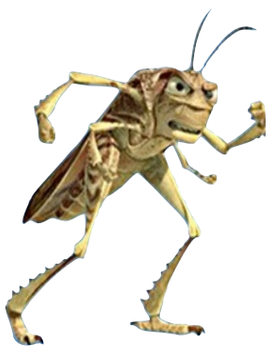



Cooperative Program Analysis for Reliable Mobile Applications

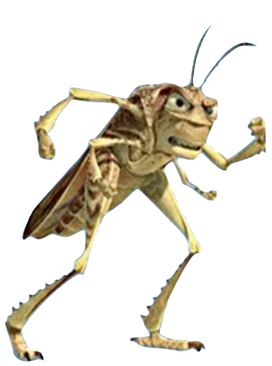
Bor-Yuh Evan Chang
University of Colorado Boulder



Huawei Vision Forum
October 21, 2015

PLV

A program analysis story ...




A380

Software is everywhere and varying more and more

traditional

mobile

cloud

cyberphysical

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Software is getting more and more complex

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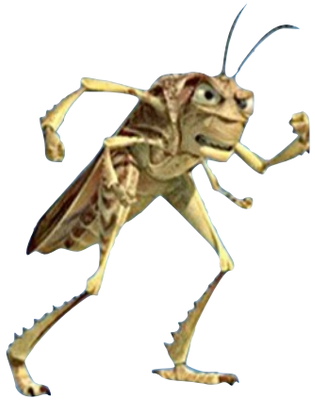
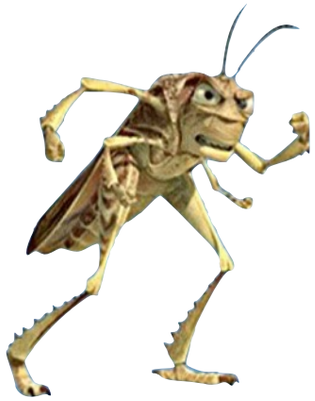
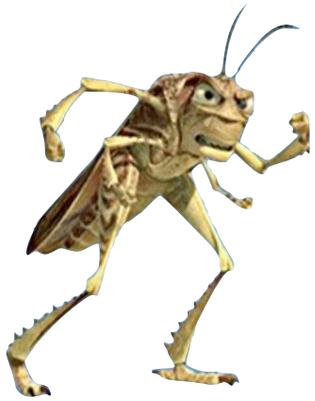



HELP!



1980s Bug in Therac-25 kills 6



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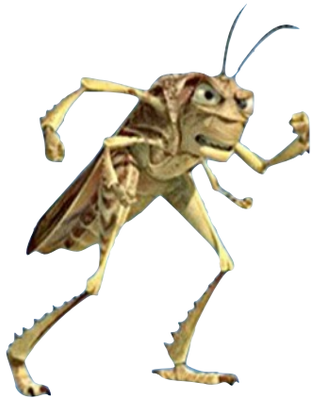
2000s: Conficker worm costs $9.1 billion in damages



1980s Bug in Therac-25 kills 6

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Today: "Don't buy this app, it crashes."


Program
Analysis

How does program analysis save the day?

Program Analysis for Formal Verification

Program

Systematically examine the program to "simulate" running it on "all inputs"

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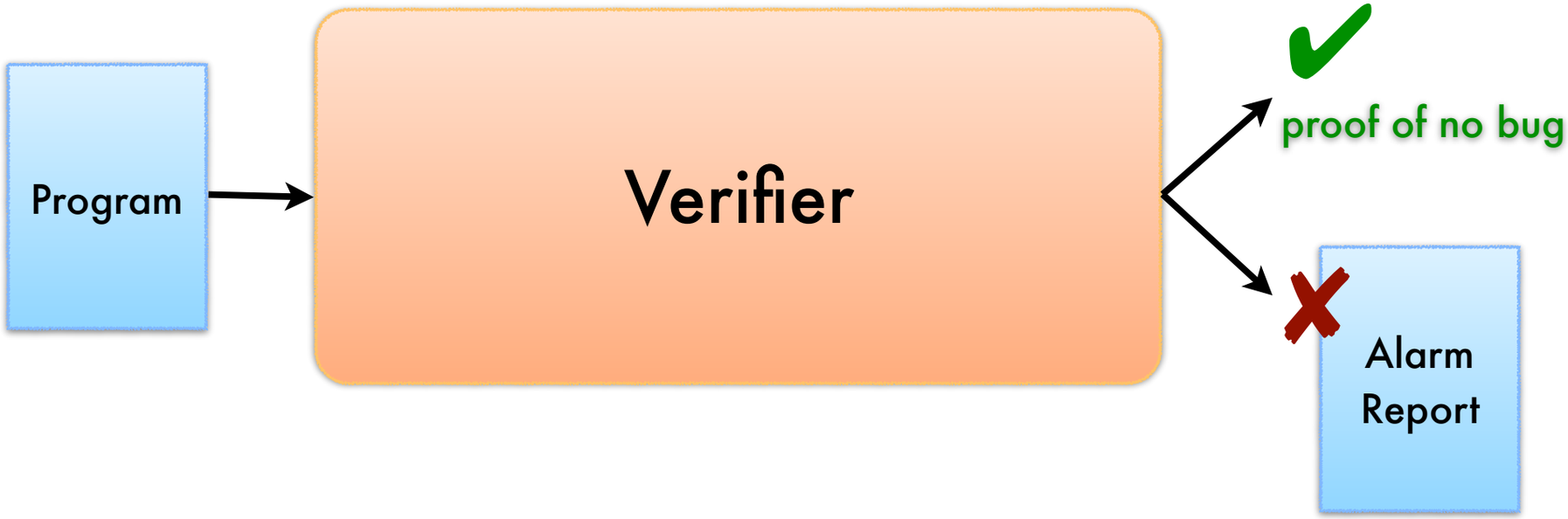
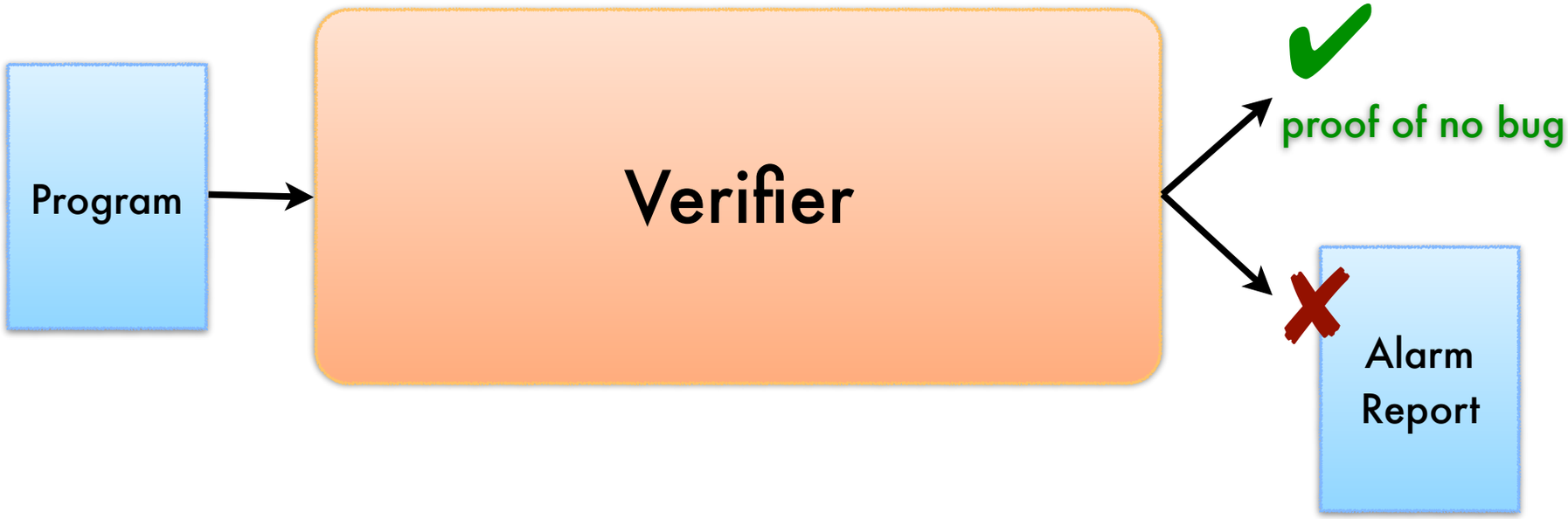


Systematically examine the program to "simulate" running it on "all inputs"

The End?

The Ugly, Hidden Truth

Program Analysis for Formal Verification



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The Ugly, Hidden Truth

Program Analysis for Formal Verification

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The Ugly, Hidden Truth

Program Analysis for Formal Verification

Undecidability necessitates the possibility of false alarms. We hope not too many.

Uncooperative Program Analysis?

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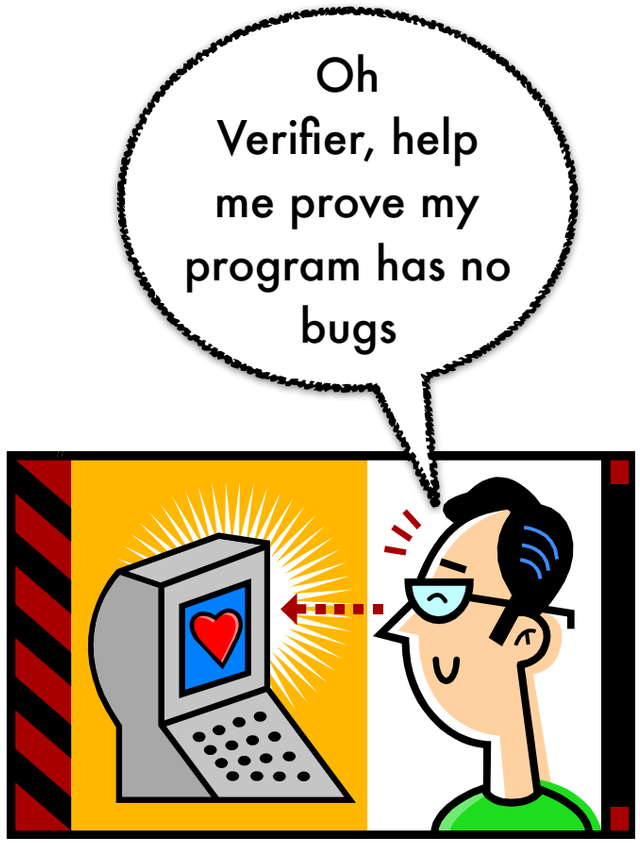

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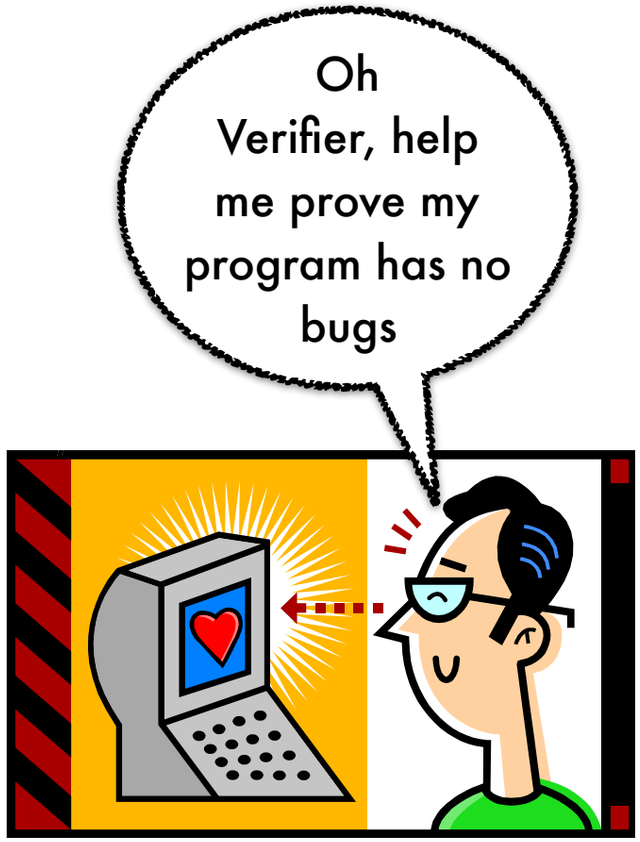

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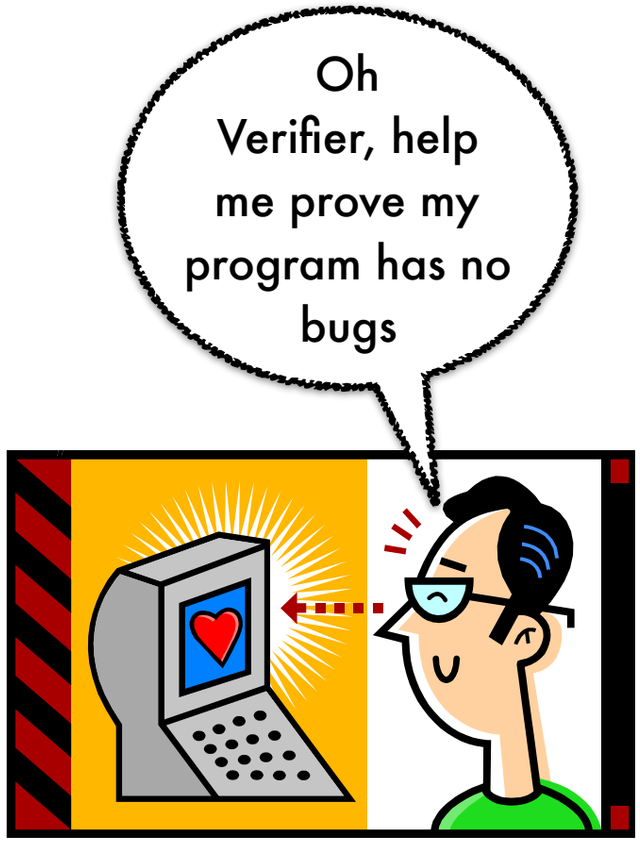

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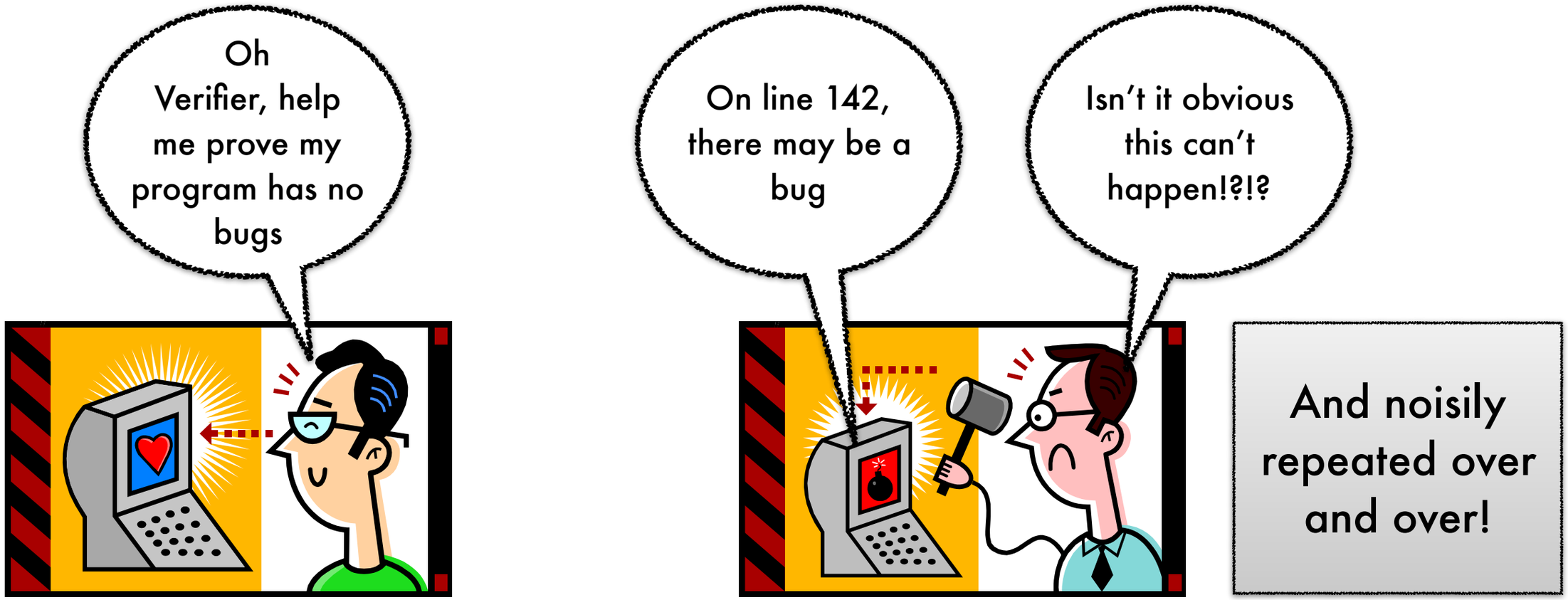

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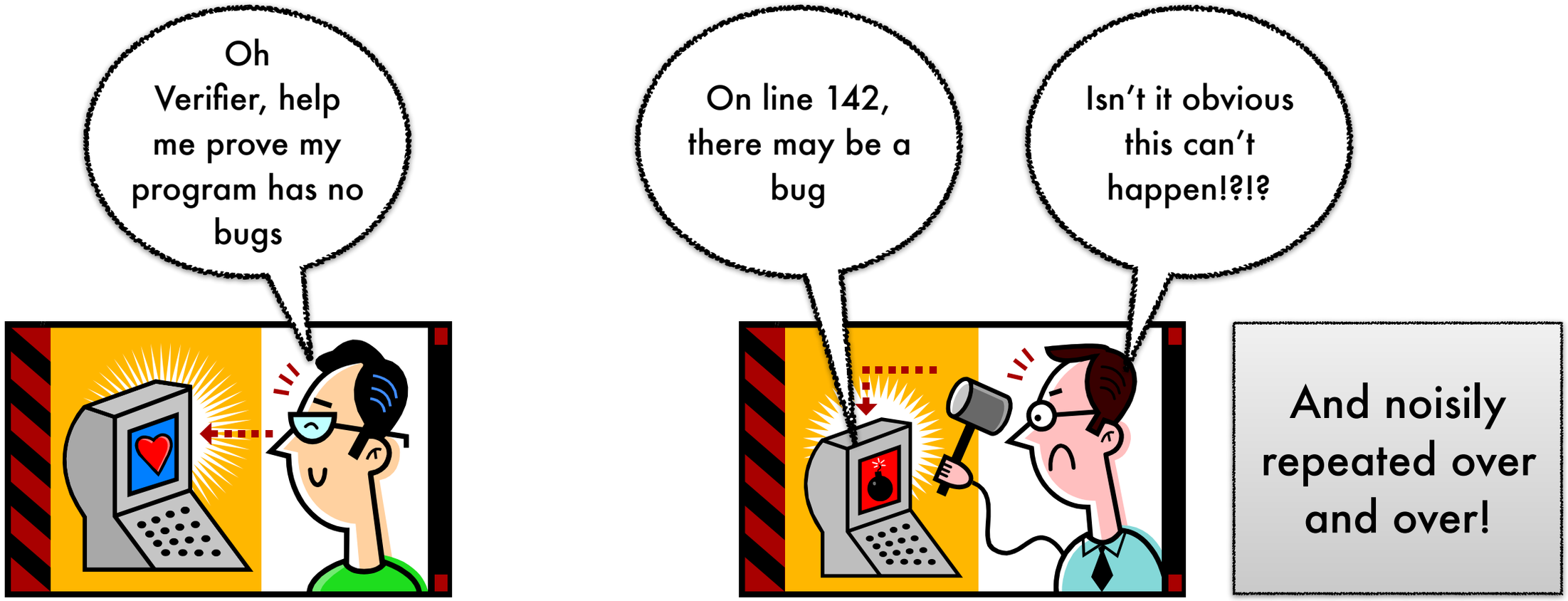
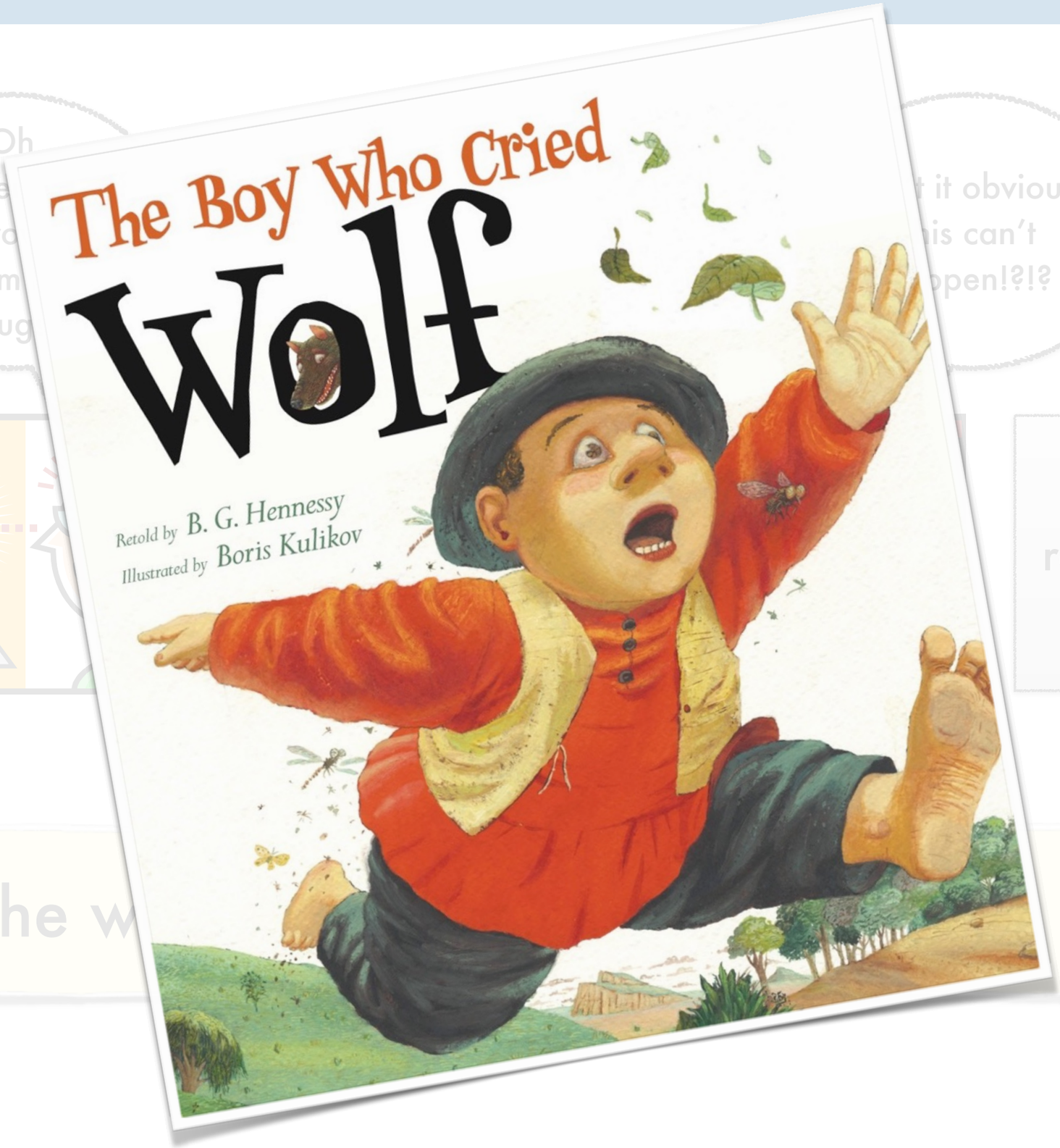


The well-known false alarm problem

Uncooperative Program Analysis?



Oh
Verifie
me pro
program
bug

t it obvious
is can't
open!?!?

And noisily repeated over and over!

The w

"[M]ore than a 30% [false alarm rate] easily causes problems. True bugs get lost in the false. A vicious cycle starts where low trust causes complex [true] bugs to be labeled false [alarms], leading to yet lower trust."

"A stupid false [alarm] implies the tool is stupid."

Bessey, A., Block, K., Chelf, B., Chou, A., Fulton, B., Hallem, S., Henri-Gros, C., Kamsky, A., McPeak, S. and Engler, D. 2010. A few billion lines of code later: using static analysis to find bugs in the real world. *Commun. ACM*. 53, 2 (2010), 66–75.

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The traditional approach to the false alarm problem focuses on improving the verifier.

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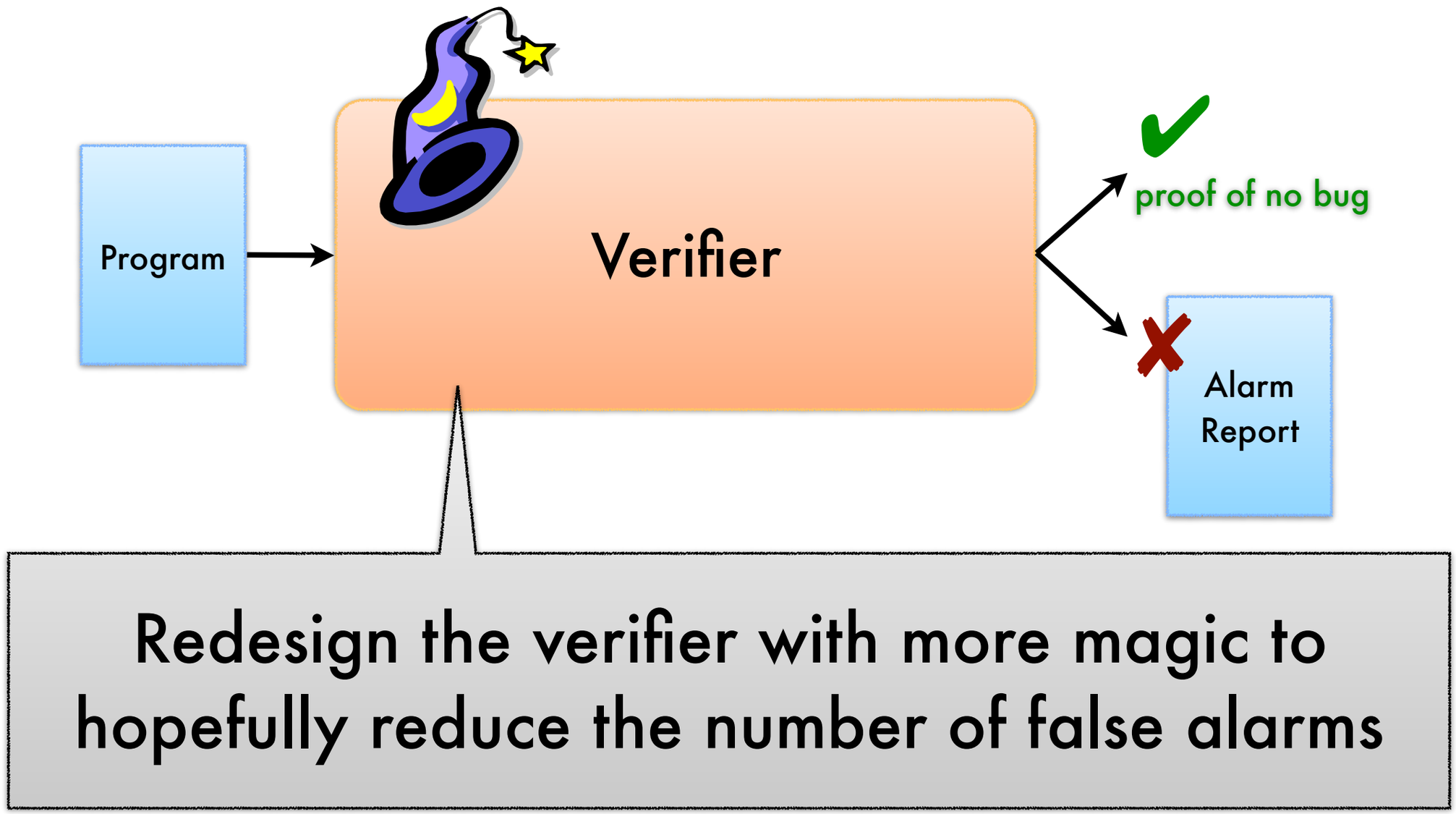

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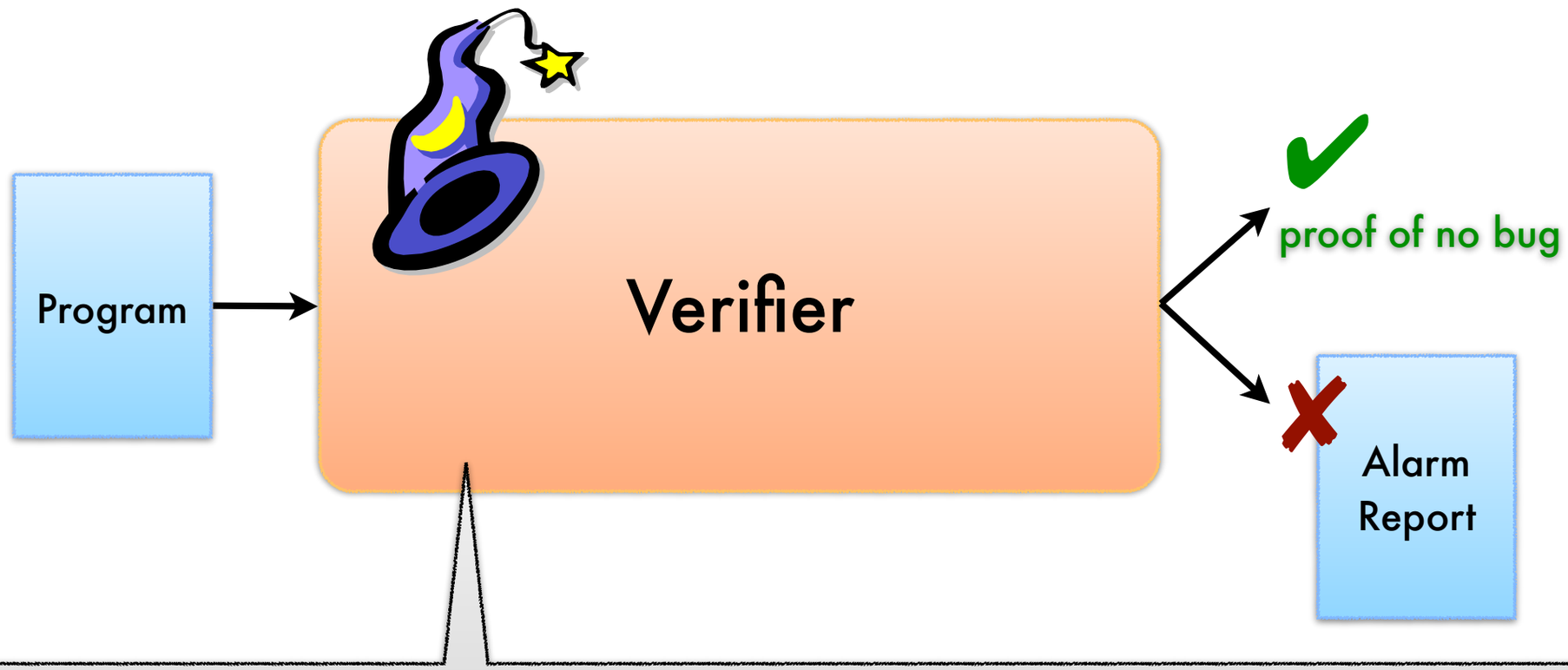

Redesign the verifier with more magic to hopefully reduce the number of false alarms

But it can never be perfect (undecidability)

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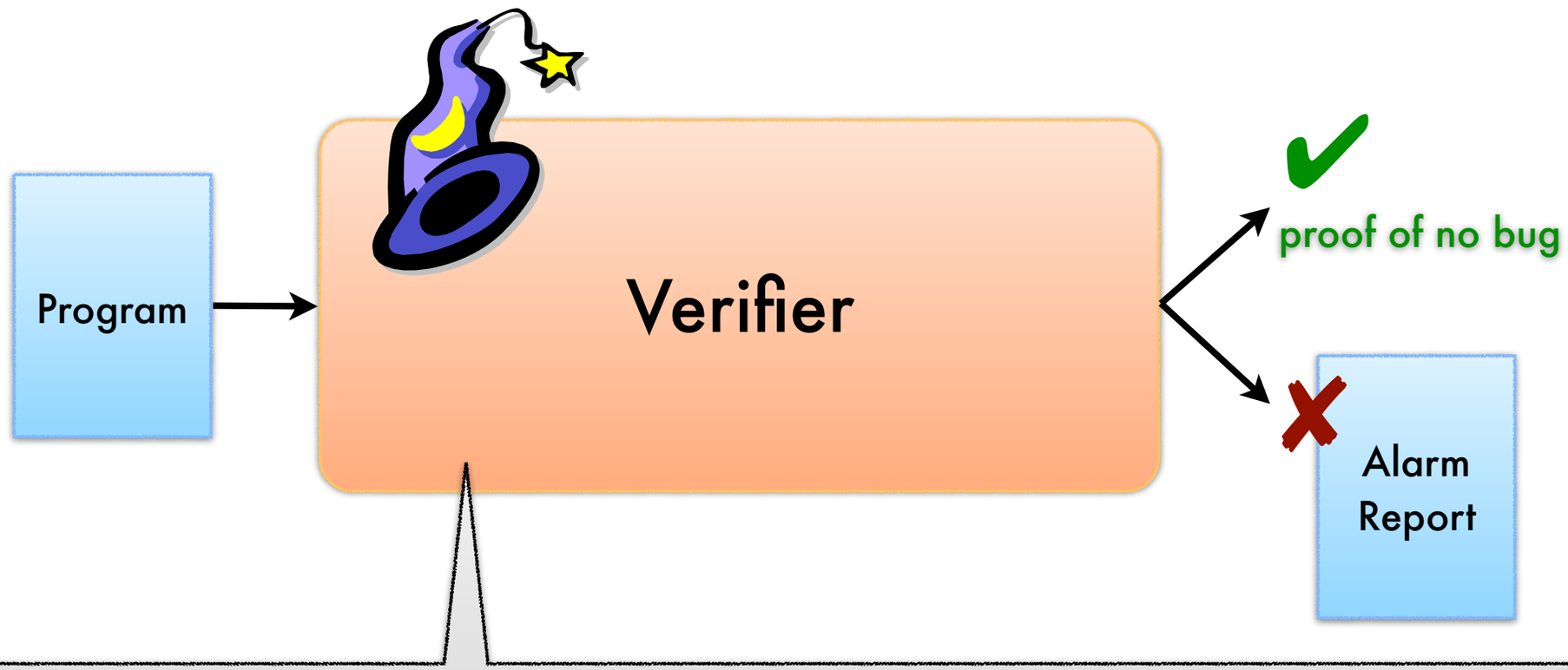

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But it can never be perfect (undecidability)

Also not a sufficient "excuse"

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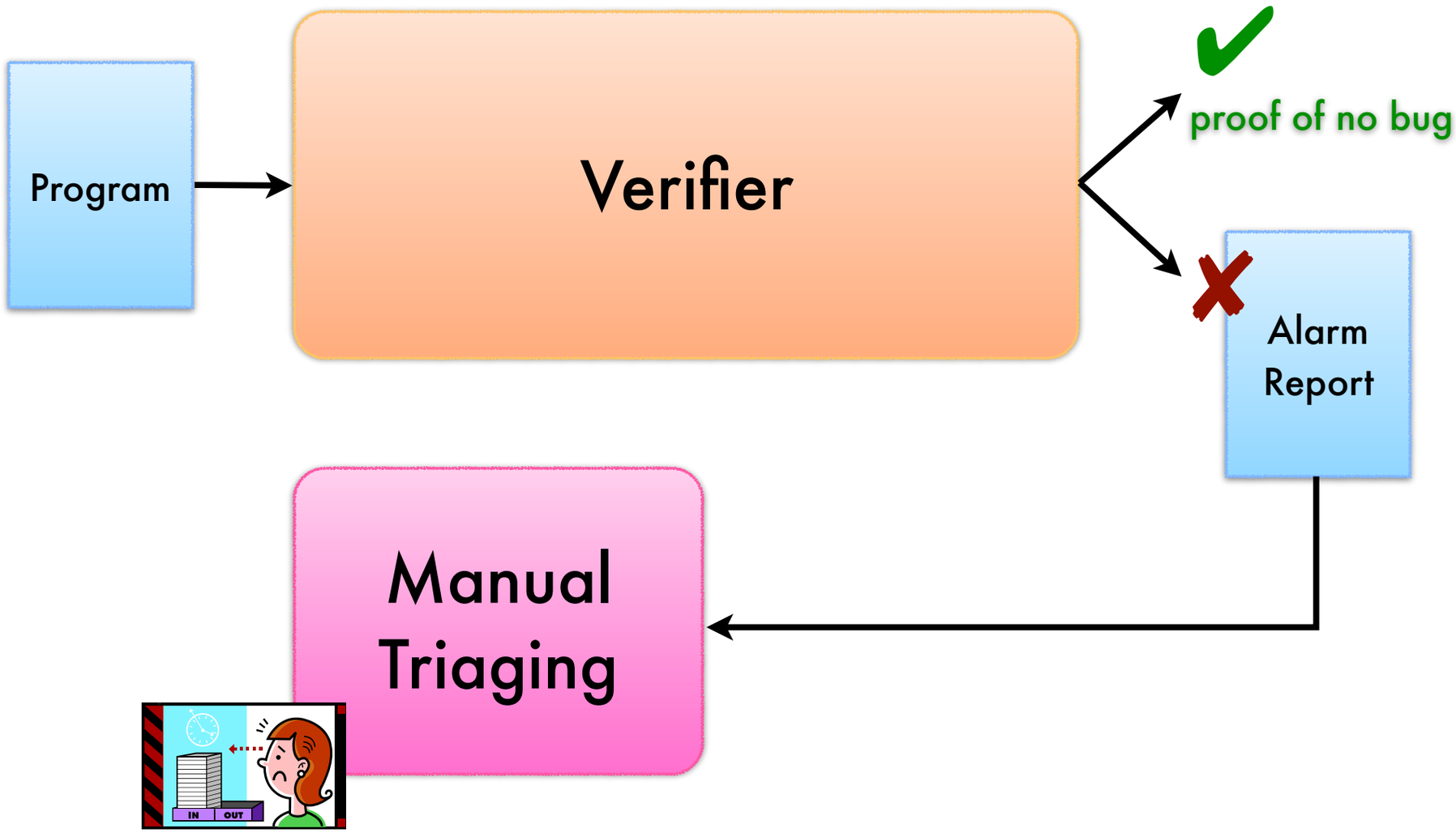

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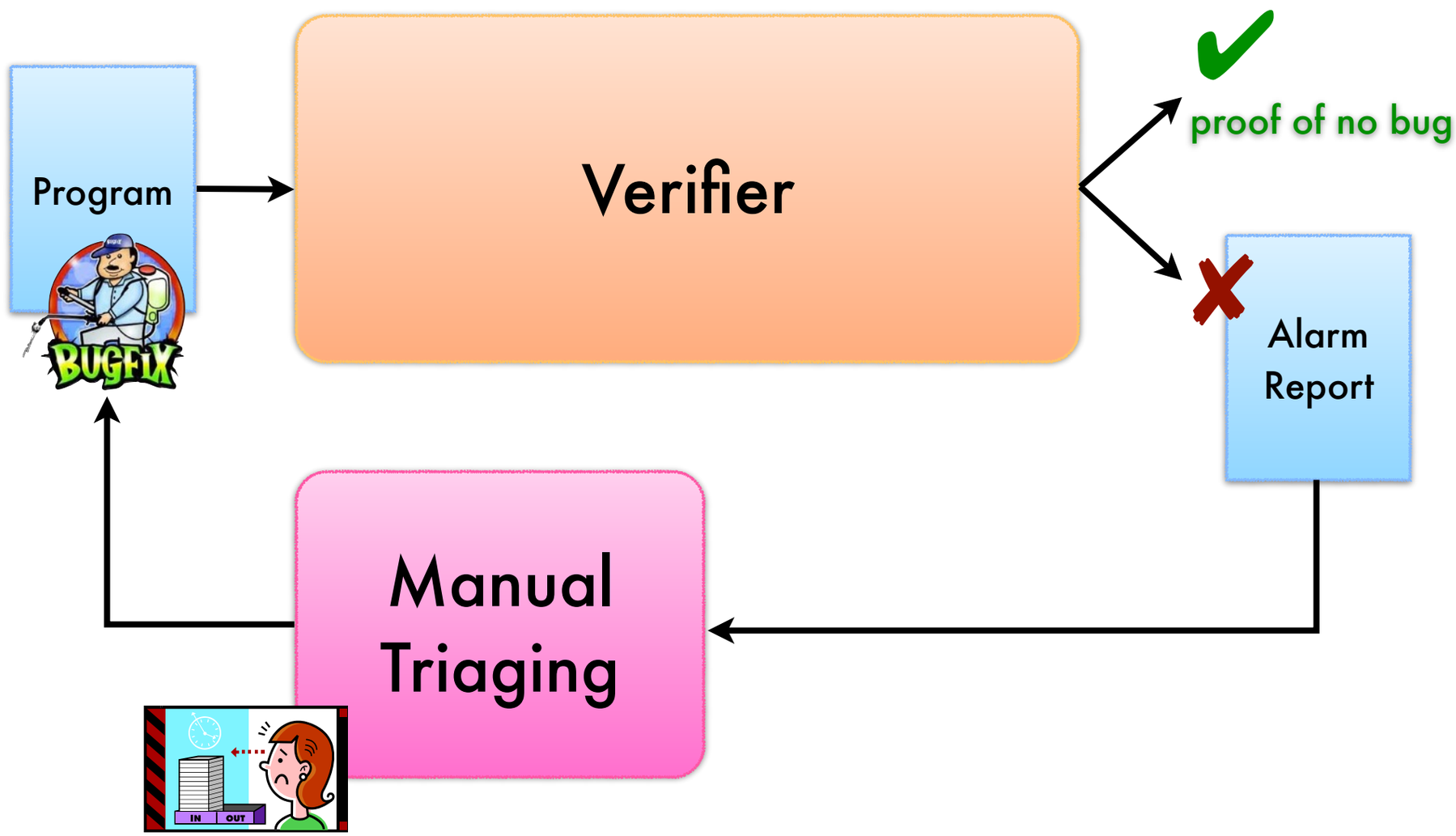

