[ASE15] Qing Gao, Hansheng Zhang, Jie Wang, Yingfei Xiong, Lu Zhang, Hong Mei. Fixing Recurring Crash Bugs via Analyzing Q&A Sites. ASE'15

[ICSE17] Yingfei Xiong, Jie Wang, Runfa Yan, Jiachen Zhang, Shi Han, Gang Huang, Lu Zhang. Precise Condition Synthesis for Program Repair. ICSE'17

[ICSE18] Yingfei Xiong, Xinyuan Liu, Muhan Zeng, Lu Zhang, Gang Huang, Identifying Patch Correctness in Test-Based Automatic Program Repair. ICSE'18

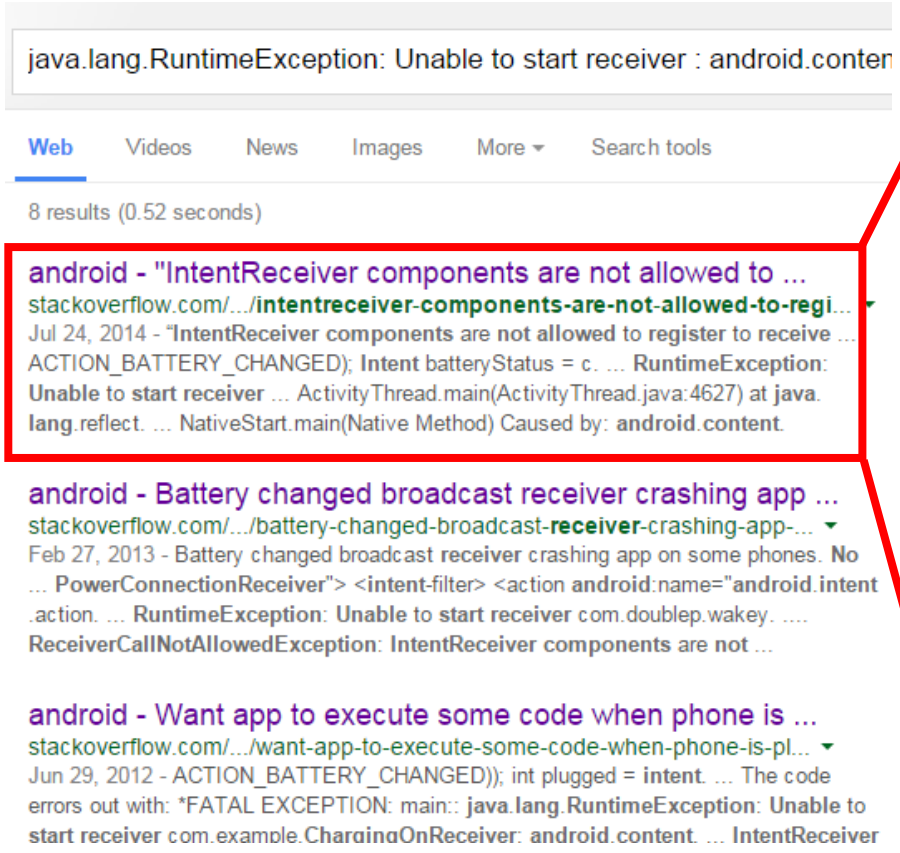
Fixing from QA Sites

- How do developers get their experience?

```
29    public void onReceive (final Context context, final Intent intent) {
30       final int action = intent.getExtras().getInt(KEY_ACTION, -1);
31       final float bl = BatteryHelper.level(context);
32       LOG.i("AlarmReceiver invoked: action=%s bl=%s.", action, bl);
33       switch (action) {
...          ...
51       }
52    }
```

java.lang.RuntimeException: Unable to start receiver com.vaguehope.onosendai.update.AlarmReceiver:

Fixing from QA Sites



Challenge: Understanding natural language is hard

Learn from QA Sites

- Observation: programmers communicates in programming languages
- Solution: Directly compare the code pieces

My broadcast receiver is

```
    @Override
    public void onReceive(Context context, Intent intent) {

        Bundle extras = intent.getExtras();
        String message = extras != null ? extras.getString("com.parse.Data")
                : "";

        Log.e("message ", " " + message);
        JSONObject jObject;
        try {
            jObject = new JSONObject(message);
            //objectId = jObject.getString("id");
            time = jObject.getString("time");
            msg = jObject.getString("title");
            title = jObject.getString("msg");
                GCMMessage gcmMessage = new GCMMessage();

            //gcmMessage.setMsg_id(1);
            gcmMessage.setMsg_body(msg);
            gcmMessage.setMsg_title(title);
            gcmMessage.setType(0);
            gcmMessage.setDateTime(time);

                DatabaseUtil.insertMessage(context, gcmMessage);

        }
        catch (JSONException e) {
            e.printStackTrace();
        }
}
```

When I reboot my phone then also it showing same error..., otherwise it is working fine.

