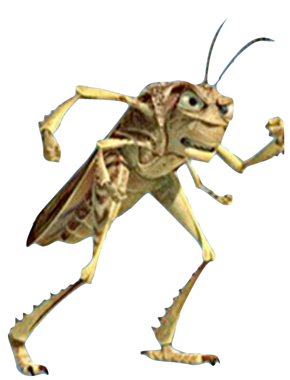



Cooperative Program Analysis

Bor-Yuh Evan Chang

University of Colorado Boulder

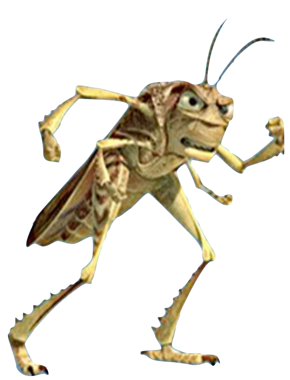


National Taiwan University 國立臺灣大學
August 5, 2014

PLV




A program analysis story ...




A380

Software is everywhere and varying more and more

traditional

Software is everywhere and varying more and more

traditional

mobile

Software is everywhere and varying more and more

traditional

mobile

cloud

Software is everywhere and varying more and more

traditional

mobile

cloud

cyberphysical

Software is everywhere and varying more and more

traditional

mobile

cloud

cyberphysical

Software is everywhere and varying more and more

Software is getting more and more complex

traditional

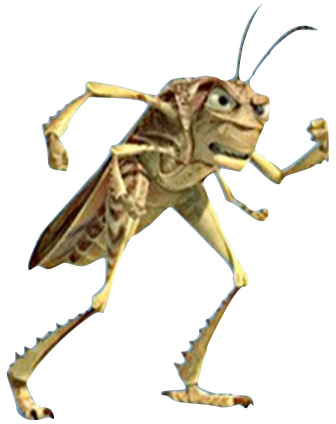
mobile

cloud

cyberphysical

Software is everywhere and varying more and more

Software is getting more and more complex




HELP!

1980s: Bug in Therac-25 kills 6

1980s: Bug in Therac-25 kills 6

2000s: Conficker worm costs $9.1 billion in damages

1980s: Bug in Therac-25 kills 6

2000s: Conficker worm costs $9.1 billion in damages

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"

How does program analysis save the day?

Program Analysis for Formal Verification

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

Program Analysis for Formal Verification

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

How does program analysis save the day?

Program Analysis for Formal Verification

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


The End?