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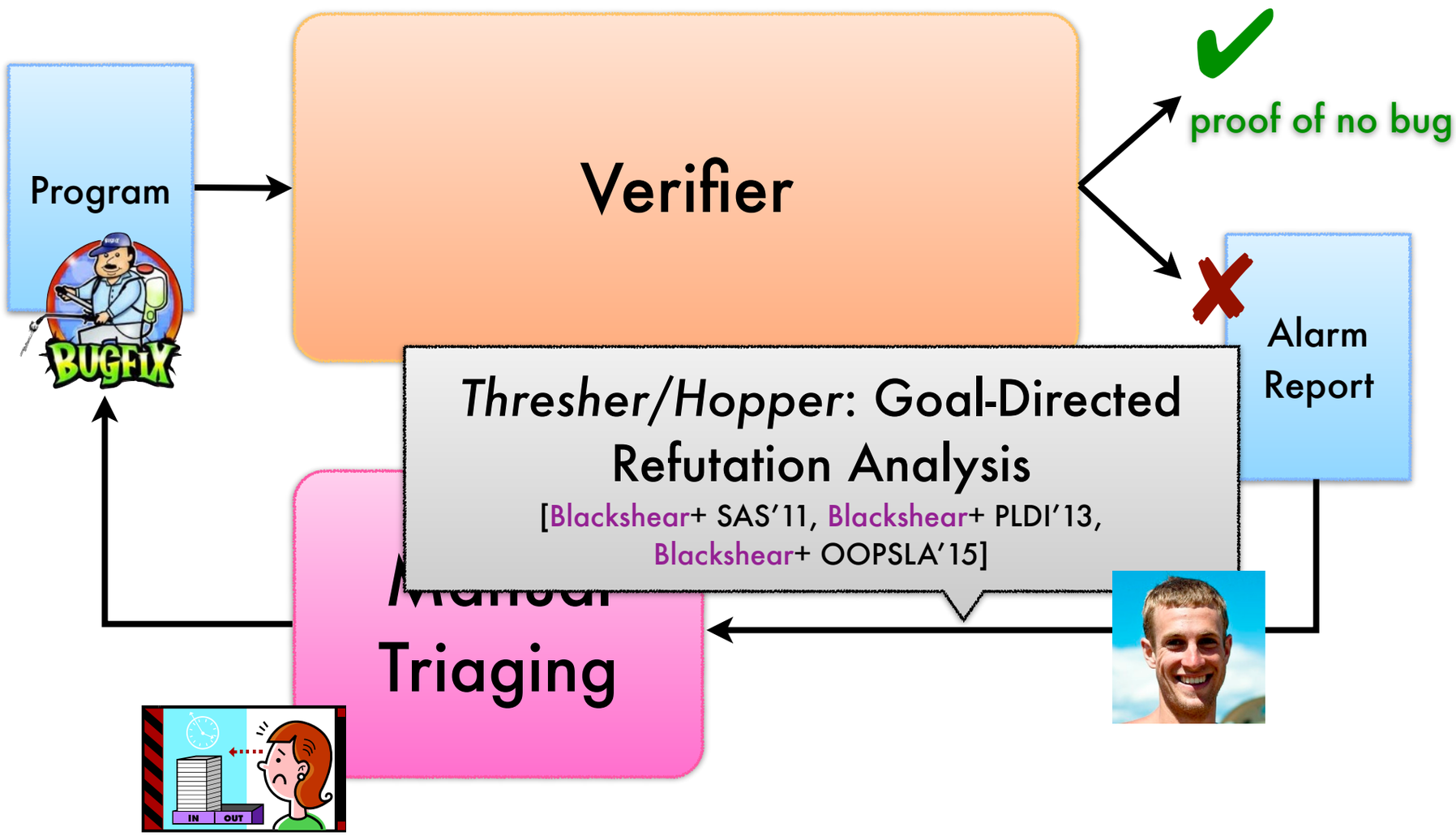

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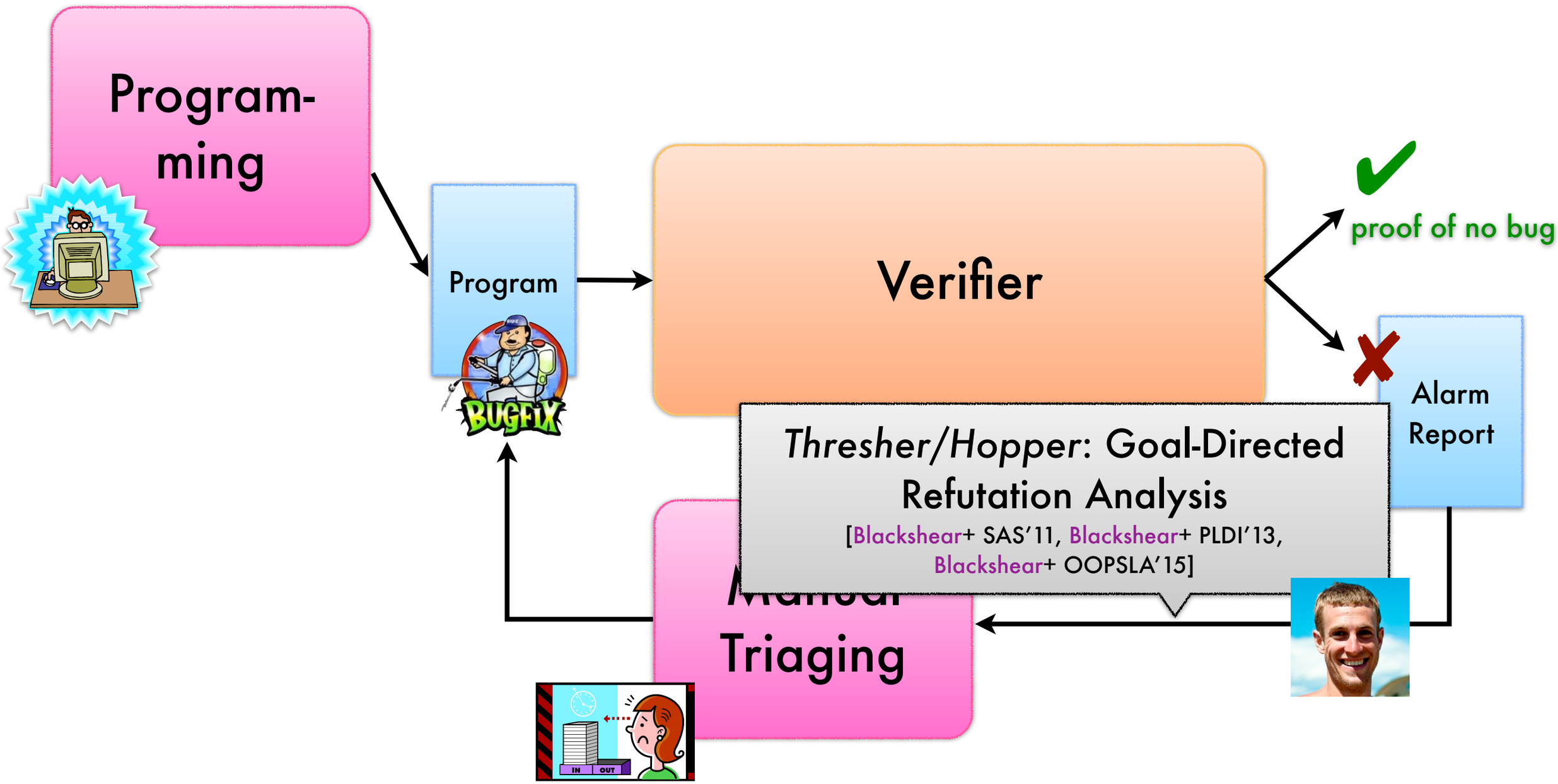

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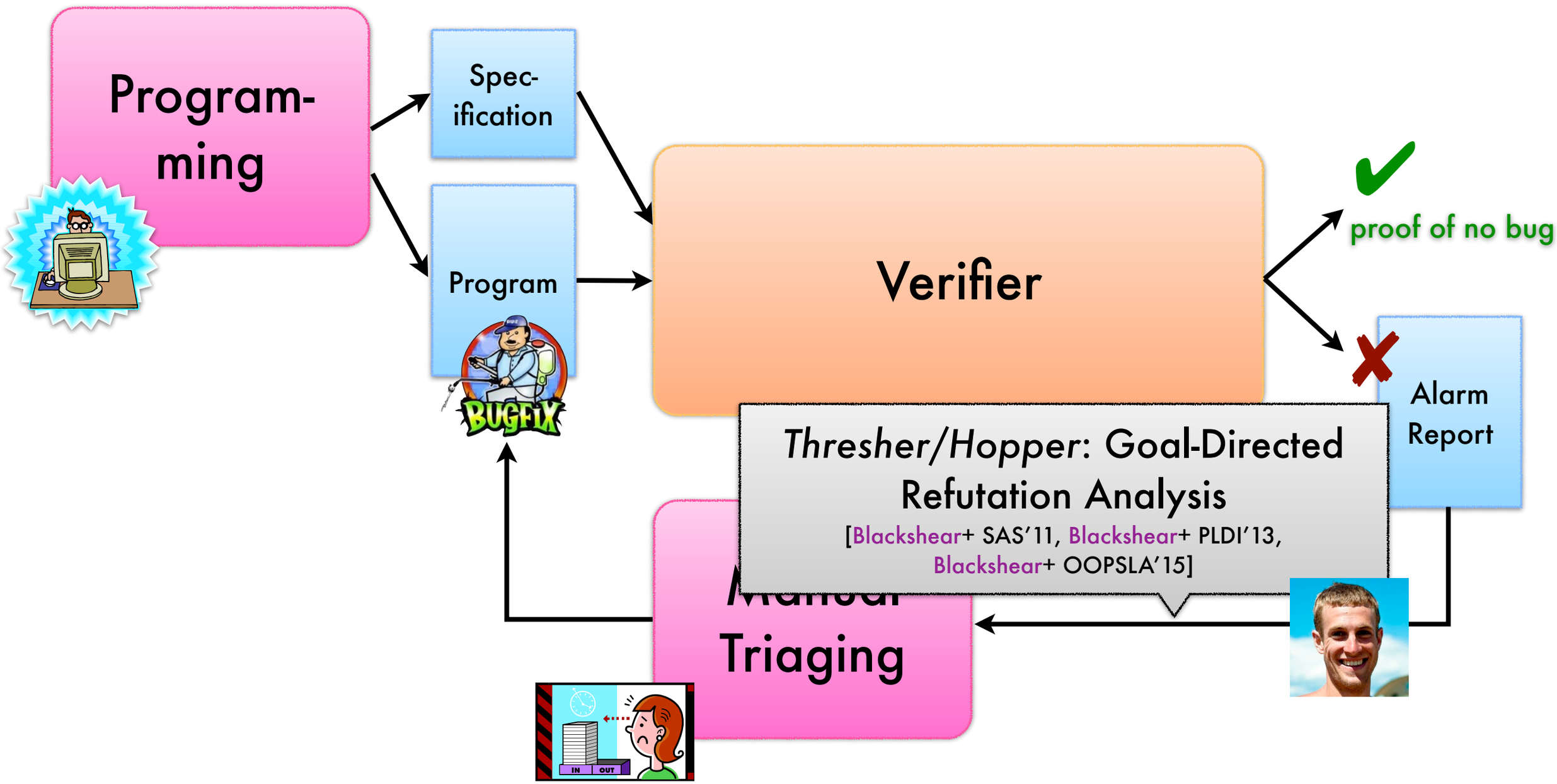

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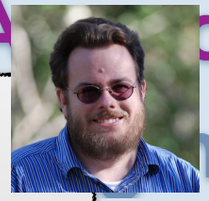


Fissile Types: Checking Almost Everywhere Invariants
[Coughlin+ POPL'14]

Program-ming

Spec-ification

Program

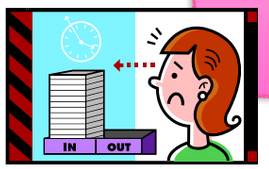
Verifier

✔ proof of no bug

✘ Alarm Report

Thresher/Hopper: Goal-Directed Refutation Analysis
[Blackshear+ SAS'11, Blackshear+ PLDI'13, Blackshear+ OOPSLA'15]

Manual Triaging



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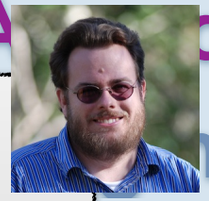

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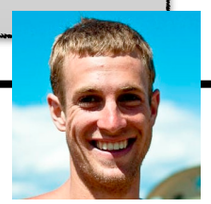

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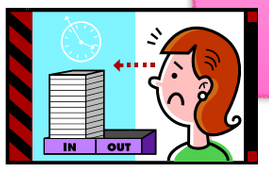

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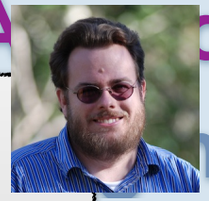

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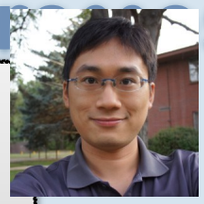

Divva: Synthesizing Short-Circuiting Data Structure Checks
[in prep]

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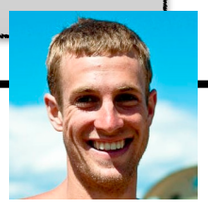

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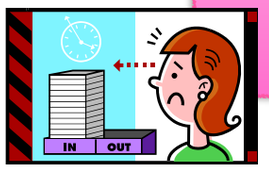

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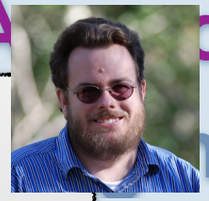

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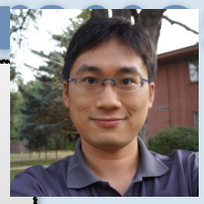

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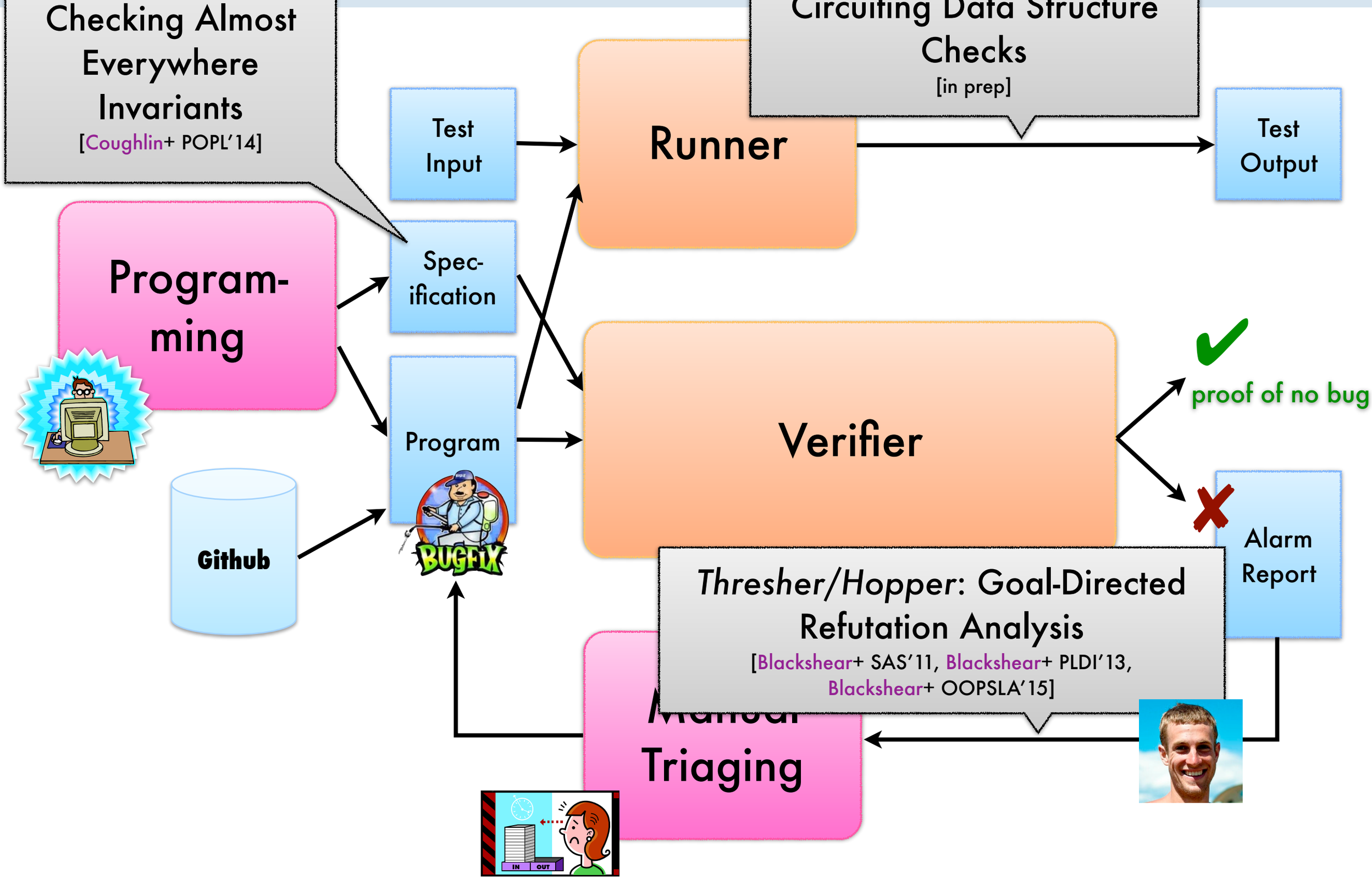

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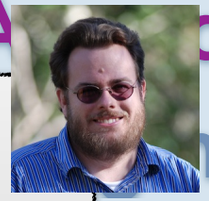

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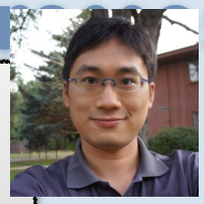

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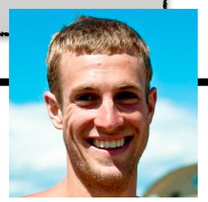
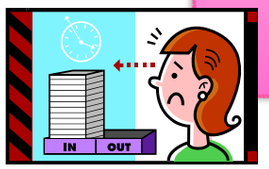


Manual Triaging

Fixr: Mining Bug Fixes from Commits
[in progress]



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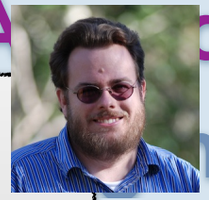

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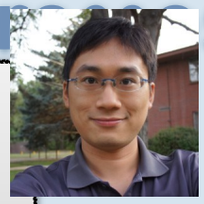

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Jsana: Abstract Domain Combinators for Dynamic Languages
[Cox+ ECOOP'13, Cox+ SAS'14, Cox+ ESOP'15]

✔ proof of no bug

Program

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✘

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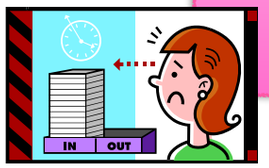

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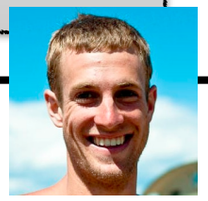

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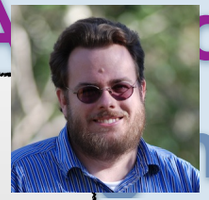

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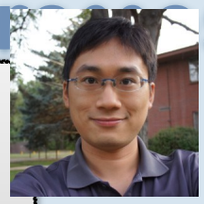

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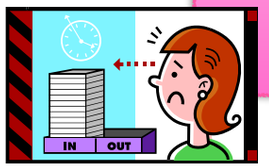

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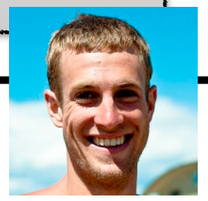

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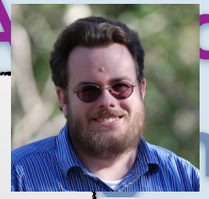
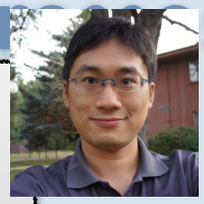


Fissile Types: Checking Almost Everywhere Invariants
[Coughlin+ POPL'14]



Divva: Synthesizing Short-Circuiting Data Structure Checks
[in prep]

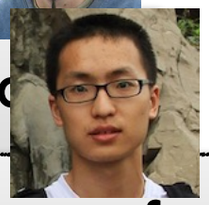
Test Input

Runner

Test Output

Program-ming

Spec-ification



Jsana: Abstract Domain Combin

Auditr: Securing Against "Inputs of Coma and Exposure"
[in progress]

of of no bug

Program

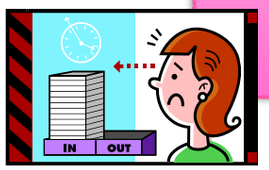
Alarm Report

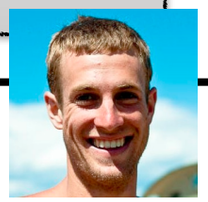
Github

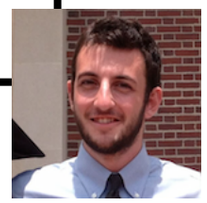
Thresher/Hopper: Goal-Directed Refutation Analysis
[Blackshear+ SAS'11, Blackshear+ PLDI'13, Blackshear+ OOPSLA'15]

Fixr: Mining Bug Fixes from Commits
[in progress]

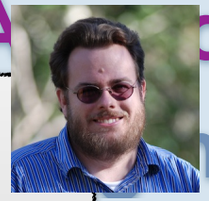
Manual Triaging







Research Agenda: The cooperative approach addresses mitigation process.



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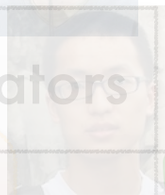

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Verifier → proof of no bug / Alarm Report

Github → Program

This Talk

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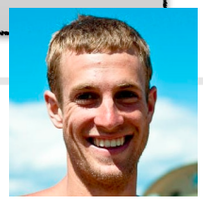

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Manual Triaging

This Talk: Highlights

Thresher and Hopper: Goal-Directed Refutations for Heap Reachability

Assist in triage of queries about heap relations

- Idea: Assume alarms false, prove them so automatically
- Application: Find memory leaks and eliminate crashes in Android
  - Filters out ~90% of false alarms to expose true bugs
  - Going from ~450 hours of manual work to ~30 hours
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  - Prove ~92% dereferences safe

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- Interactive checking speeds: making IDE integration possible
- Application: Prevent "MethodNotFound" errors in Objective-C (MacOS/iOS)

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Goal-Directed Refutations for Heap Reachability

A bug that manifests spectacularly …

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Android memory leaks underly rotation-based crashes.

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App crashes when ... Samsung phone

How can you have memory leaks with a garbage collected run-time?

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`Activity` **objects encapsulate the UI**

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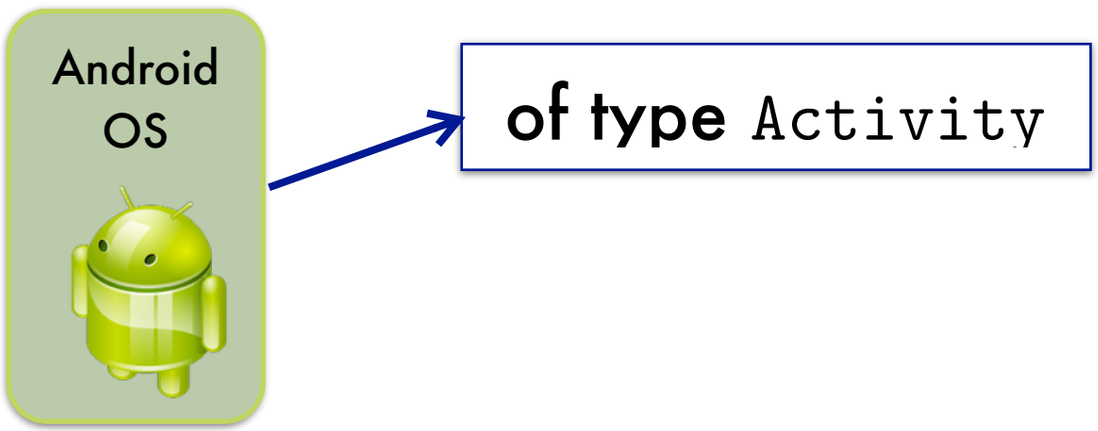

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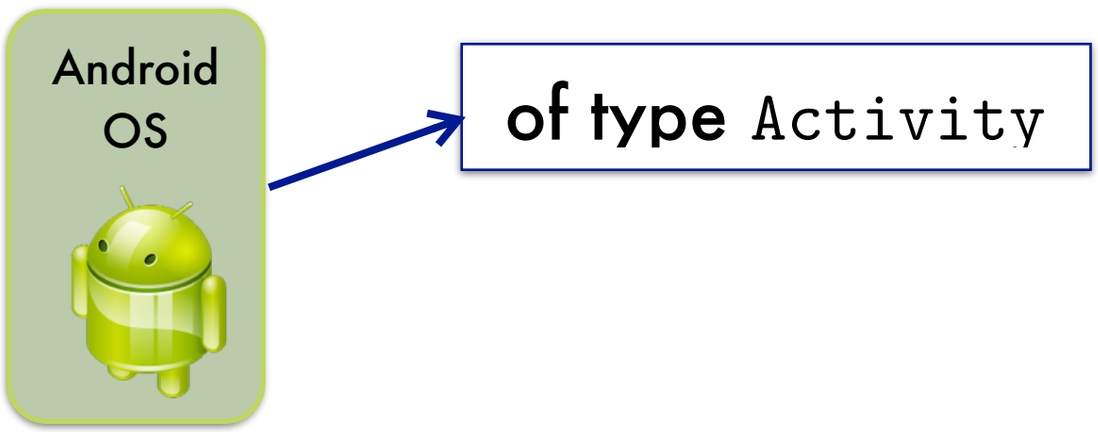

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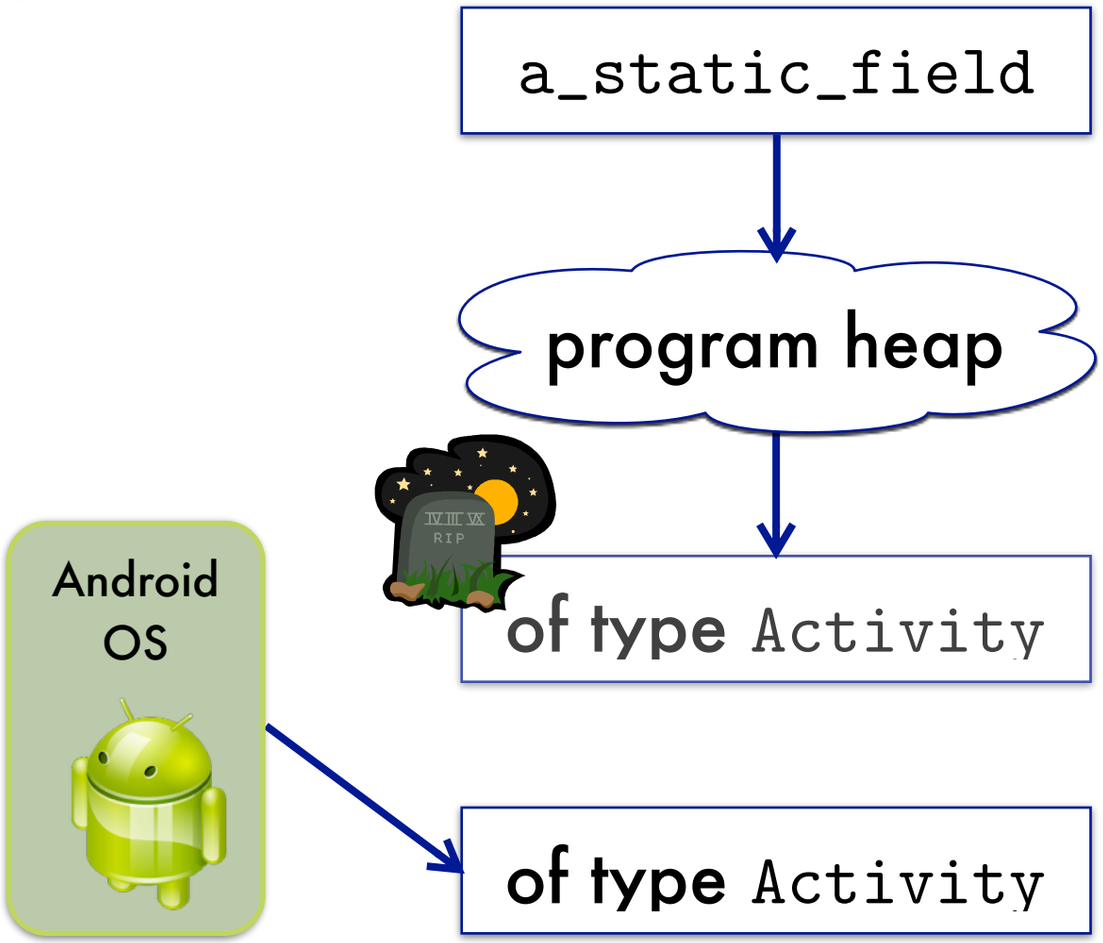

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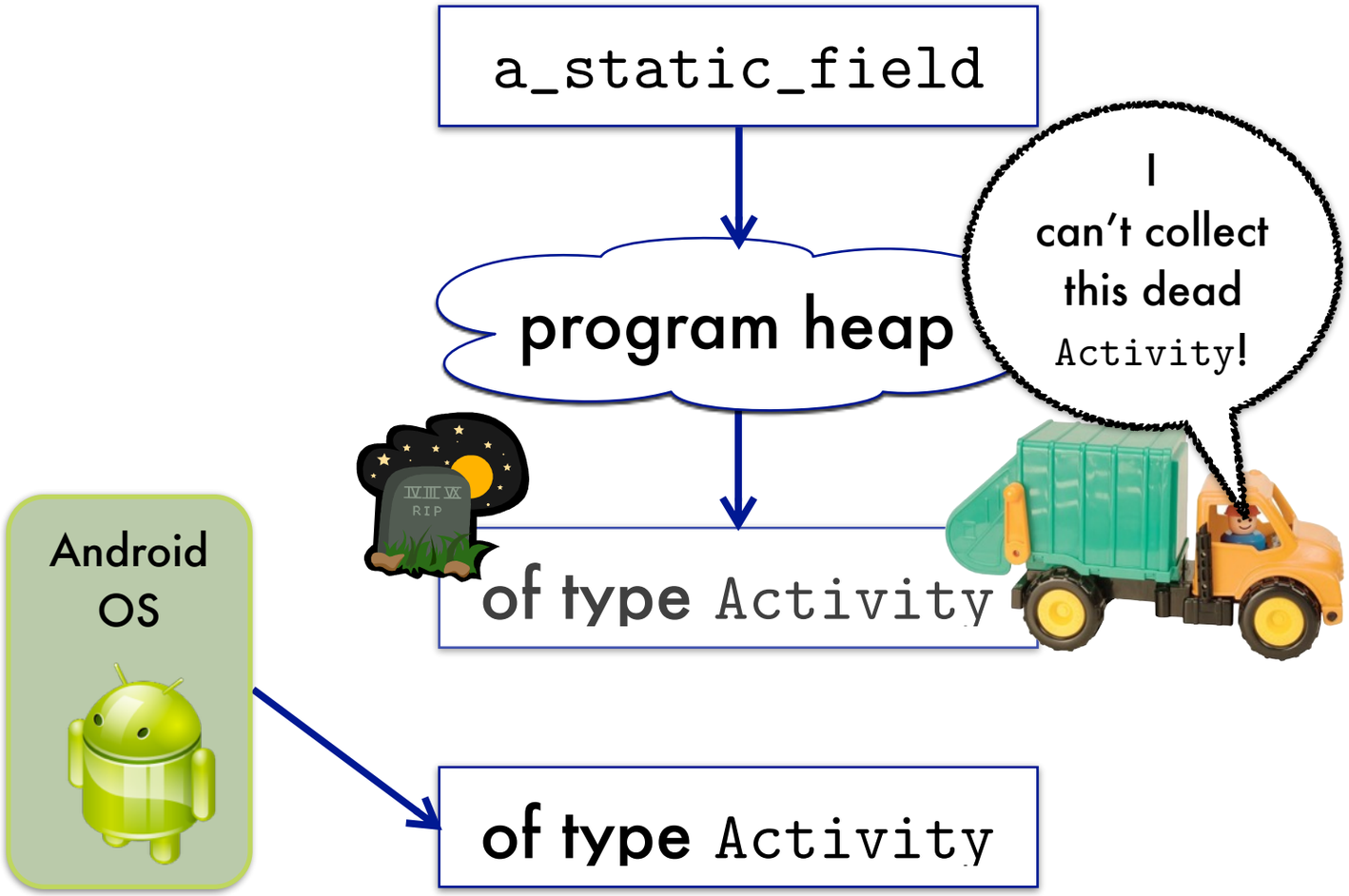

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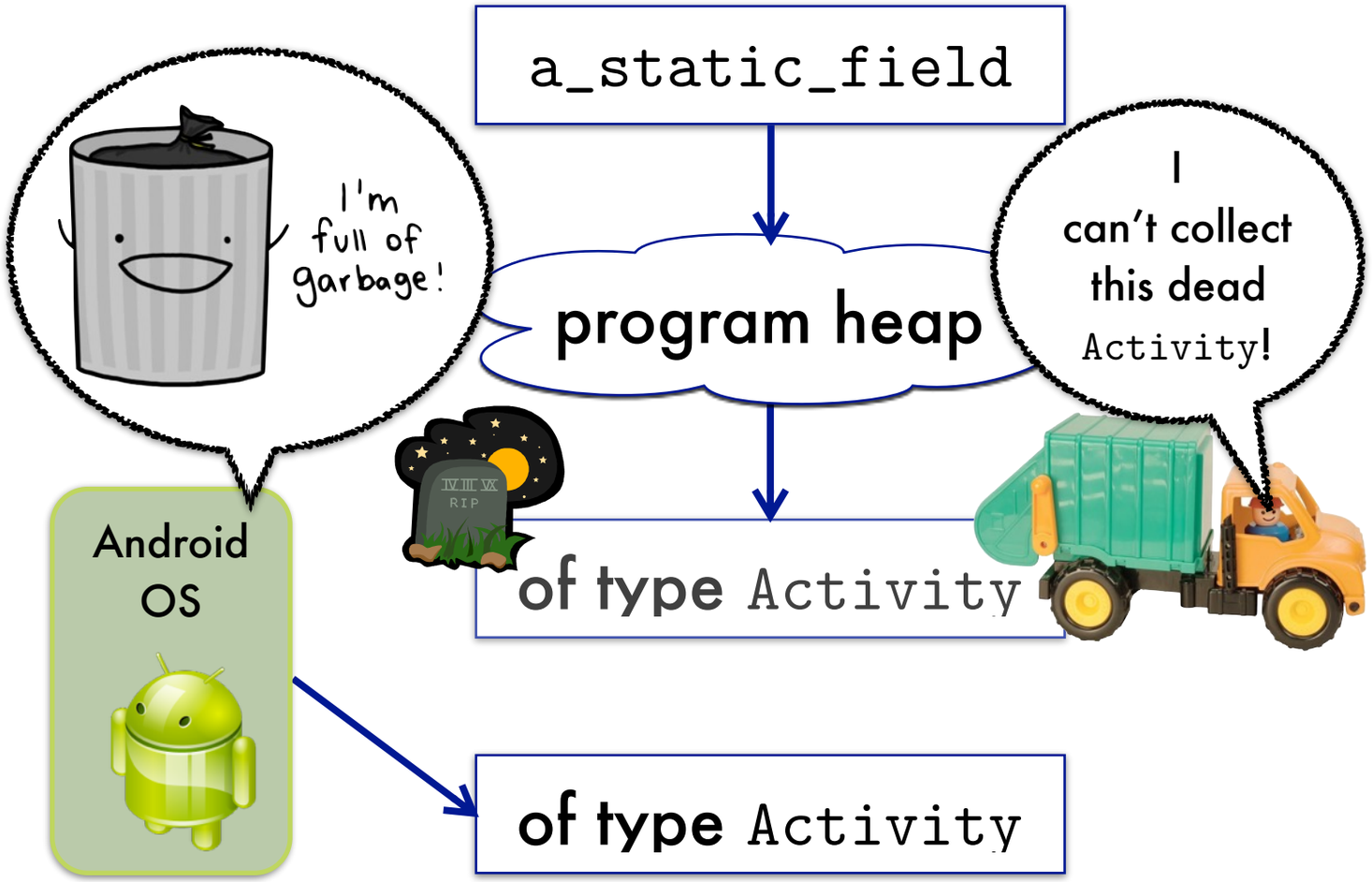

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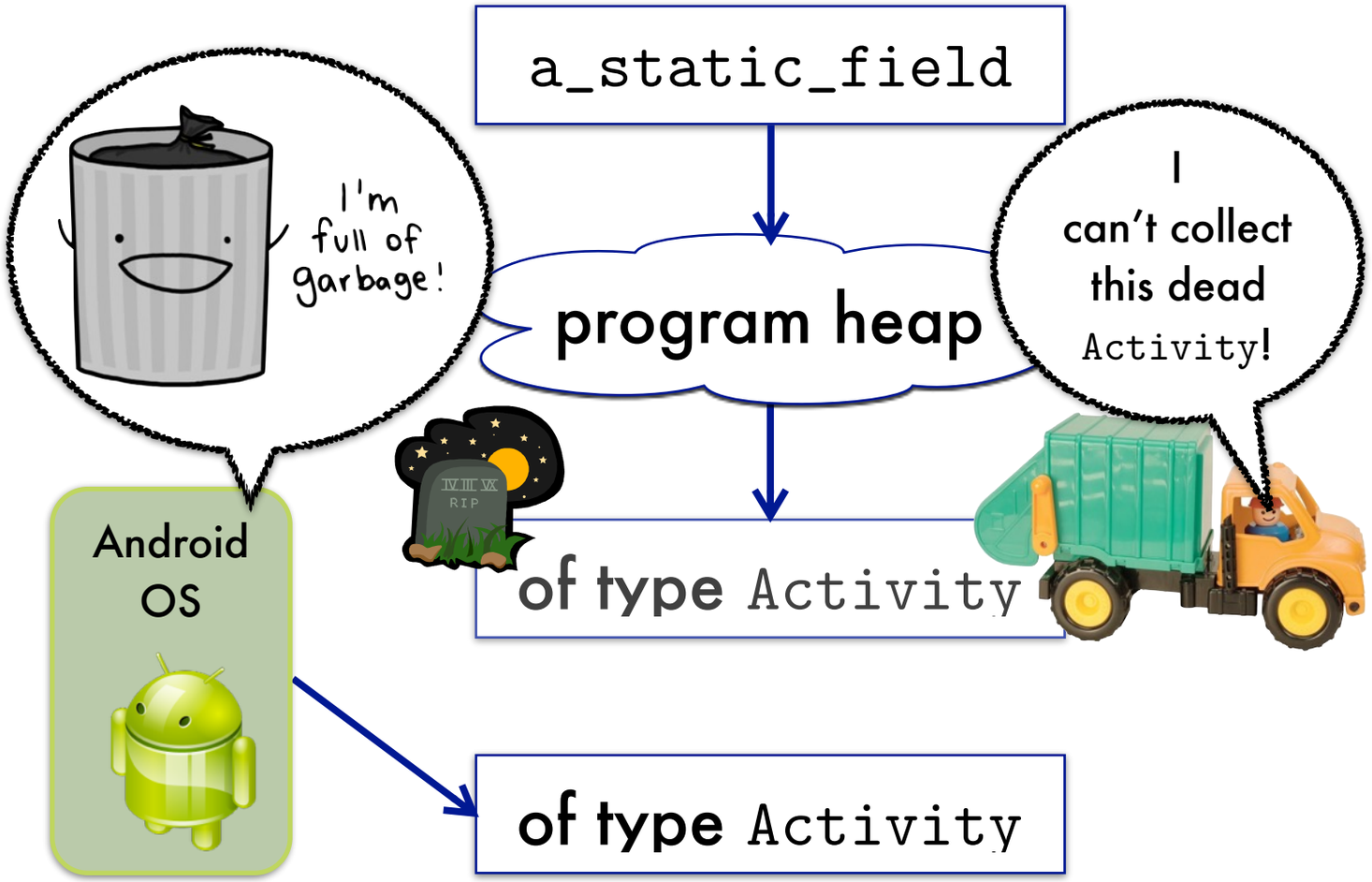

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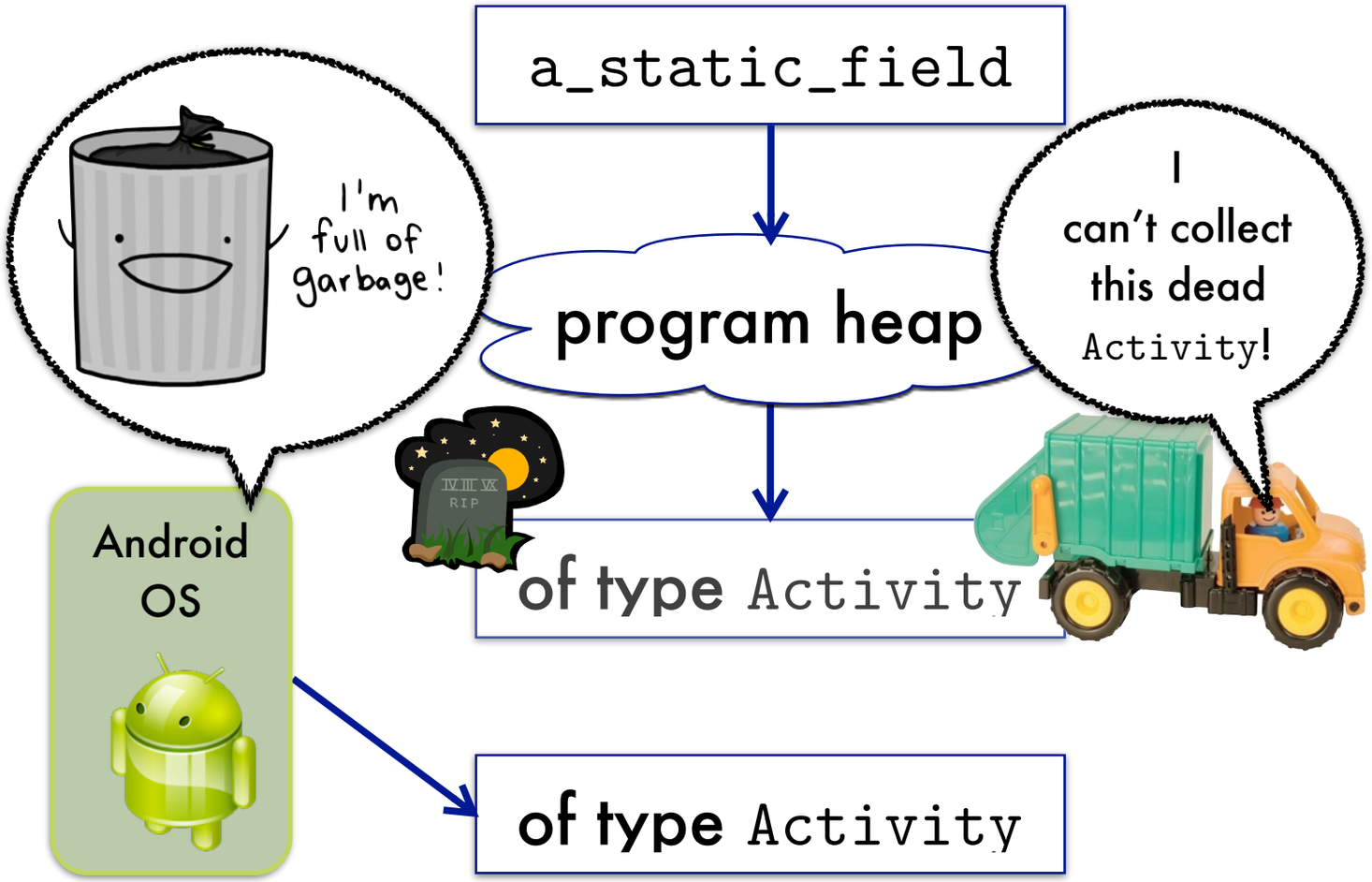

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The expert recommendation ...