Questions

I'll have a guess that `message` has the value of `""` or `NULL`

1

```
    JSONObject jObject;
    try {
        if (message != null && !message.equals("") {
          jObject = new JSONObject(message);
          //objectId = jObject.getString("id");
          time = jObject.getString("time");
          msg = jObject.getString("title");
          title = jObject.getString("msg");
          GCMMessage gcmMessage = new GCMMessage();

          //gcmMessage.setMsg_id(1);
          gcmMessage.setMsg_body(msg);
          gcmMessage.setMsg_title(title);
          gcmMessage.setType(0);
          gcmMessage.setDateTime(time);

          DatabaseUtil.insertMessage(context, gcmMessage);
        }

      }
      catch (JSONException e) {
        e.printStackTrace();
      }
```

Instead of:

4

```
context.registerReceiver(null, new IntentFilter(Intent.ACTION_BATTERY_CHANGED));
```

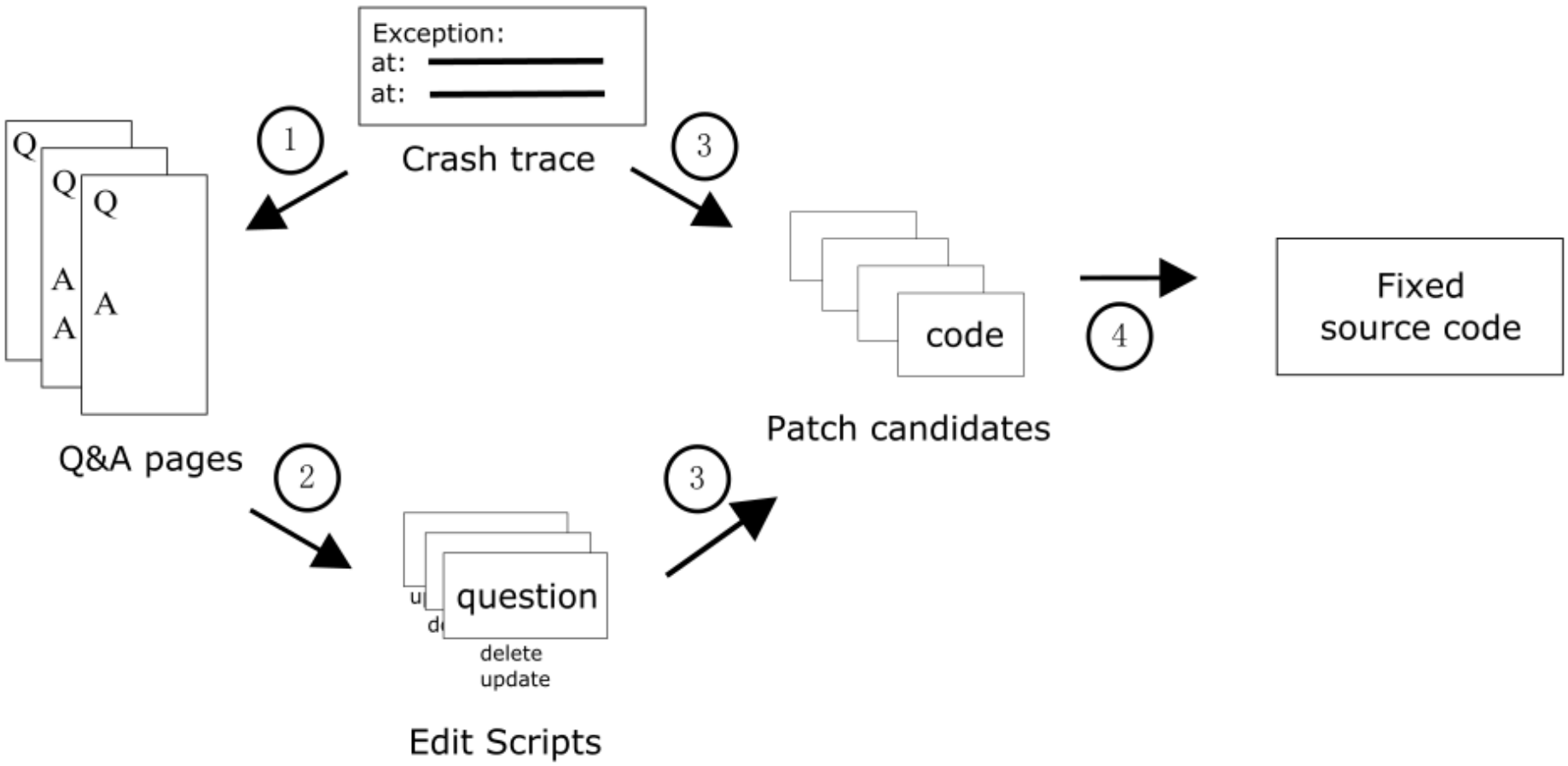
use:

```
context.getApplicationContext().registerReceiver(null, new IntentFilter(Intent.ACTION_BATTER
```