The Ugly, Hidden Truth

Program Analysis for Formal Verification

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

The Ugly, Hidden Truth

Program Analysis for Formal Verification

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

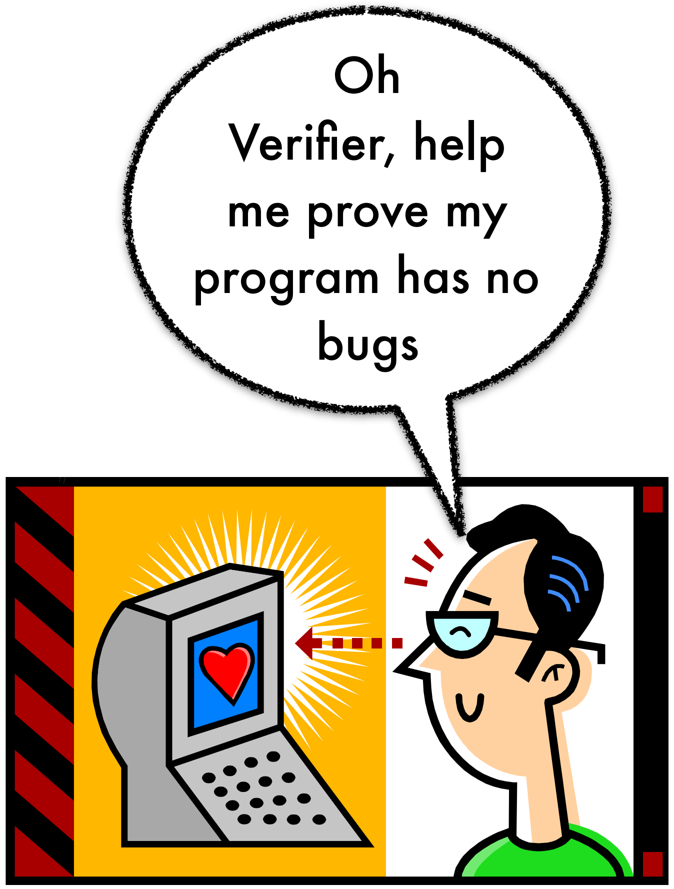
The Ugly, Hidden Truth

Program Analysis for Formal Verification

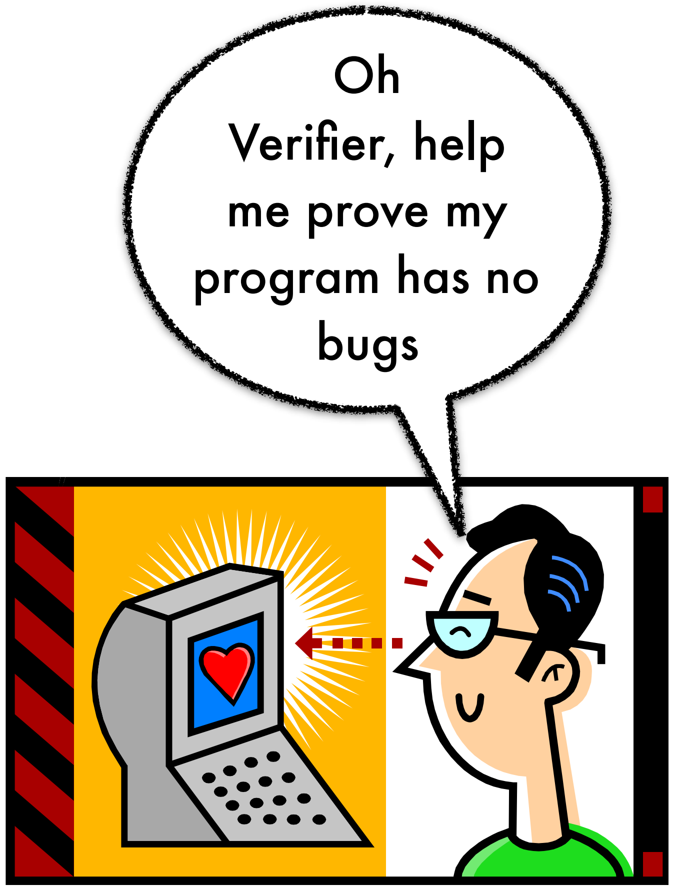
Undecidability necessitates the possibility of **false alarms**. We hope not too many.

Uncooperative Program Analysis?

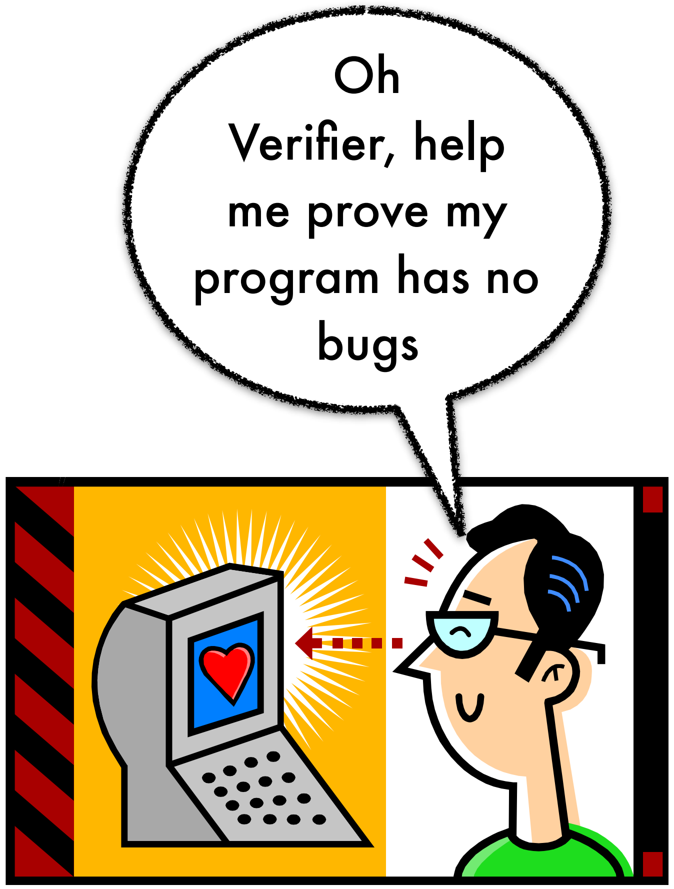
Uncooperative Program Analysis?



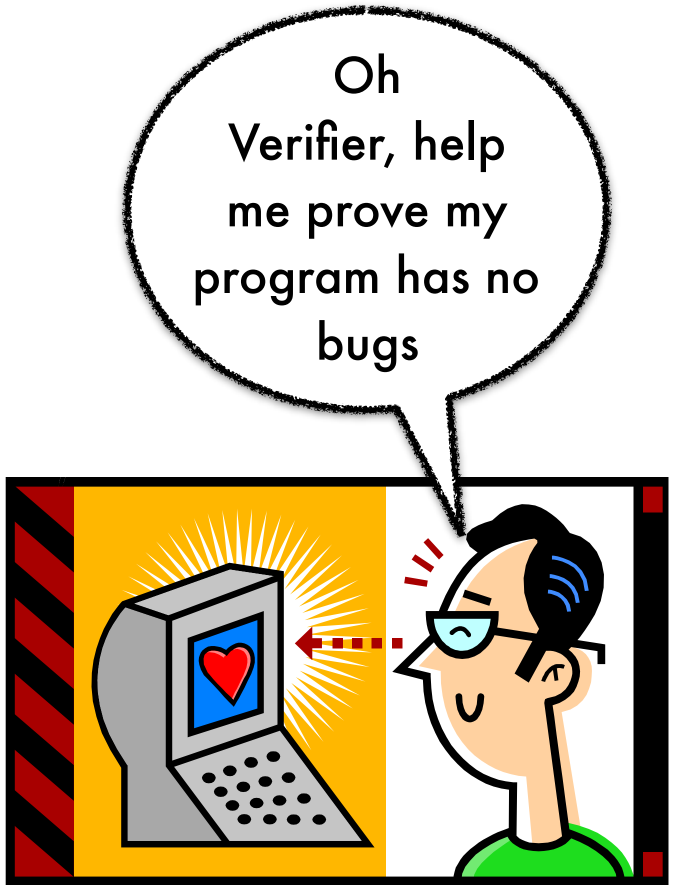
Uncooperative Program Analysis?