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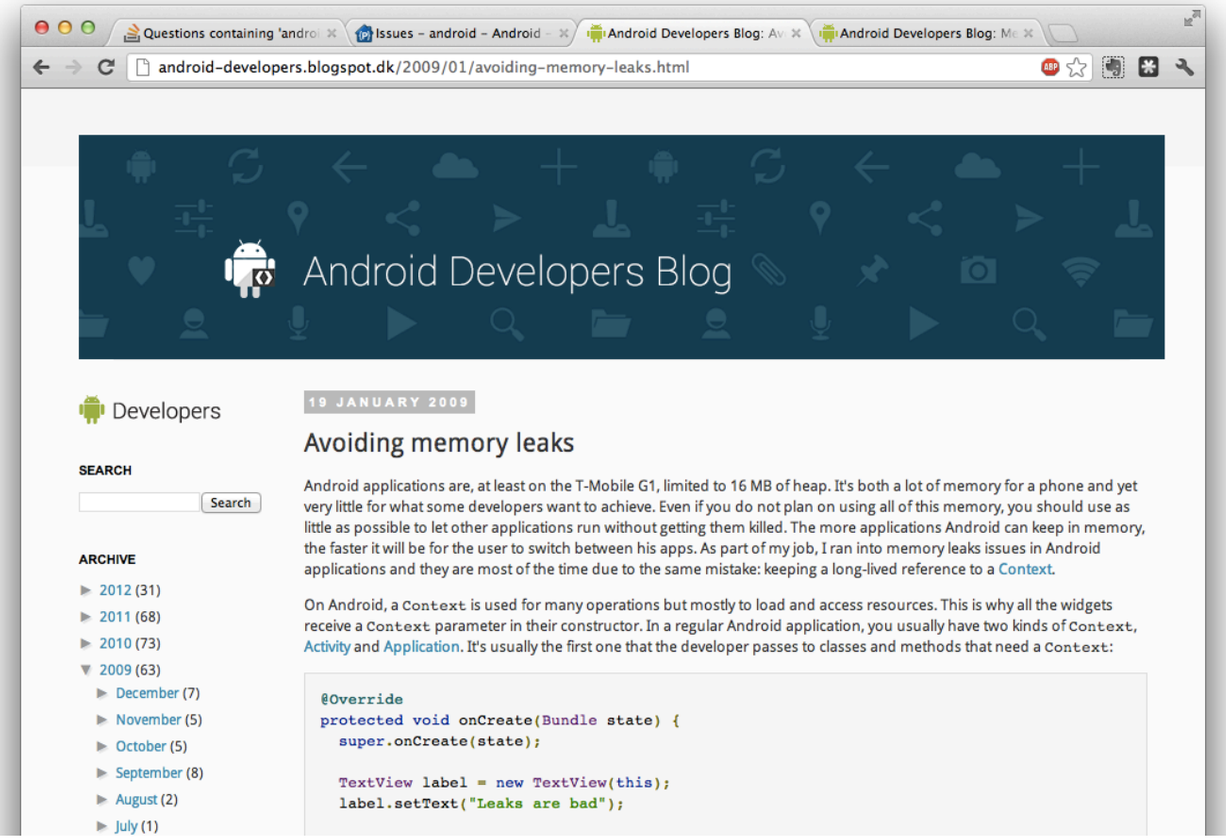

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Avoiding memory leaks

Android applications are, at least on the T-Mobile G1, limited to 16 MB of heap. It's both a lot of memory for a phone and yet very little for what some developers want to achieve. Even if you do not plan on using all of this memory, you should use as little as possible to let other applications run without getting them killed. The more applications Android can keep in memory, the faster it will be for the user to switch between his apps. As part of my job, I ran into memory leaks issues in Android applications and they are most of the time due to the same mistake: keeping a long-lived reference to a Context.