This is annoying -- `registerReceiver()` should be smarter than this -- but it's the workaround for this particular case.

Answers

Approach Overview



Experiments

- 24 Android crash bugs that have answers on StackOverflow
  - Selected out of 161 Android crash bugs

- Correctly Fixed： 8
- Wrongly Fixed： 2
- Precision： 80%
- Recall： 33% (5% among Android crash bugs)

Can we repair more bugs?

Precise Condition Synthesis

- Targeted defect class: condition bugs

```
  lcm = Math.abs(a+b);
+ if (lcm == Integer.MIN_Value)
+   throw new ArithmeticException();
```

Missing boundary checks

```
-  if (hours <= 24)
+ if (hours < 24)
      withinOneDay=true;
```

Conditions too weak or too strong

Condition bugs are common

ACS System

- ACS = Accurate Condition Synthesis
- Two sets of templates for repair

Oracle Returning

- Inserting one of the following statement before the last executed statement
  - if ($C) throw ${Expected Exception};
  - if ($C) return ${Expected Output};

Condition Modifying

- Changing the condition located by predicate switching
  - if ($D) => if ($D || $C)
  - if ($D) => if ($D && $C)

Need to synthesize condition $C

Challenge – Many incorrect conditions pass the tests

```
  int lcm=Math.abs(
    mulAndCheck(a/gdc(a,b),b));
+if (lcm == Integer.MIN_VALUE) {
+   throw new ArithmeticException();
+}
  return lcm;
```

Test 1 (Passed):
Input: a = 1, b = 50
Oracle: lcm = 50

Test 2 (Failed):
Input: a = Integer.MIN_VALUE, b = 1
Oracle: Expected(ArithmeticException)

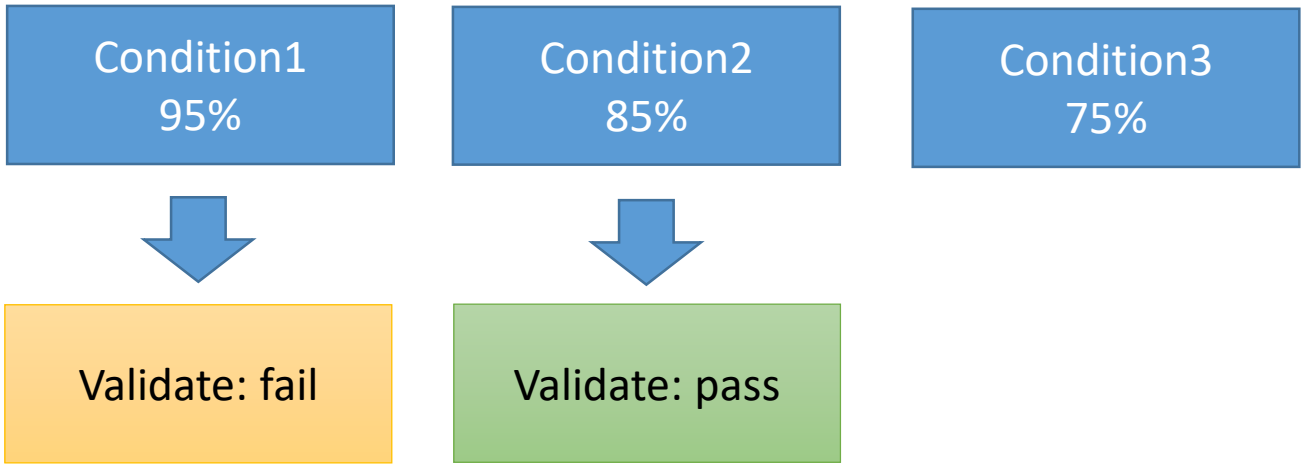
Correct condition:
lcm == Integer.MIN_VALUE