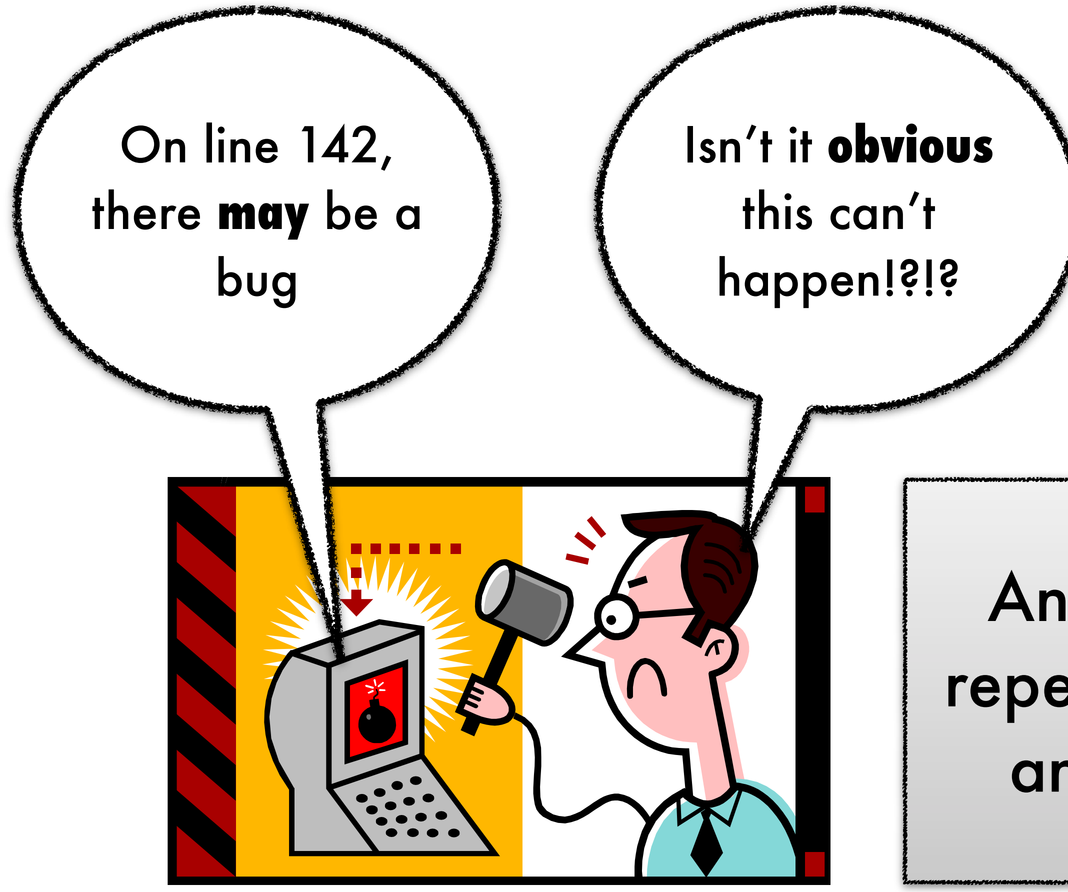


Uncooperative Program Analysis?



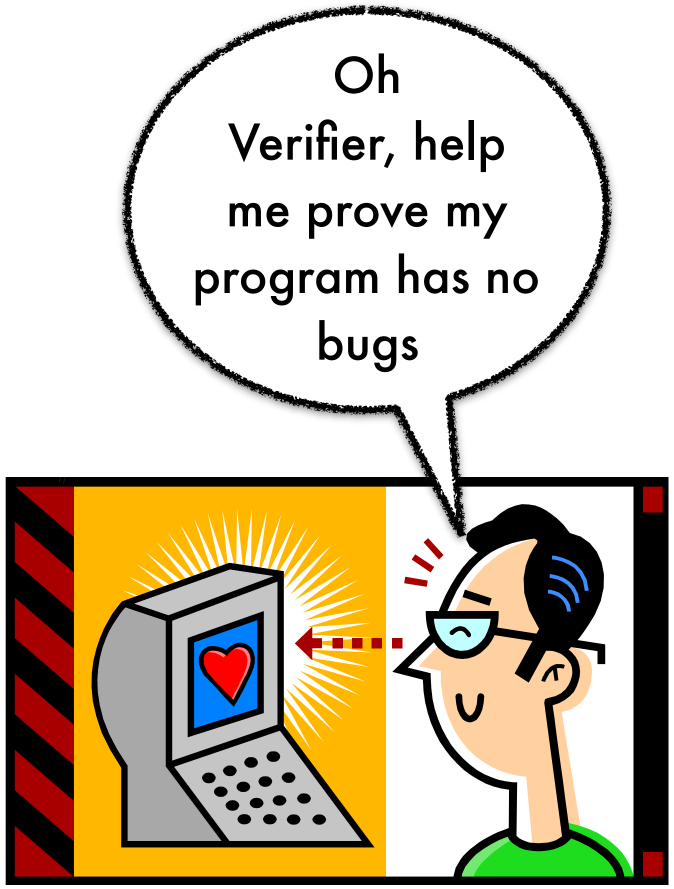
Uncooperative Program Analysis?