On Android, a `Context` is used for many operations but mostly to load and access resources. This is why all the widgets receive a `Context` parameter in their constructor. In a regular Android application, you usually have two kinds of `Context`, Activity and Application. It's usually the first one that the developer passes to classes and methods that need a `Context`:

```
@Override
protected void onCreate(Bundle state) {
  super.onCreate(state);

  TextView label = new TextView(this);
  label.setText("Leaks are bad");
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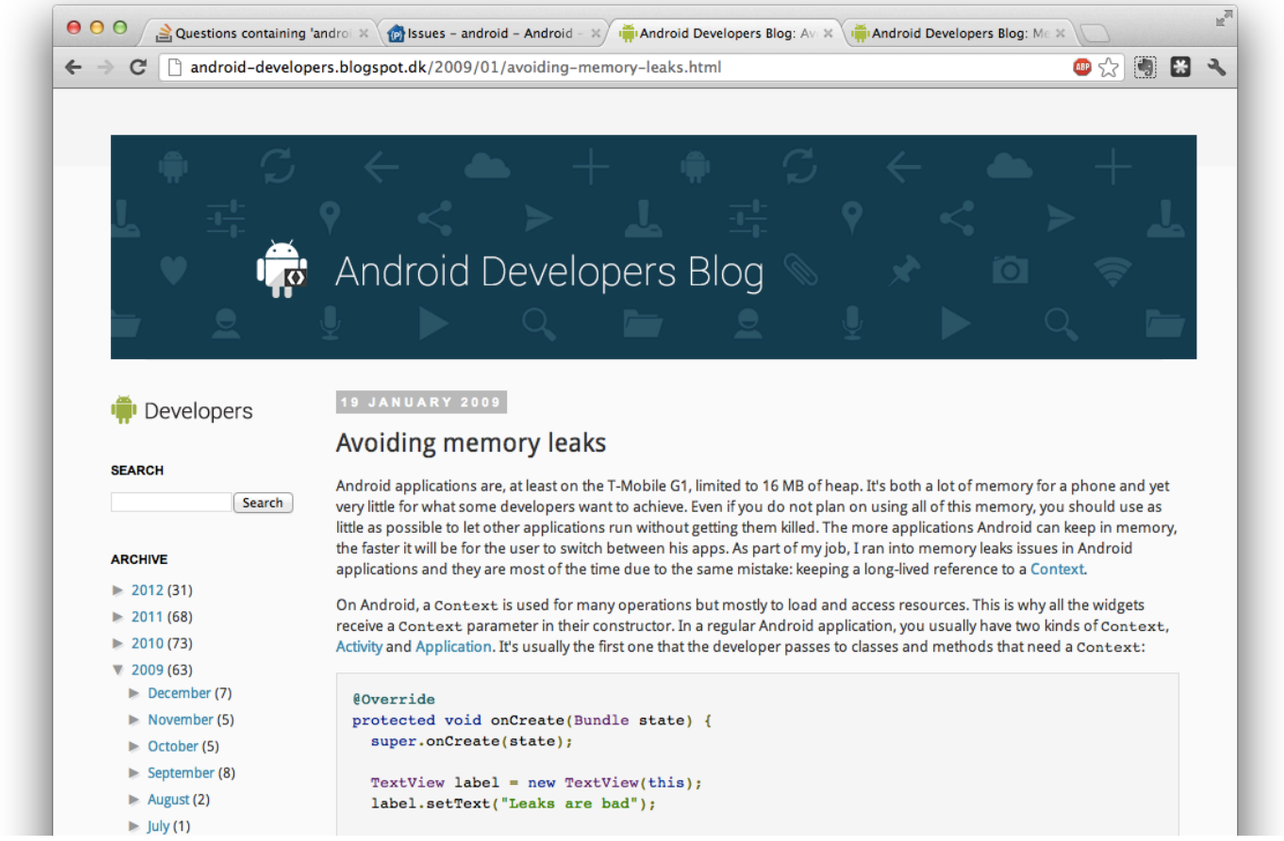
The expert recommendation ...

"Do not keep long-lived references to a context-activity"



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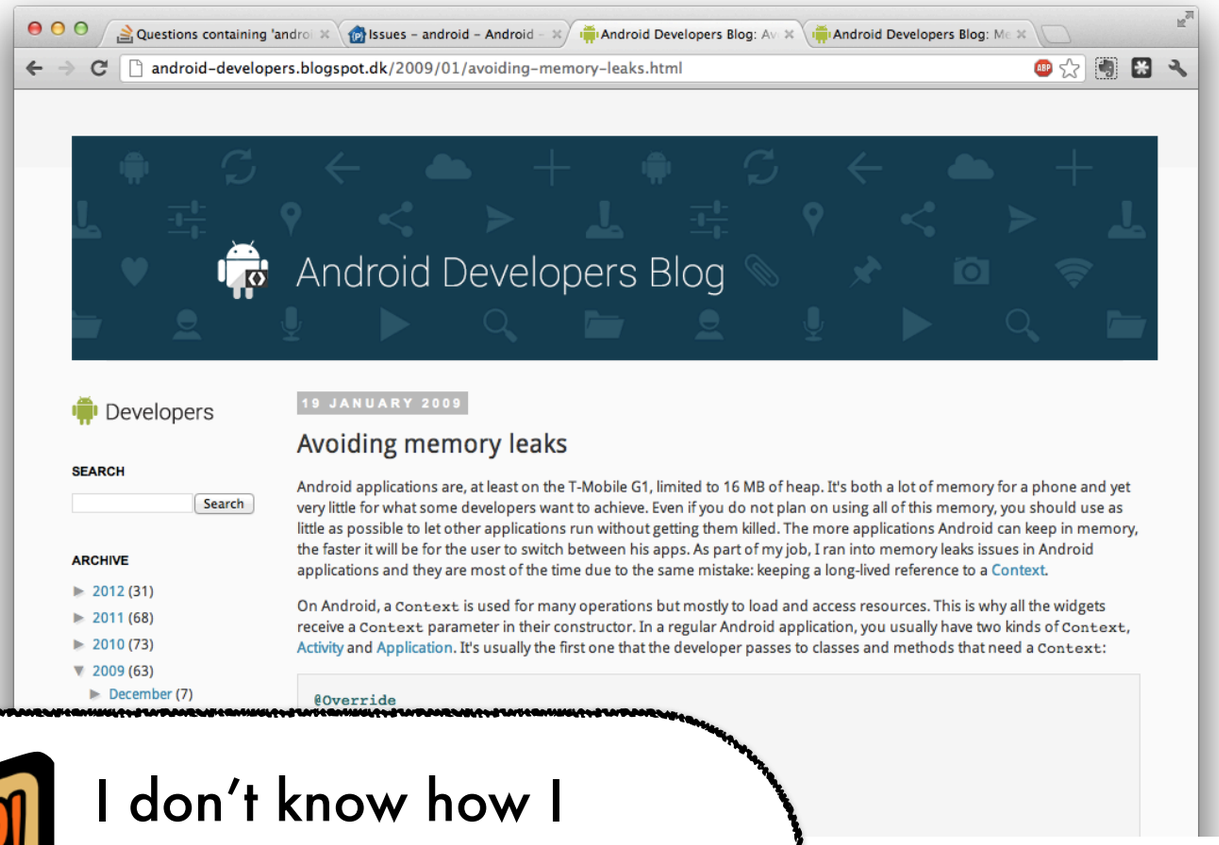

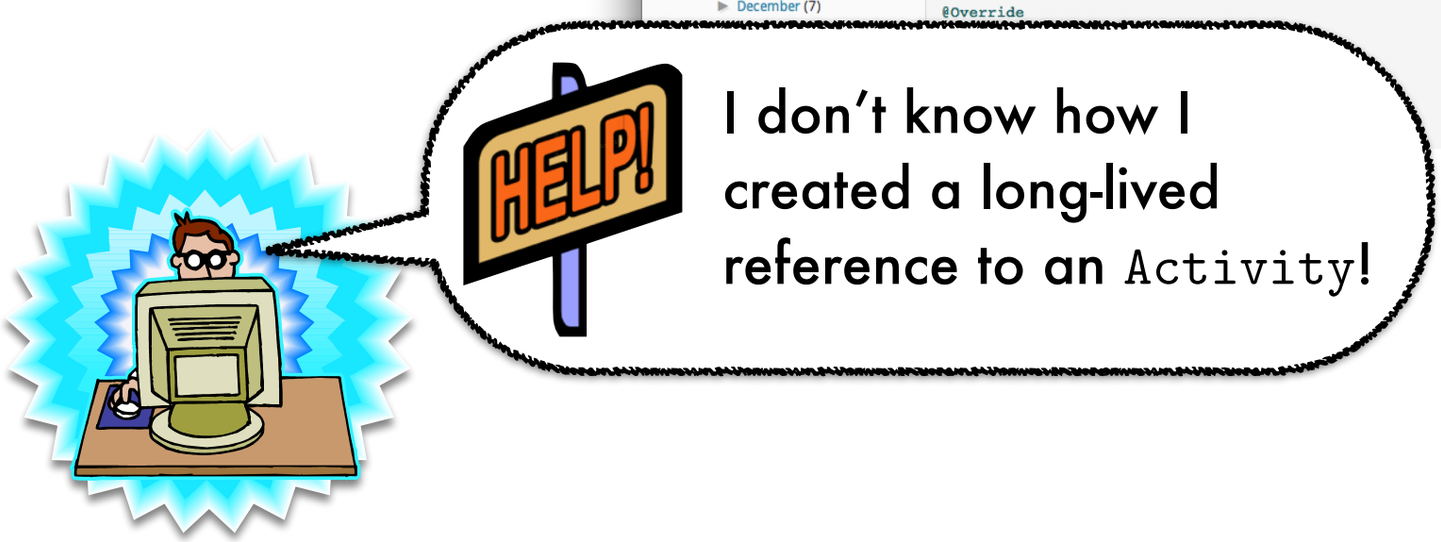

The expert recommendation ...

"Do not keep long-lived references to a context-activity"

I don't know how I created a long-lived reference to an `Activity`!

Often: A **misunderstanding** of a library causes the **library** to keep the `Activity` reference.

The state of practice in debugging `Activity` leaks ...

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24 MARCH 2011

Memory Analysis for Android Applications

[This post is by Patrick Dubroy, an Android engineer who writes about programming, usability, and interaction on his personal blog. — Tim Bray]

The Dalvik runtime may be garbage-collected, but that doesn't mean you can ignore memory management. You should be especially mindful of memory usage on mobile devices, where memory is more constrained. In this article, we're going to take a look at some of the memory profiling tools in the Android SDK that can help you trim your application's memory usage.

Some memory usage problems are obvious. For example, if your app leaks memory every time the user touches the screen, it will probably trigger an `OutOfMemoryError` eventually and crash your app. Other problems are more subtle, and may just degrade the performance of both your app (as garbage collections are more frequent and take longer) and the entire system.

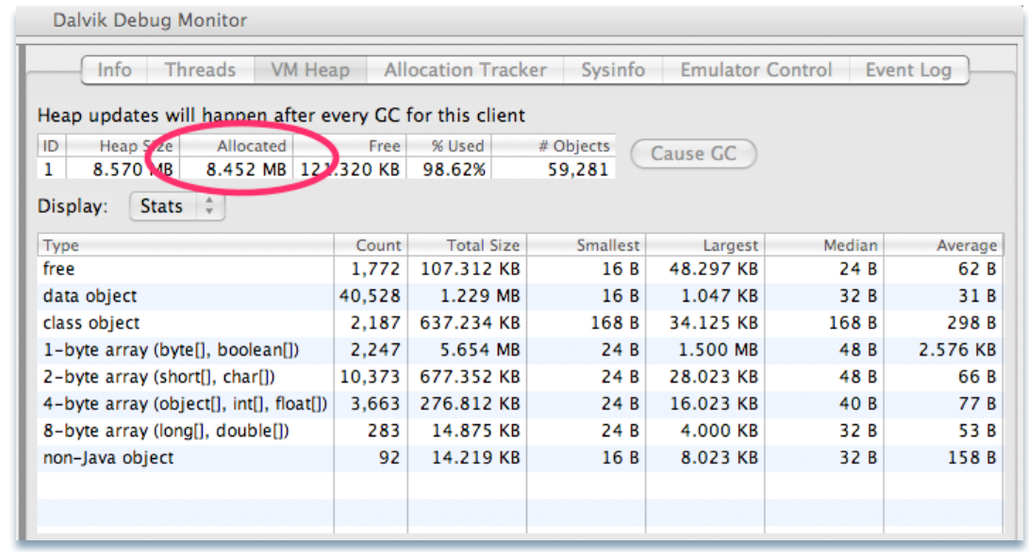
Tools of the trade

The Android SDK provides two main ways of profiling the memory usage of an app: the *Allocation Tracker* tab in DDMS, and heap dumps. The Allocation Tracker is useful when you want to get a sense of what kinds of allocation are happening over a

The state of practice in debugging `Activity` leaks ...

1. Run the app

The state of practice in debugging `Activity` leaks ...



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2. Watch the heap usage

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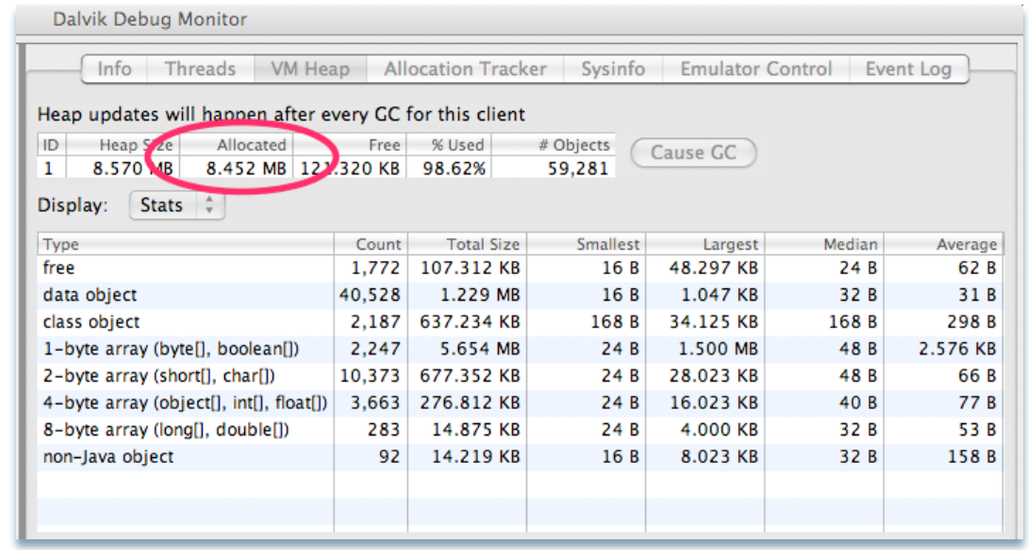

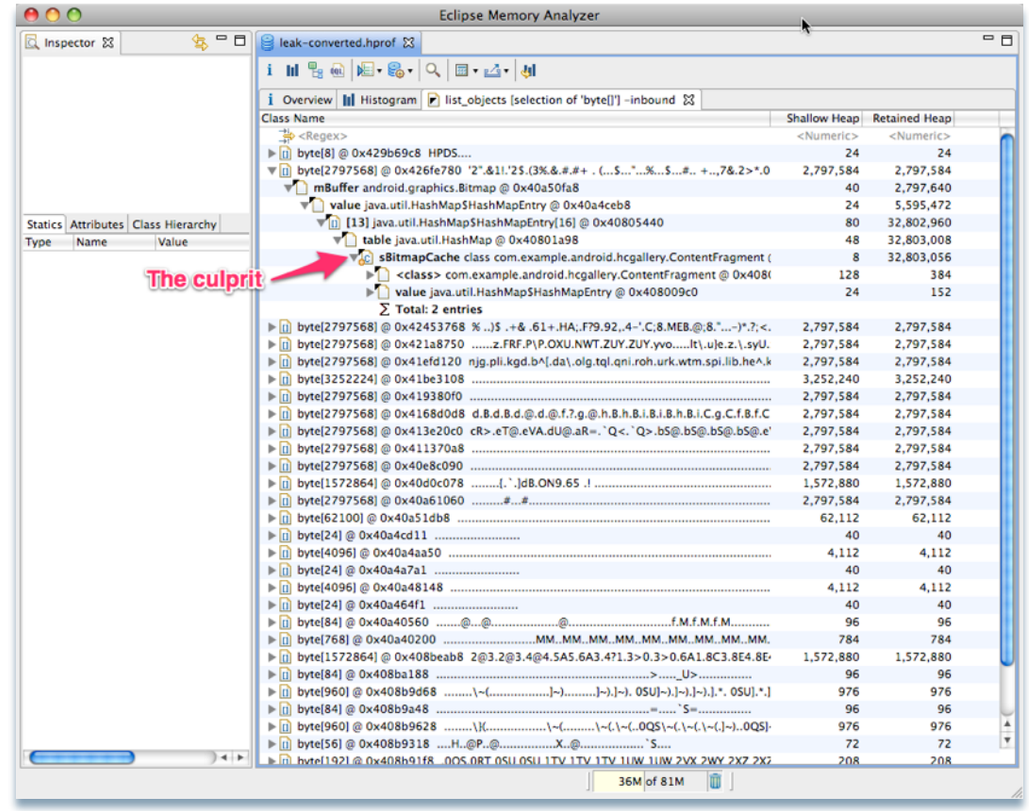

1. Run the app
2. Watch the heap usage
3. Dump the heap. Dig around and hope to find the culprit

The state of practice in debugging `Activity` leaks ...

Suppose we're lucky and find a possible culprit. Now what?

- Where in the code is this object allocated?
- What about the object that references it?
- Where is the reference created?
- Is this reference needed?
- For what periods?

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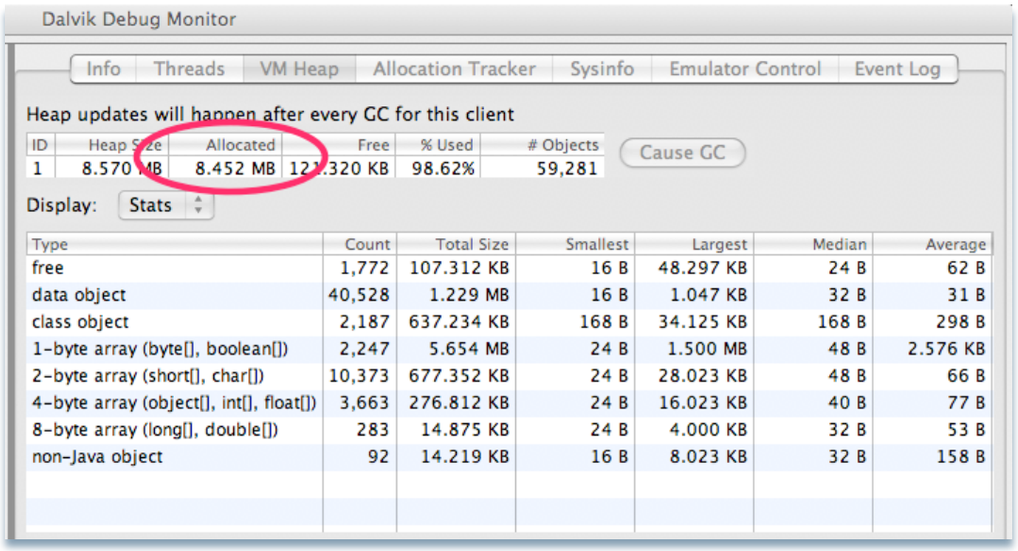

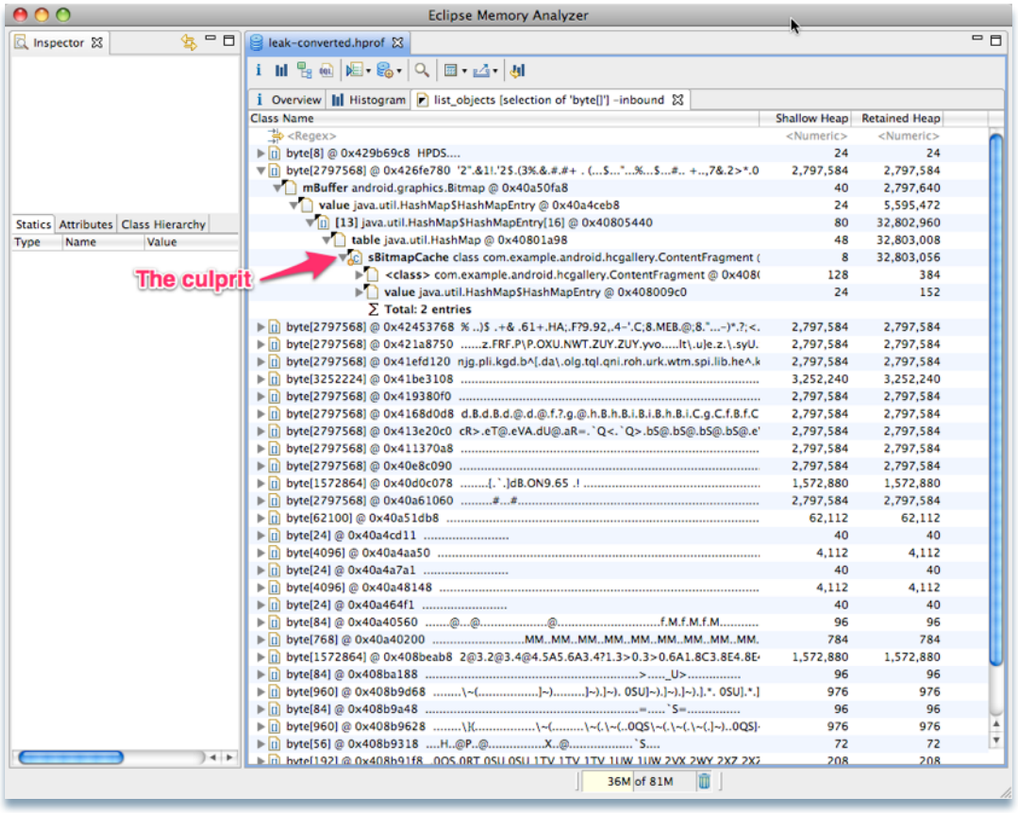

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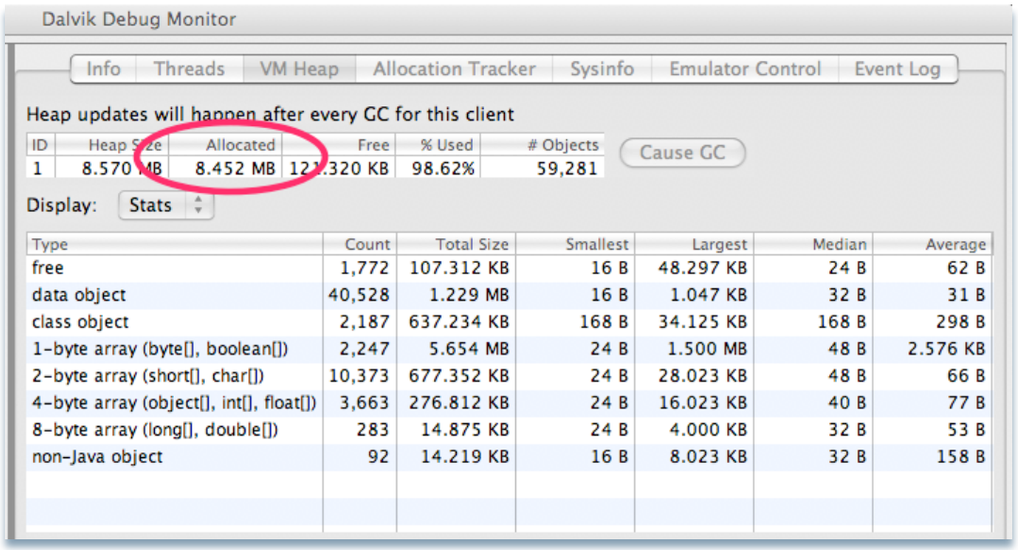
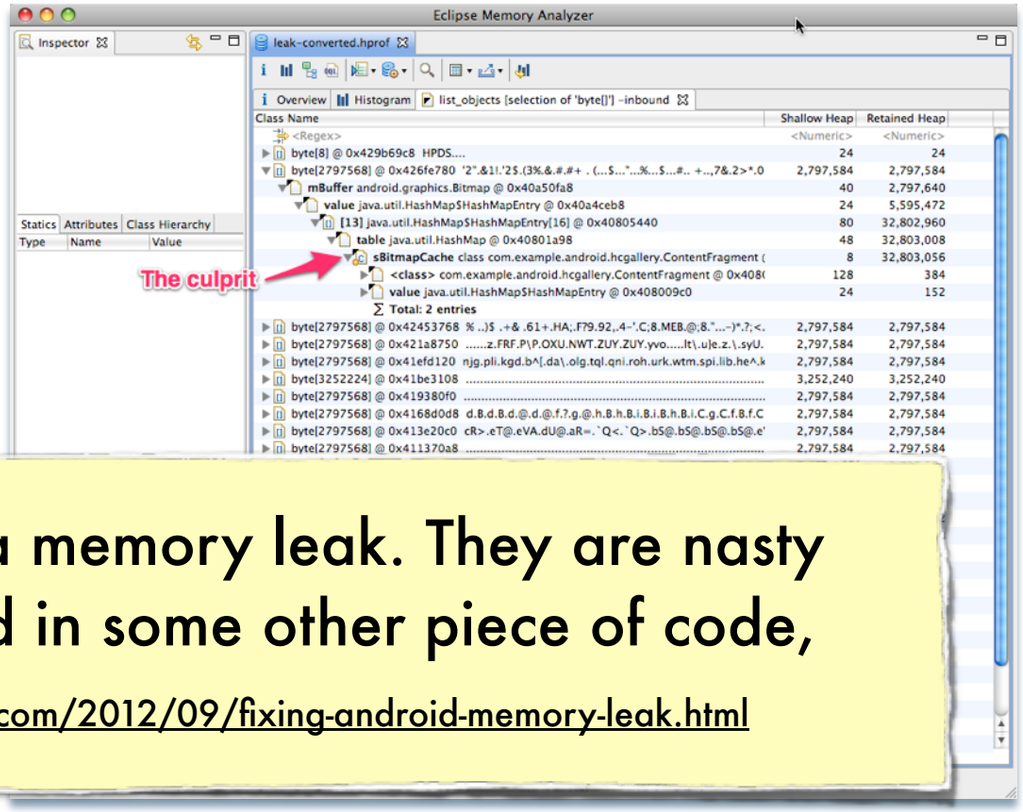




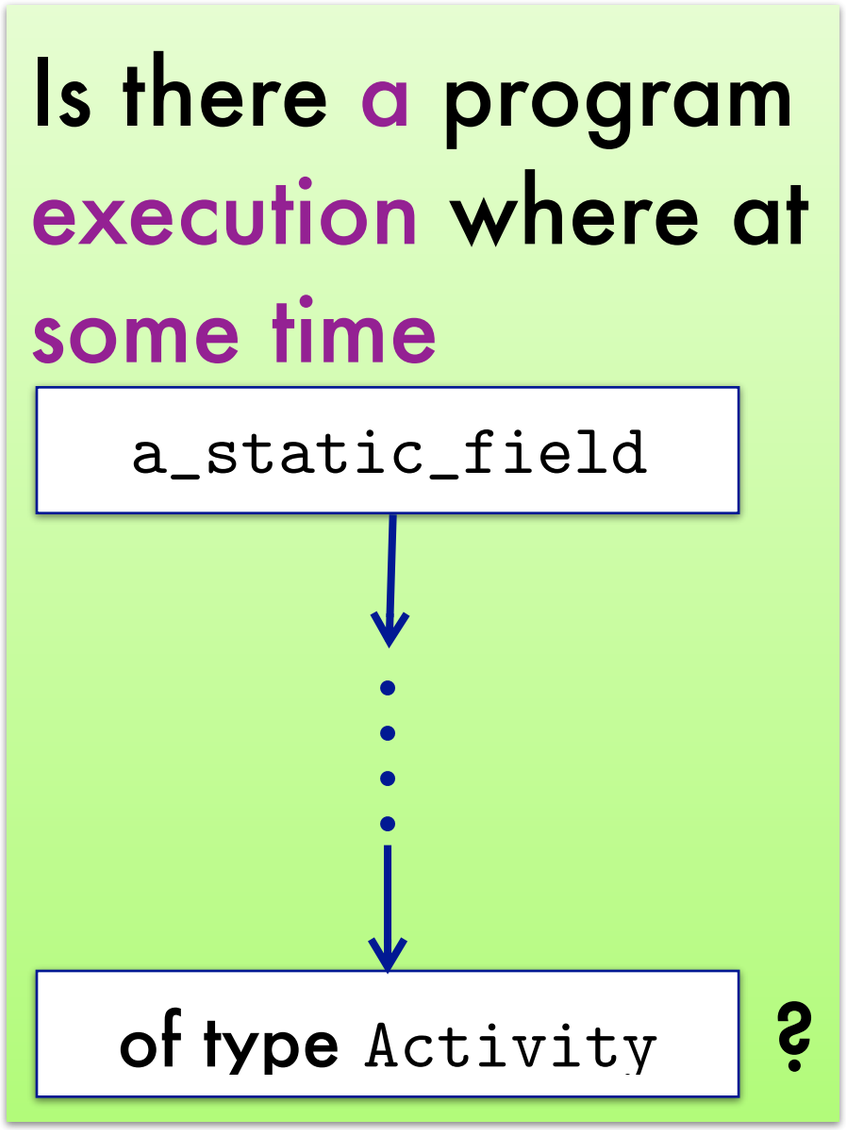
3. Dump the heap. Dig

"One of the most dreaded bugs in Android is a memory leak. They are nasty because one piece of code causes an issue and in some other piece of code, your application crashes." – http://therockncoder.blogspot.com/2012/09/fixing-android-memory-leak.html


Program
Analysis

Answering "Is there an `Activity` leak?" with program analysis ...

Can an object ever be reached from another object via pointer dereferences?



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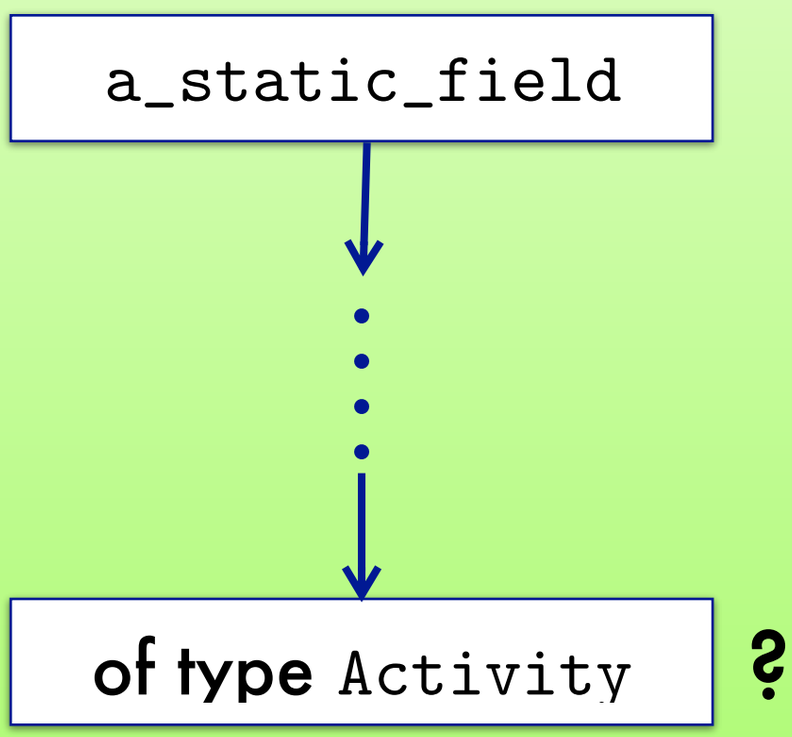

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Can be answered with a points-to analysis

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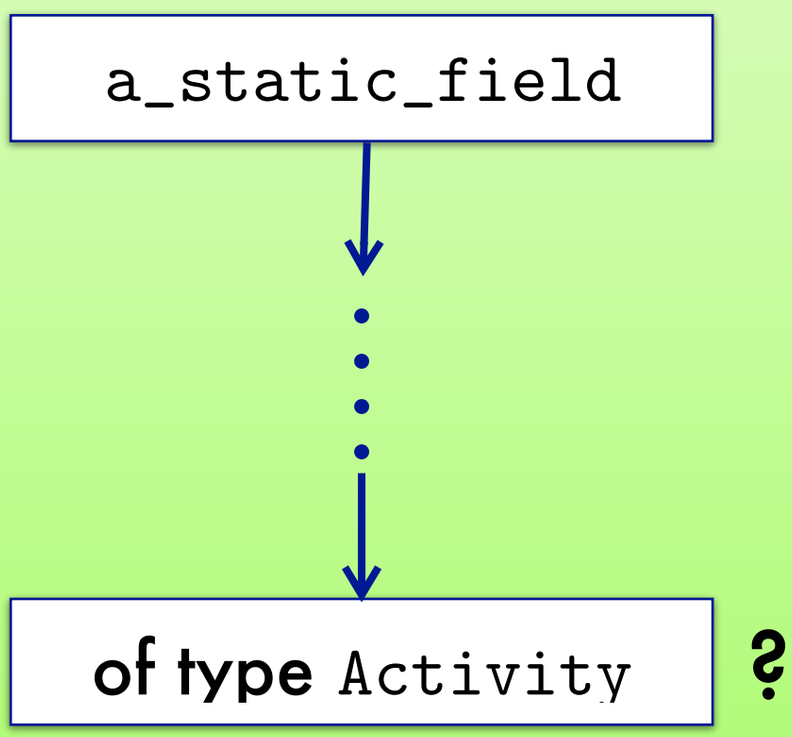

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with approximation

Hidden Truth

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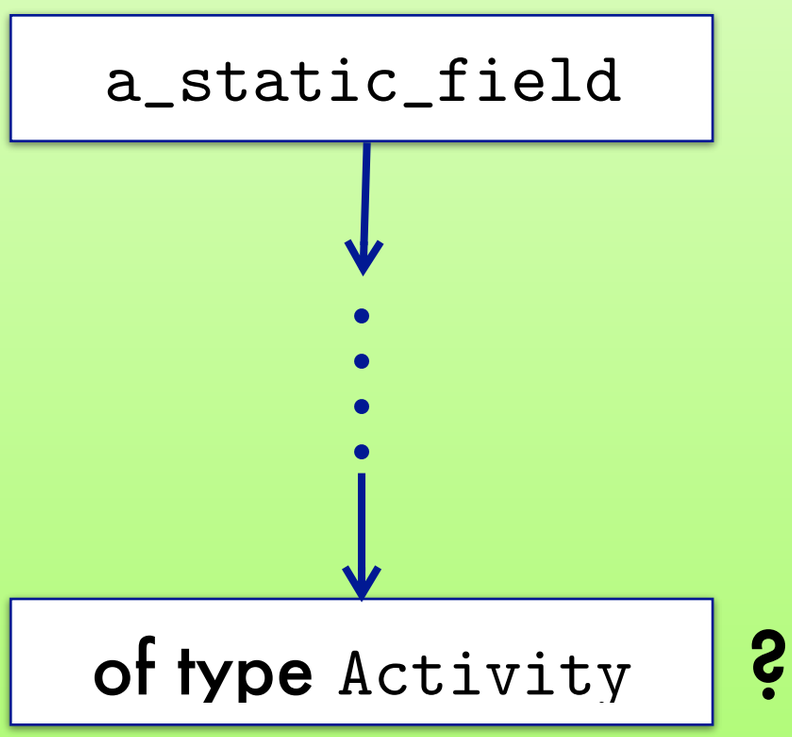


Example

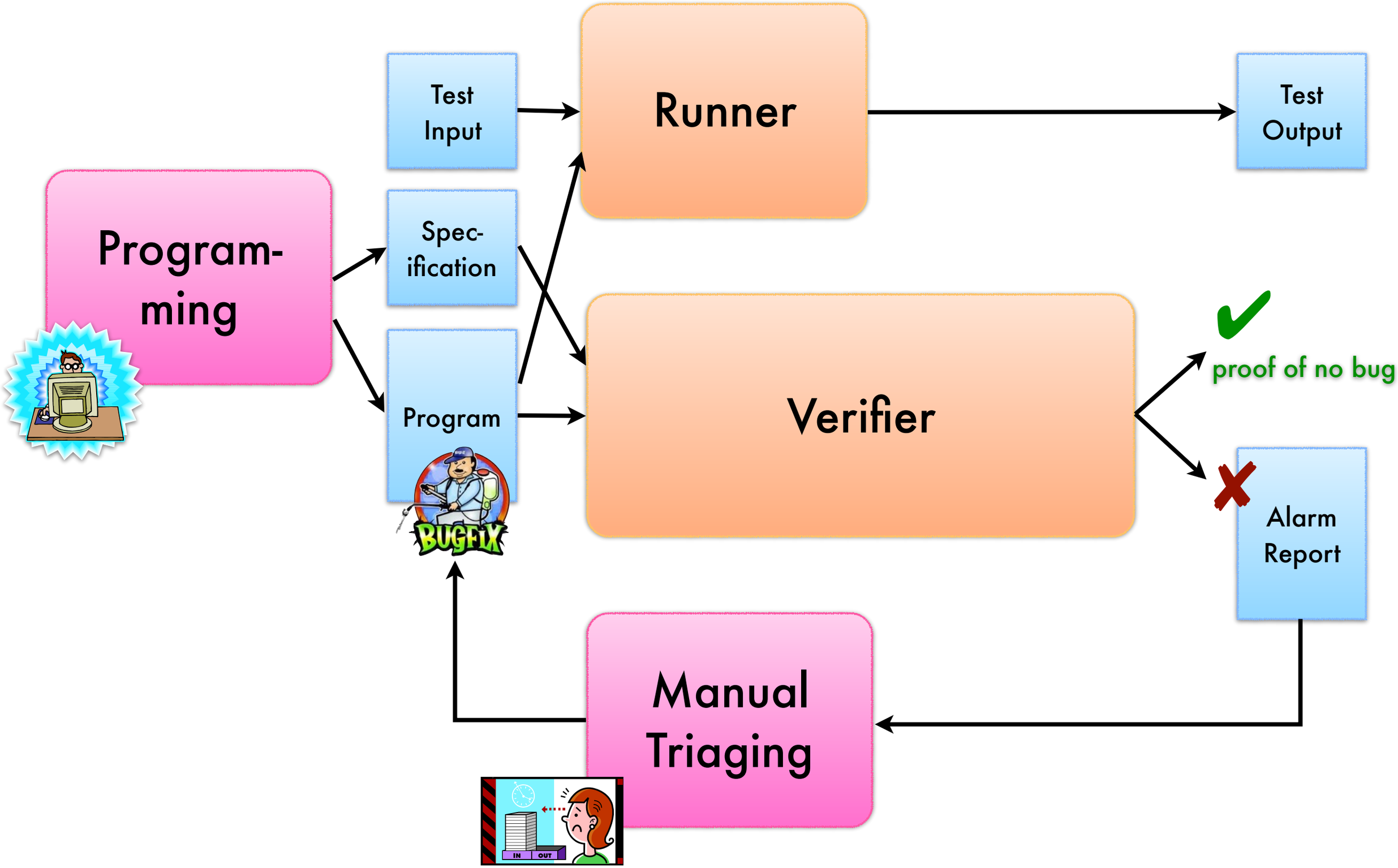
Can be answered with a points-to analysis

with approximation

Hidden Truth

Some pointer relations may be false

But with the cooperative approach ...



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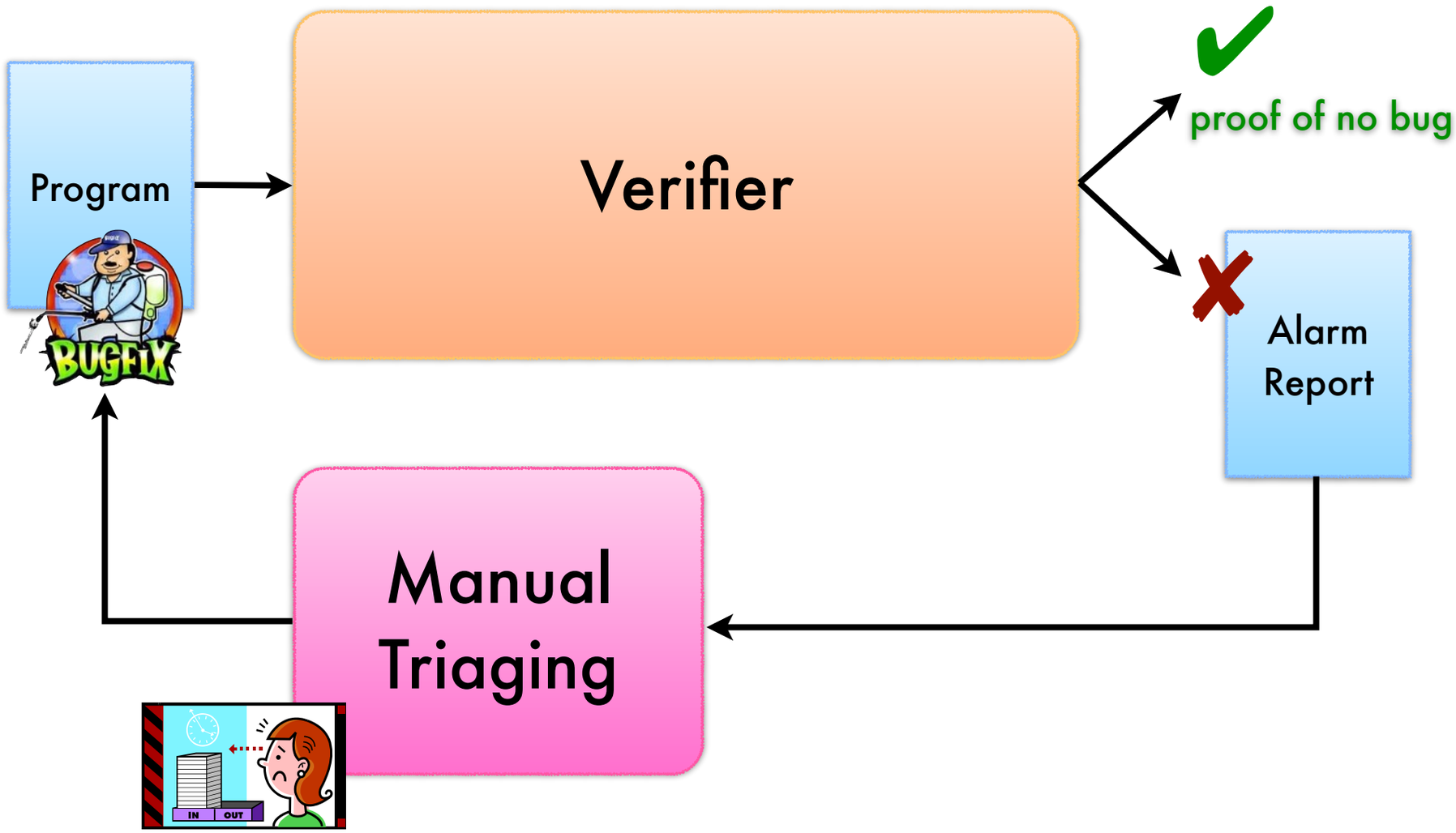