Incorrect conditions:

- a != 1
- b == 1
- lcm != 50
- …

Idea: Rank the Conditions

- Rank potential conditions by their probabilities of being correct
- Validate the conditions one by one
- Stop validating when the probability is too low



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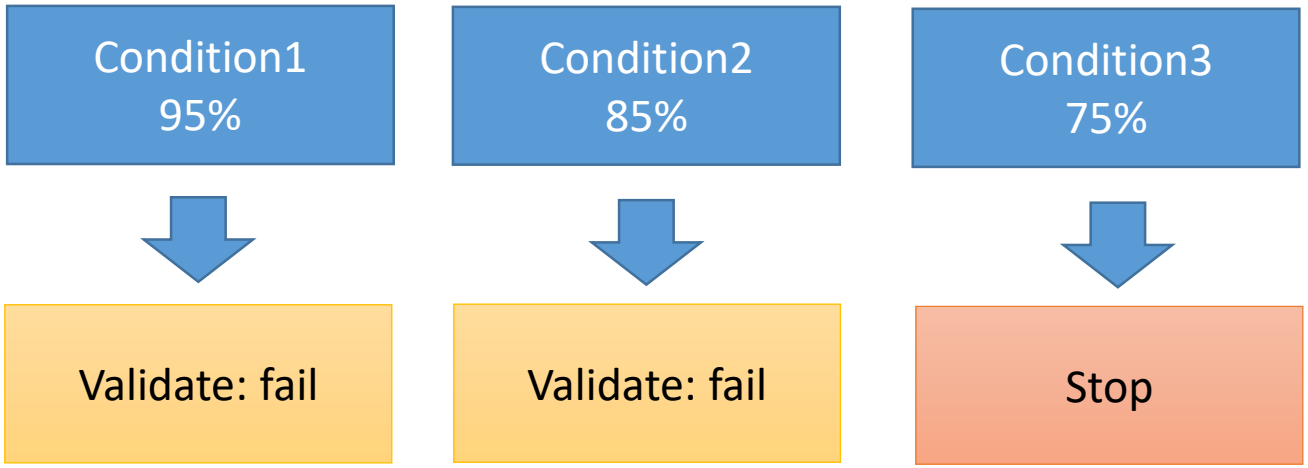
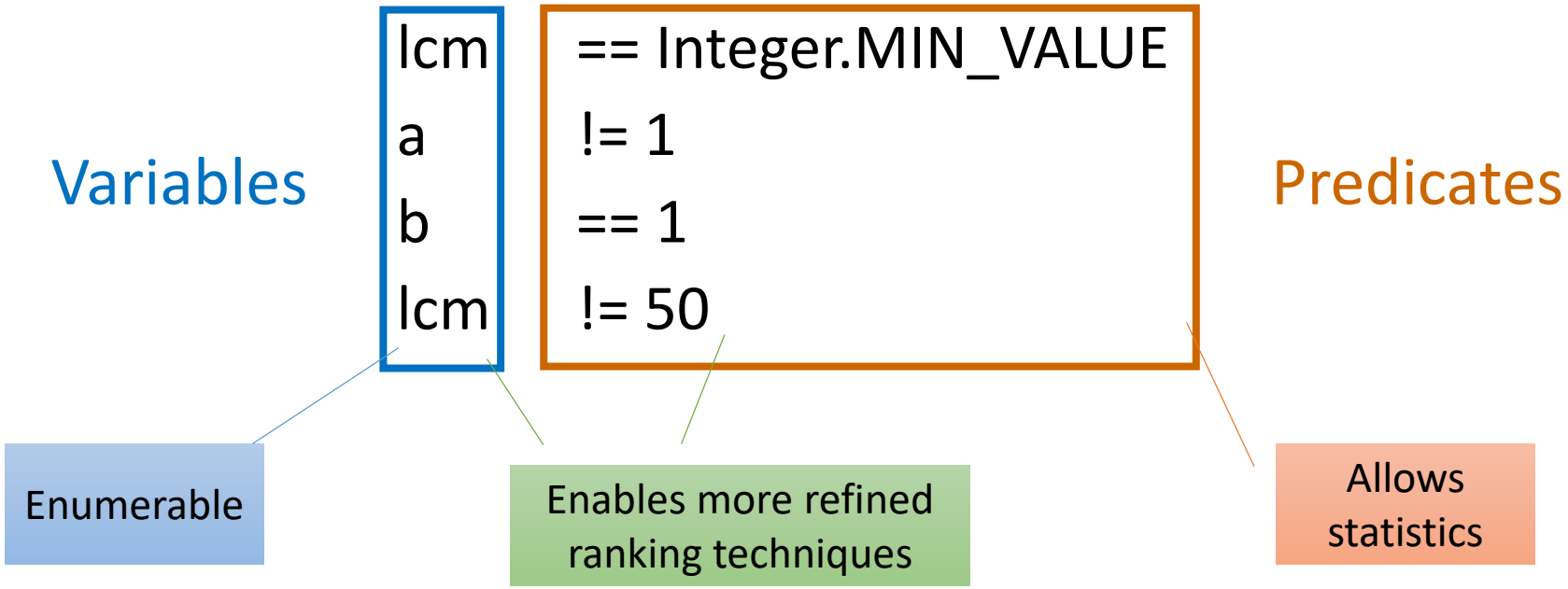