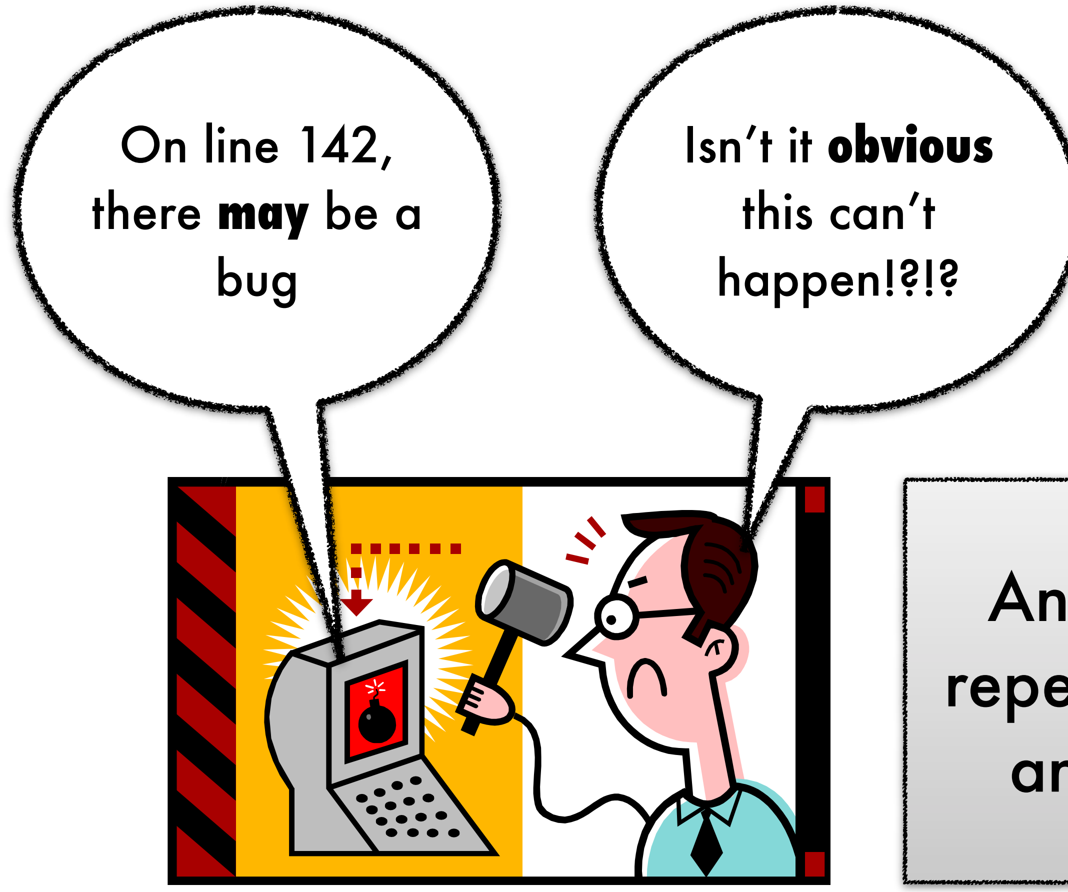




And noisily repeated over and over!

Uncooperative Program Analysis?