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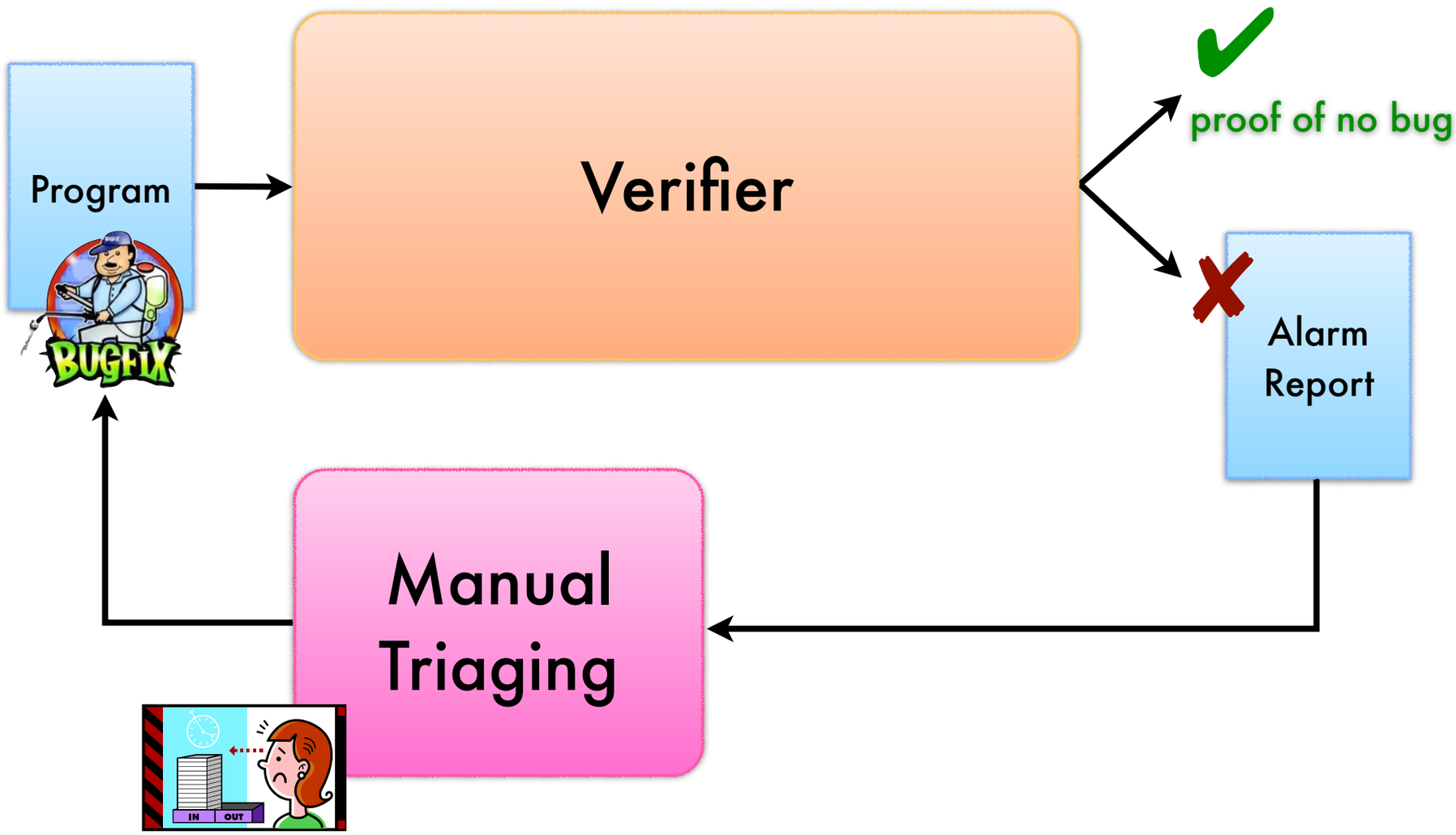

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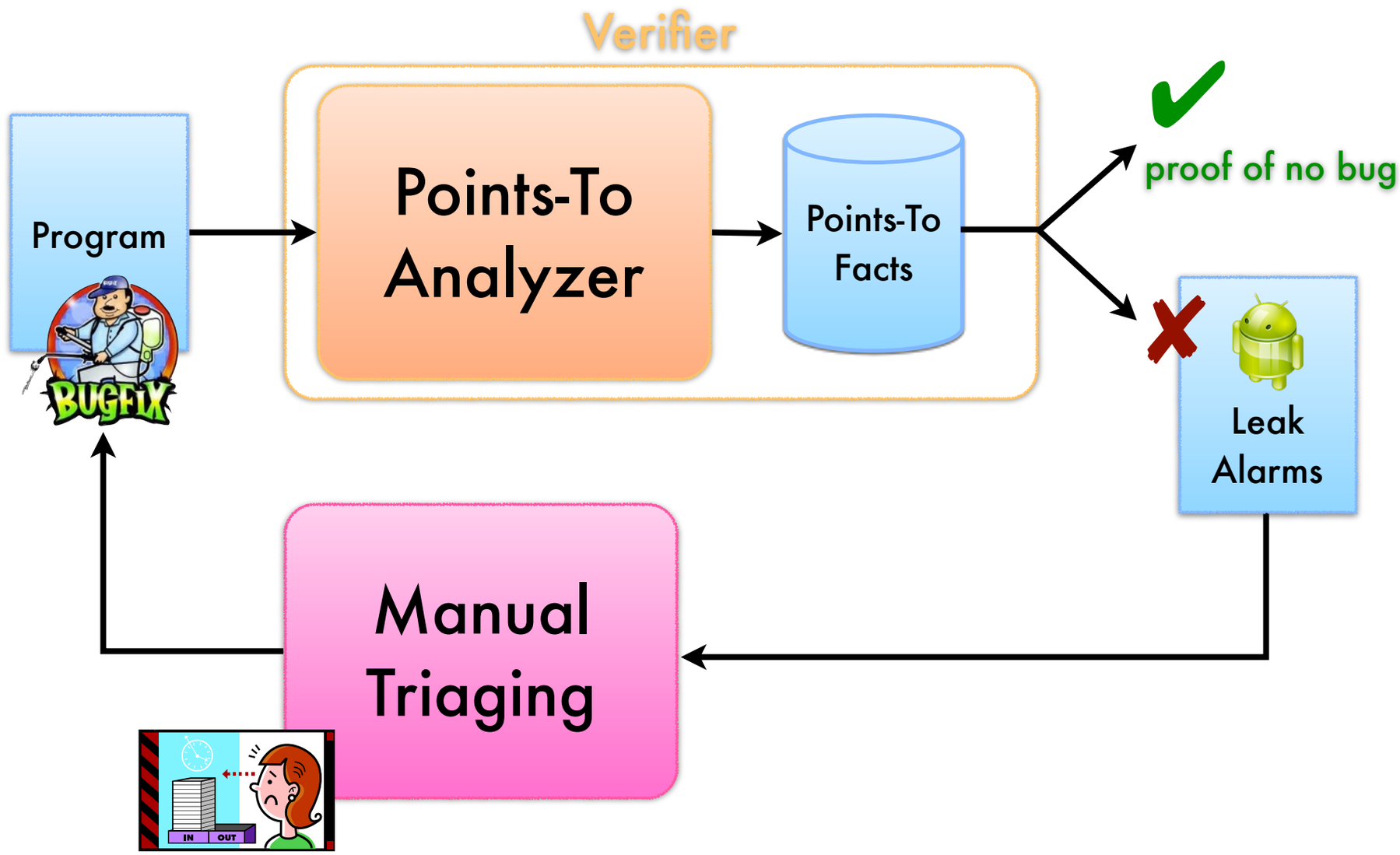

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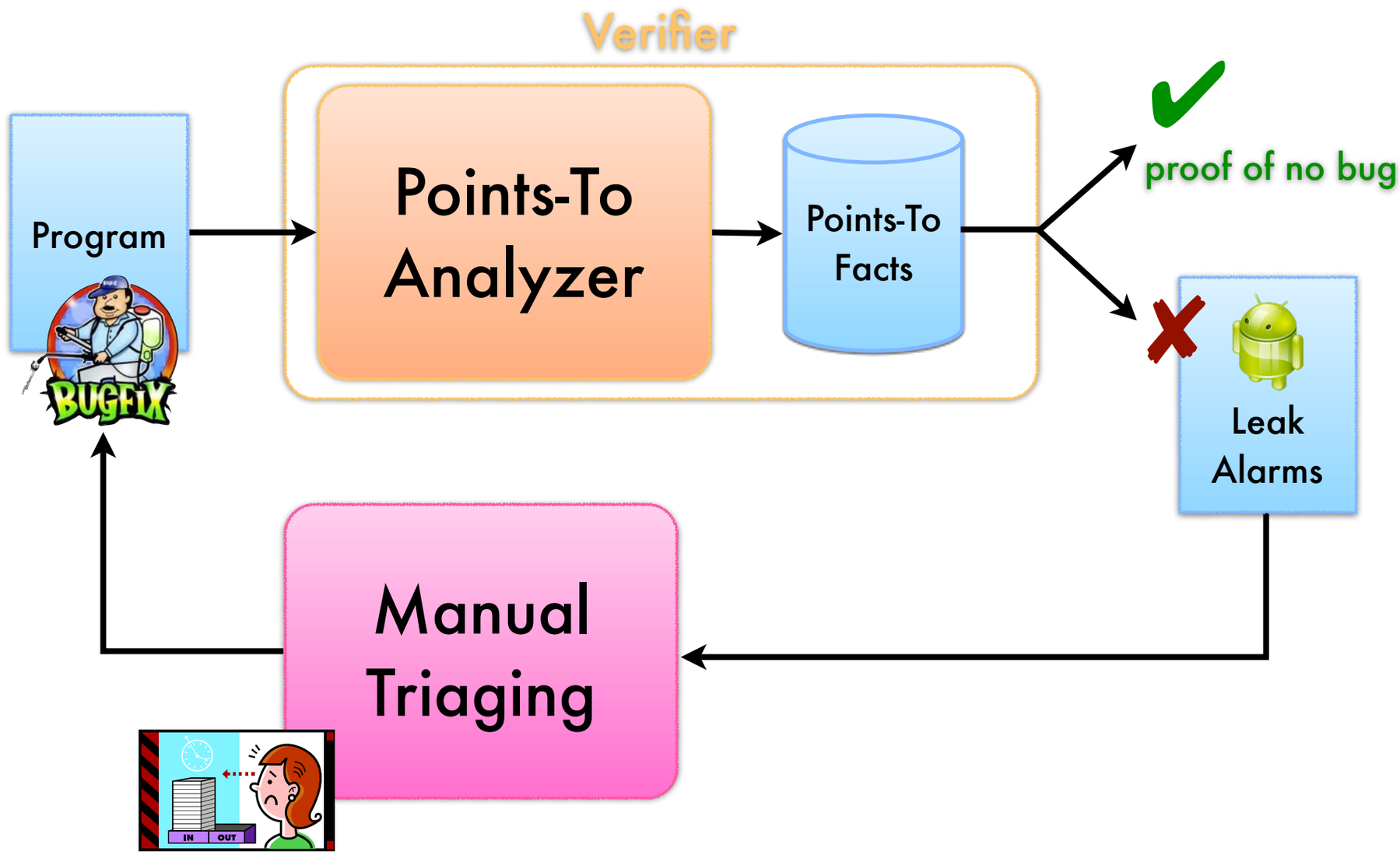

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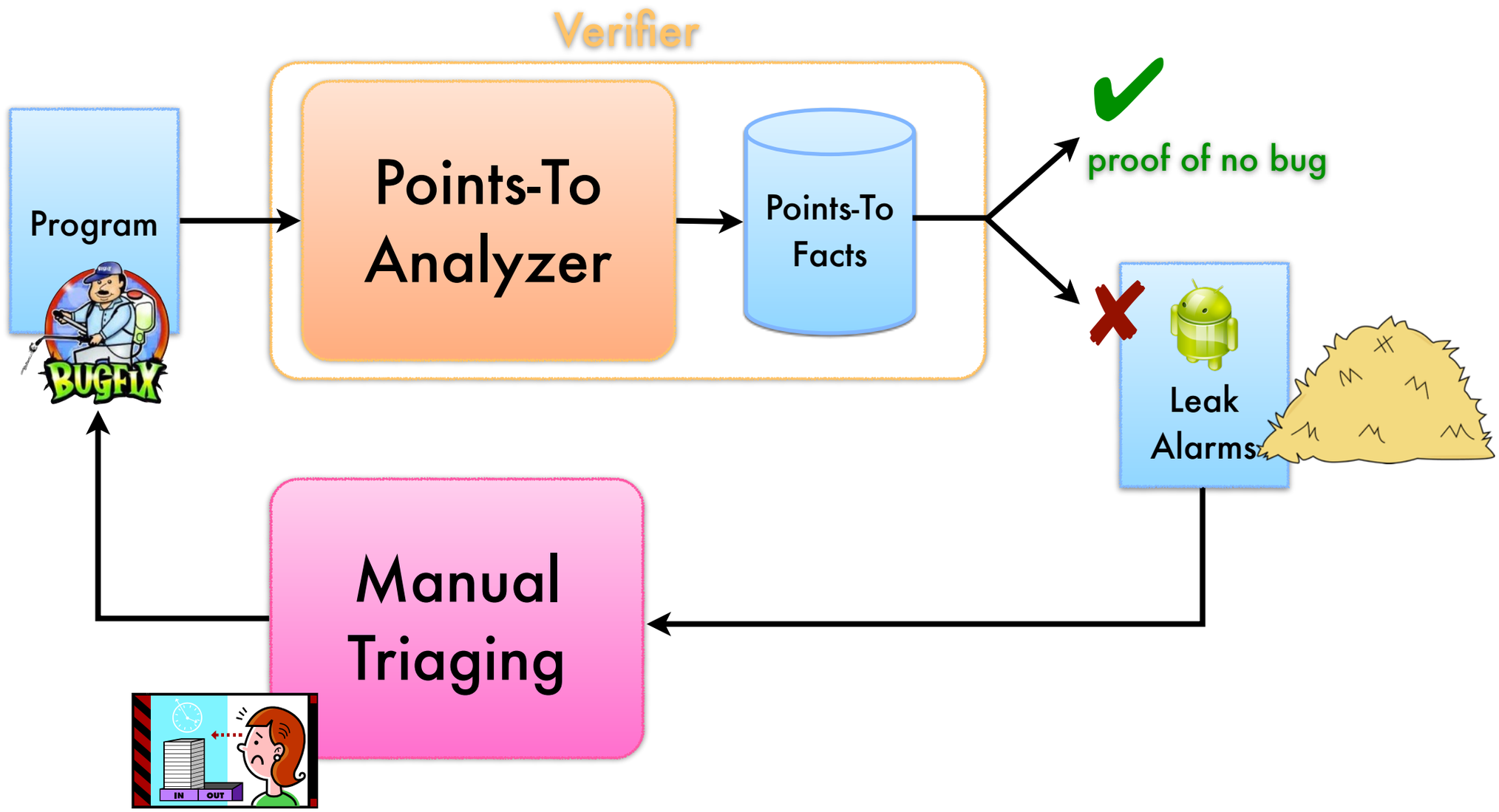

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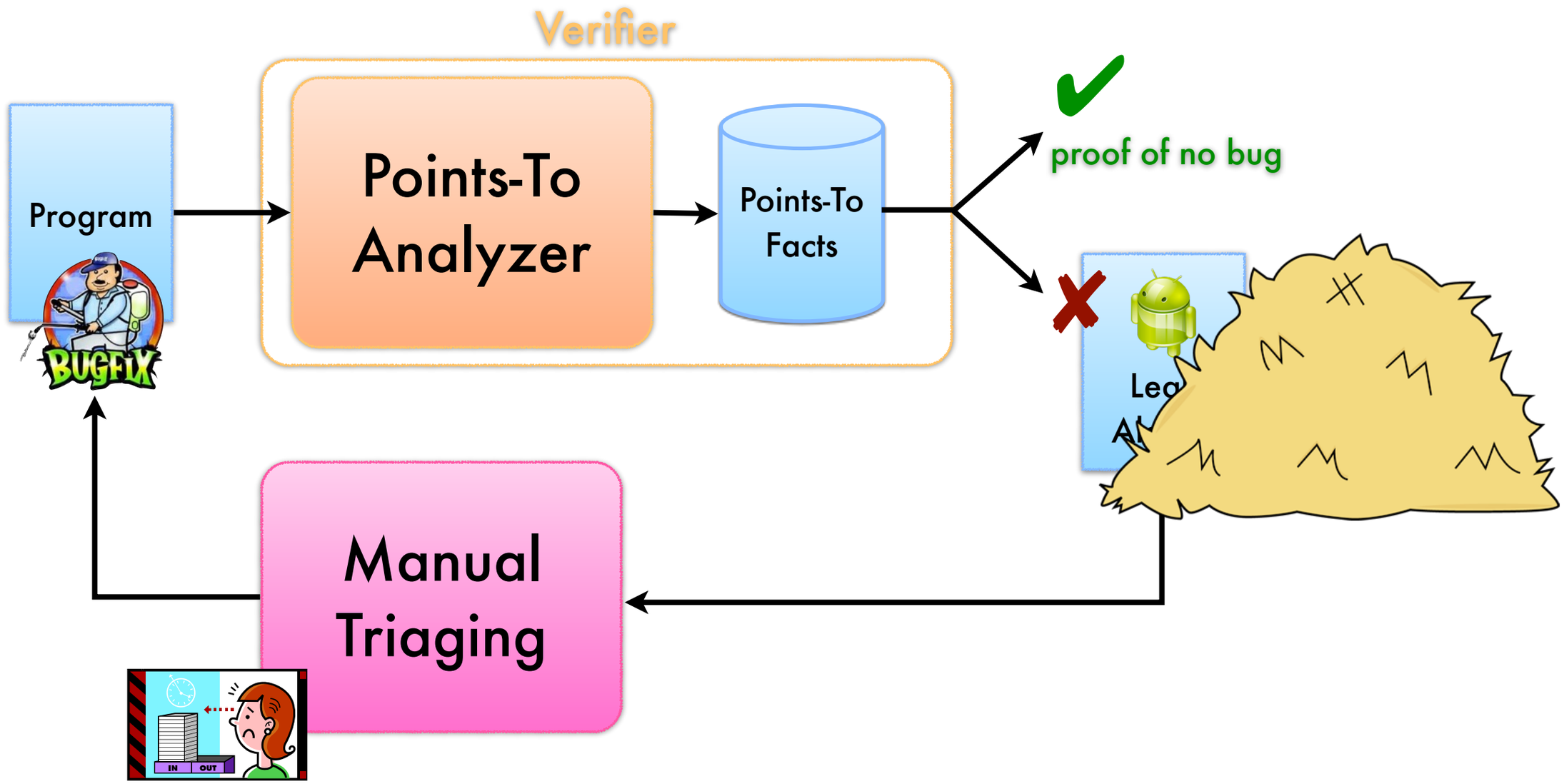

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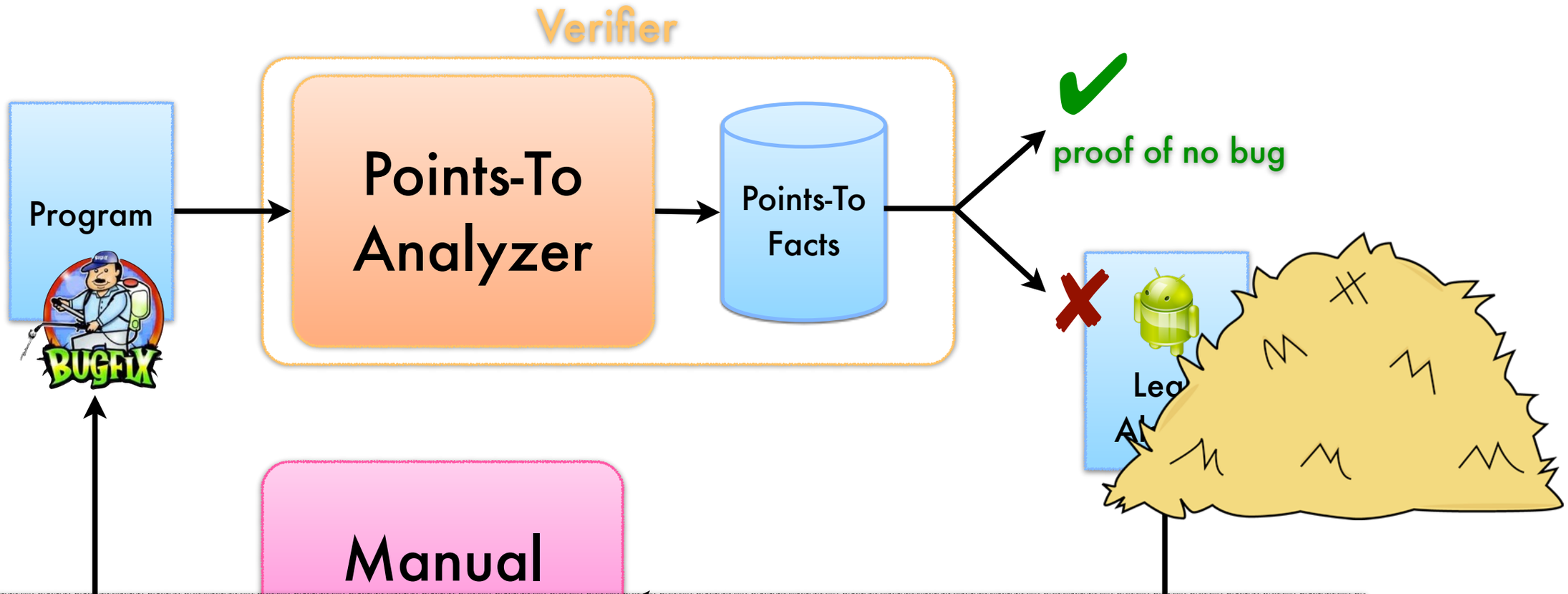

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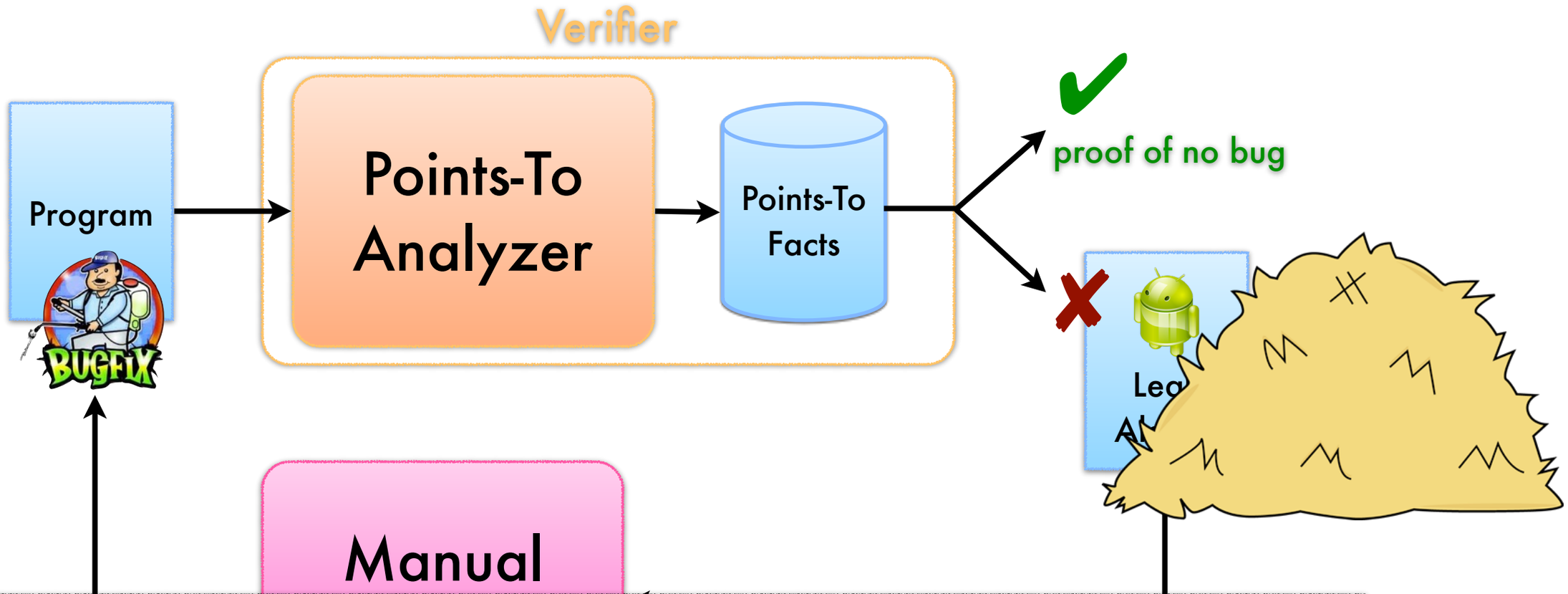

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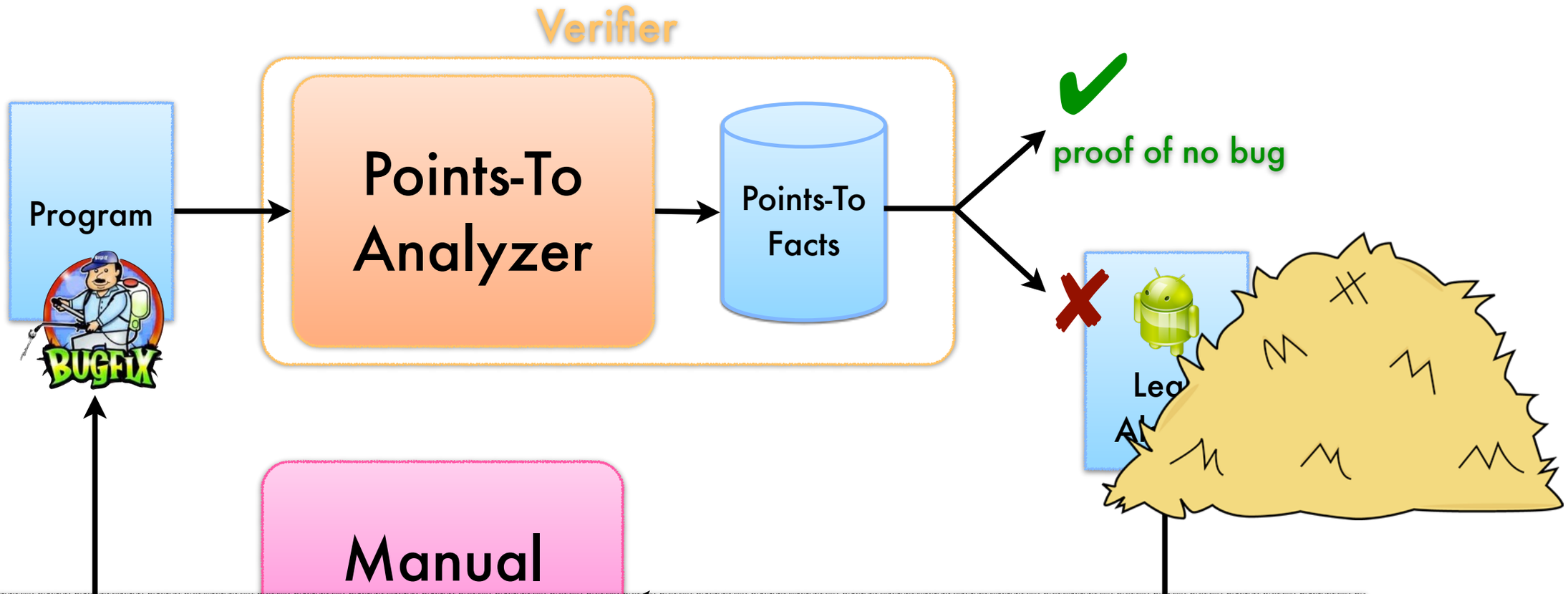

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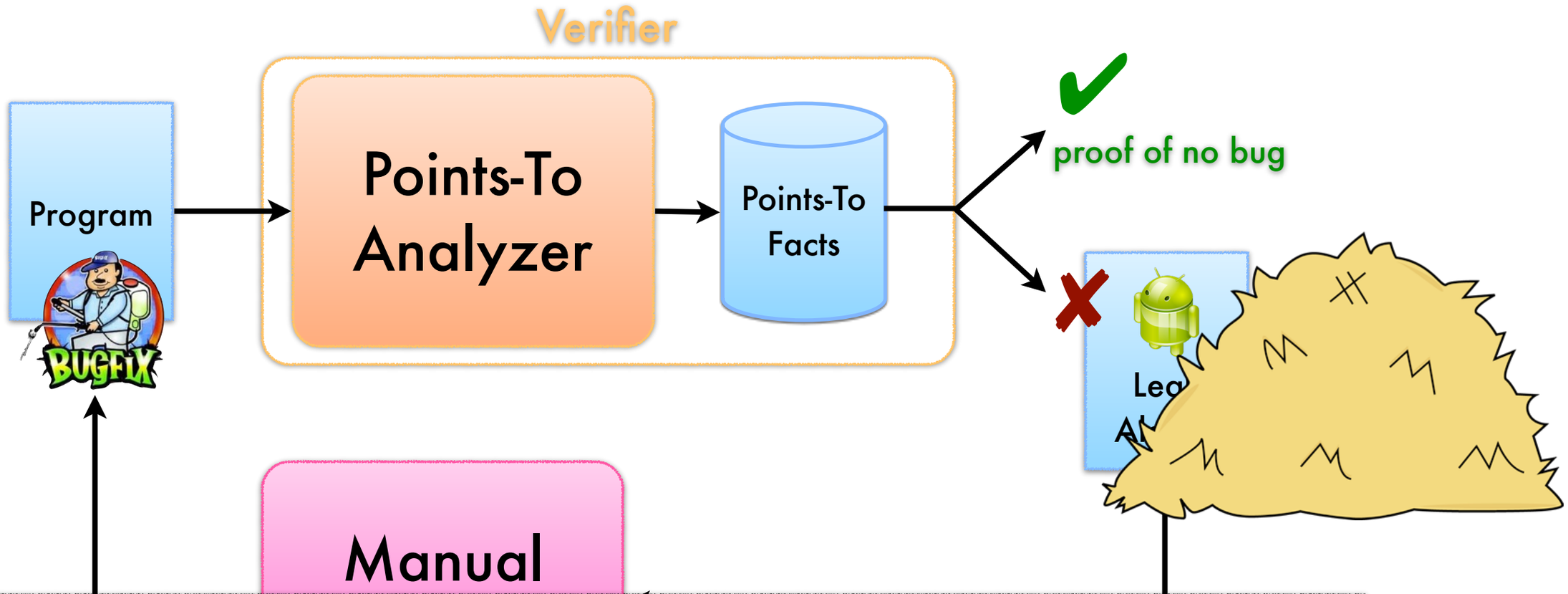

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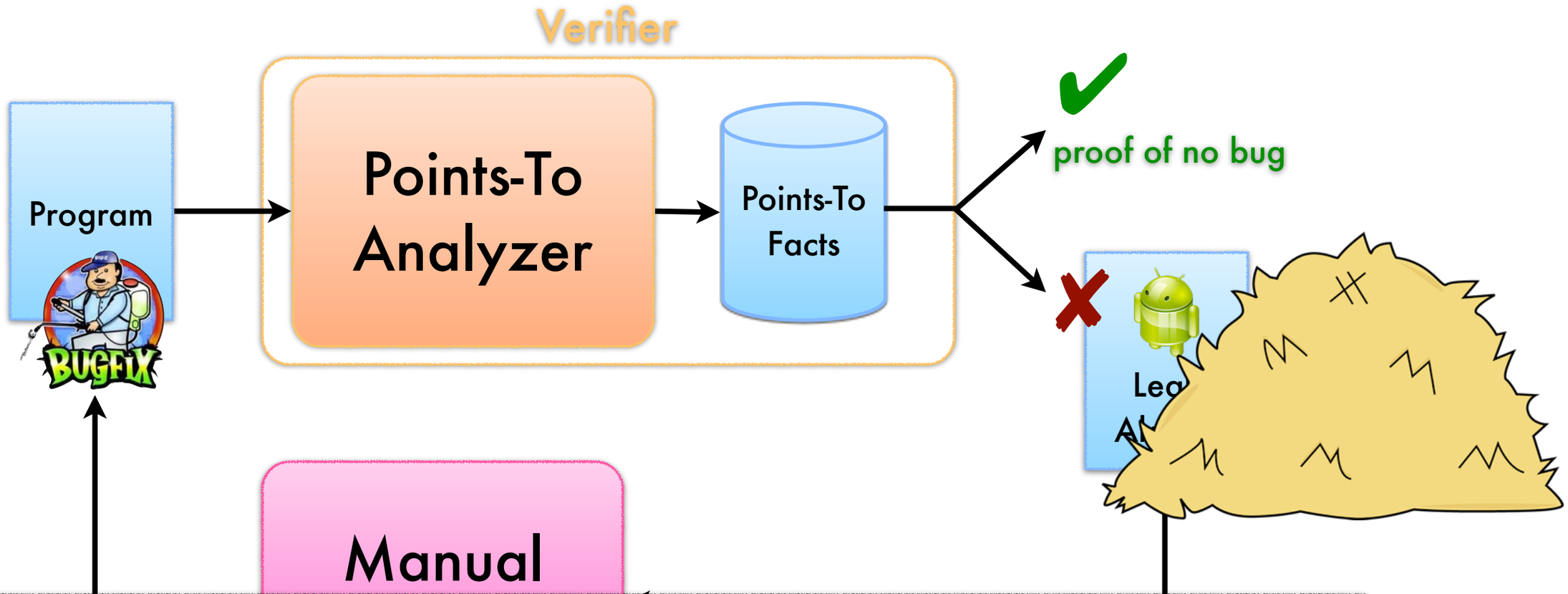

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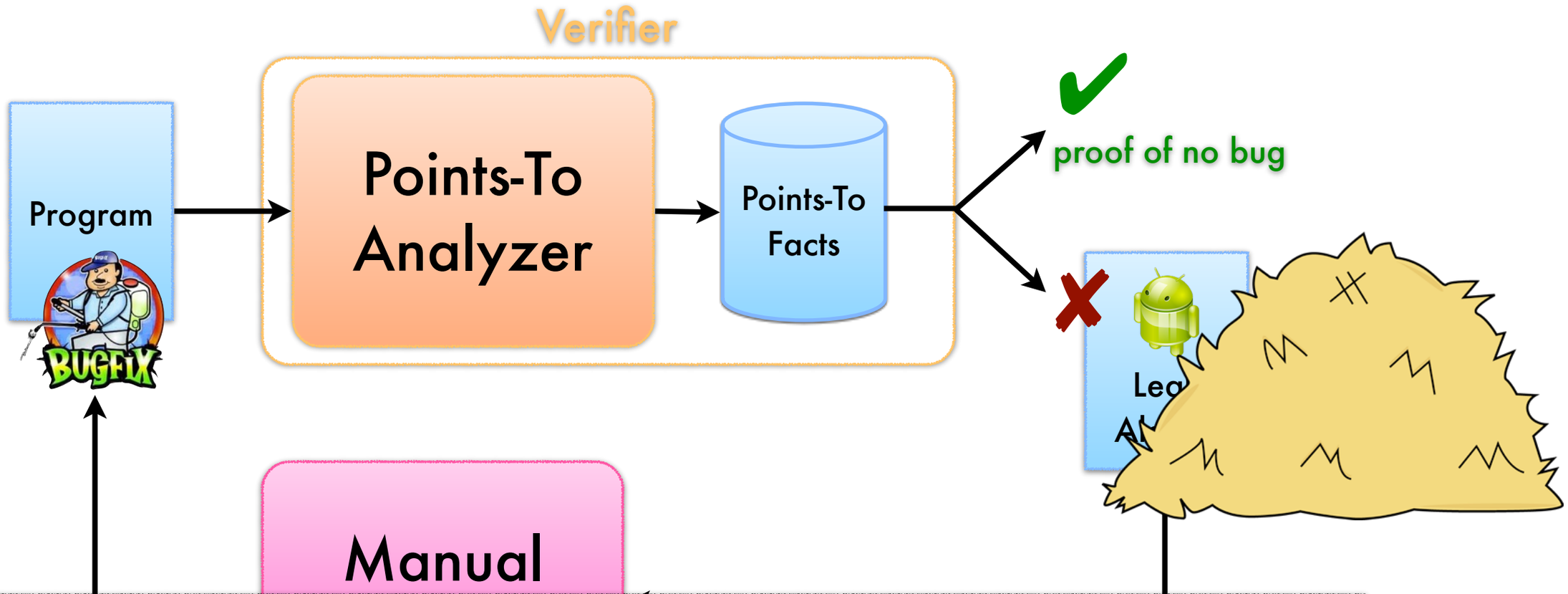

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Dagstuhl 13162: Pointer Analysis (2013)

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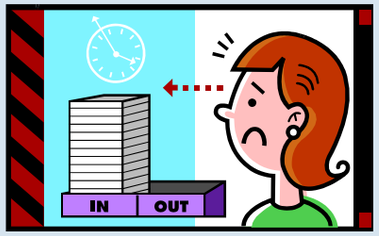
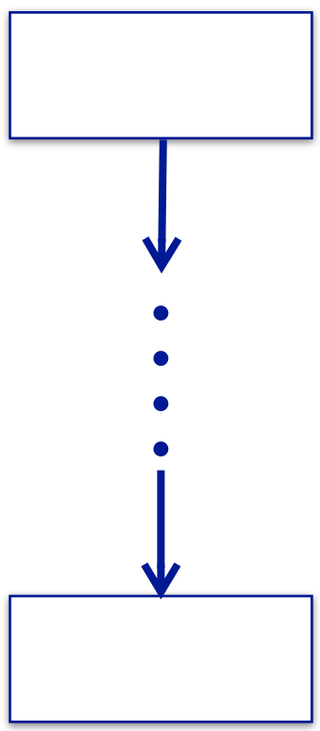
enough impossible?

Manual triage is particularly hard for heap reachability reports.





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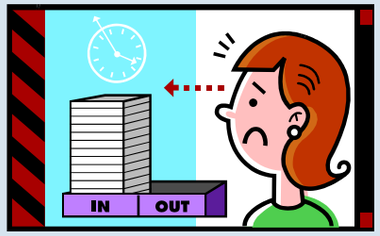

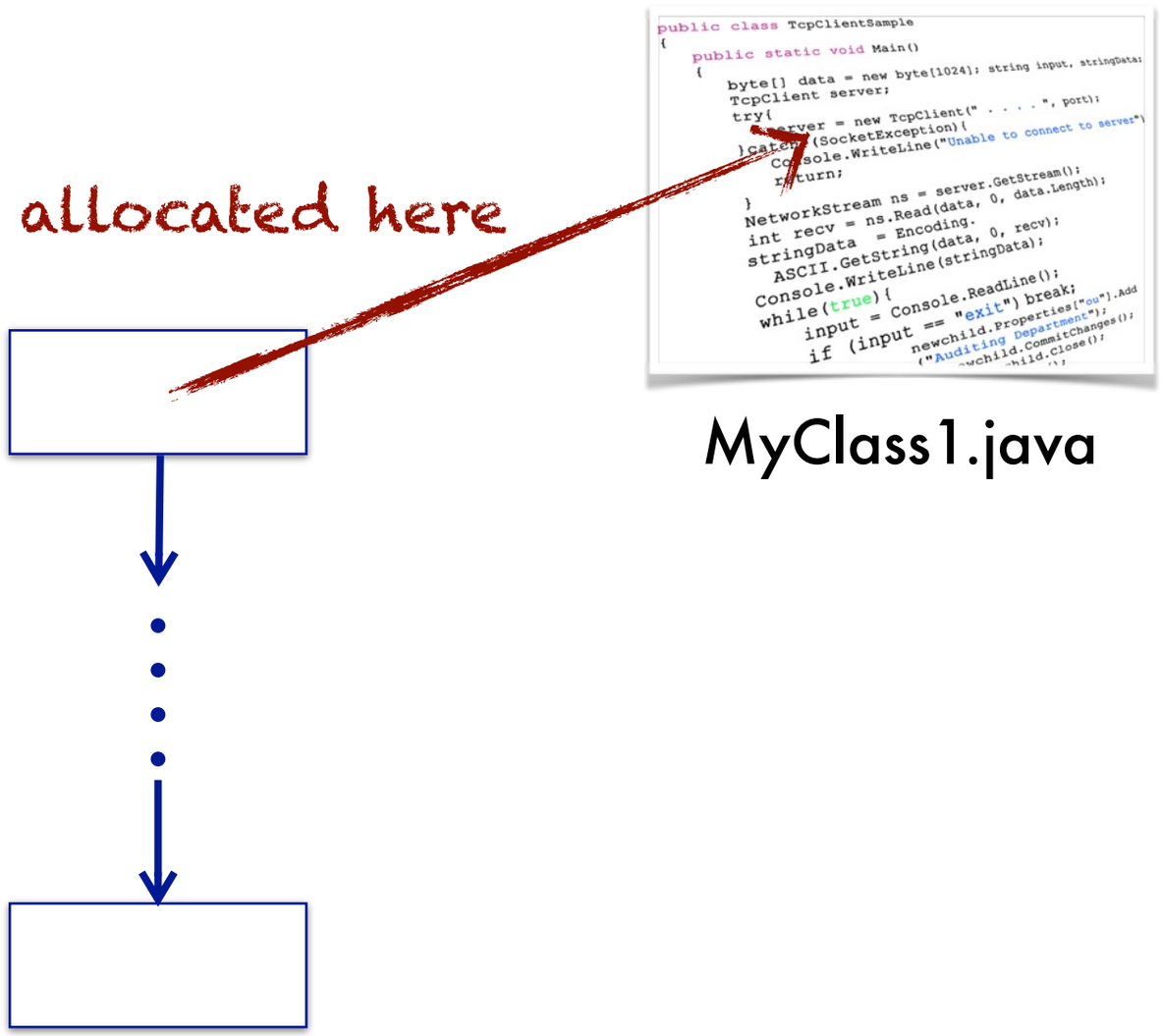

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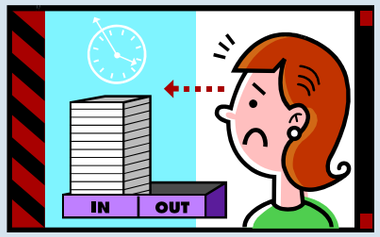

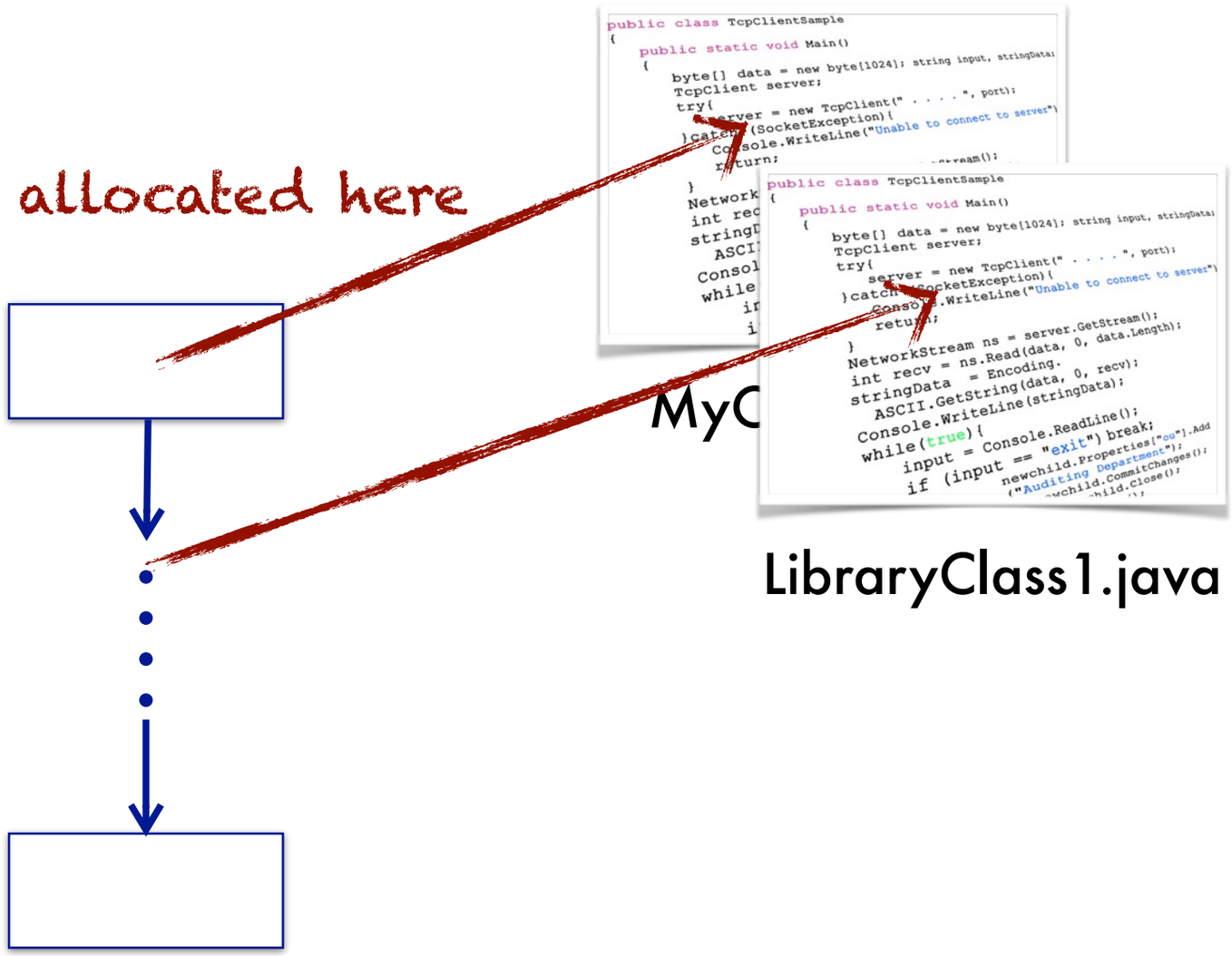

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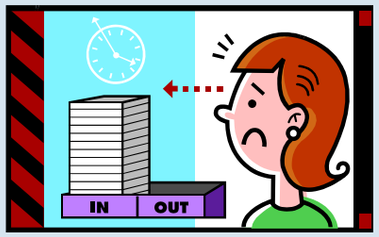

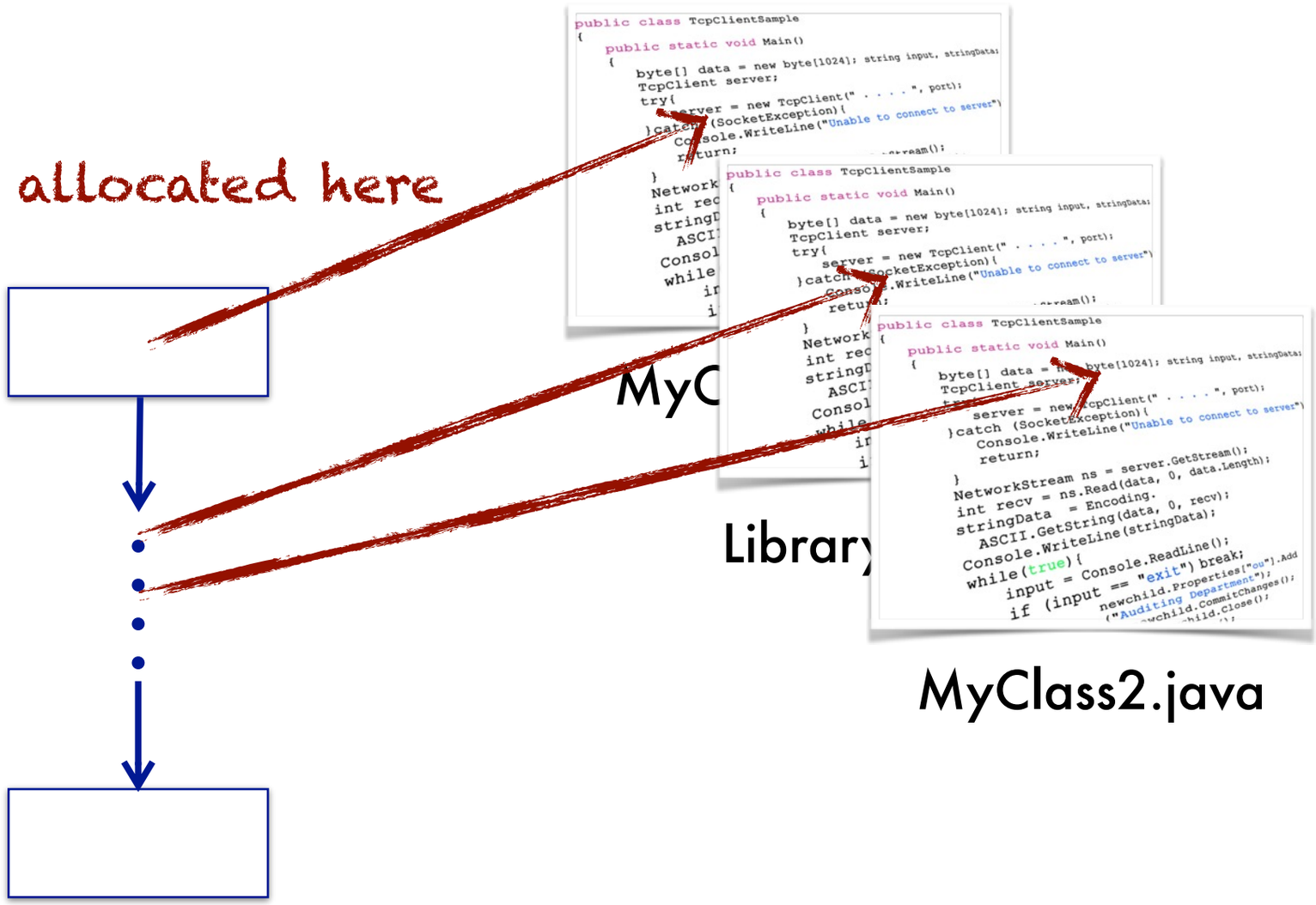

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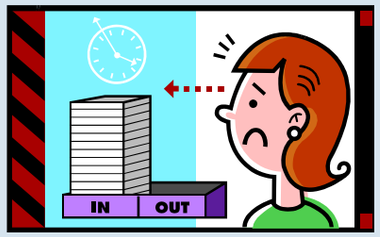

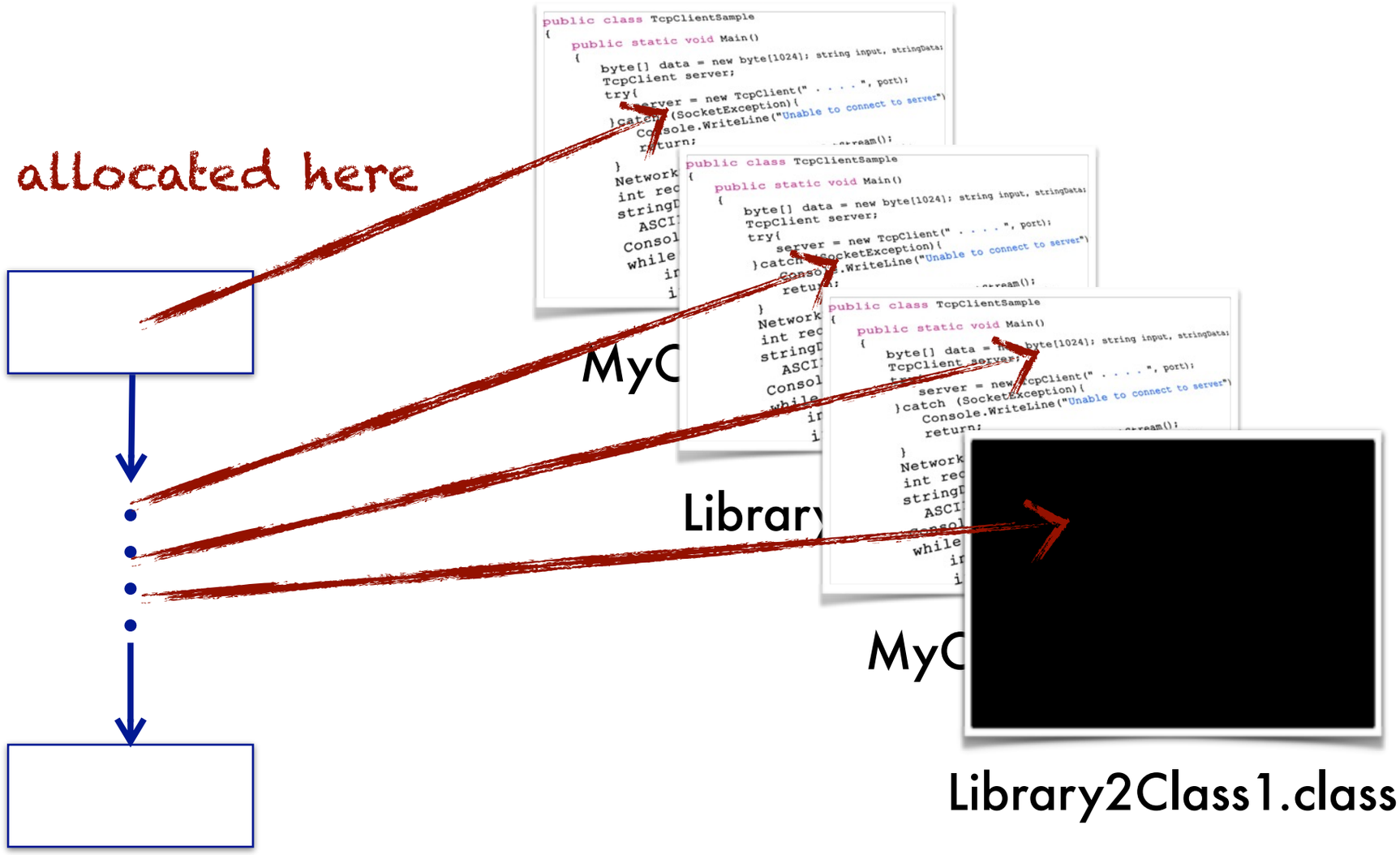

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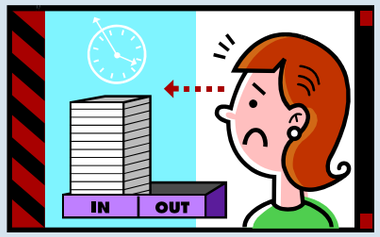

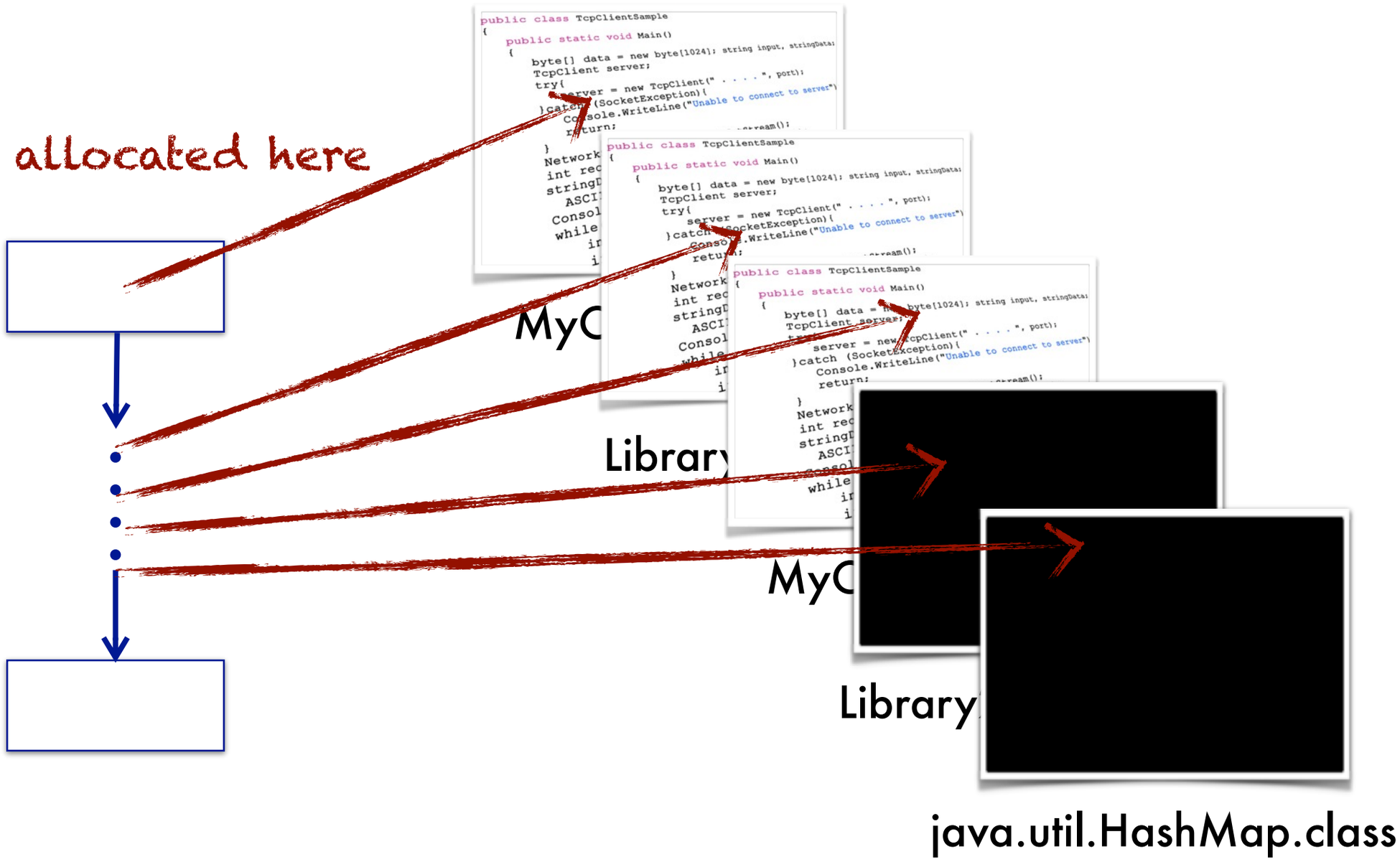

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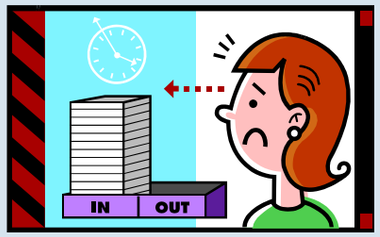

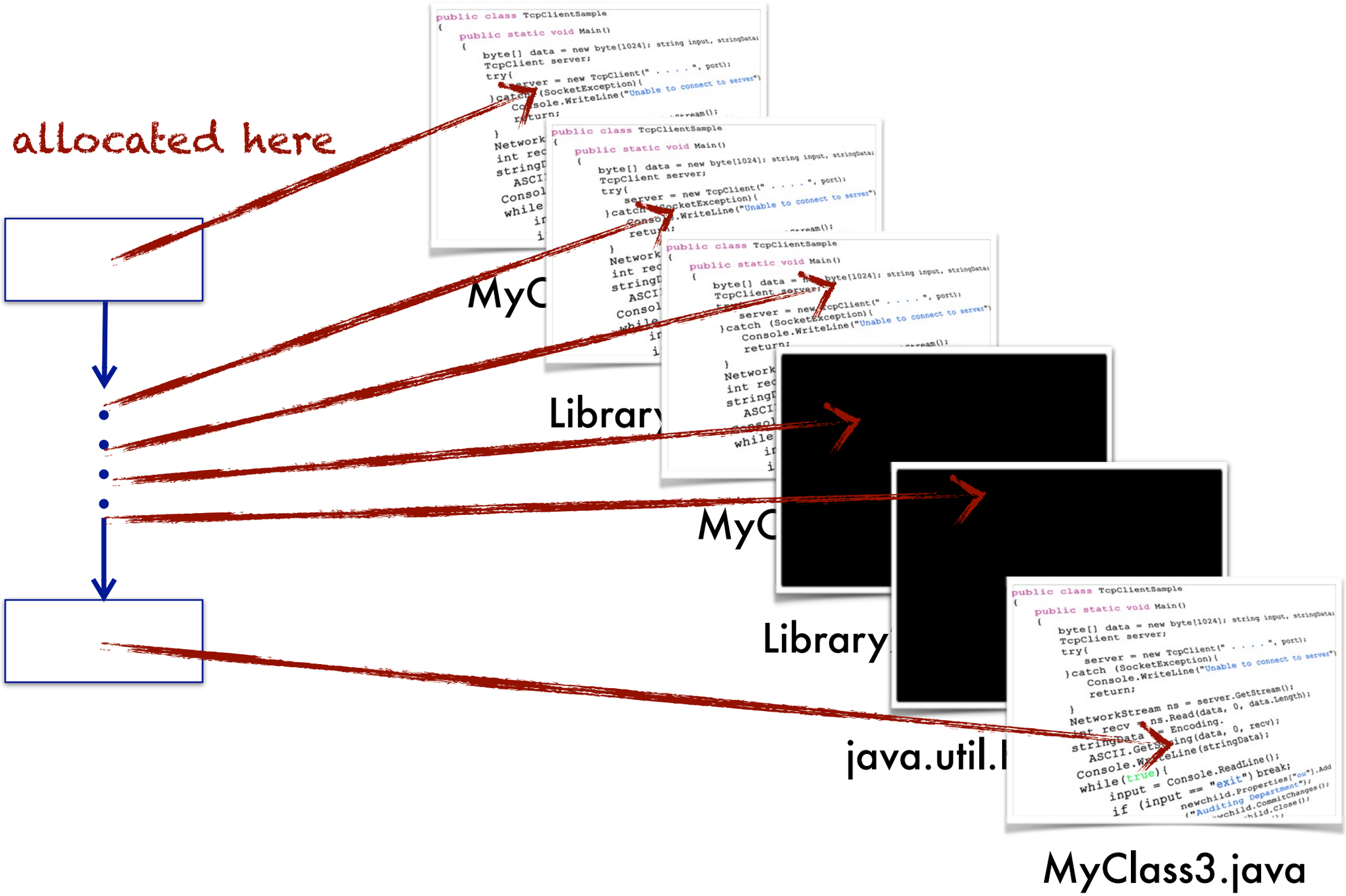

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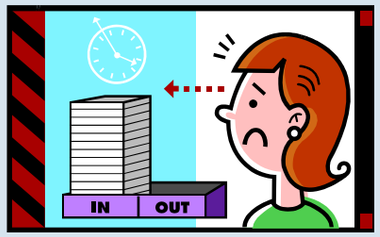
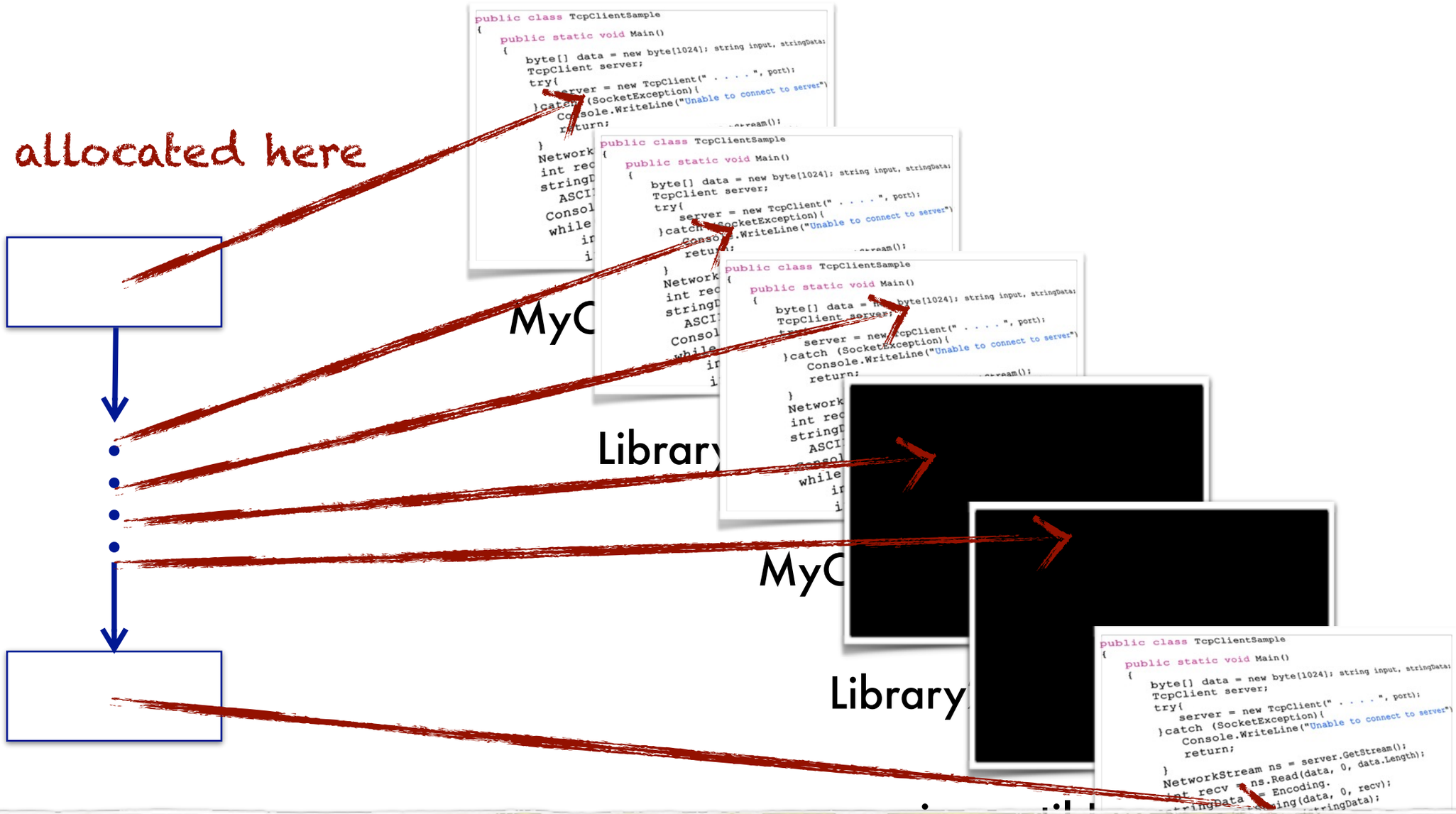
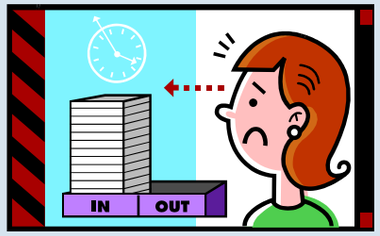




Get abstract heap path + maybe allocation sites

Guesstimate: >1 to 2 hours per alarm to triage "well"

Examining manual triage ...



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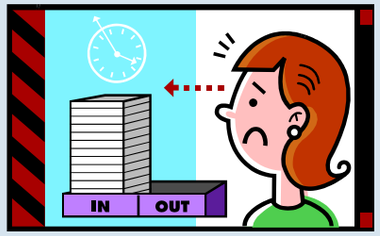

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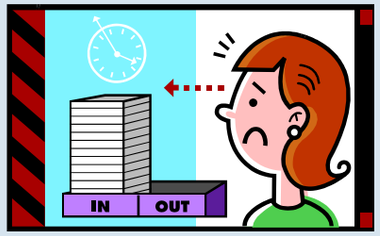

What does the user need to do with an alarm? He starts at, say, line 142 and traces back to see if a bug is possible given what's happening.

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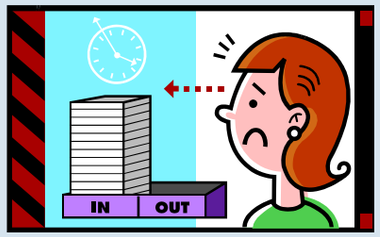

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We can do this with analysis!

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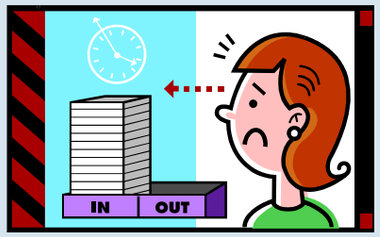

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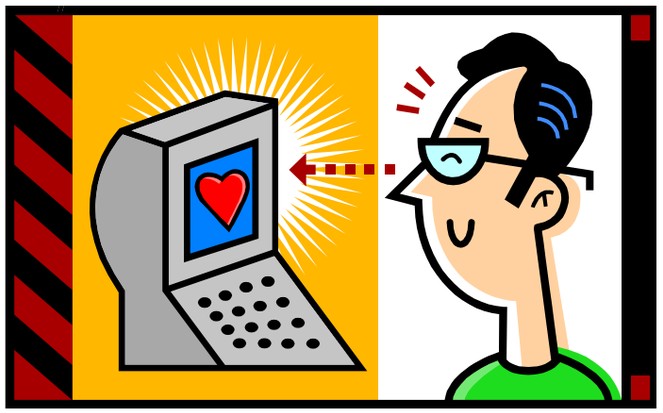

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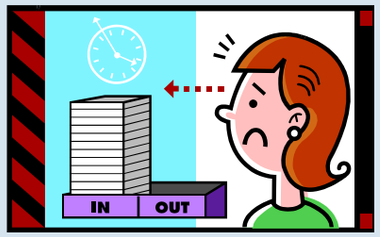

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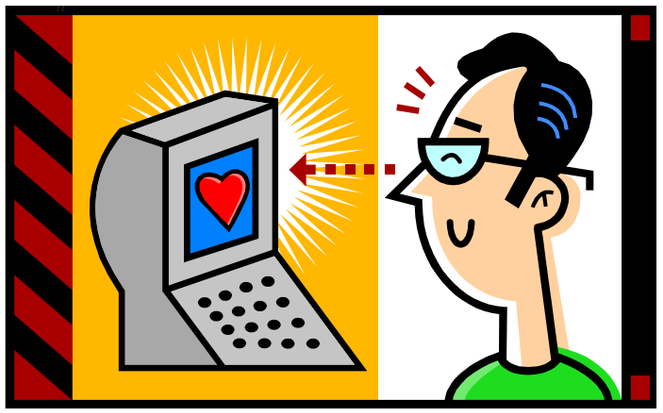
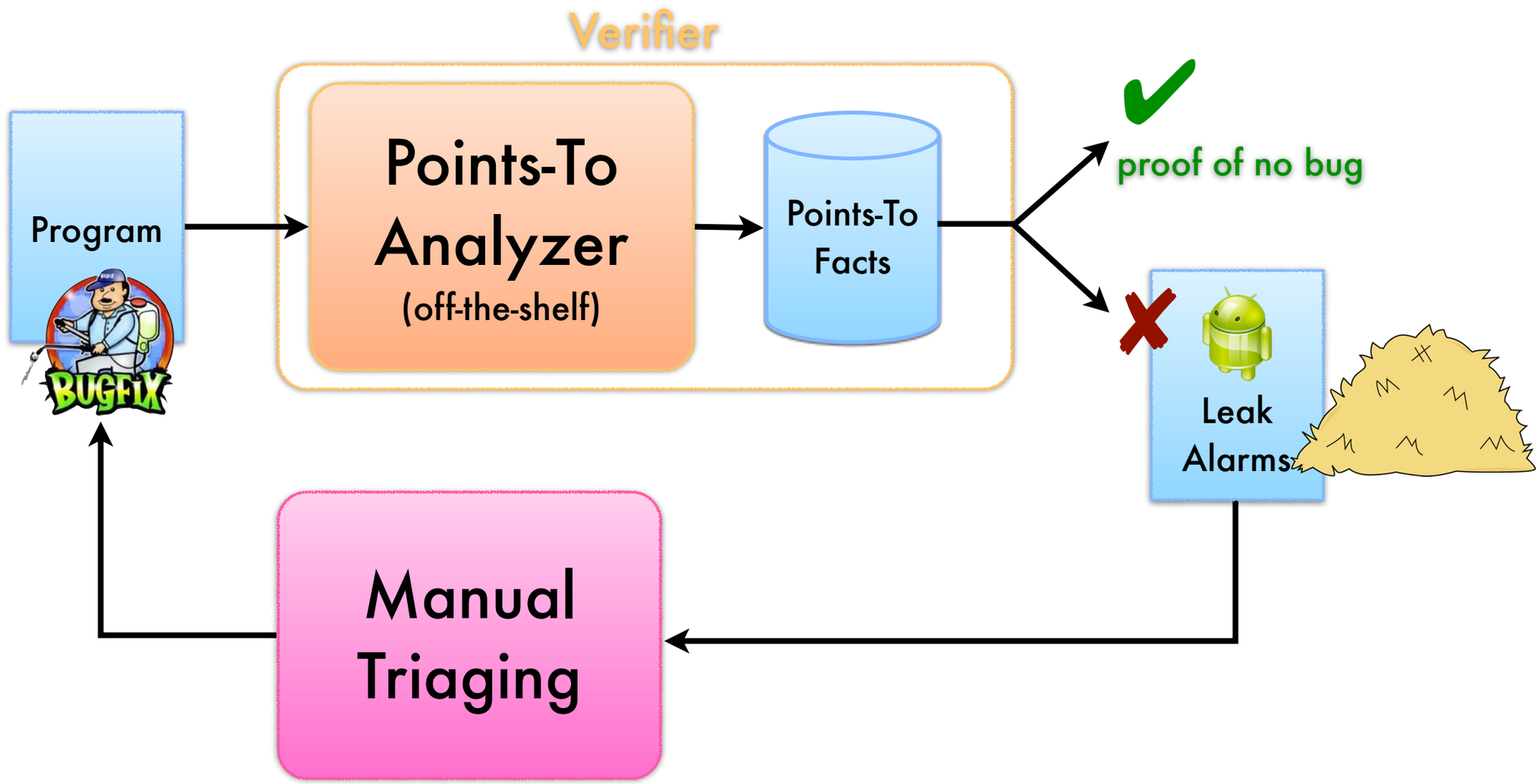


If we filter most false alarms, the user can triage more quickly and get to true bugs earlier (without frustration).

Thresher filters out false alarms by refuting them one-by-one.



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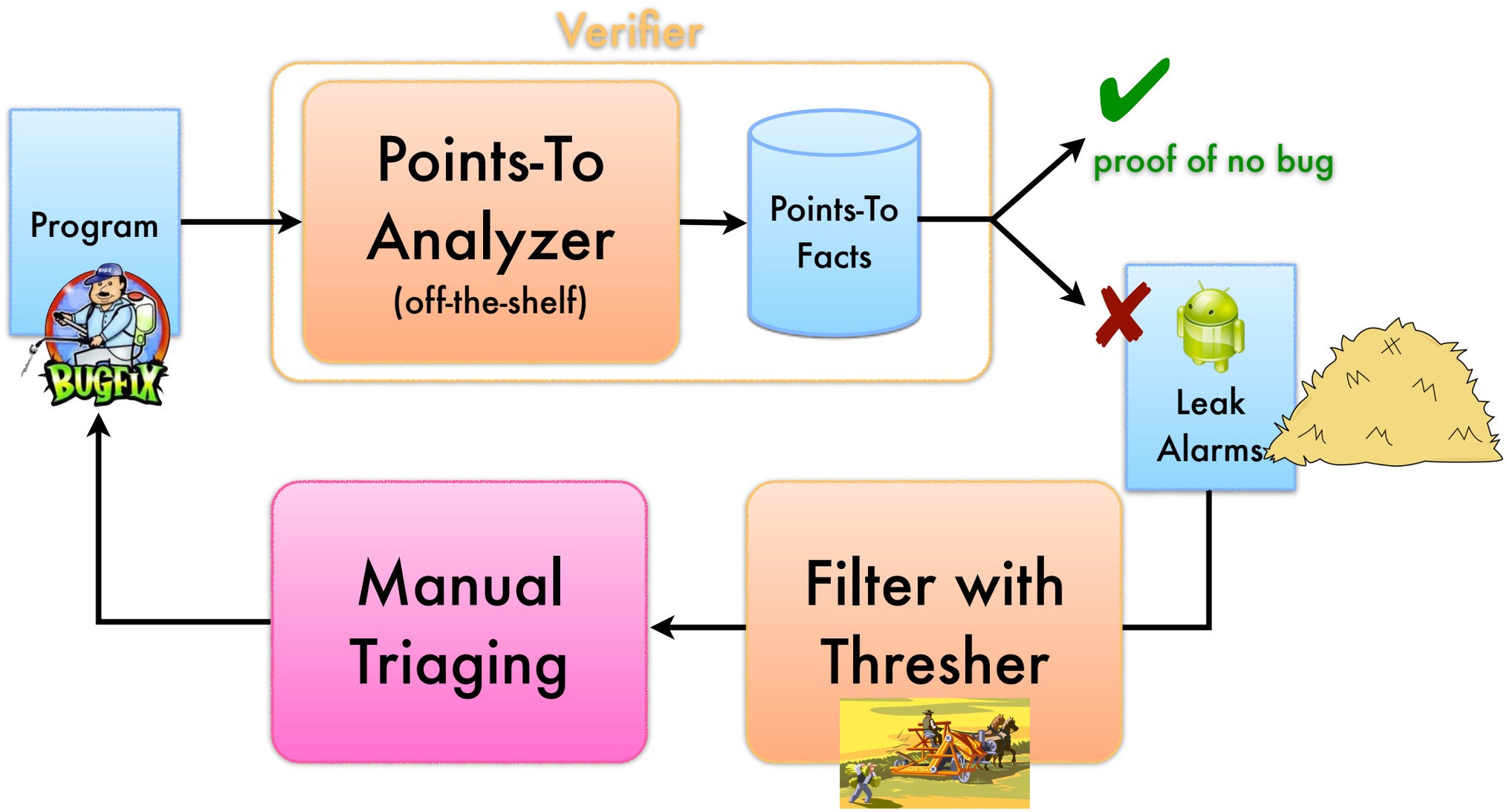

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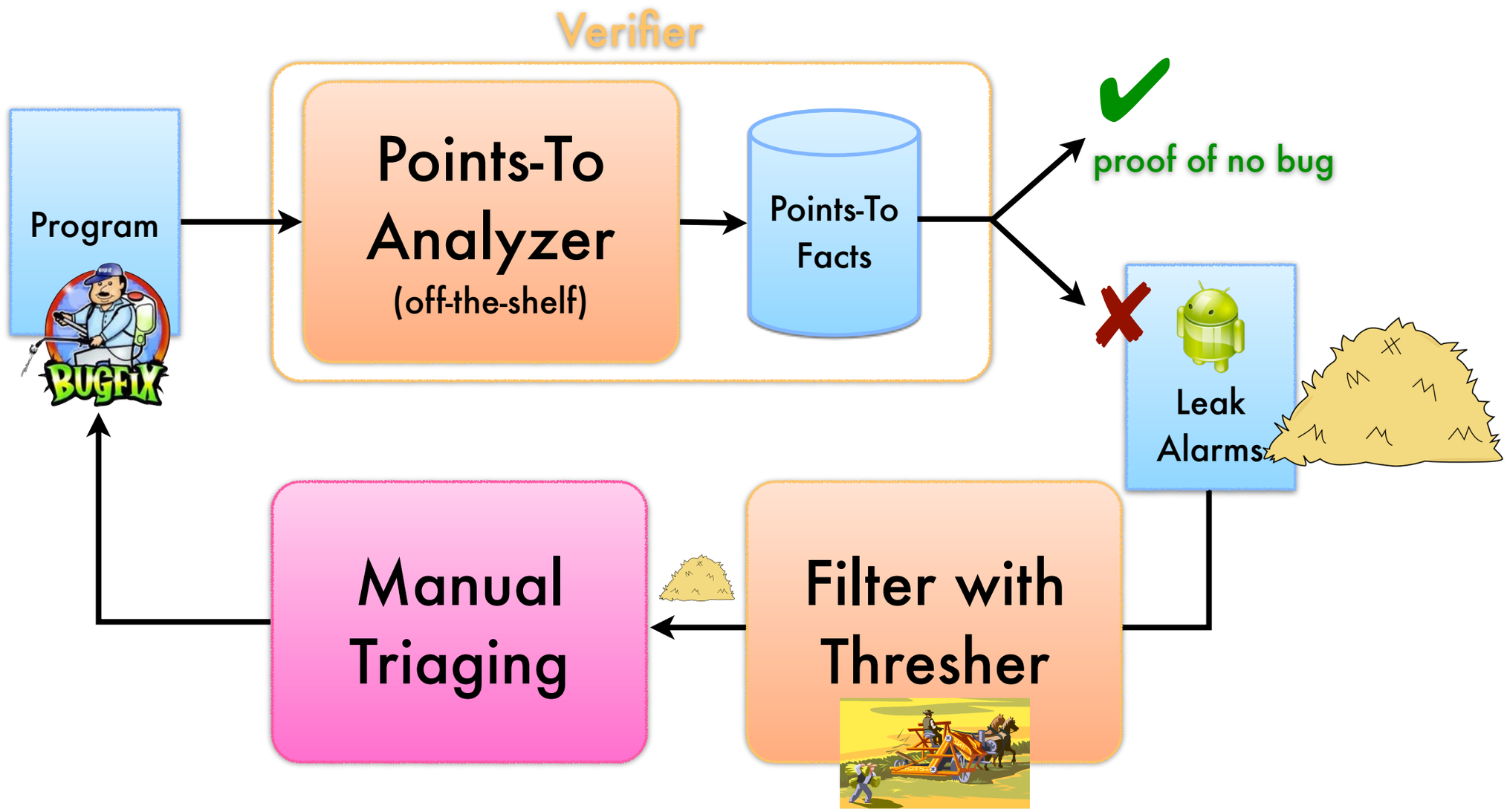

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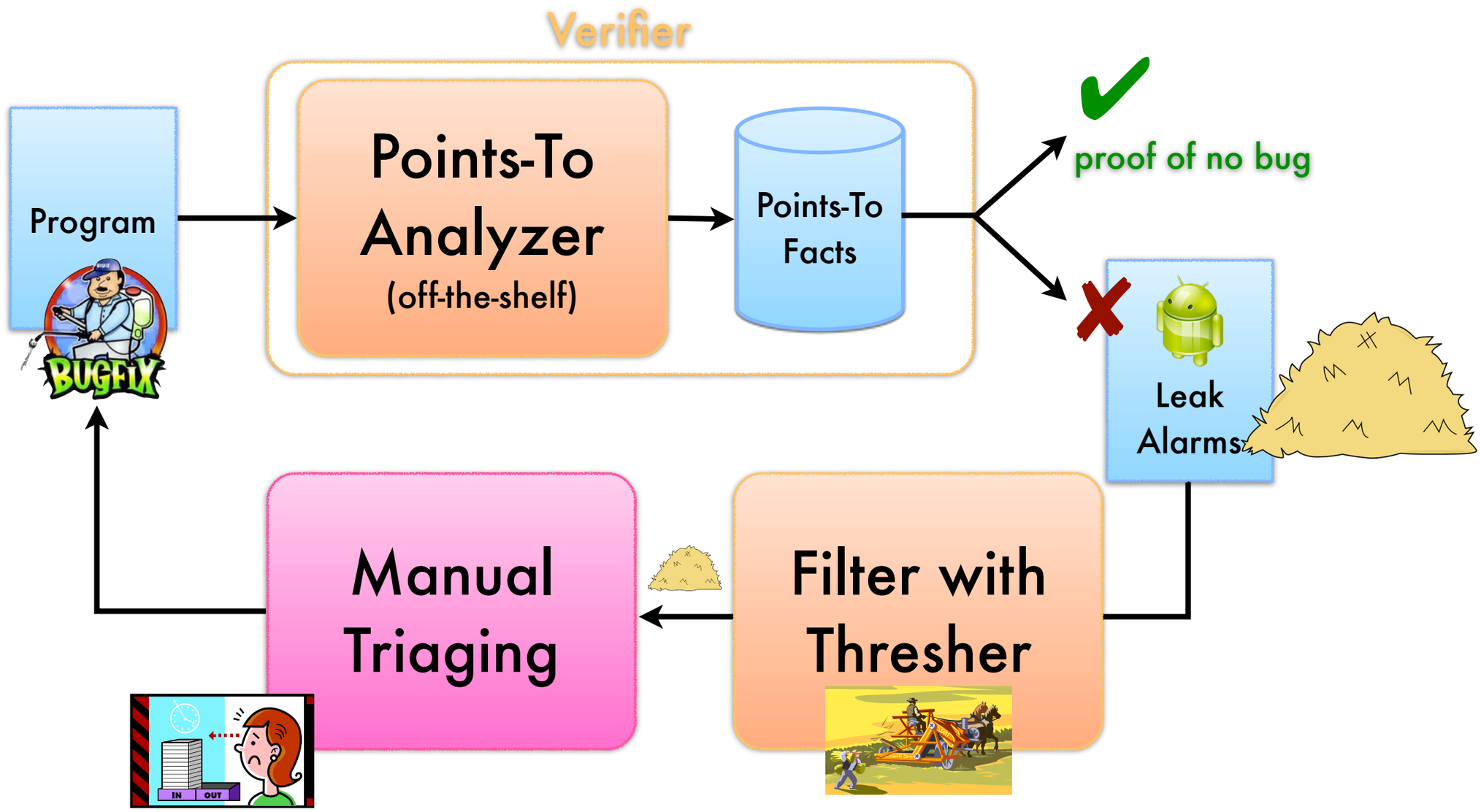

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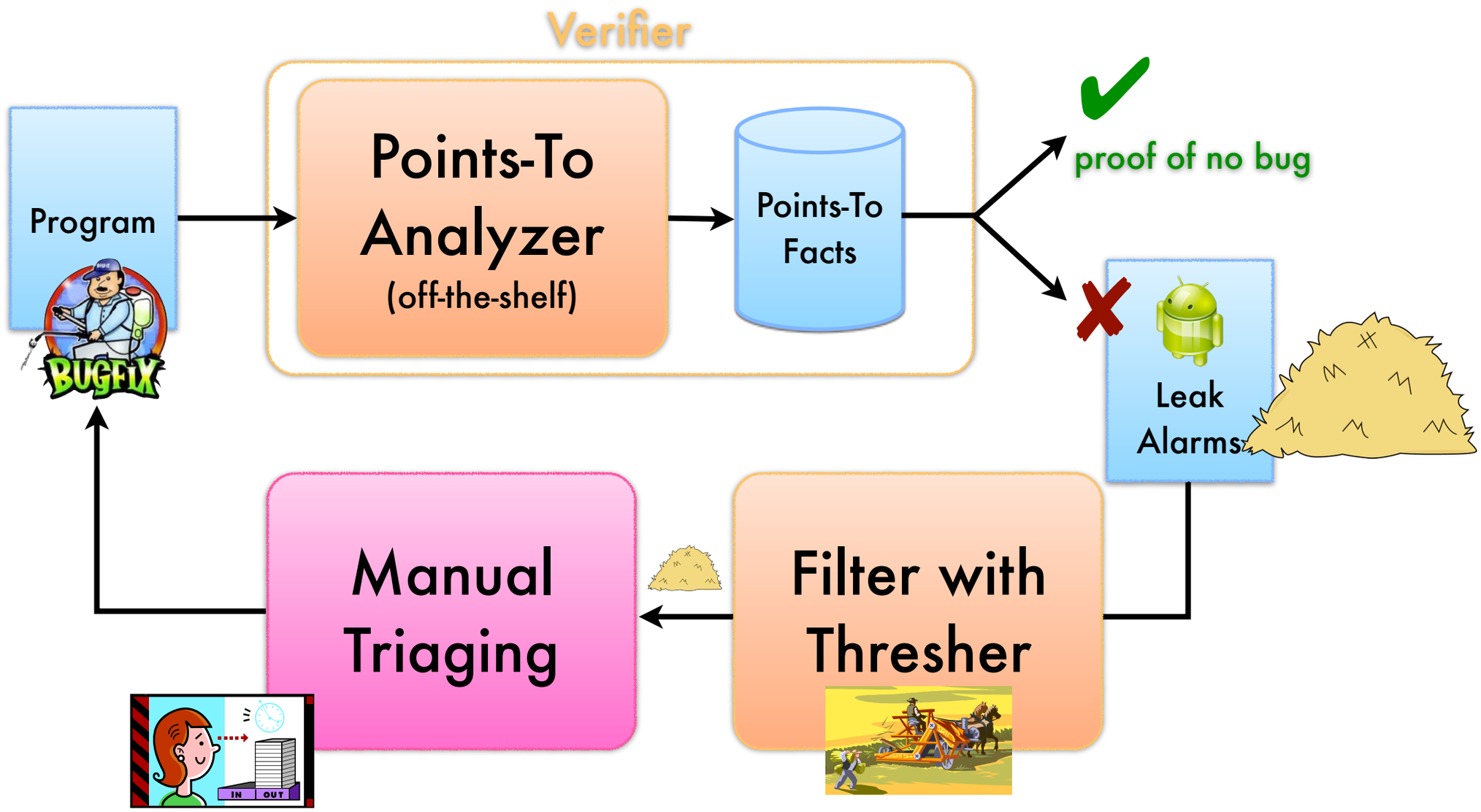

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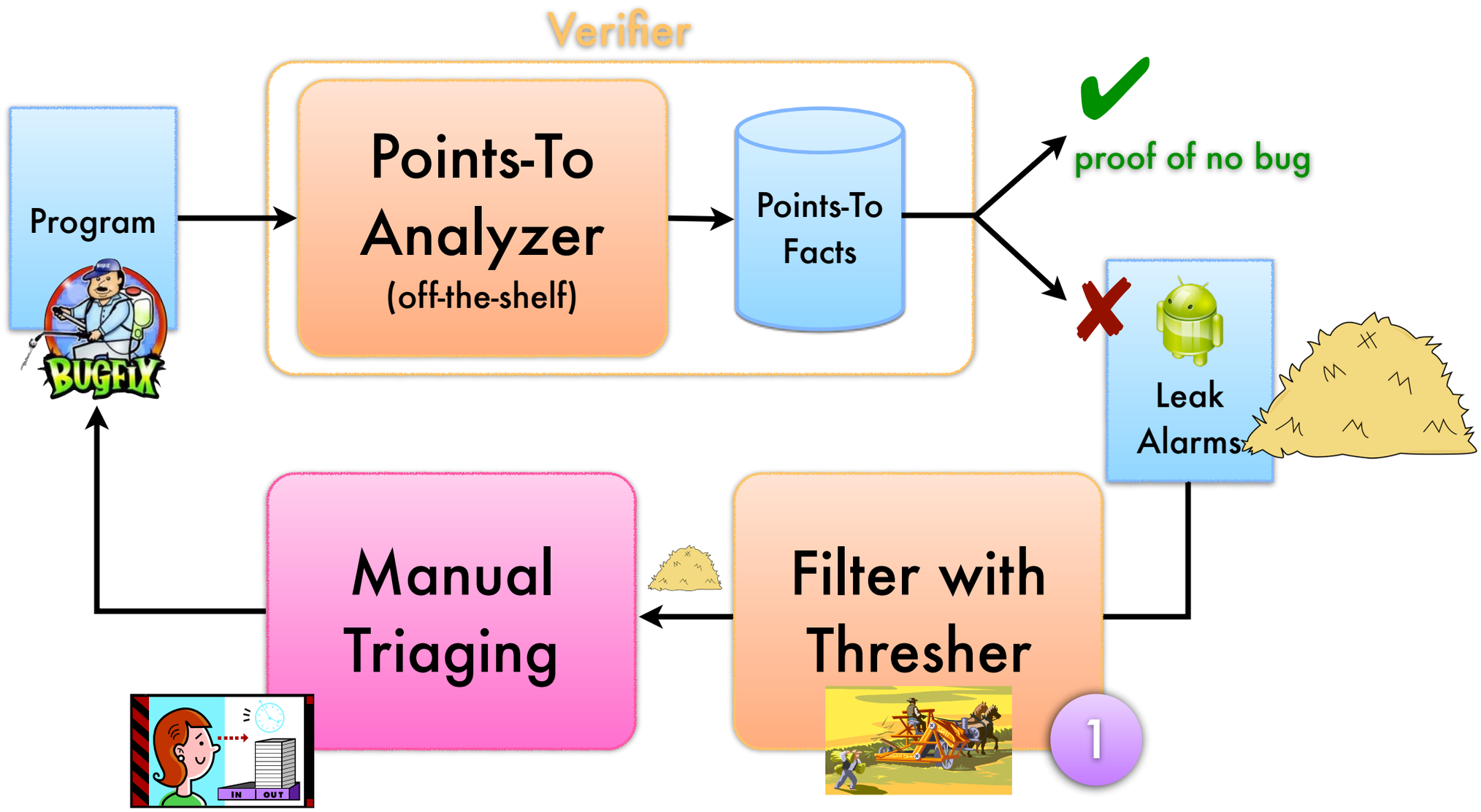
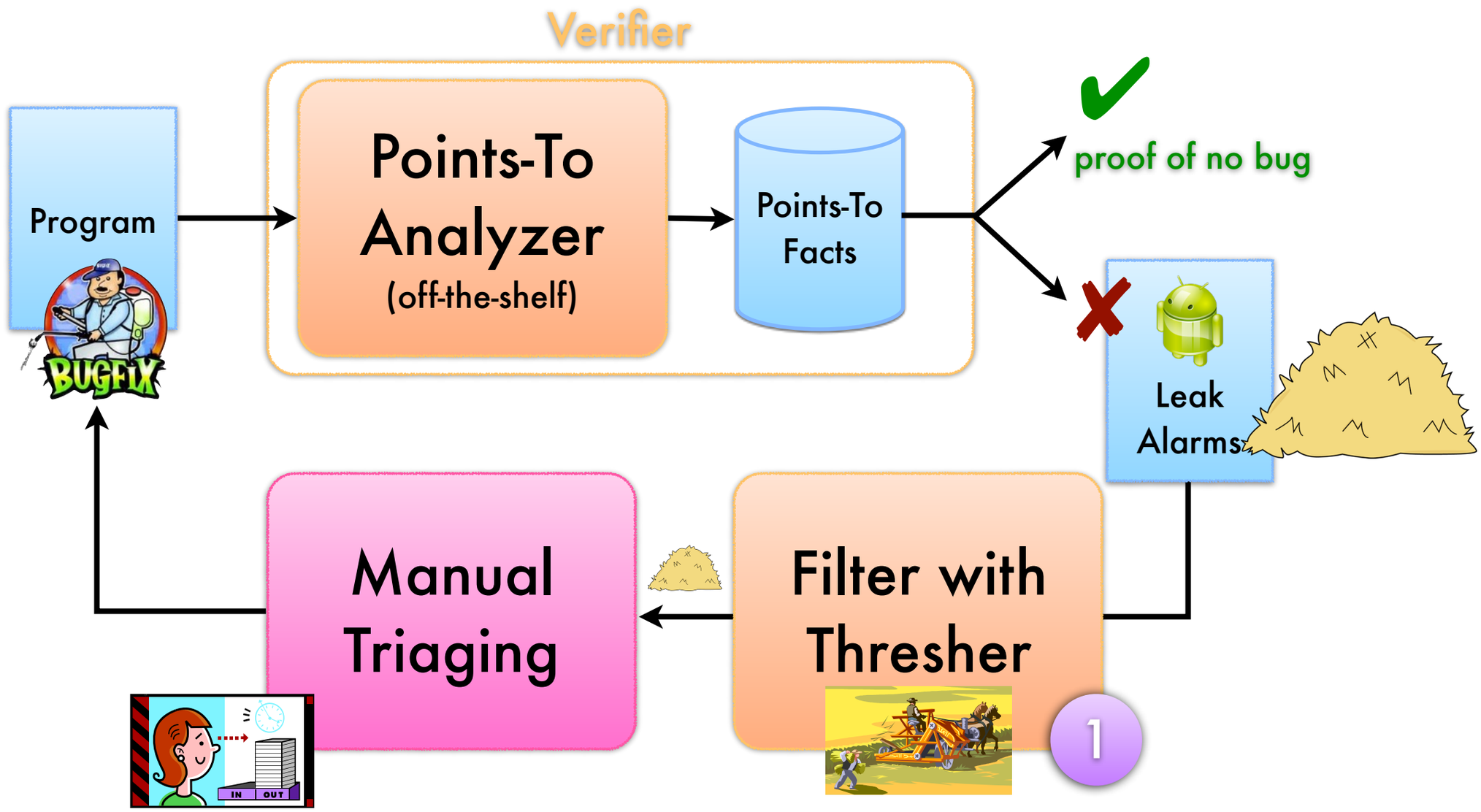


Idea 1: Refute points-to on-demand with second "uber-precise" filter analysis

Thresher filters out false alarms by refuting them one-by-one.



Idea 1: Refute points-to on-demand with second "uber-precise" filter analysis

*-sensitive

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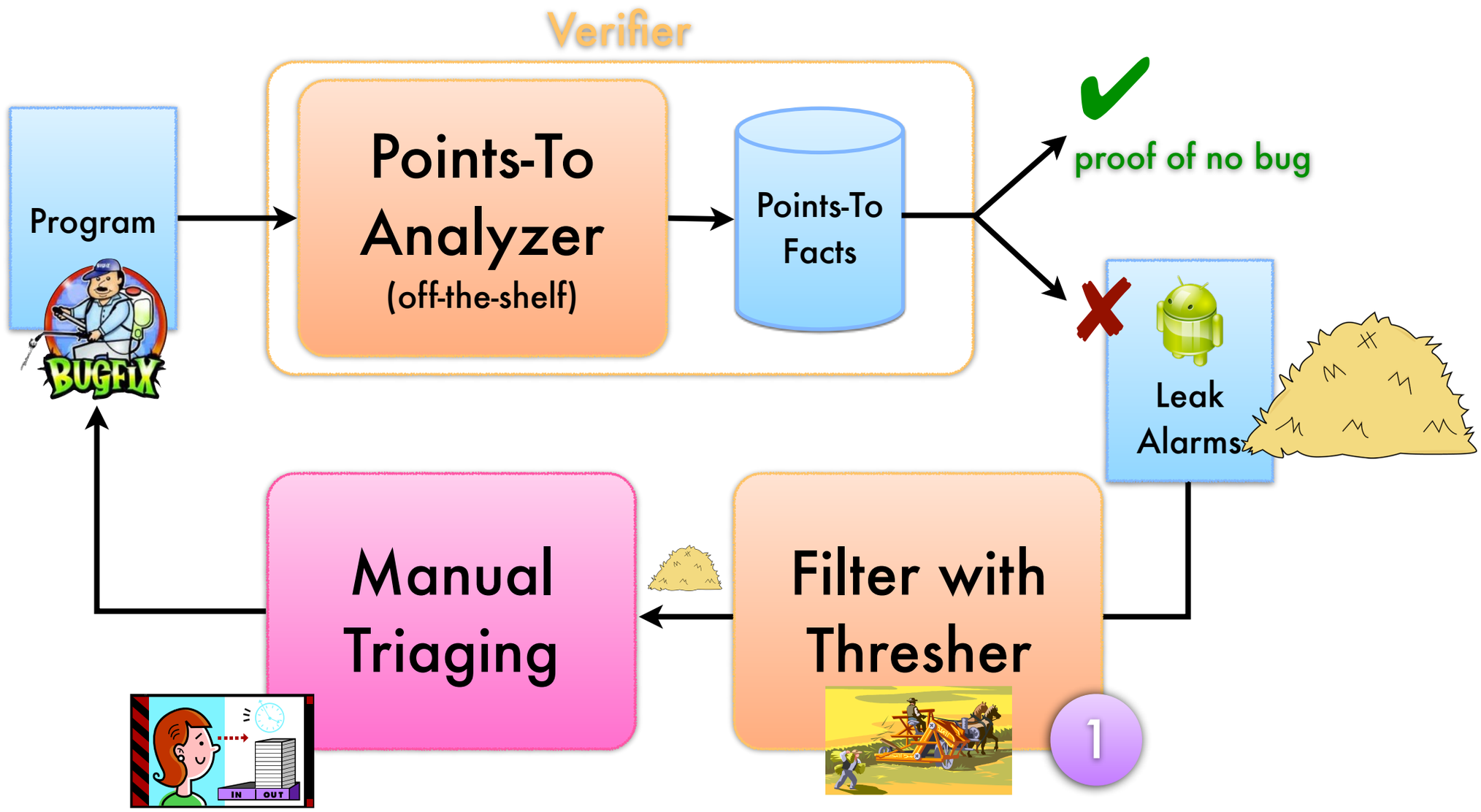

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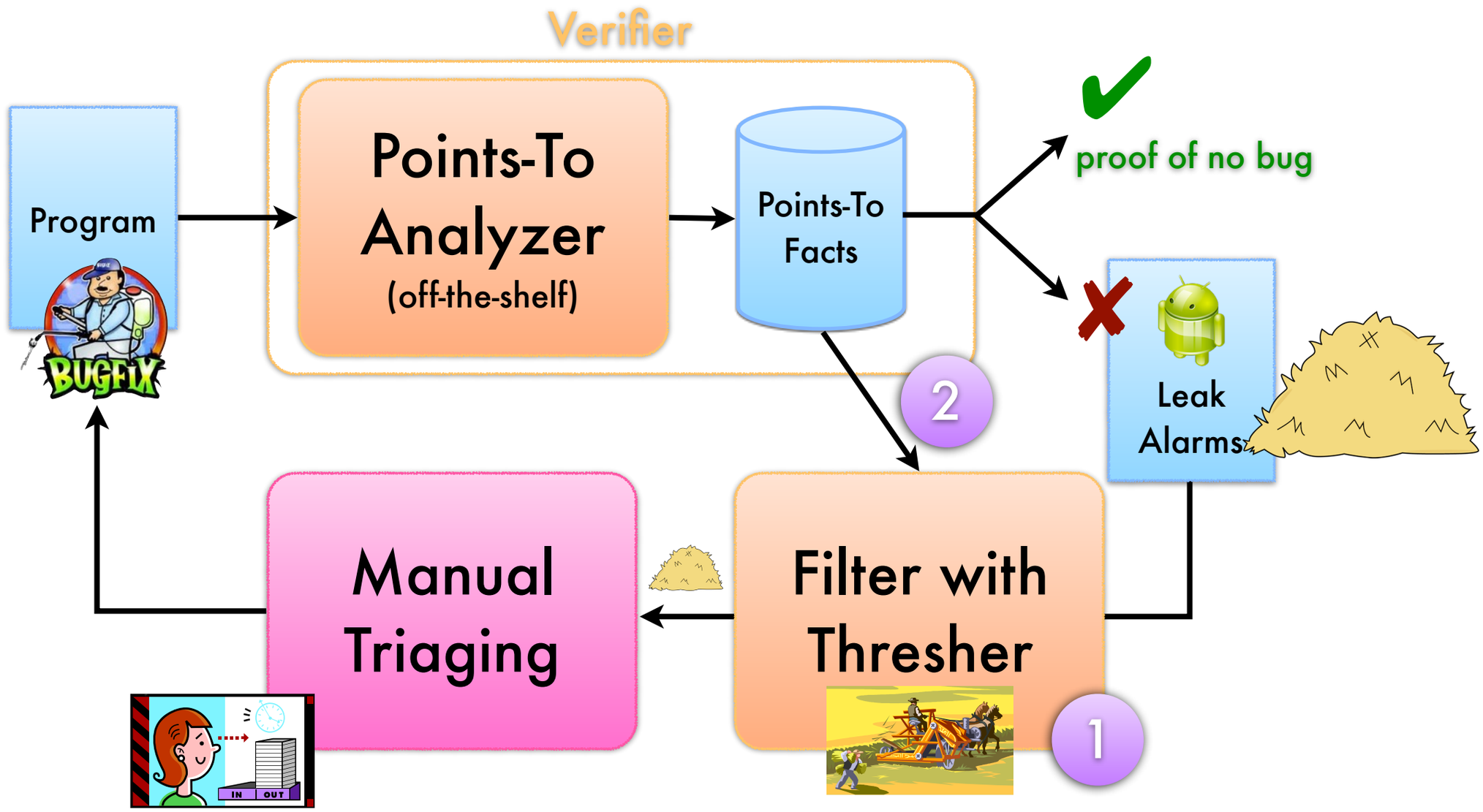

Idea 1: Refute points-to on-demand with second "uber-precise" filter analysis

Idea 2: Leverage the facts from the first analysis in the filter analysis to scale

Is Thresher effective at filtering?

Thresher analyzes Java VM bytecode