Ranking Conditions is Difficult

- The number of potential conditions is large
  - Cannot enumerate the conditions
  - Difficult to perform statistics: not enough samples for each condition

Solution: Divide-and-Conquer

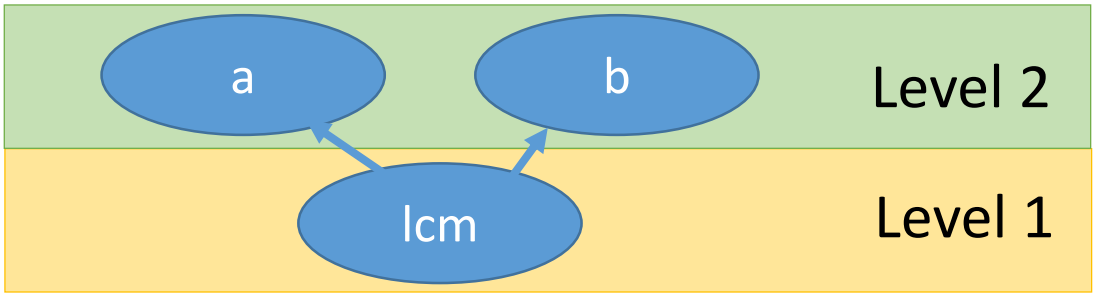


Step 1: Rank variables

Step 2: Rank predicates for each variable

Ranking Method 1: Rank Variables by Data-Dependency

- **Locality of variable uses**: recently assigned variables are more likely to be used
- Rank variables by data-dependency
  - lcm = Math.abs(mulAndCheck(a/gdc(a, b), b))



- Consider only variables in the first two levels

Ranking Method 2: Filter Variables by JavaDoc

```
/** ...
 * @throws IllegalArgumentException if initial is not between
 * min and max (even if it <em>is</em> a root)
**/
```

Only variable “initial” is considered when throwing IllegalArgumentException

Ranking Method 3: Rank Predicates by Context

- The predicates tested on the variables are related to its context

Variable Type

```
Vector v = …;
if (v == null) return 0;
```

Variable Name

```
int hours = …;
if (hours < 24)
    withinOneDay=true;
```

Method Name

```
int factorial() {
  …
  if (n < 21) {
    …
```

- Approximate the conditional probabilities by querying GitHub
- Consider only the predicates whose probabilities are larger than a threshold

Evaluation: Performance of ACS

Dataset: Four projects from Defects4J benchmark:

- Time, Lang, Math, Chart
- In total 224 defects

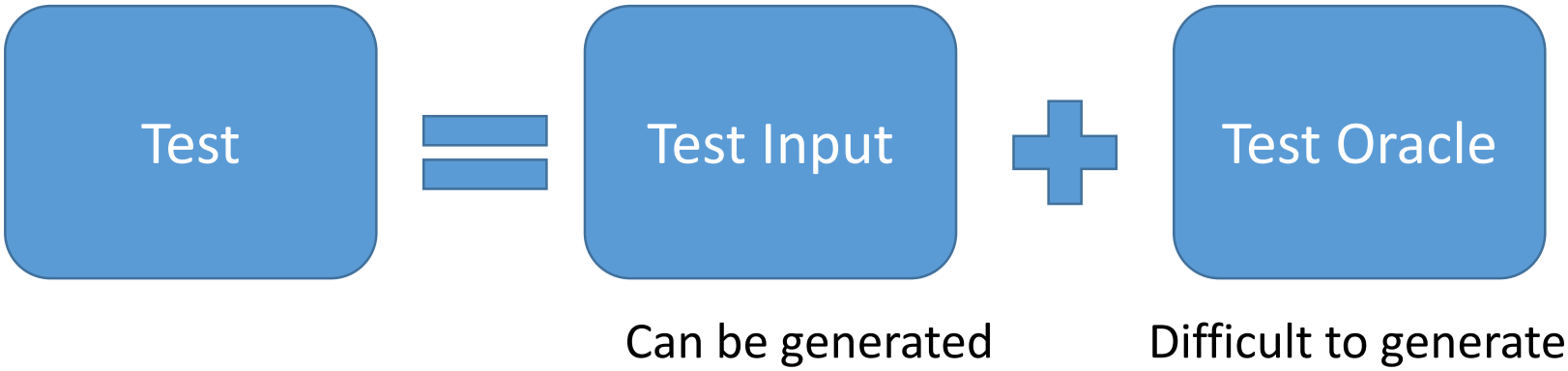
Approach	Correct	Incorrect	Precision	Recall
ACS	**17**	**6**	**73.9%**	**7.5%**
jGenProg	5	22	18.5%	2.2%
Nopol	5	30	14.3%	2.2%
xPAR	3	–[4]	–[4]	1.3%[2]
HistoricalFix[1]	10(16)[3]	–[4]	–[4]	4.5%(7.1%)[2,3]

Can we further improve precision?