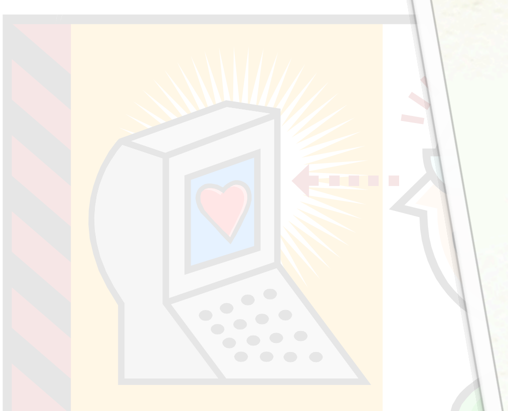




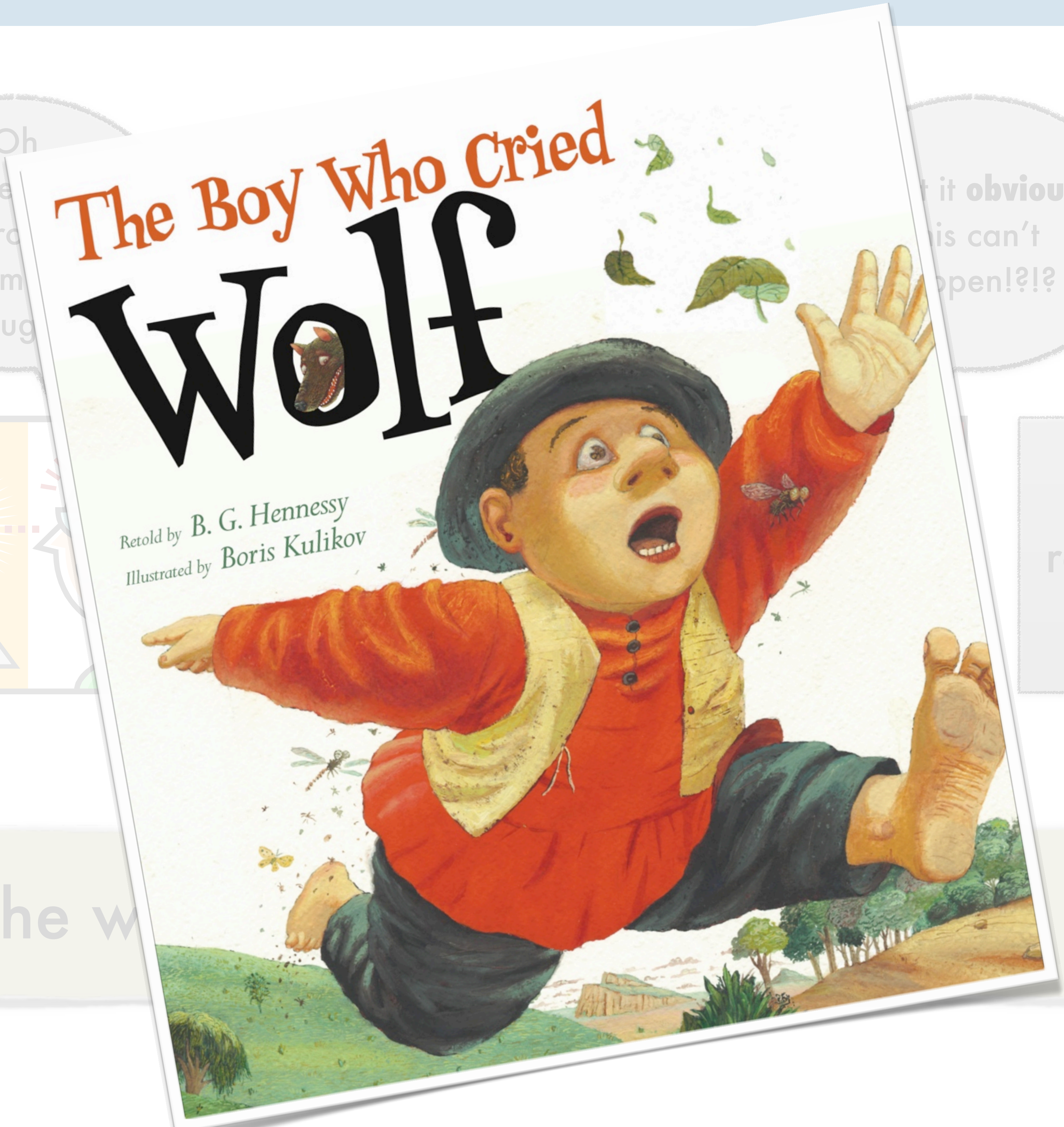
And noisily repeated over and over!

The well-known **false alarm** problem

Uncooperative Program Analysis?



And noisily repeated over and over!



"[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."

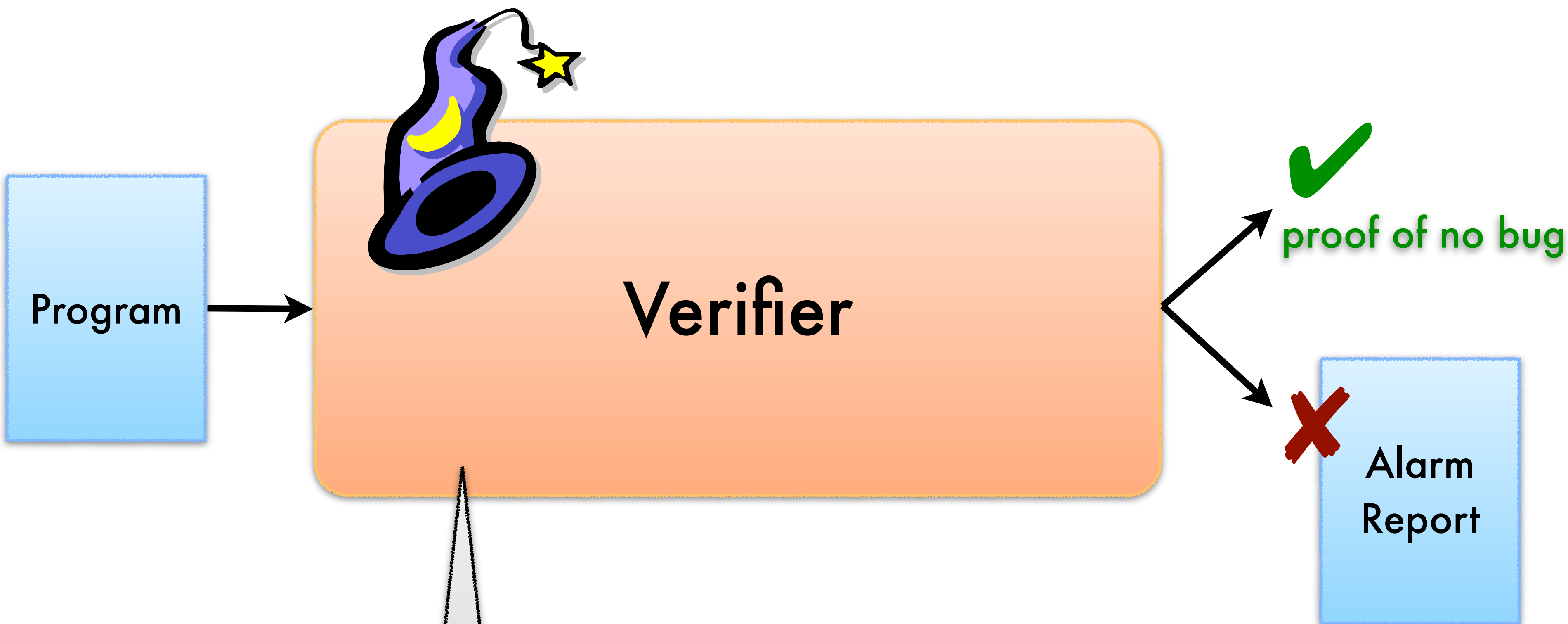
"A stupid false [alarm] implies the tool is stupid."