7 Android app benchmarks

2,000 to 40,000 source lines of code

+ 880,000 sources lines of Android framework code

Off-the-shelf, state-of-the-art points-to analysis from WALA

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms
PulsePoint	unknown	16
StandupTimer	2K	25
DroidLife	3K	3
SMSPopUp	7K	5
aMetro	20K	54
K9Mail	40K	208
Total	**72K**	**311**

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`staticfield-Activity` **pairs**

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Total		**311**

triage "well" at ~1–2 hours per alarm

`staticfield-Activity` pairs

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms	Thresher Refuted
PulsePoint	unknown	16	8
StandupTimer	2K	25	15
DroidLife	3K	3	0
SMSPopUp	7K	5	1
aMetro	20K	54	18
K9Mail	40K	208	130
Total	**72K**	**311**	**172**

`staticfield-Activity` pairs

Filtered

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms	Thresher Refuted	True Bugs
PulsePoint	unknown	16	8	8
StandupTimer	2K	25	15	0
DroidLife	3K	3	0	3
SMSPopUp	7K	5	1	4
aMetro	20K	54	18	36
K9Mail	40K	208	130	64
Total	**72K**	**311**	**172**	**115**

`staticfield-Activity` pairs

Filtered

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms	Thresher Refuted	True Bugs
PulsePoint	unknown	16	8	8
StandupTimer	2K	25	15	0
DroidLife	3K	3	0	3
SMSPopUp	7K	5	1	4
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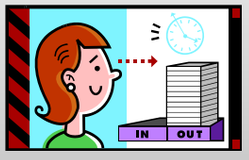
Total	**72K**	**311**	**172**	**115**

`staticfield-Activity` **pairs**

Filtered

Manual



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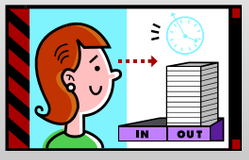
PulsePoint	unknown	16	8	8
StandupTimer	2K	25	15	0
DroidLife	3K	3	0	3
SMSPopUp	7K	5	1	4
aMetro	20K			36
K9Mail	40K			64
Total	**72K**			**115**

triage "well" at 10–15 minutes per

`staticfield-Activity` pairs

Filtered

Manual



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aMetro	20K	54	18	36
K9Mail	40K	208	130	64
Total	**72K**	**311**	**172**	**115**

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms	Thresher Refuted	True Bugs	Thresher Time (s)
PulsePoint	unknown	16	8	8	95
StandupTimer	2K	25	15	0	1068
DroidLife	3K	3	0	3	1
SMSPopUp	7K	5	1	4	46
aMetro	20K	54	18	36	18
K9Mail	40K	208	130	64	374
Total	**72K**	**311**	**172**	**115**	**1602**

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms	Thresher Refuted	True Bugs	Thresher Time (s)
PulsePoint	unknown	16	8	8	95
StandupTimer	2K	25	15	0	1068
DroidLife	3K	3	0	3	1
SMSPopUp	7K	5	1	4	46
aMetro	20K	54	18	36	18
K9Mail	40K	208	130	64	374
Total	**72K**	**311**	**172**	**115**	**1602**

< ~coffee to lunch break

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False alarms down to 17% from 63% (points-to analysis only)

Thresher filters 88% of false alarms from points-to analysis

Guesstimate

Triage "well" without versus with: ~450 hours versus ~30 hours

Triage "ok" without: ~30 hours

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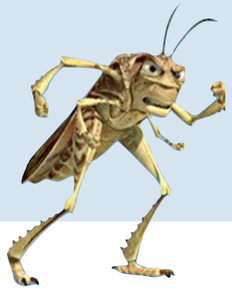
Android OS

... in the process of finding leaks in apps

Find the Android's HashMap bug ...



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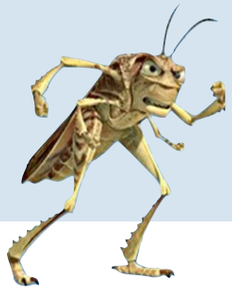

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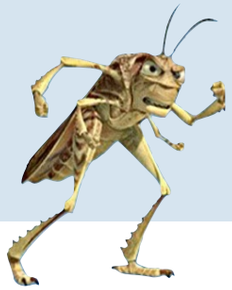

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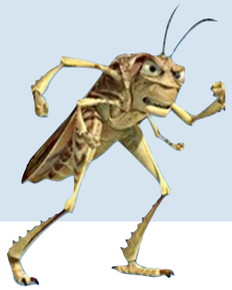

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return "evil" content

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Find the Android's HashMap bug ...

What if you store **passwords** in a `HashMap`?

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  s
  H

  v

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We reported this, Google fixed it

https://android-review.googlesource.com/#/c/52183/

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  H

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Contribution: Addressed the false alarm problem with

a "smart and precise filter"

a goal-directed refutation analysis

Another more challenging reason for ...

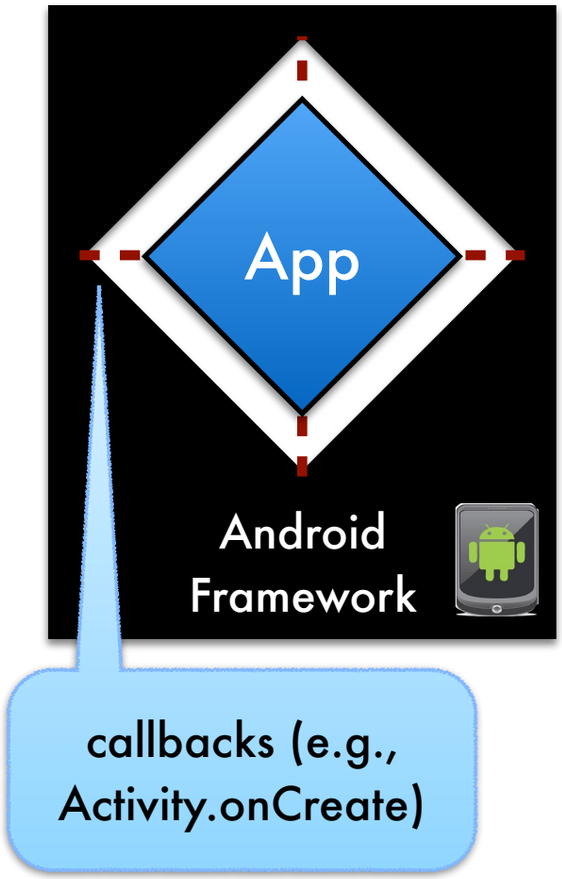
Another more challenging reason for ...

Roughly, 3% of all commits fix NullPointerExceptions

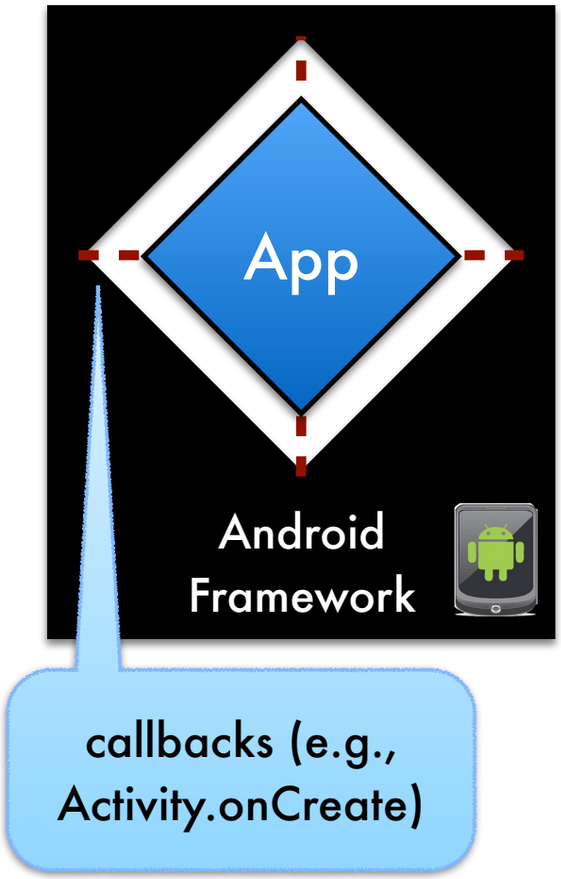
Callback-oriented programming ...

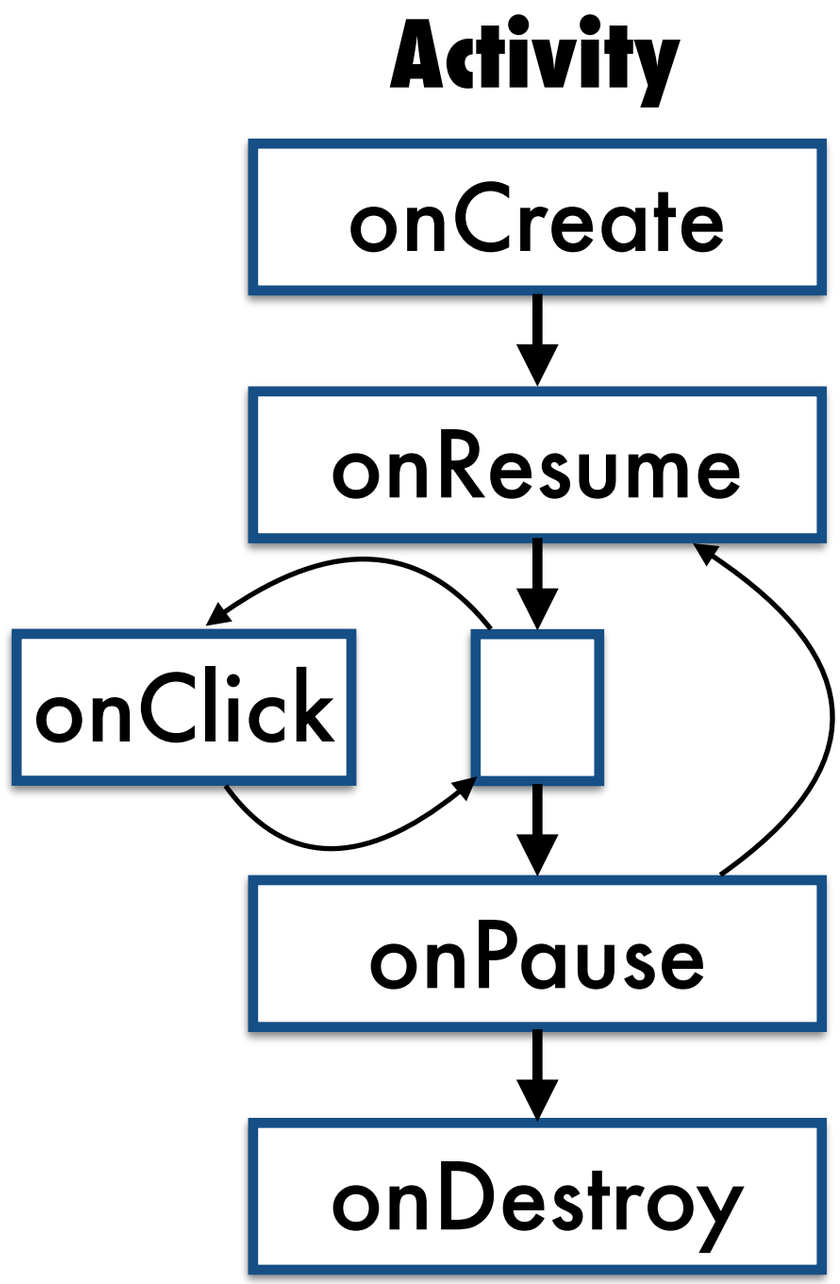
Callback-oriented programming ...

Callback-oriented programming …



Callback-oriented programming …





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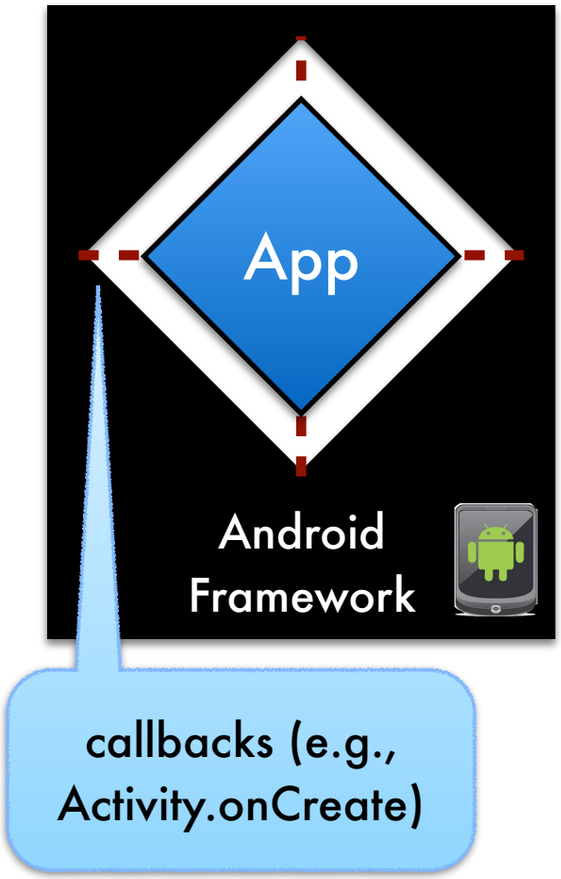
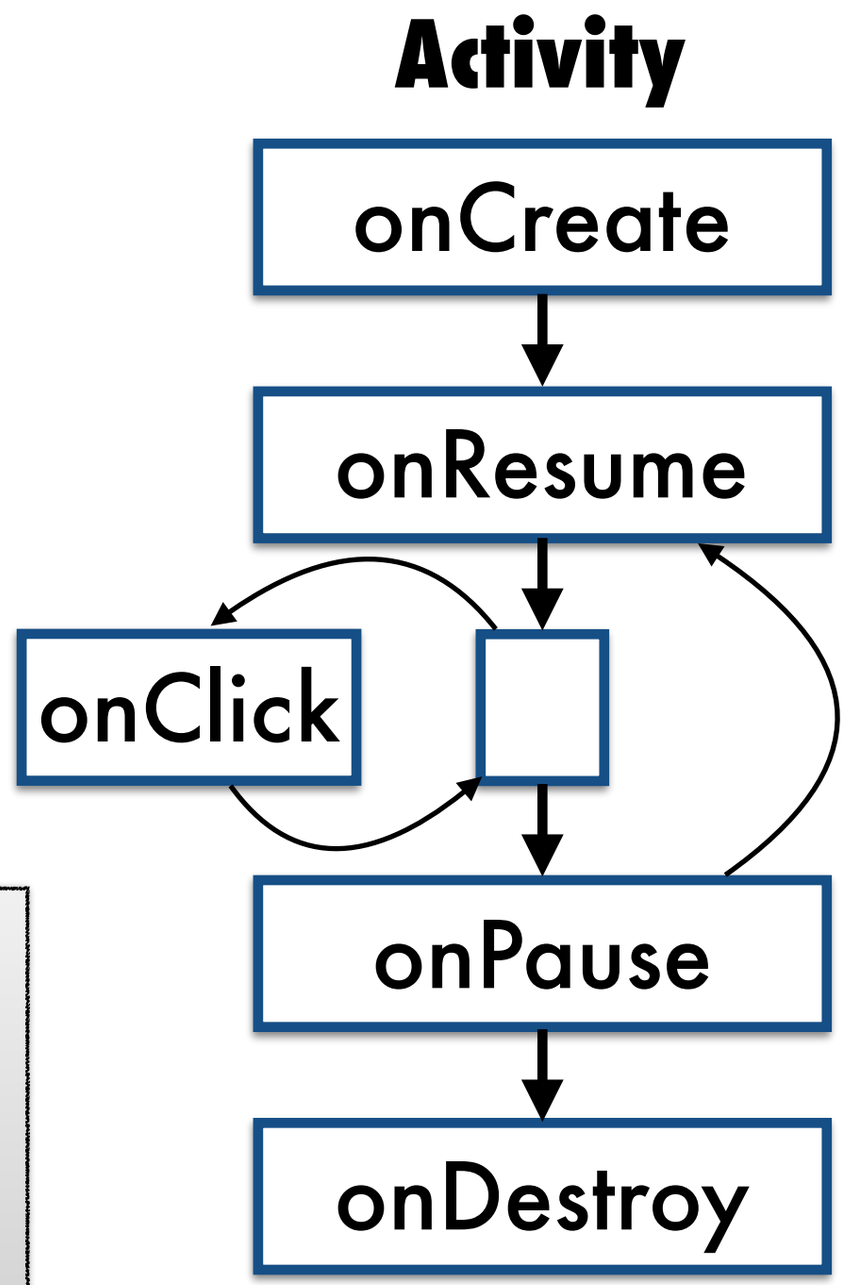
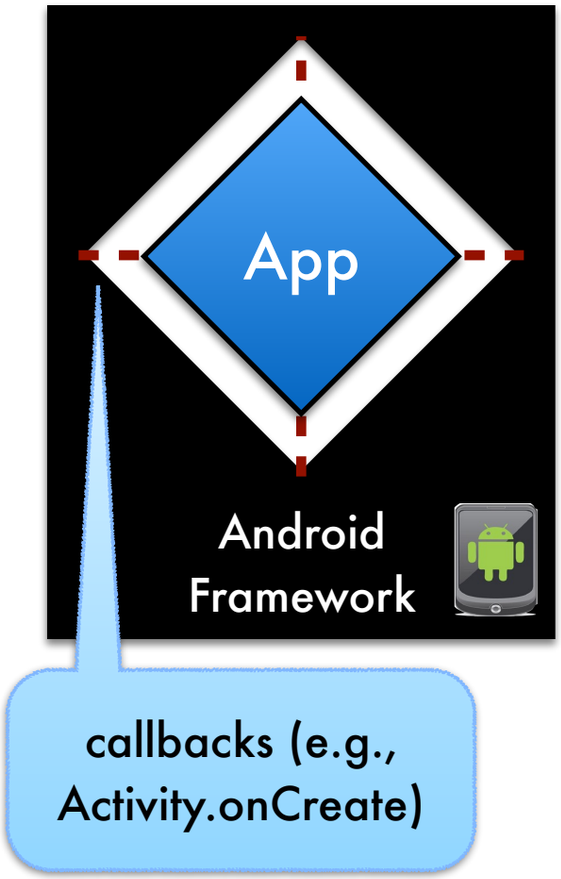
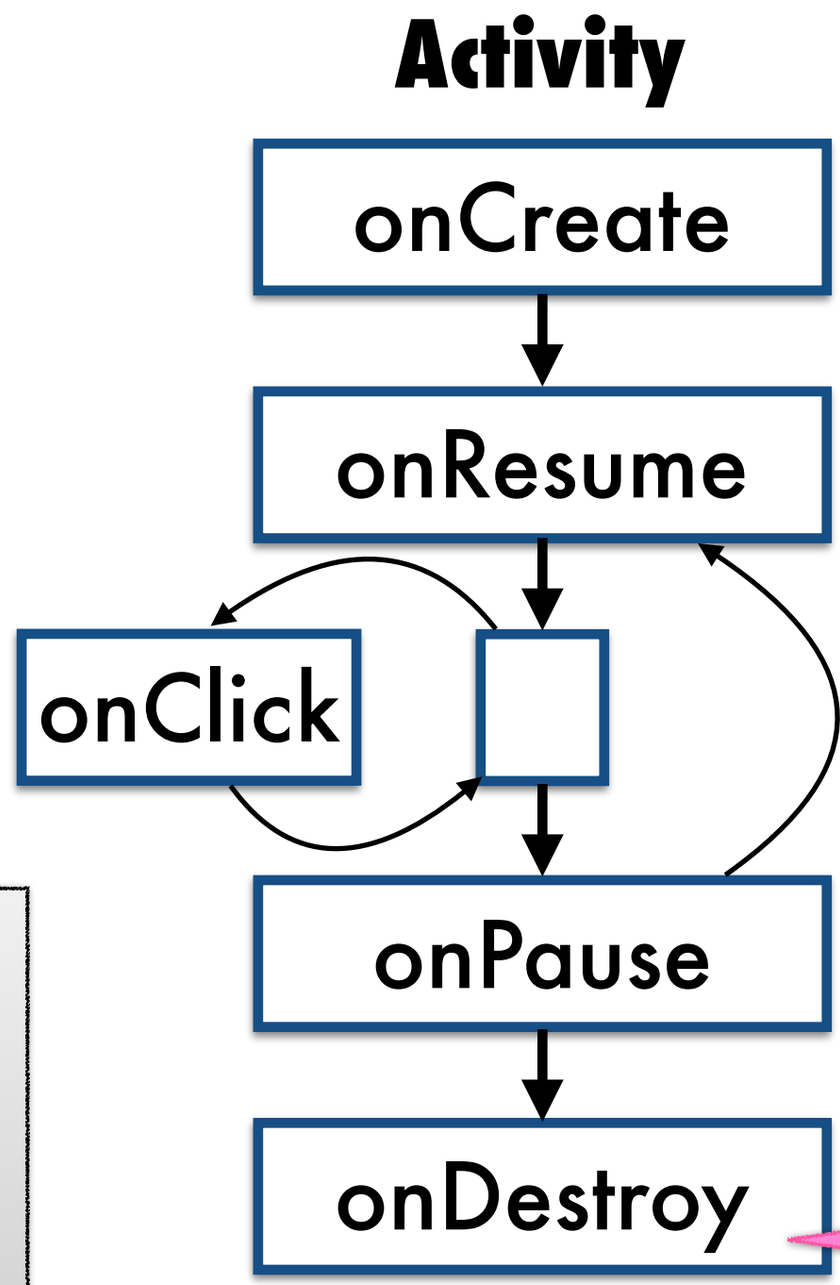




Android components have an ordered, event-driven lifecycle

Callback-oriented programming …



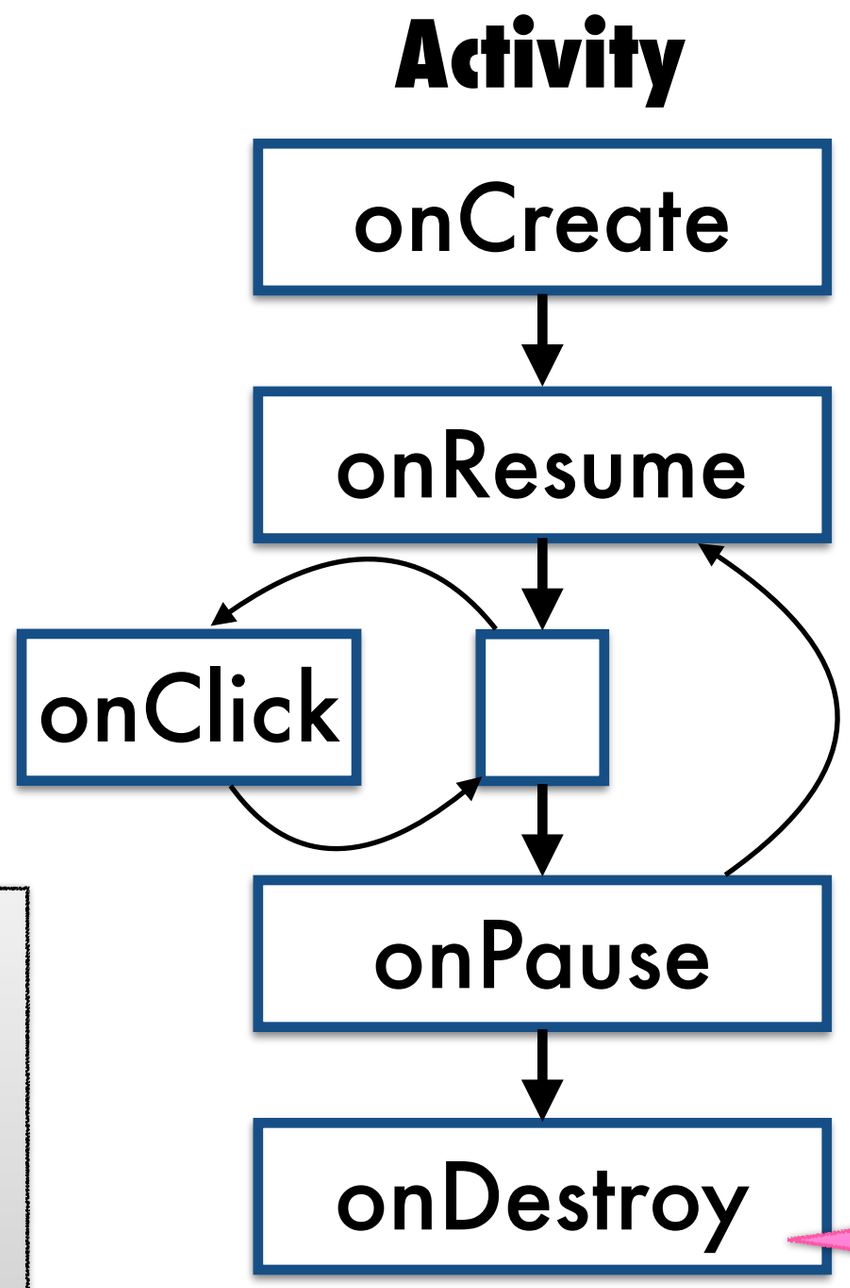