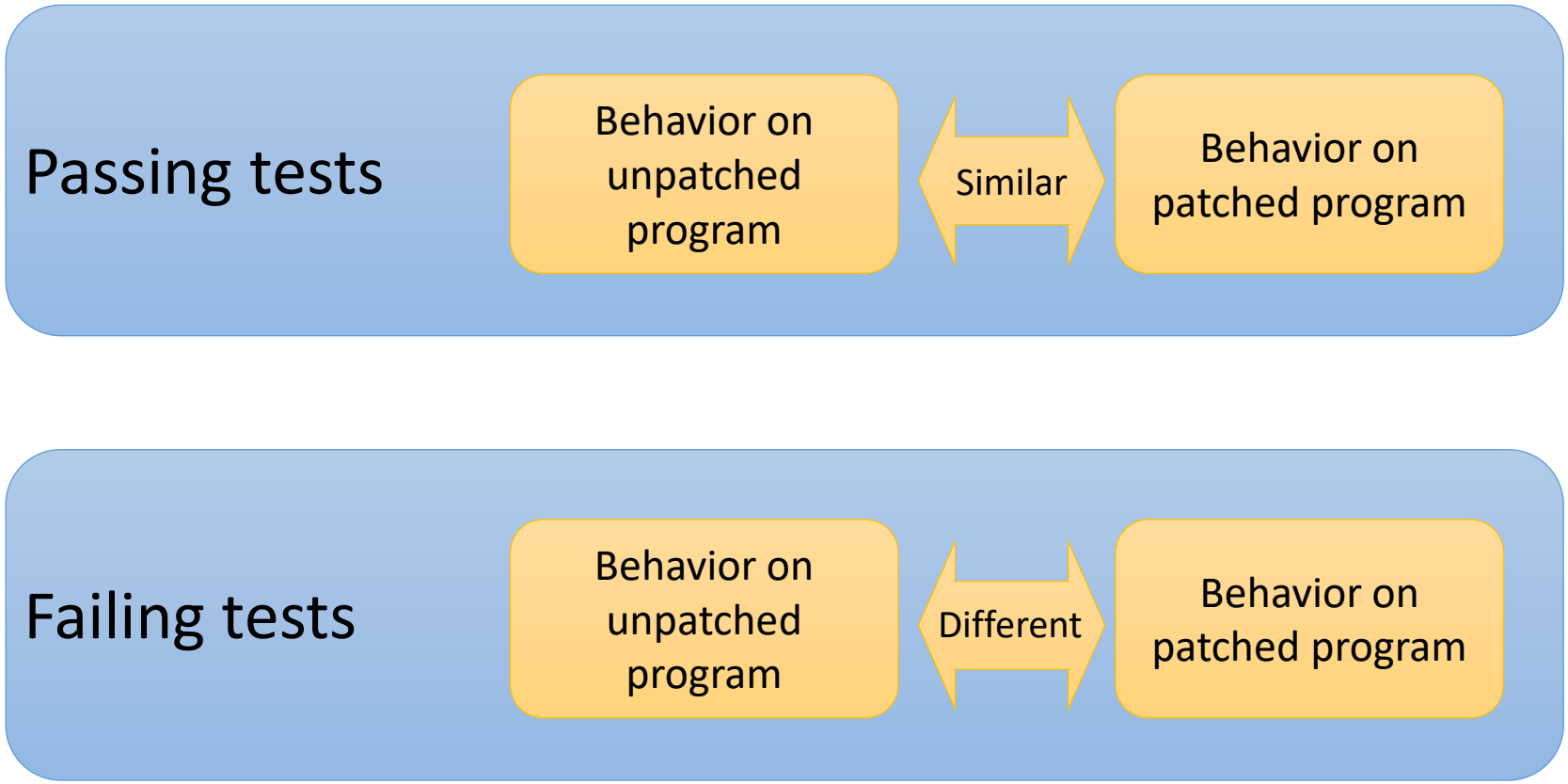
Analysis: Weak test suites are the reason for low precision

Idea: Can we improve test suites?