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.

coverity®

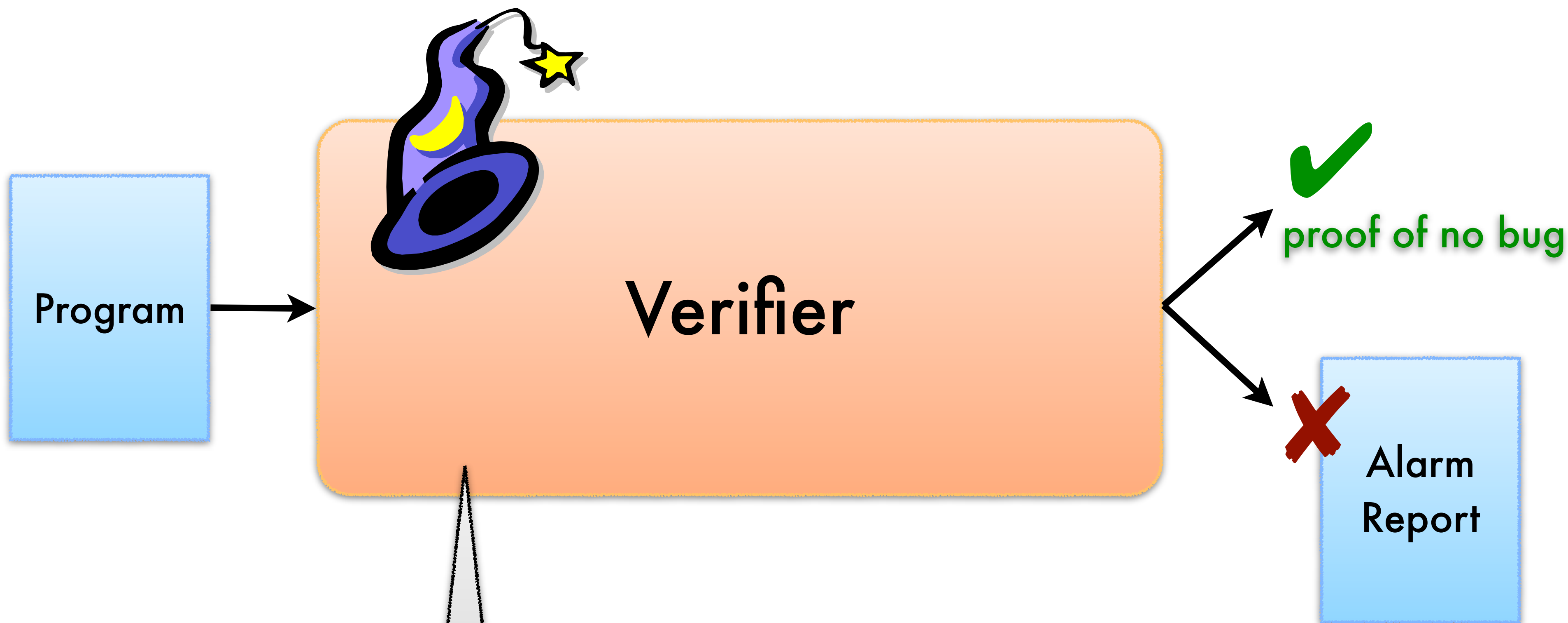
The traditional approach to the false alarm problem focuses on improving the verifier.