```
mHostDb = null;
mService = null;
```

Android components have an ordered, event-driven lifecycle

Callback-oriented programming …

callbacks (e.g., Activity.onCreate)



But, lifecycles of different components and other callbacks can interleave …

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Android components have an ordered, event-driven lifecycle

Callback-oriented programming …

Challenge: Verifying safety (of dereferences) depends on callback interleaving

safe?

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mHostDb.s();
```

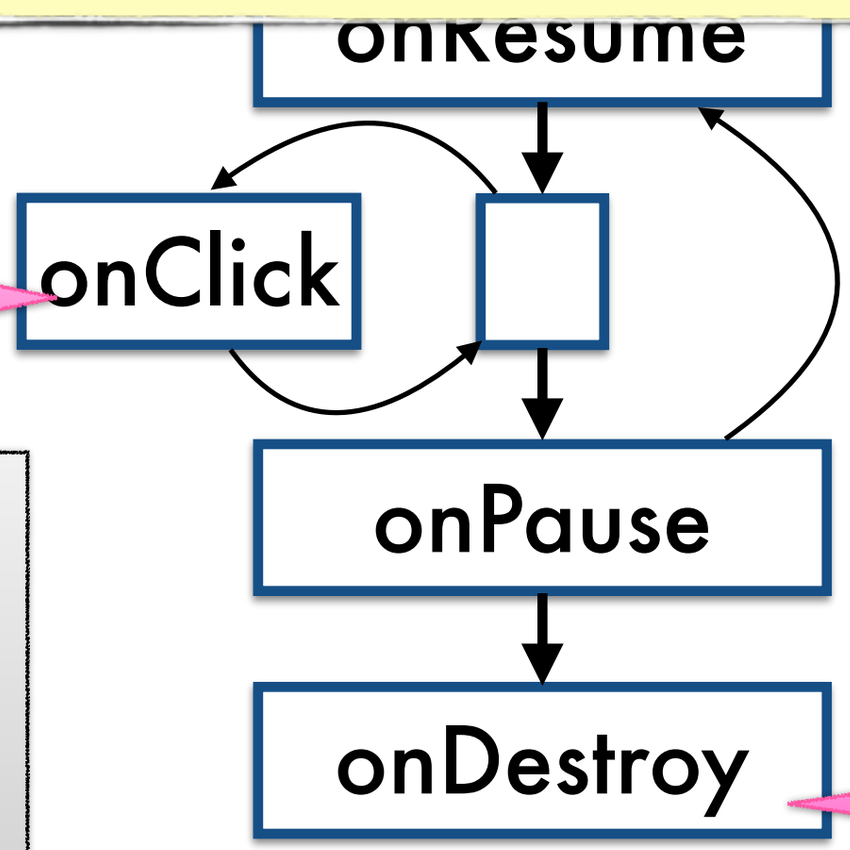


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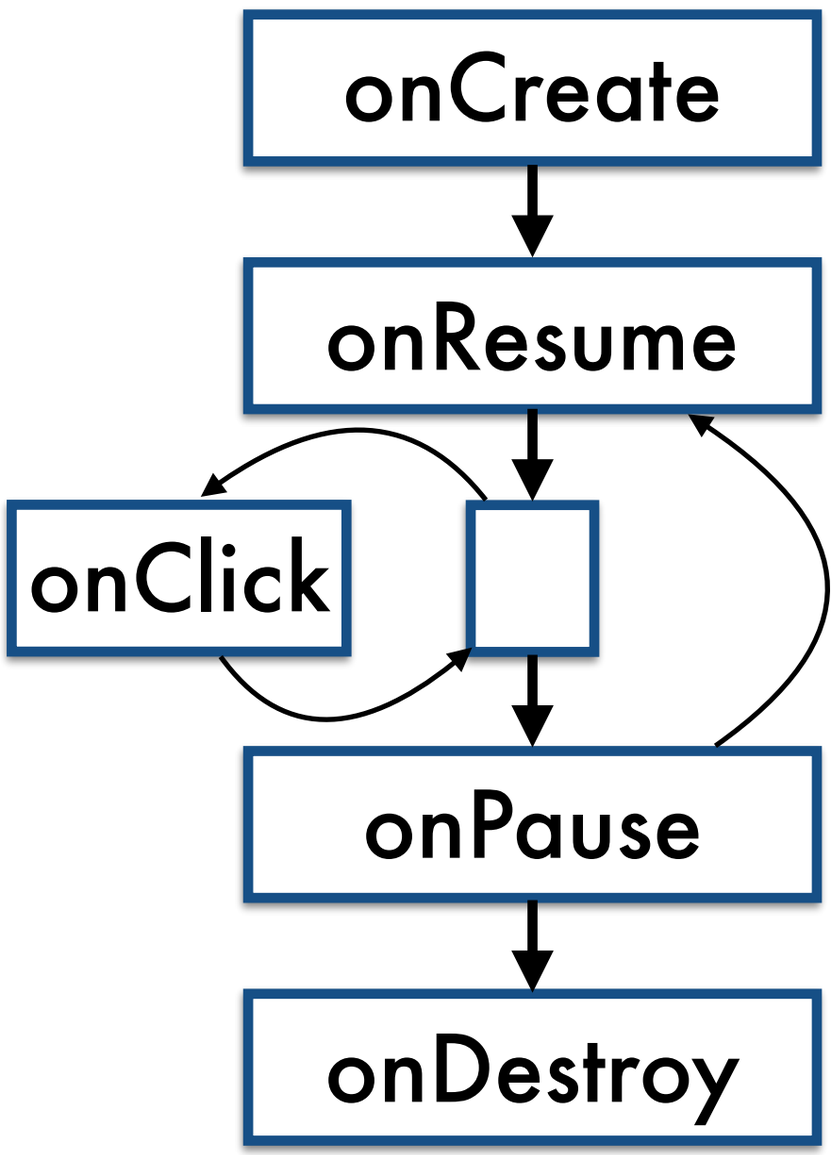
But, lifecycles of different components and other callbacks can interleave …

Android components have an ordered, event-driven lifecycle

… over a shared, global heap



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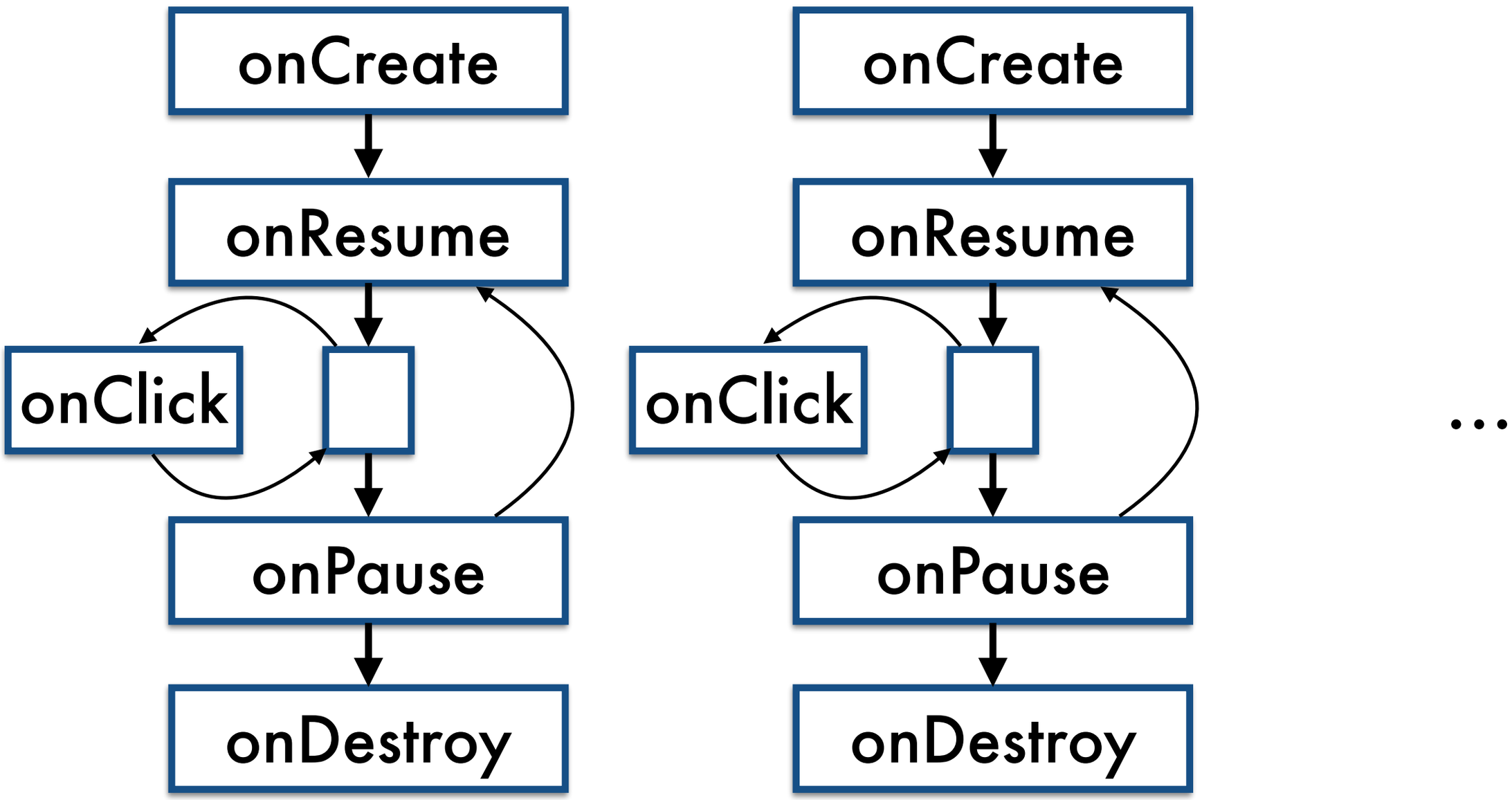

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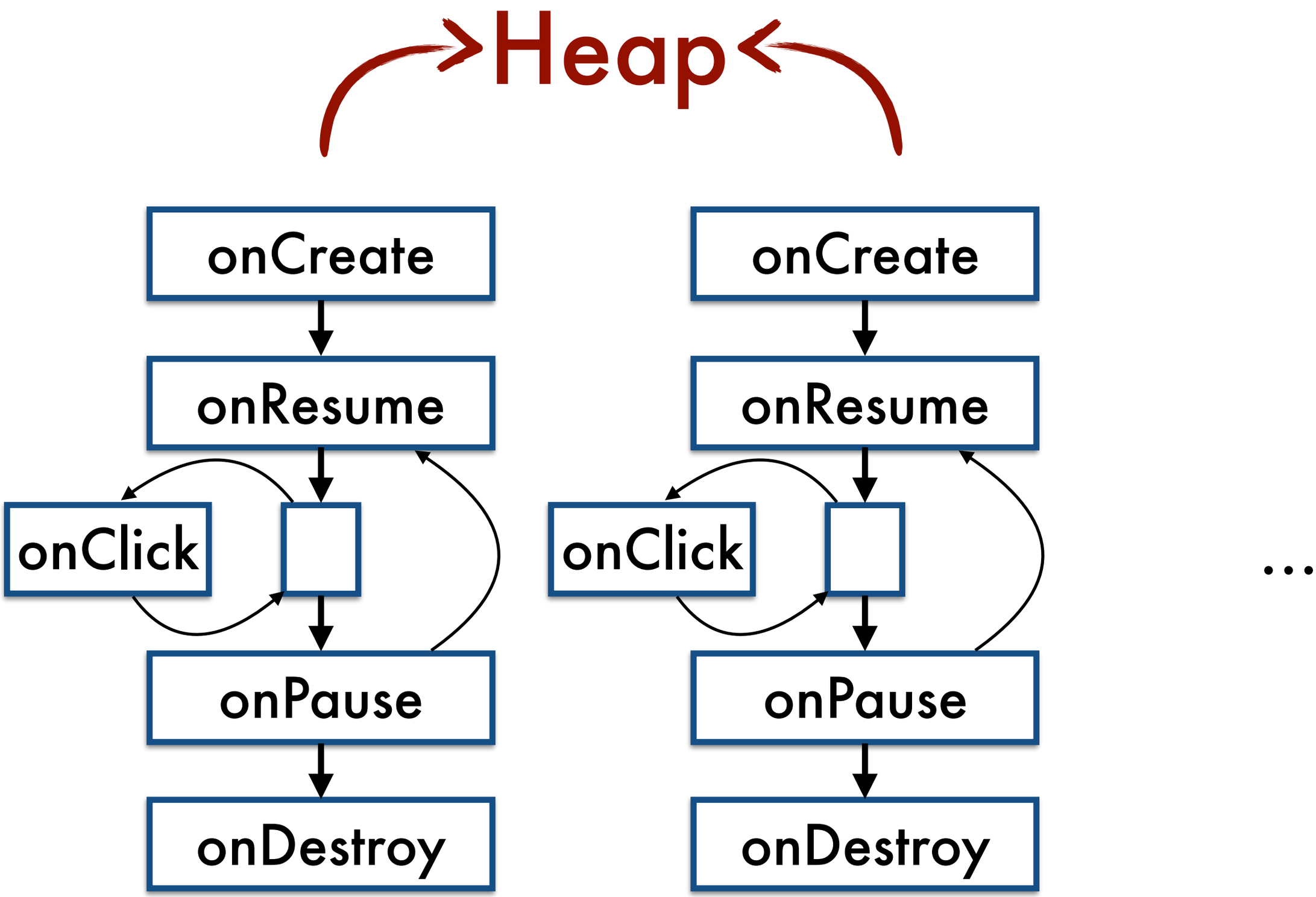

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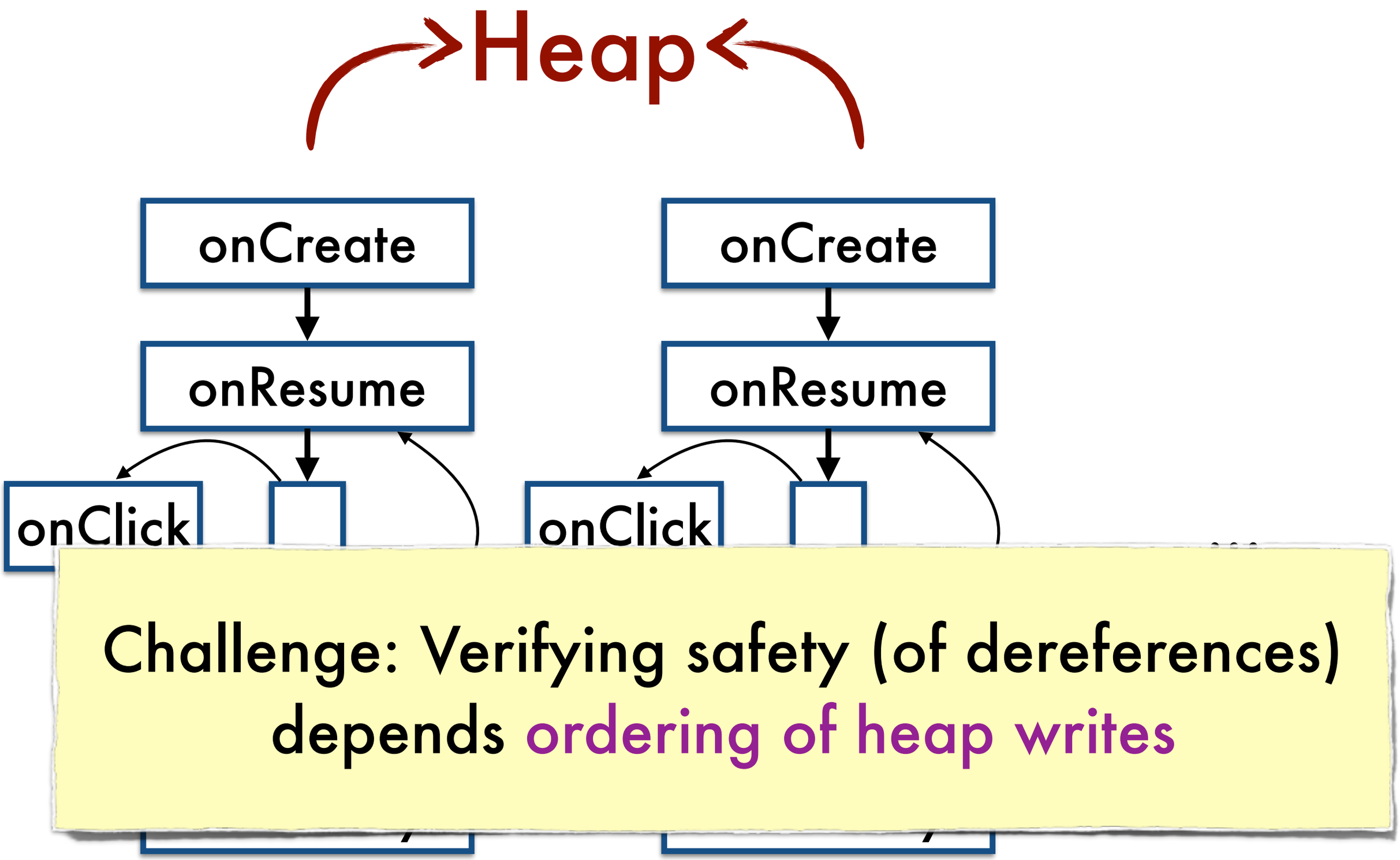
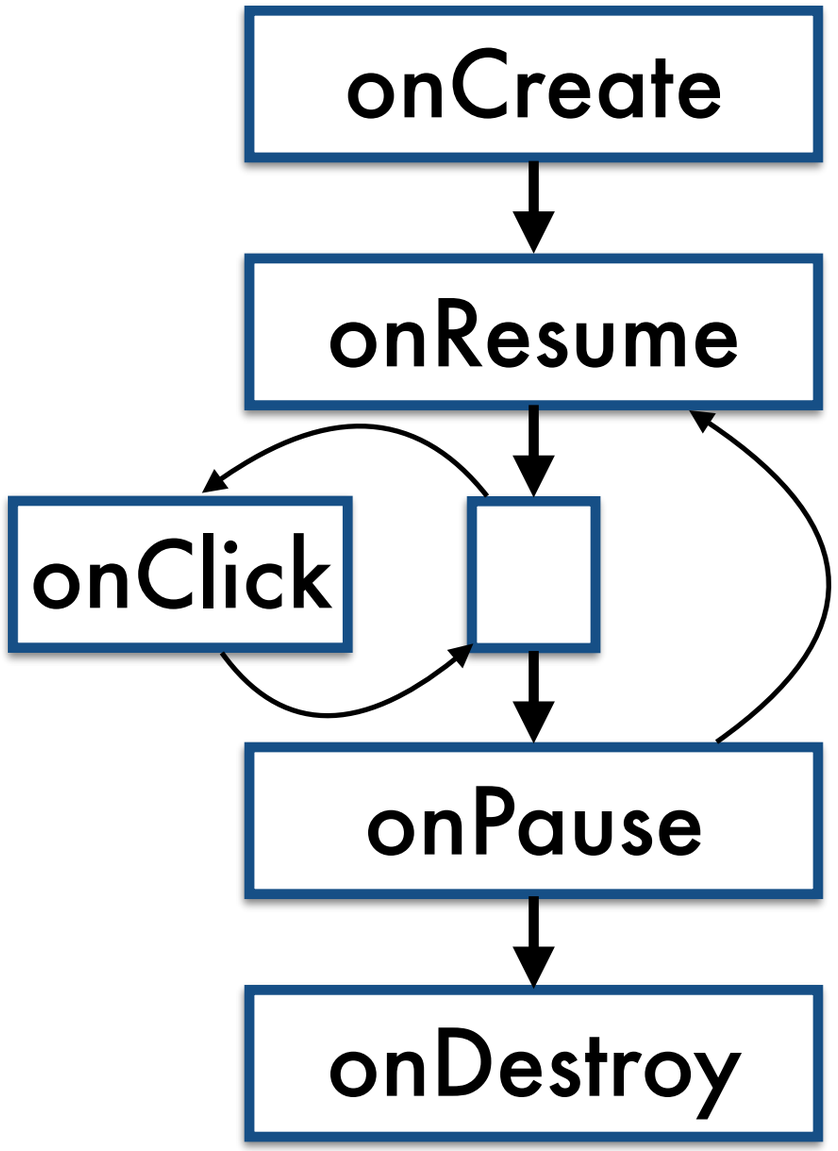


Challenge: Verifying safety (of dereferences) depends ordering of heap writes

But verifying safety shouldn't be so hard ...



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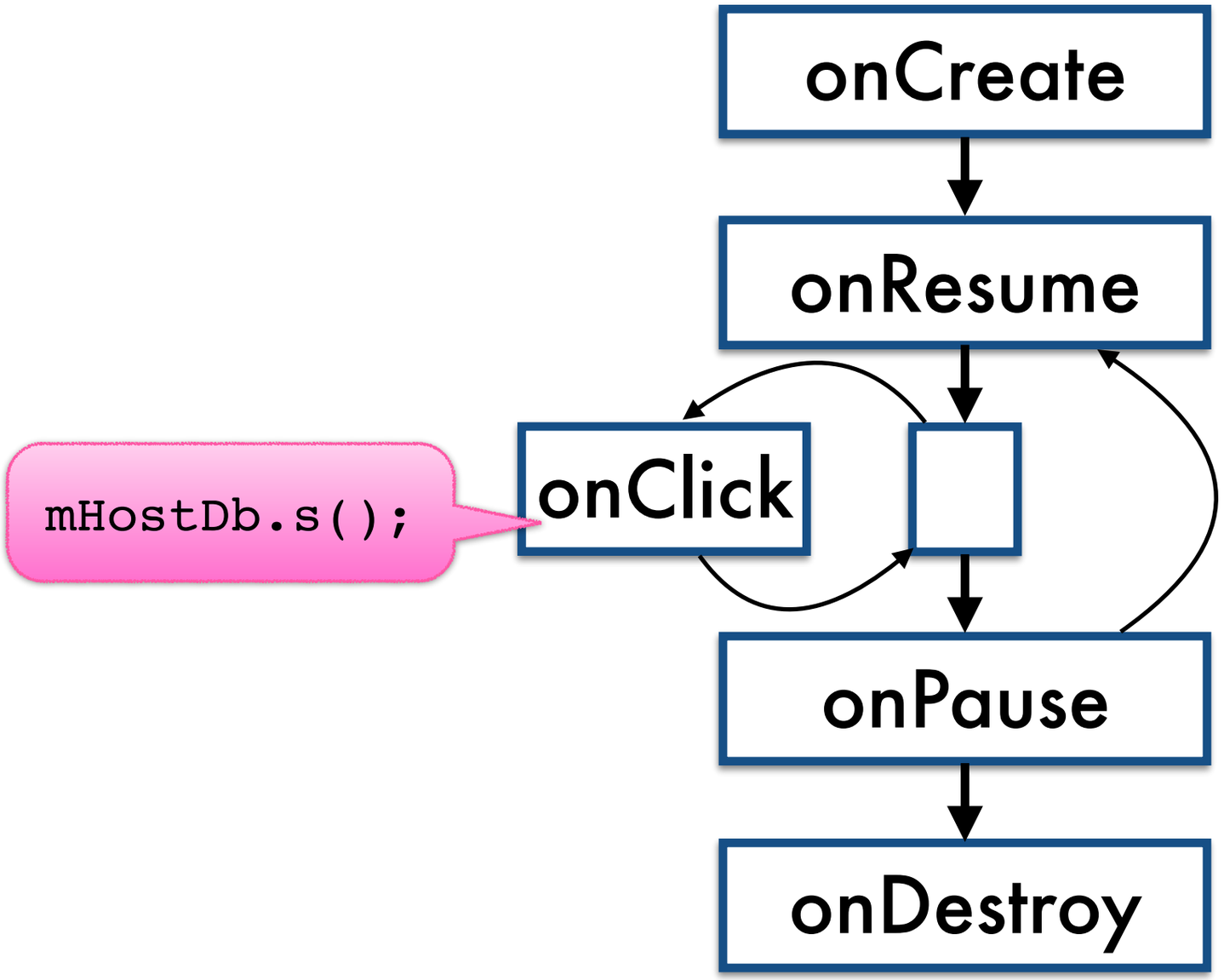

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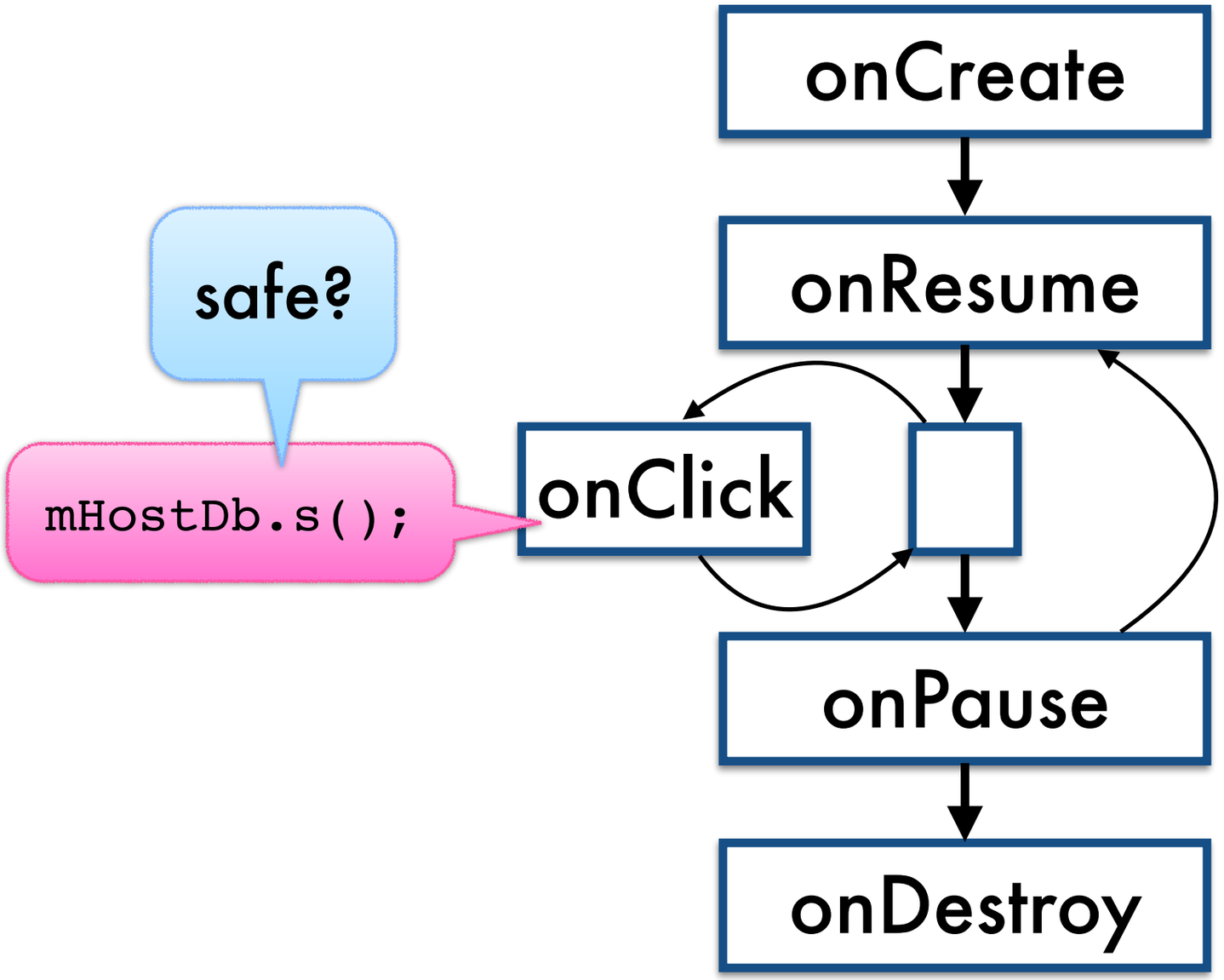

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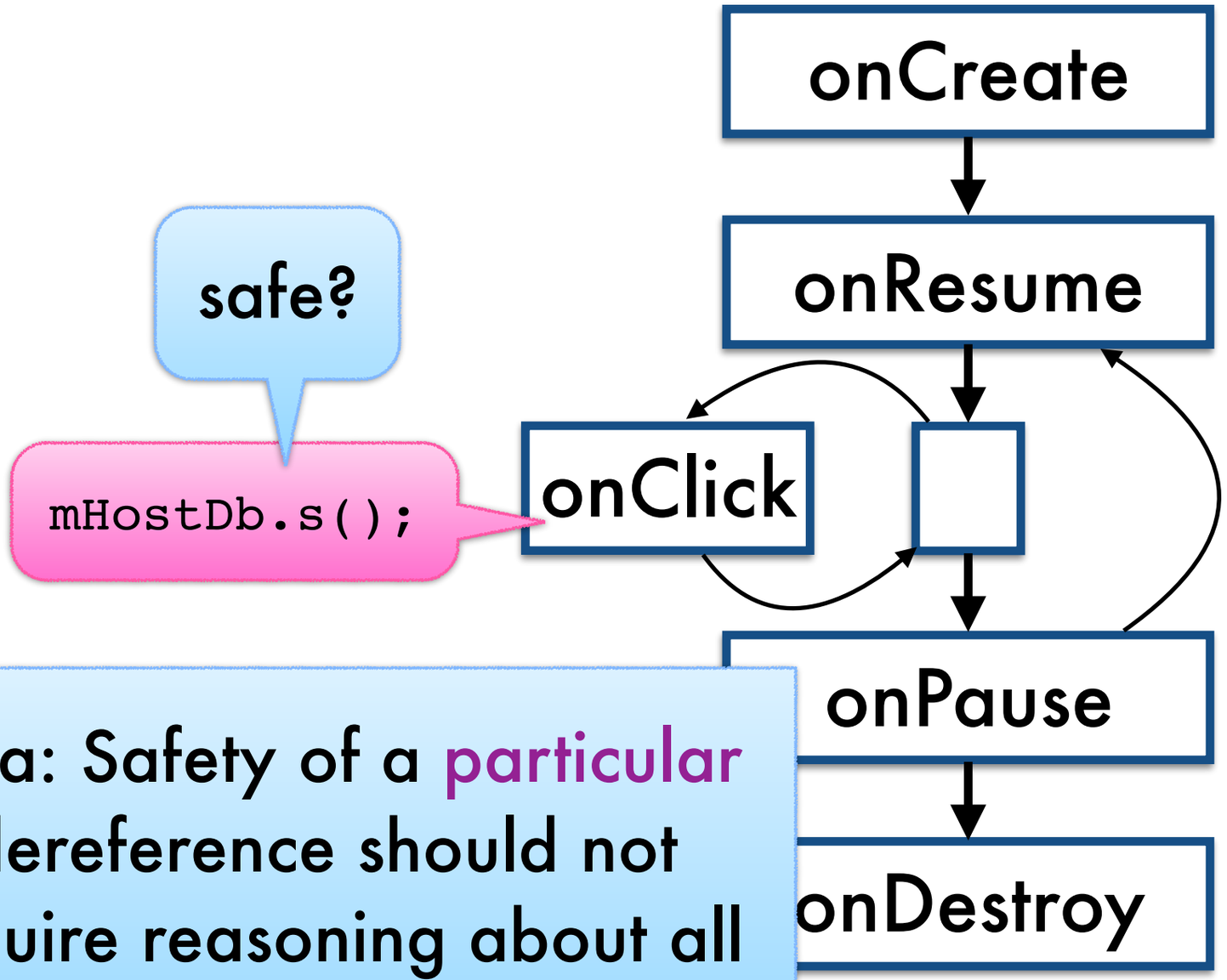
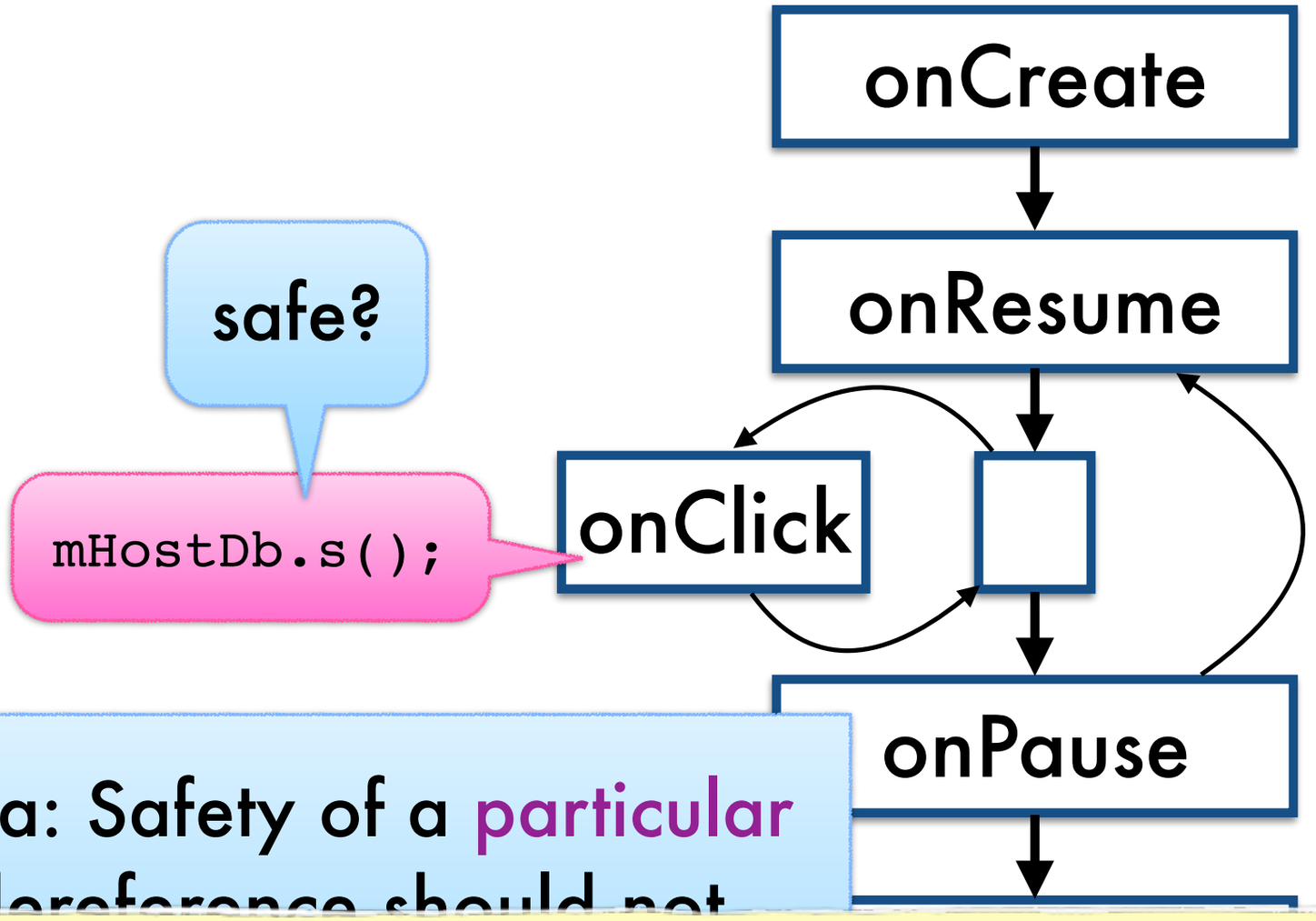


Idea: Safety of a particular dereference should not require reasoning about all callback interleavings

But verifying safety shouldn't be so hard ...



Idea: Safety of a particular dereference should not

A "smart" goal-directed analysis could consider relevant callback orderings without considering all of them—jumping analysis

Evaluation: Proving dereferences safe

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10 open source Android apps

3,000 to 55,000 lines of code
10 to 100 components
120 to 1,320 callbacks

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Event product graph would have 10^{10} to 10^{111} nodes (with one instance per class)

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Compared 3 analyses

Nit: type inference
Thresher: no jumping
Hopper: jumping

Is Hopper effective at proving safety?

	KLOC	Deref	Nit	Thr	Hop (Impr %)
drupaleditor	3	928	679	179	72 (60)
npr	5	829	617	181	51 (72)
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lastfm	13	4840	3528	954	477 (50)
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Total	**266**	**62562**	**41071**	**9968**	**5412 (54)**

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Many derefs

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Thr and Hop: 10 second budget per deref

Is Hopper effective at proving safety?

		unproven derefs			
	KLOC	Deref	Nit	Thr	Hop (Impr %)
drupaleditor	3	928	679	179	72 (60)
npr	5	829	617	181	51 (72)
duckduckgo	11	1969	1341	518	143 (72)
lastfm	13	4840	3528	954	477 (50)
github	19	3603	2520	601	290 (52)
seriesguide	32	8184	5438	986	625 (37)
connectbot	33	2190	1562	316	74 (77)
textsecure	38	5921	3643	698	330 (53)
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Hopper has 54% fewer than Thresher

Is Hopper effective at proving safety?

		unproven derefs				
	KLOC	Deref	Nit	Thr	Hop (Impr %)	% Proven
drupaleditor	3	928	679	179	72 (60)	92
npr	5	829	617	181	51 (72)	94
duckduckgo	11	1969	1341	518	143 (72)	93
lastfm	13	4840	3528	954	477 (50)	90
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seriesguide	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	92
connectbot	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	97
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Compare with state-of-the art NPE checking work that reports 84-91% proven on normal Java programs!

Remaining manual triage ...

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Triaged 200 alarms (from Hopper), 189 false

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Found 11 bugs in 4 apps
(lastfm, seriesguide, connectbot, wordpress)

5 bugs due to bad ordering assumptions

10/11 patches accepted

Remaining manual triage ...