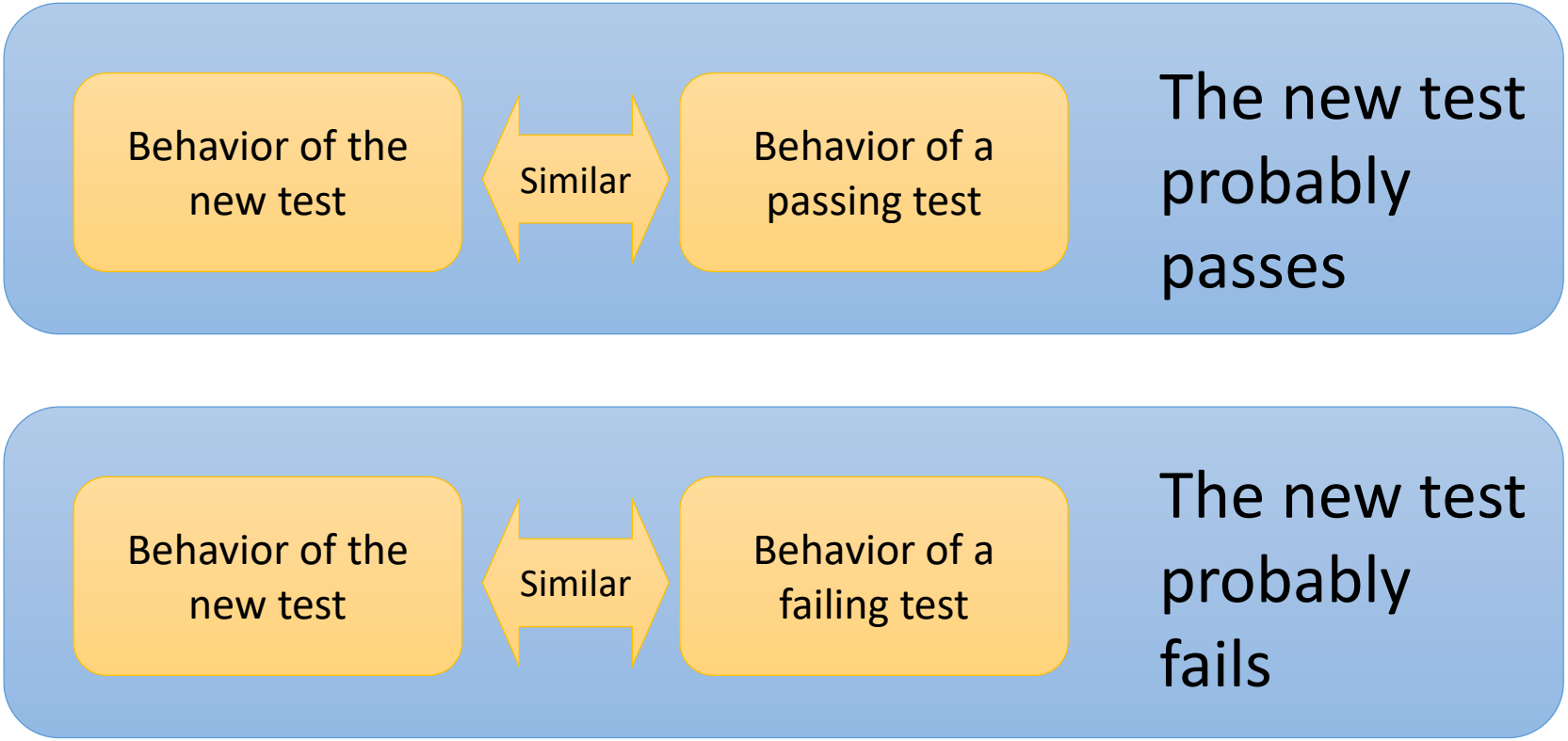
Improve Test Suites



PATCHSIM - Heuristic for test oracles

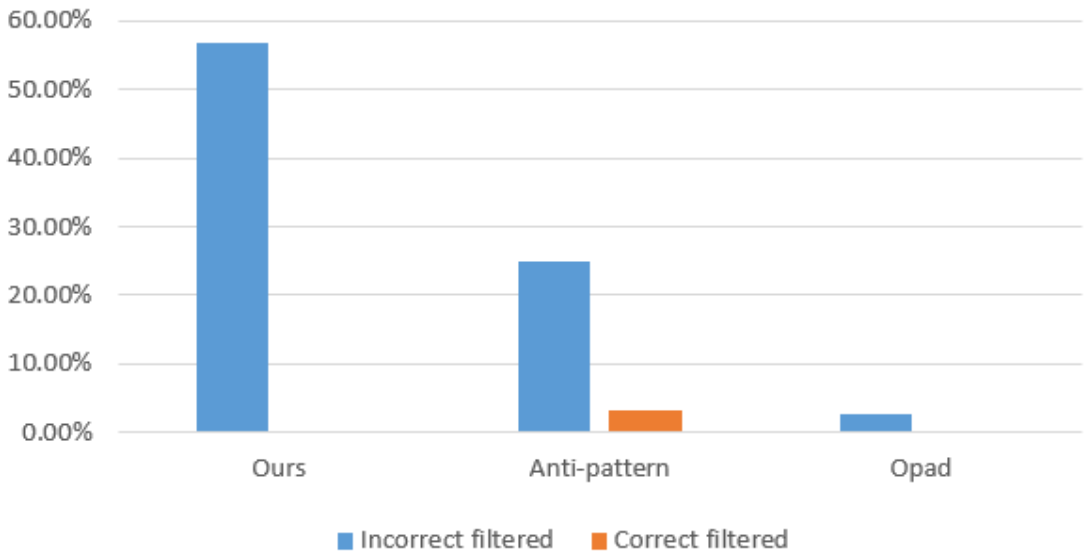


TESTSIM – Heuristic for test inputs



Experiment Results

- 139 Patches generated by different tools
  - 30 correct， 109 incorrect



- Successfully filtered out 56.9% wrong patches, filtering out no correct patch
- Improved the precision of ACS to 85%

Vision

- Long-term Goal: automate programming
- Roadmap: deal with more and more difficult issues
  - Issue = bug report + feature requests

Conclusion

- Will program repair be useful in practice?
  - Increasing precision is the key
- Can we improve precision?
  - Yes, at least for incorrect conditions and crashes
- How can we improve precision?
  - By learning from existing resources