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



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

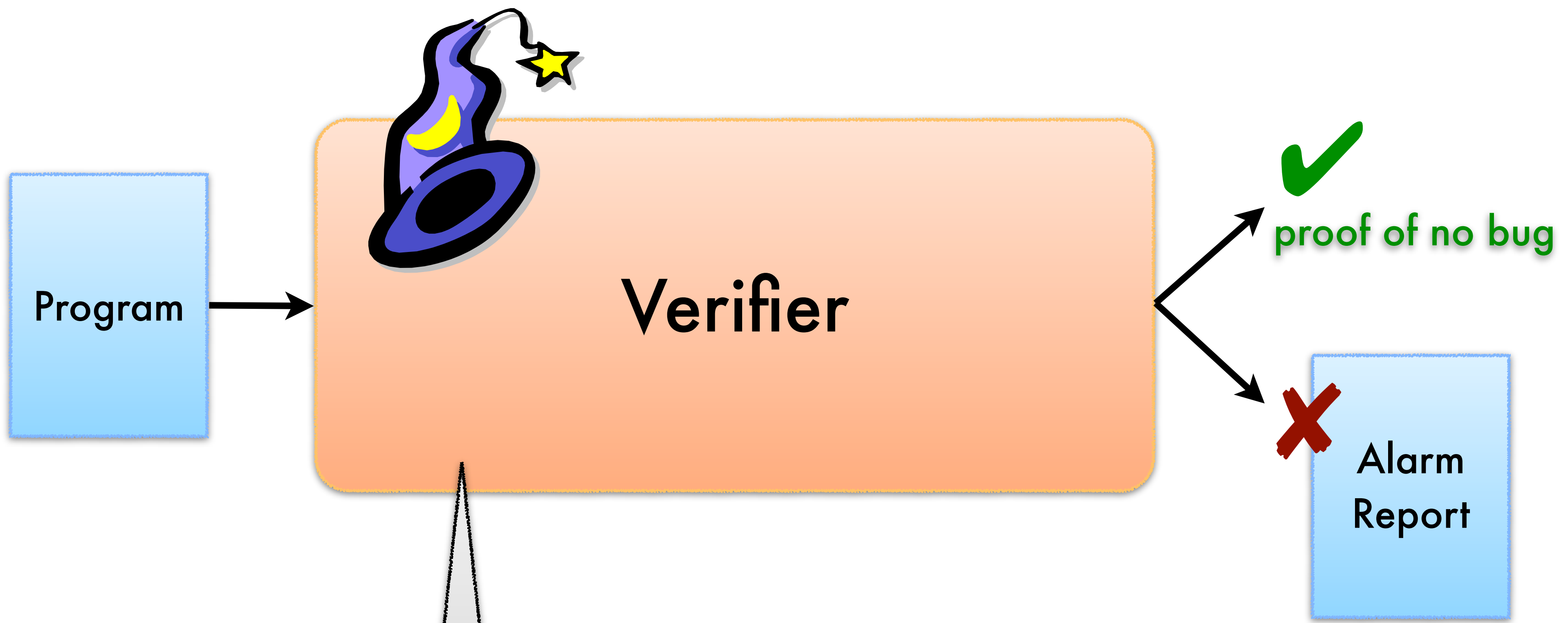
The traditional approach to the false alarm problem focuses on improving the verifier.



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

But it can never be perfect (undecidability)

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



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

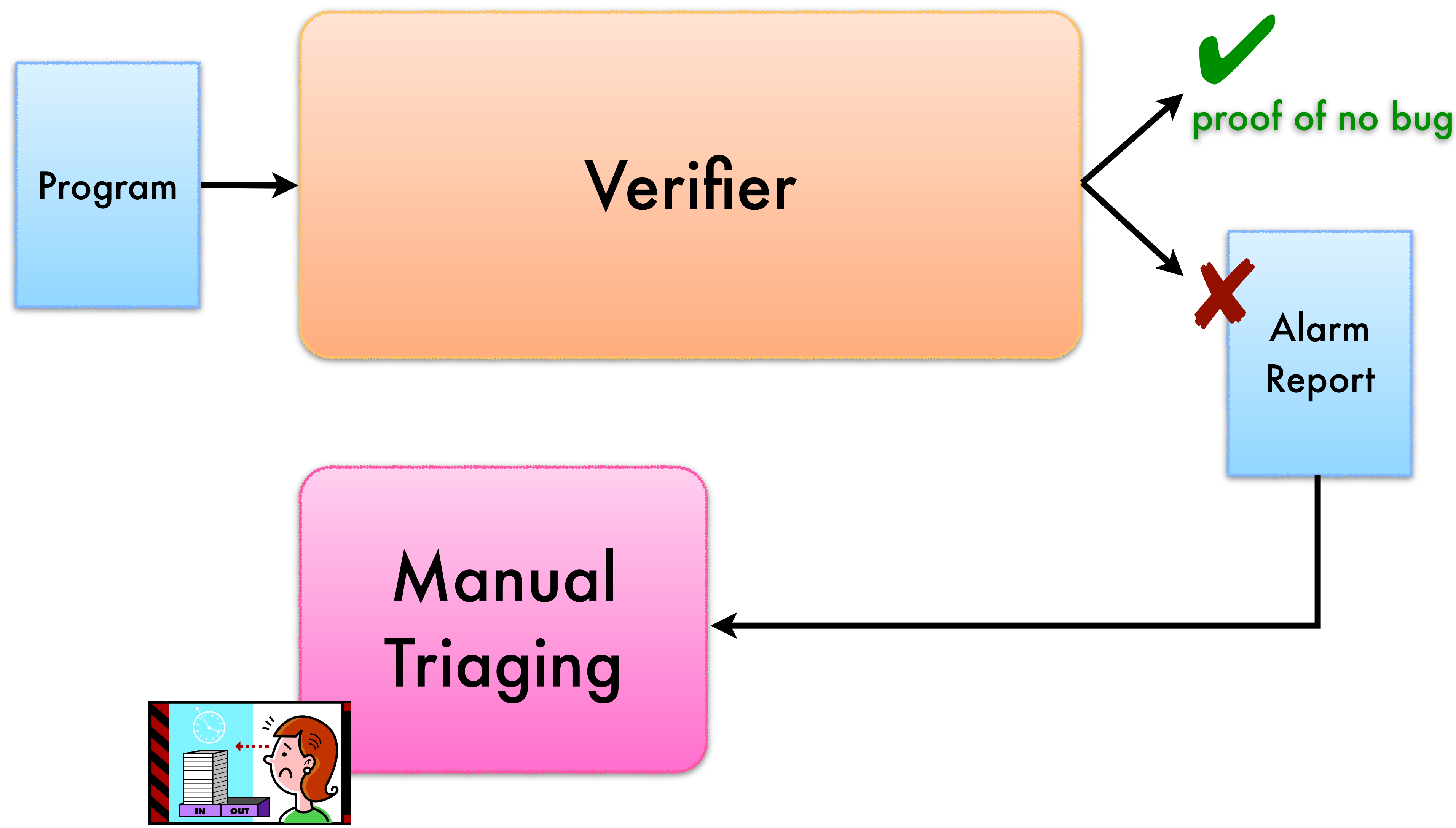
But it can never be perfect (undecidability)