Tria se

Fixing possible NPE in OverviewActivity.launchSearch #449

Merged Uw

Fixing possible NPEs when CheckInDialogFragment.newInstance returns null #450

Merged

Fix possible NPE in HostListActivity.onCreateContextMenu #60

Merged kruton merged 1 commit into connectbot:master from sblackshear:service_npe_fix on Mar 28

Re e

container

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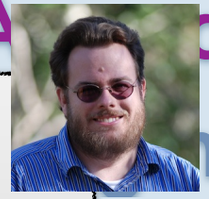
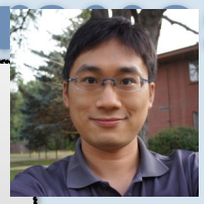
Research A da: The cooperative approach addr s mitigation proce



Fissile Types: Checking Almost Everywhere Invariants
[Coughlin+ POPL'14]



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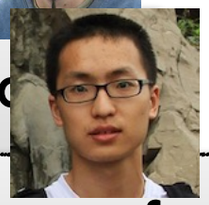

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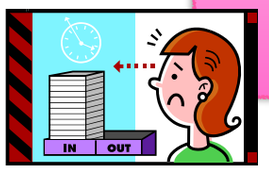
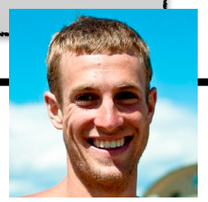
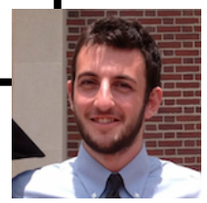
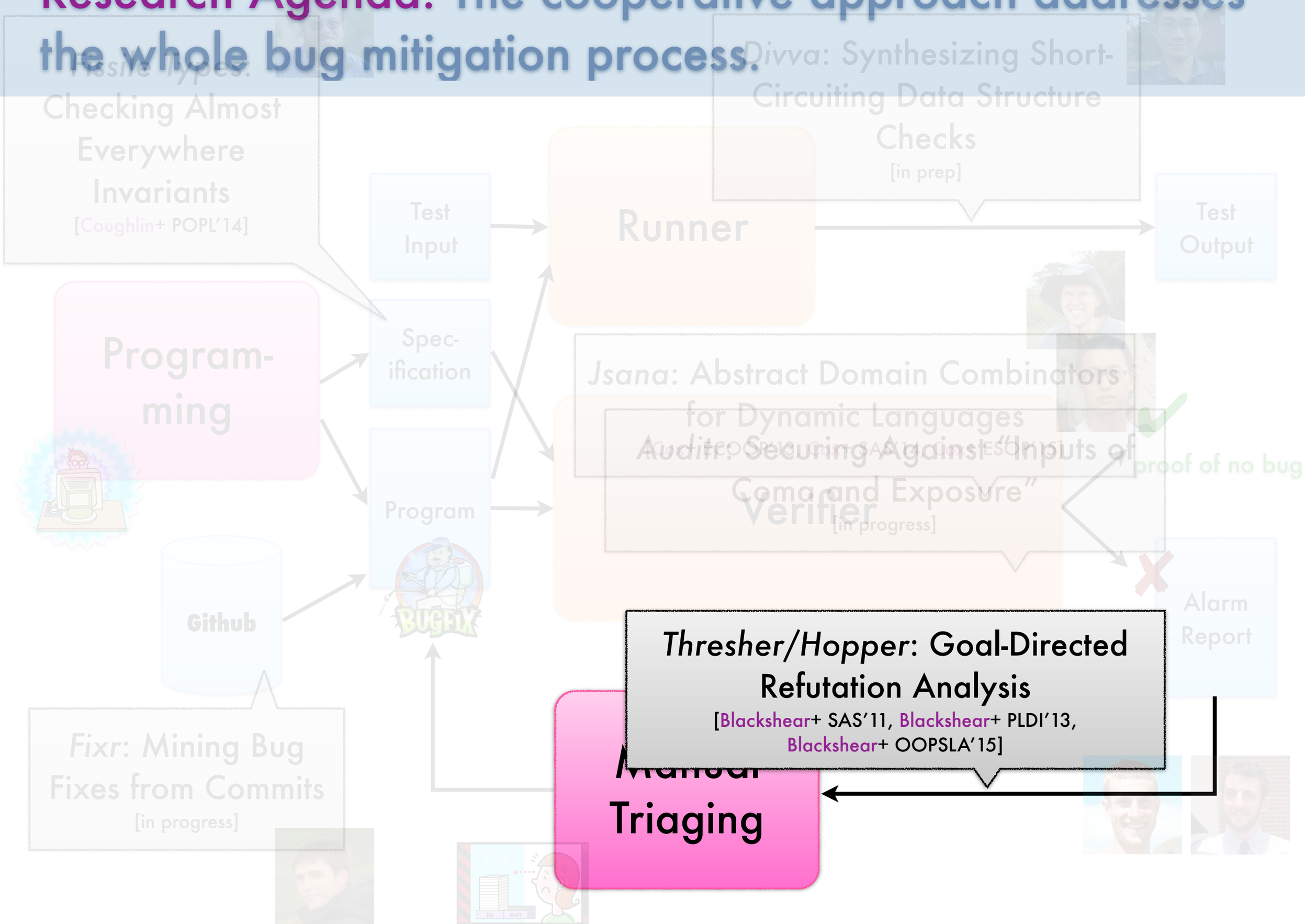






Research Agenda: The cooperative approach addresses the whole bug mitigation process.



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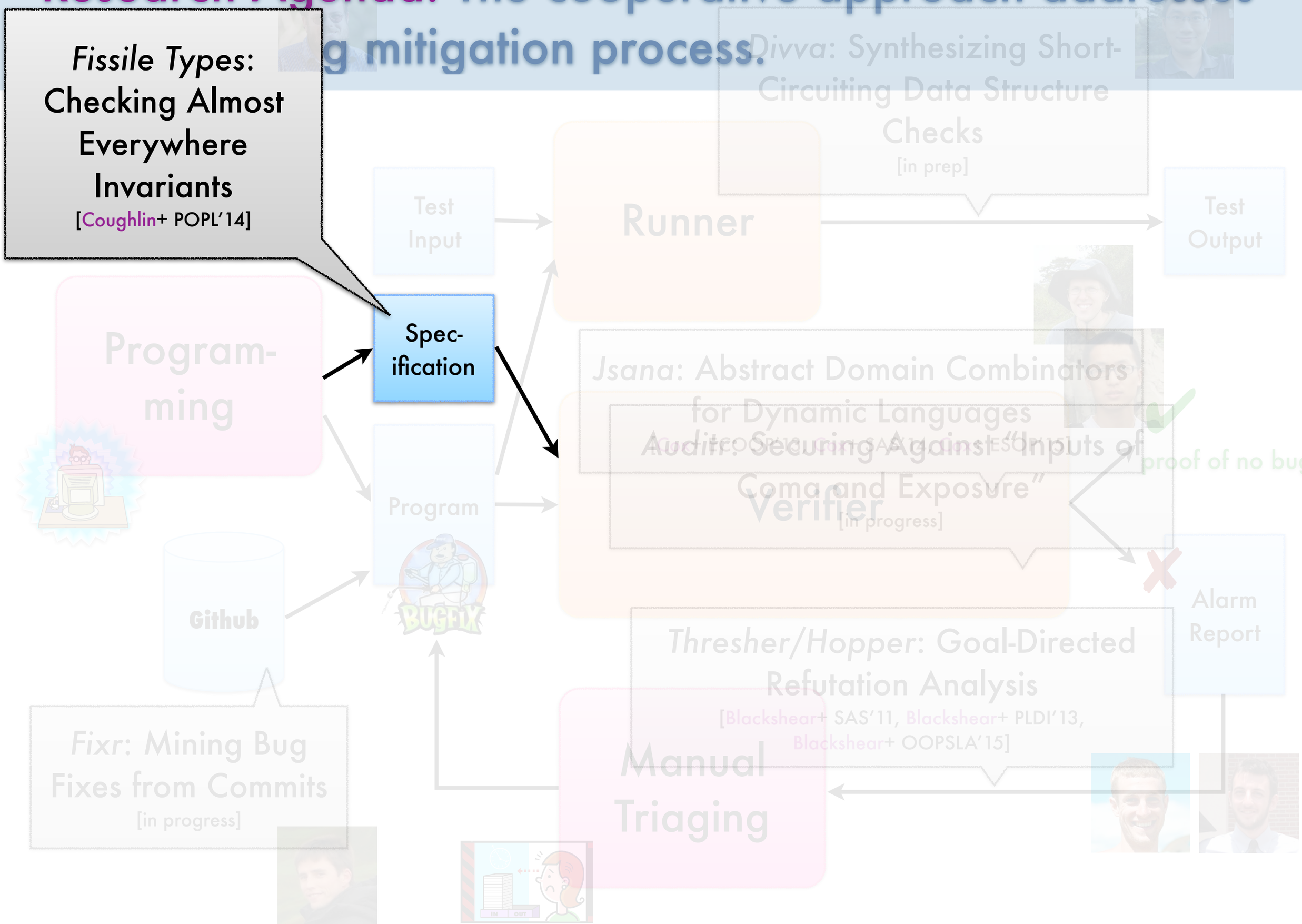

Checking Reflection with Almost Everywhere Invariants

Method Reflection and the Great Divide

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```
object[string]()
```

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reflective method call: dispatch based on run-time value (in `string`)

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Type system designers worry.

What gets called? What if `object` has no method named by `string`?

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"web 2.0" developers

"Web 2.0" developers think it's cool.

I can flexible and compact code, so I will take it over static safety.

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`object[string]()`

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Wh
obj
by

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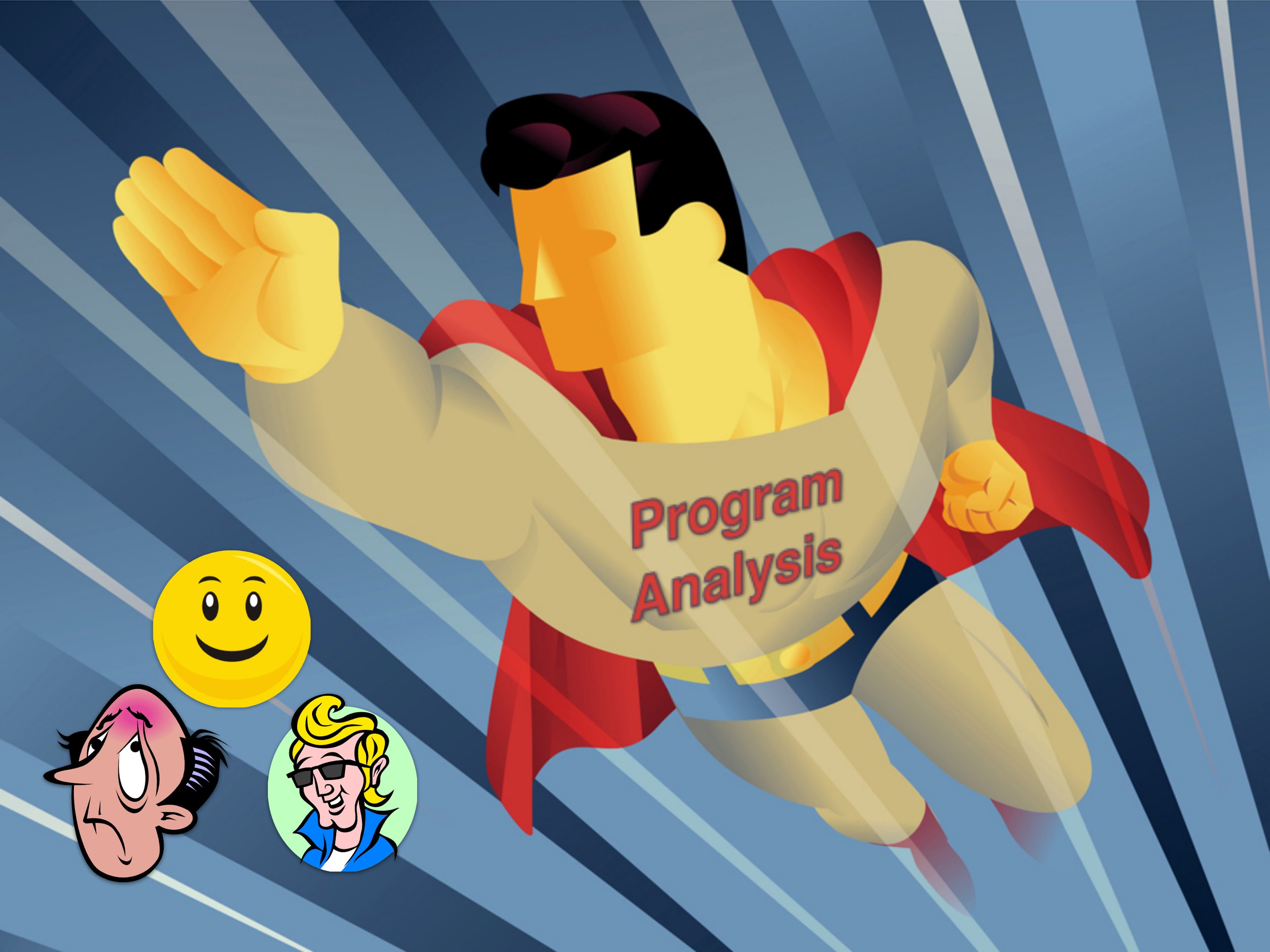
static safety.

"MethodNotFound" checked at run time


Program
Analysis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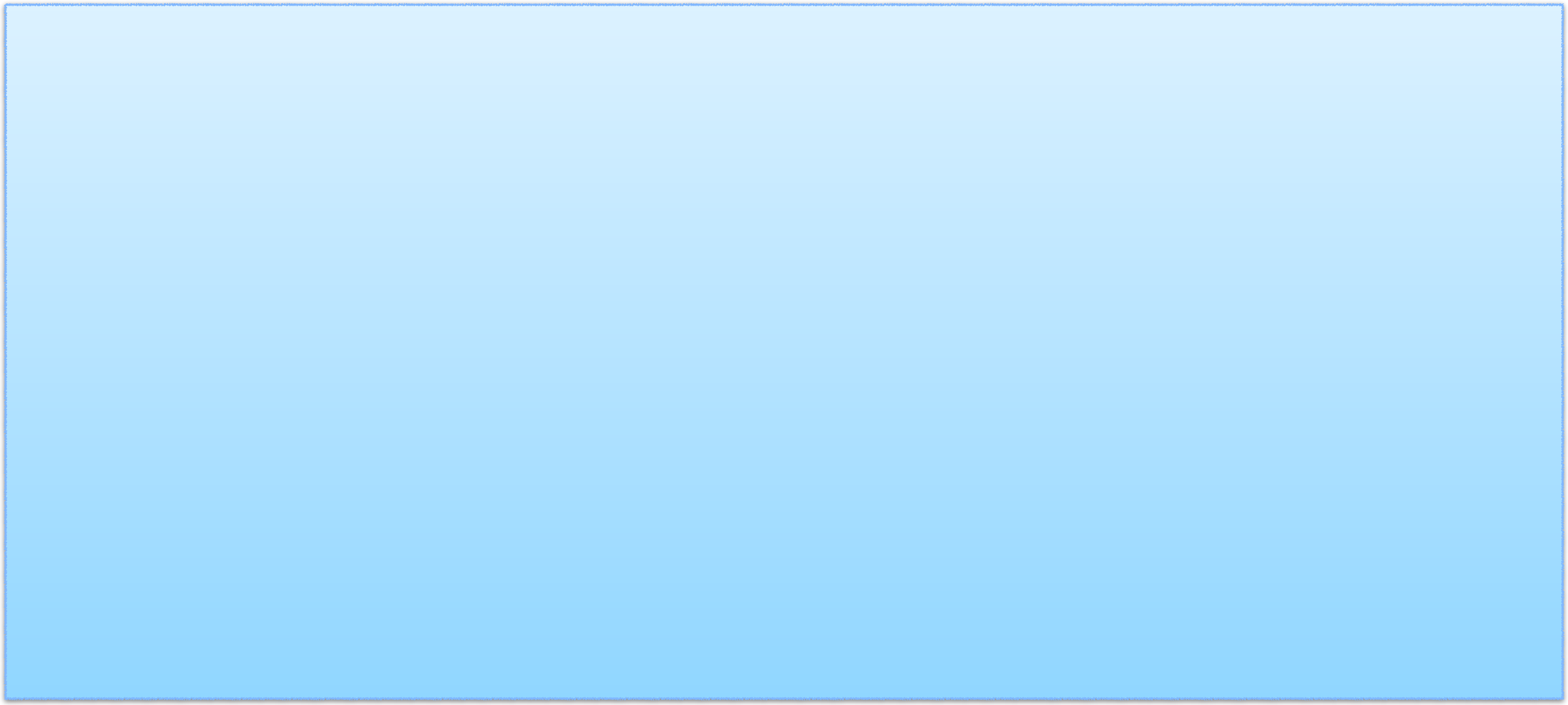

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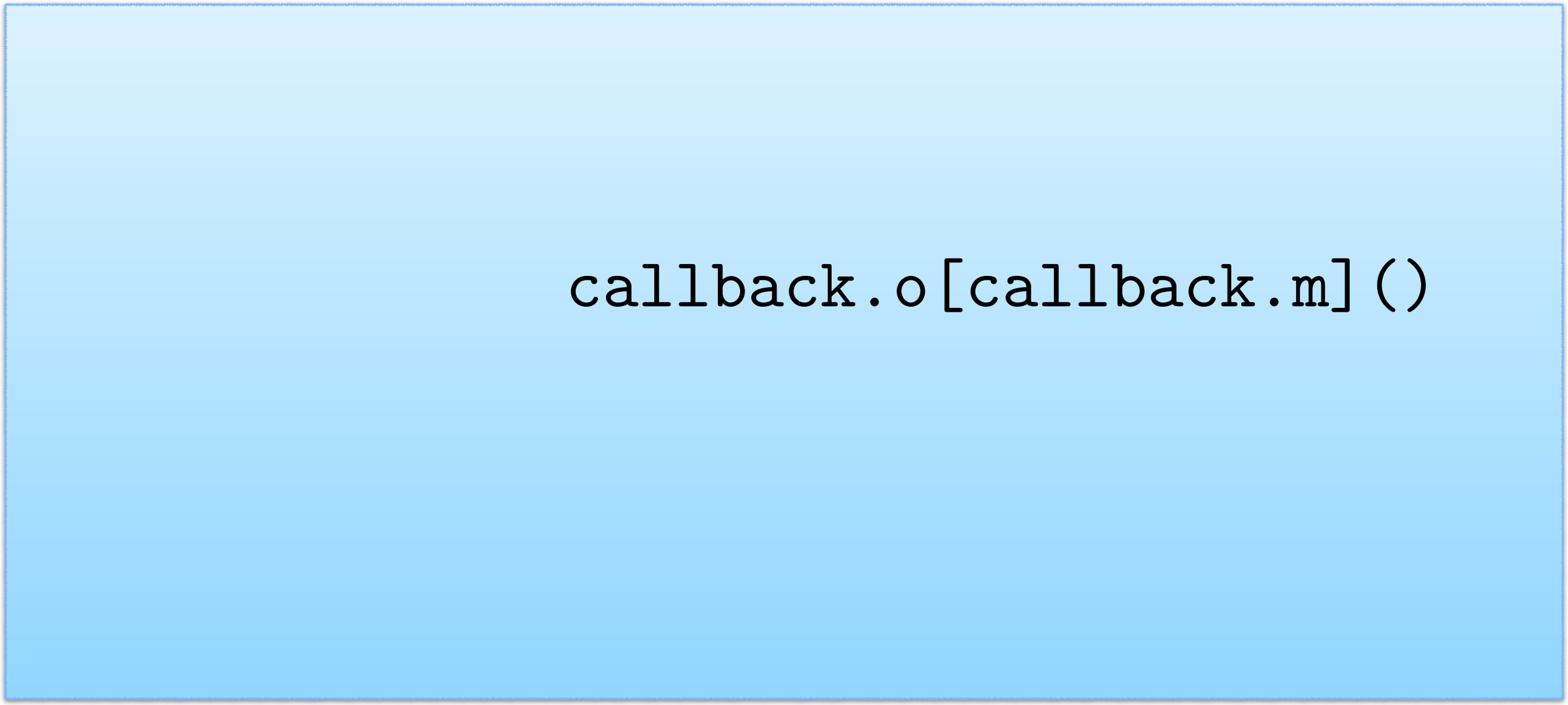

Program

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safe assuming a relationship invariant between `.o` and `.m`

```
callback.o[callback.m]()
```

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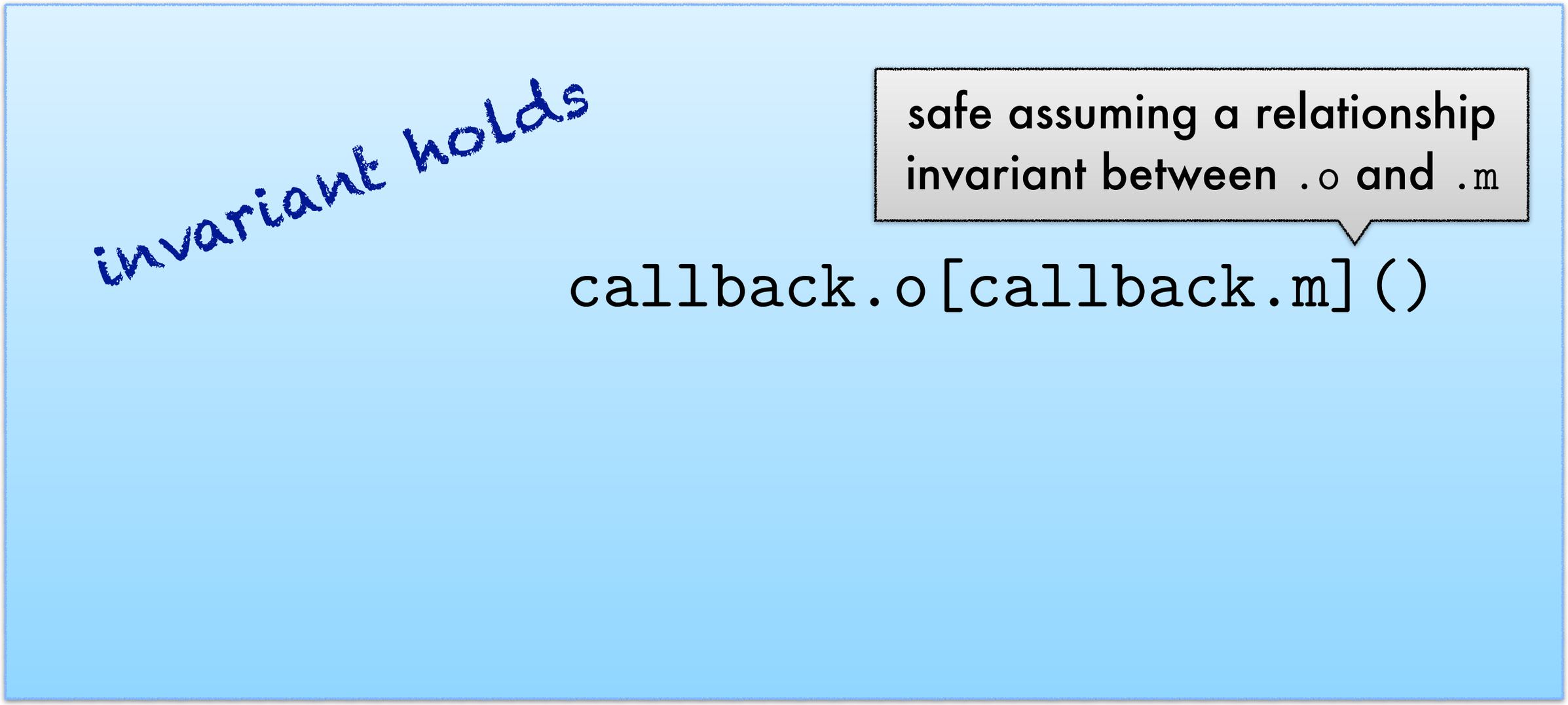

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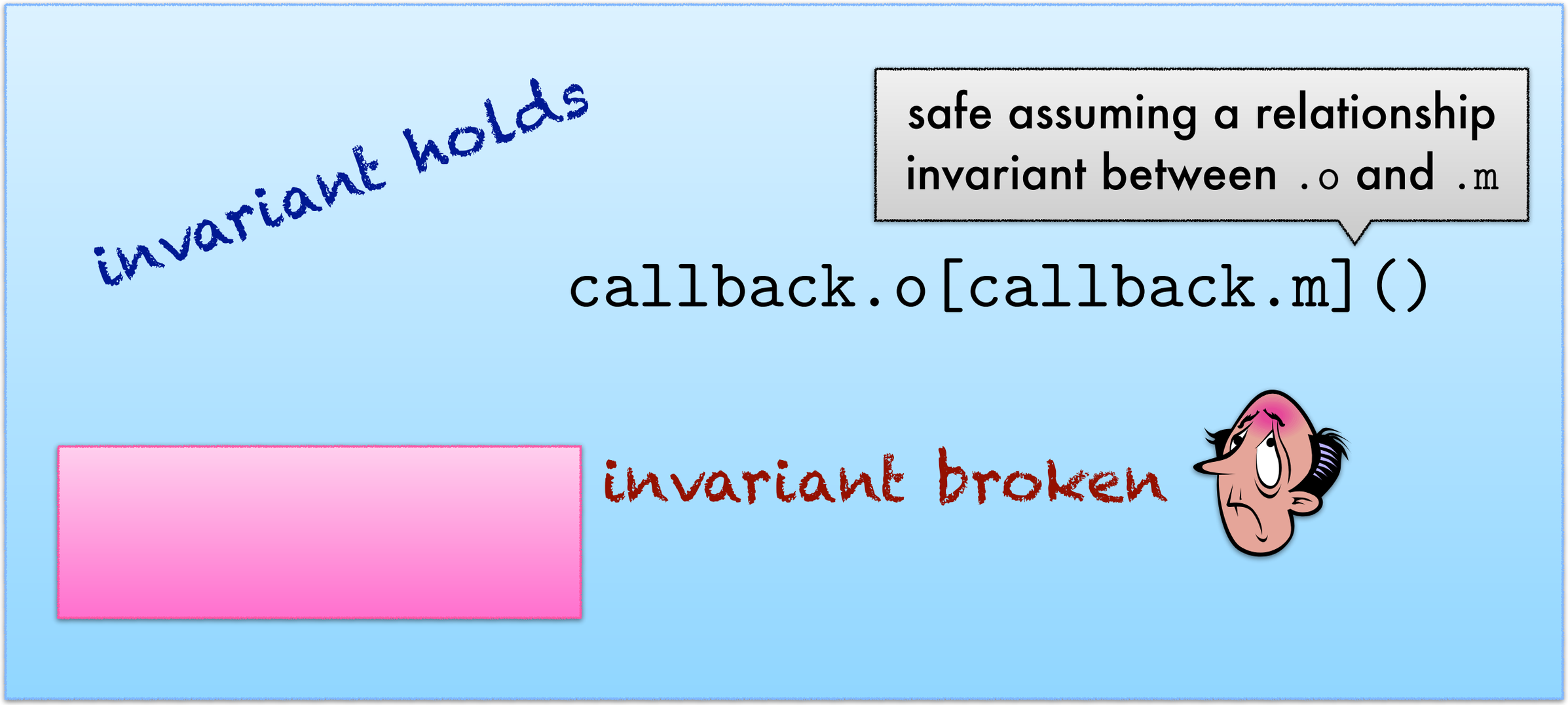

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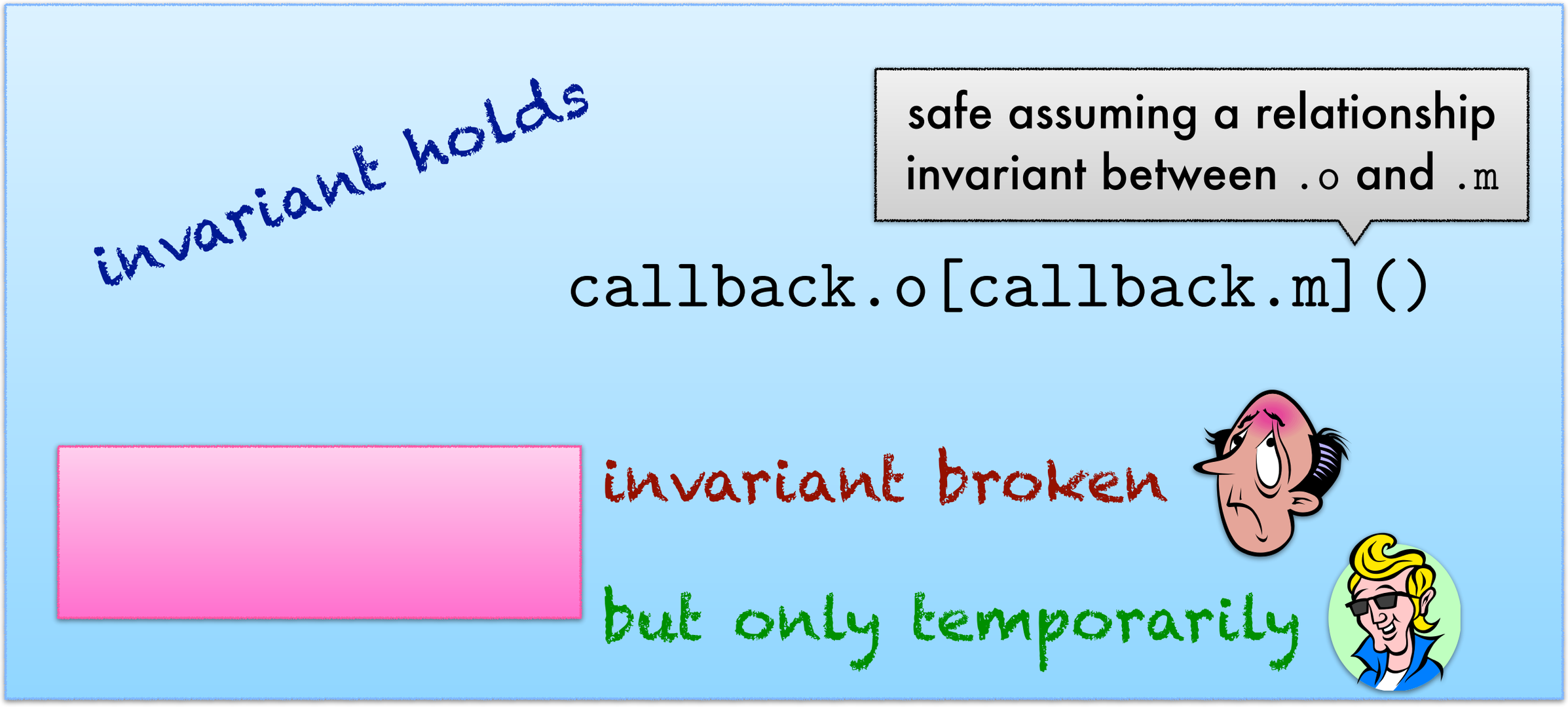

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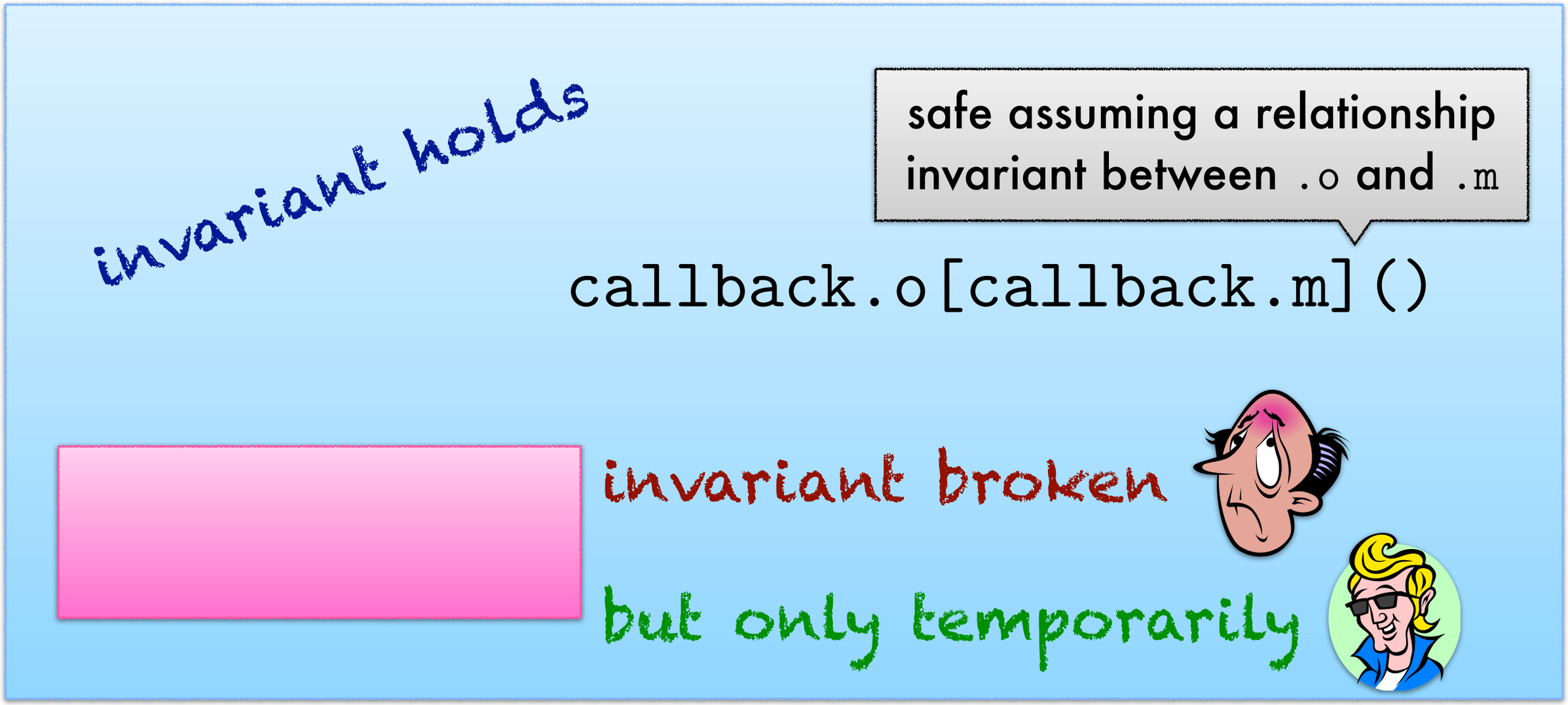

Program

Tolerate "temporary" violation with

Is Fissile effective at proving reflective call safety?

Fissile analyzes Objective-C source

9 benchmarks (6 libraries + 3 apps)

- 1,000 to 176,000 lines of code
- 461,000 lines in total

Type annotations

- seeded with 76 reflection checks in system libraries
- needed only 136 annotations in benchmarks (total)

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Big Deal: makes IDE integration possible

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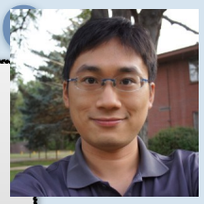

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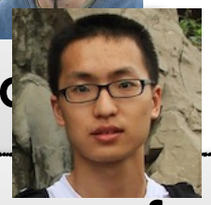

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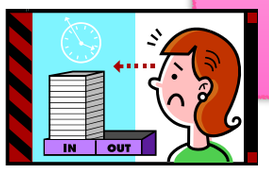

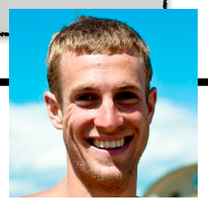

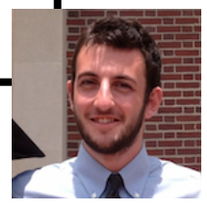

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- Unit Test Synthesis: test input + test code to unequivocally show bug
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- Hardening: synthesize efficient dynamic checks
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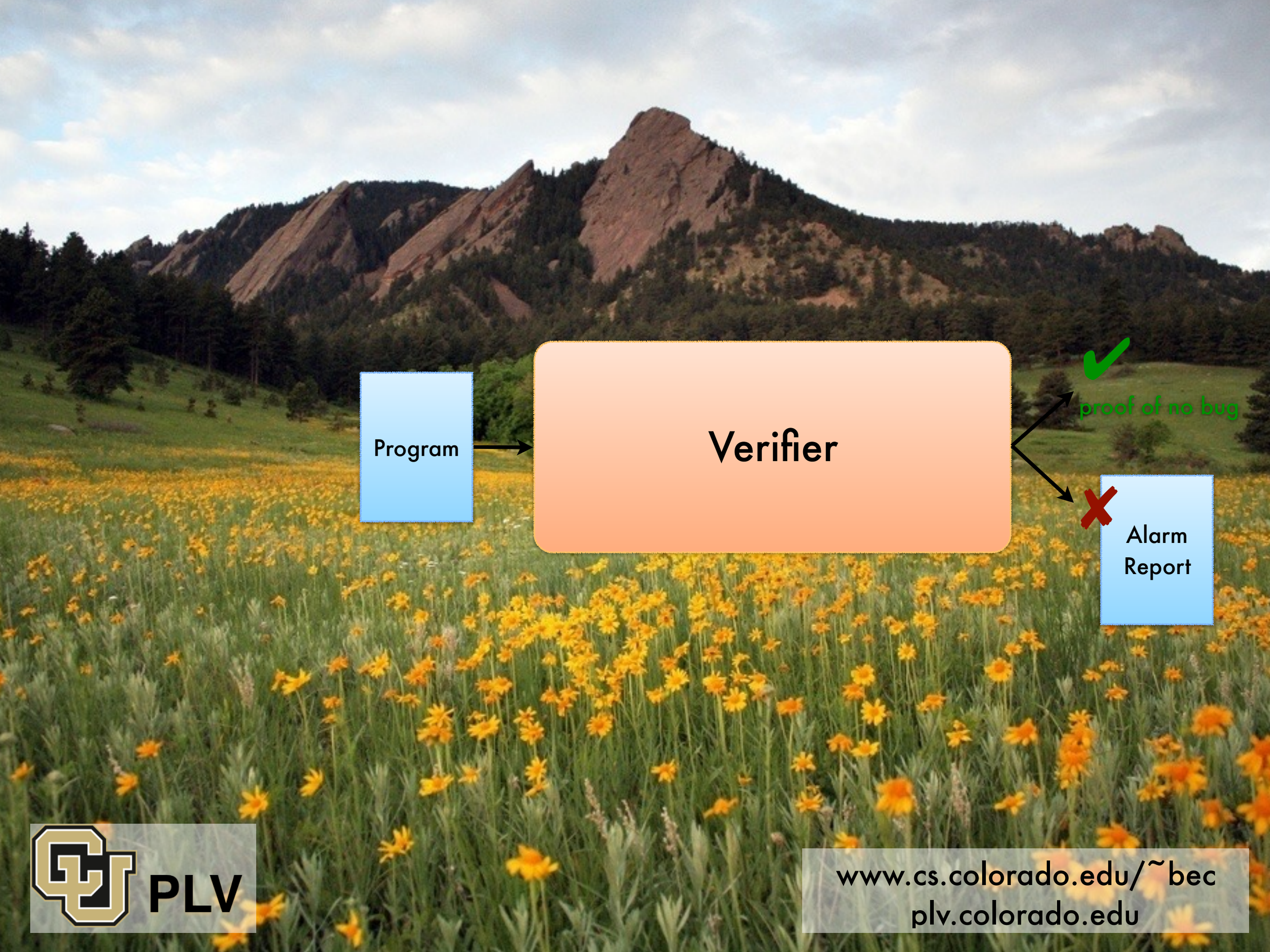
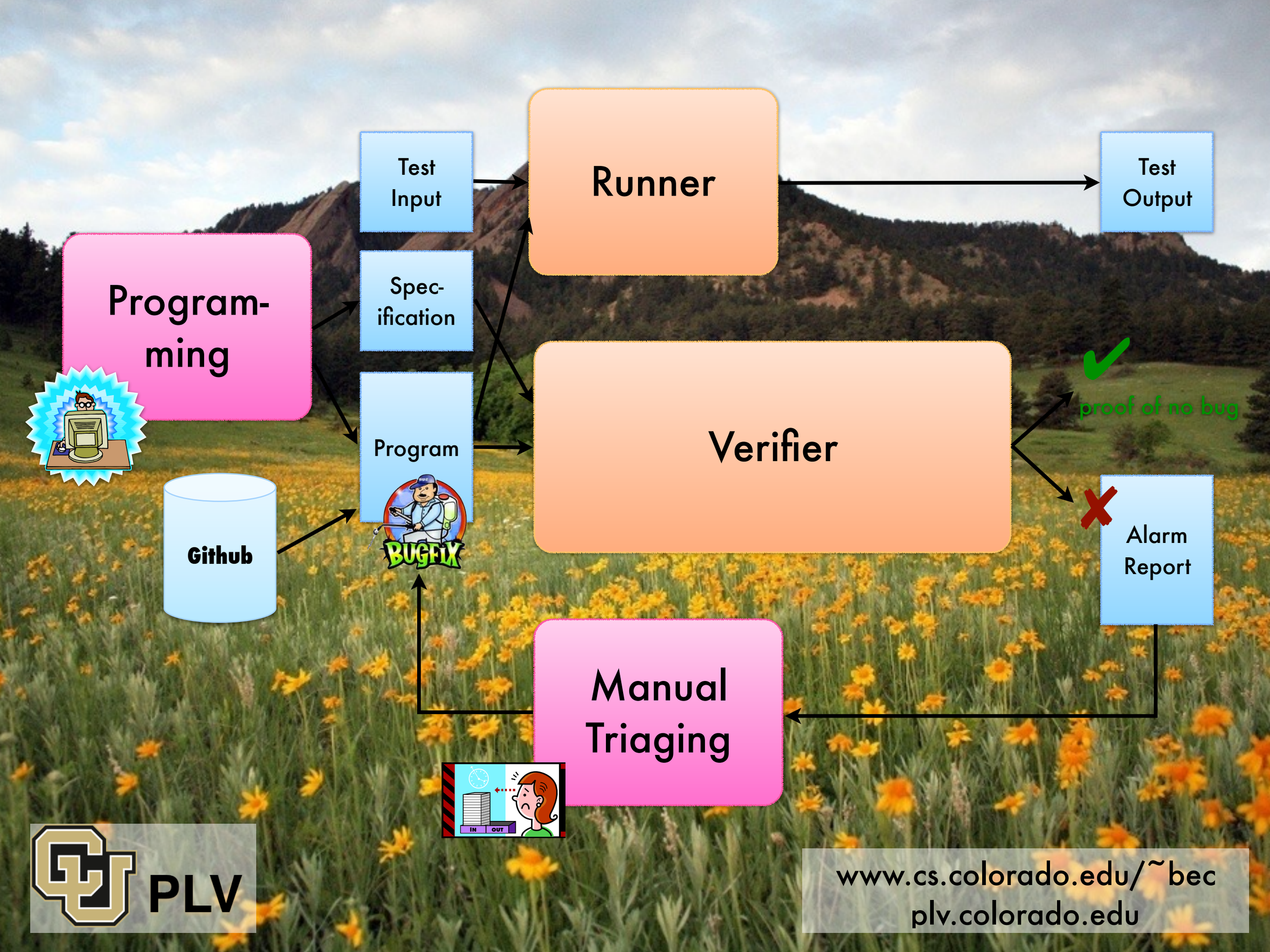
Software Domains

- Dynamically-Typed: web, science+engineering
- Concurrent: event-driven systems, user-interactive systems, servers
- Distributed: "big data" software


PLV
www.cs.colorado.edu/~bec
plv.colorado.edu


Program
Verifier
proof of no bug
Alarm Report
PLV
www.cs.colorado.edu/~bec
plv.colorado.edu


Test Input
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