Also not a sufficient "excuse"

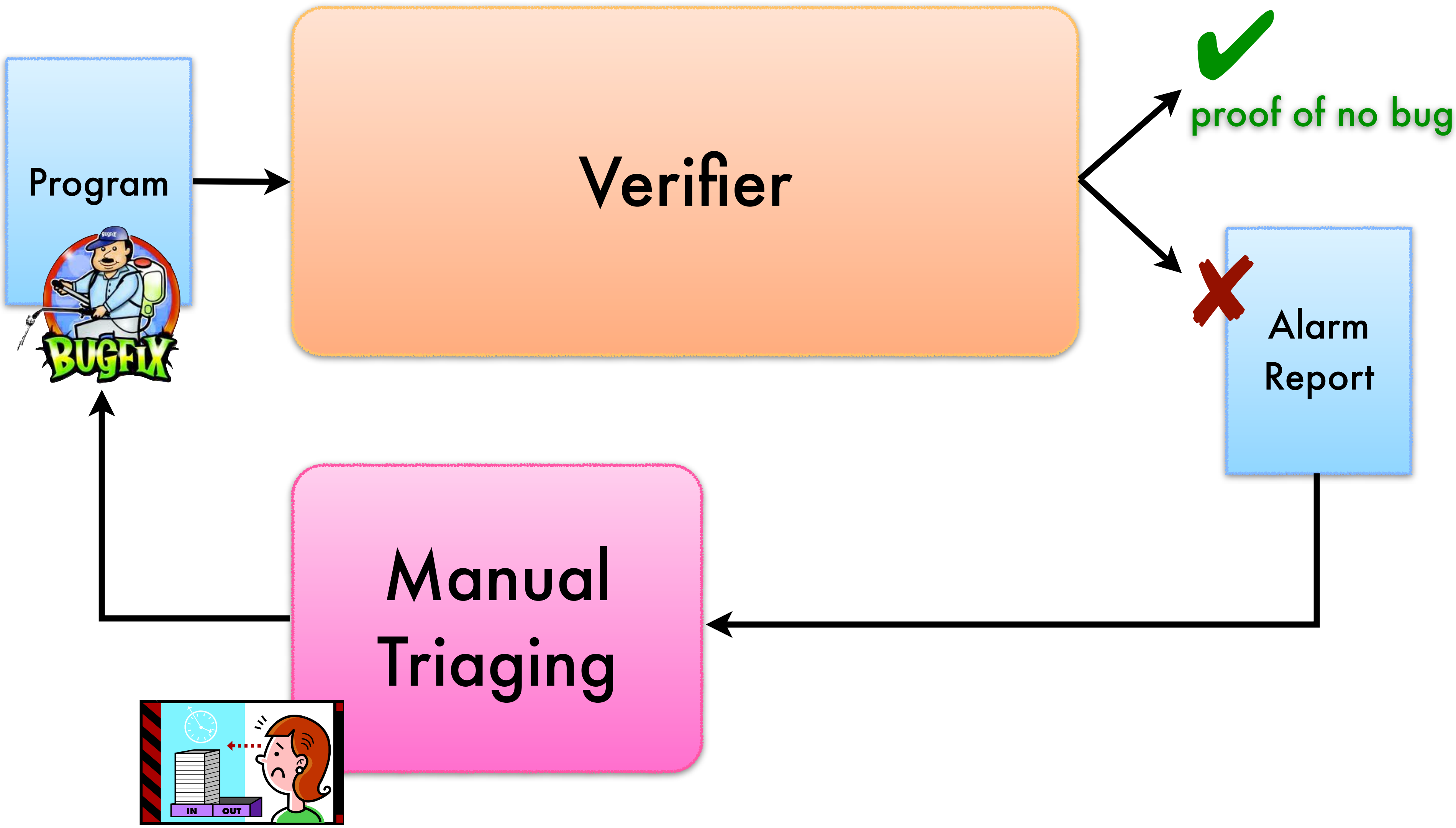
Agenda: The cooperative approach addresses the whole bug mitigation process.

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

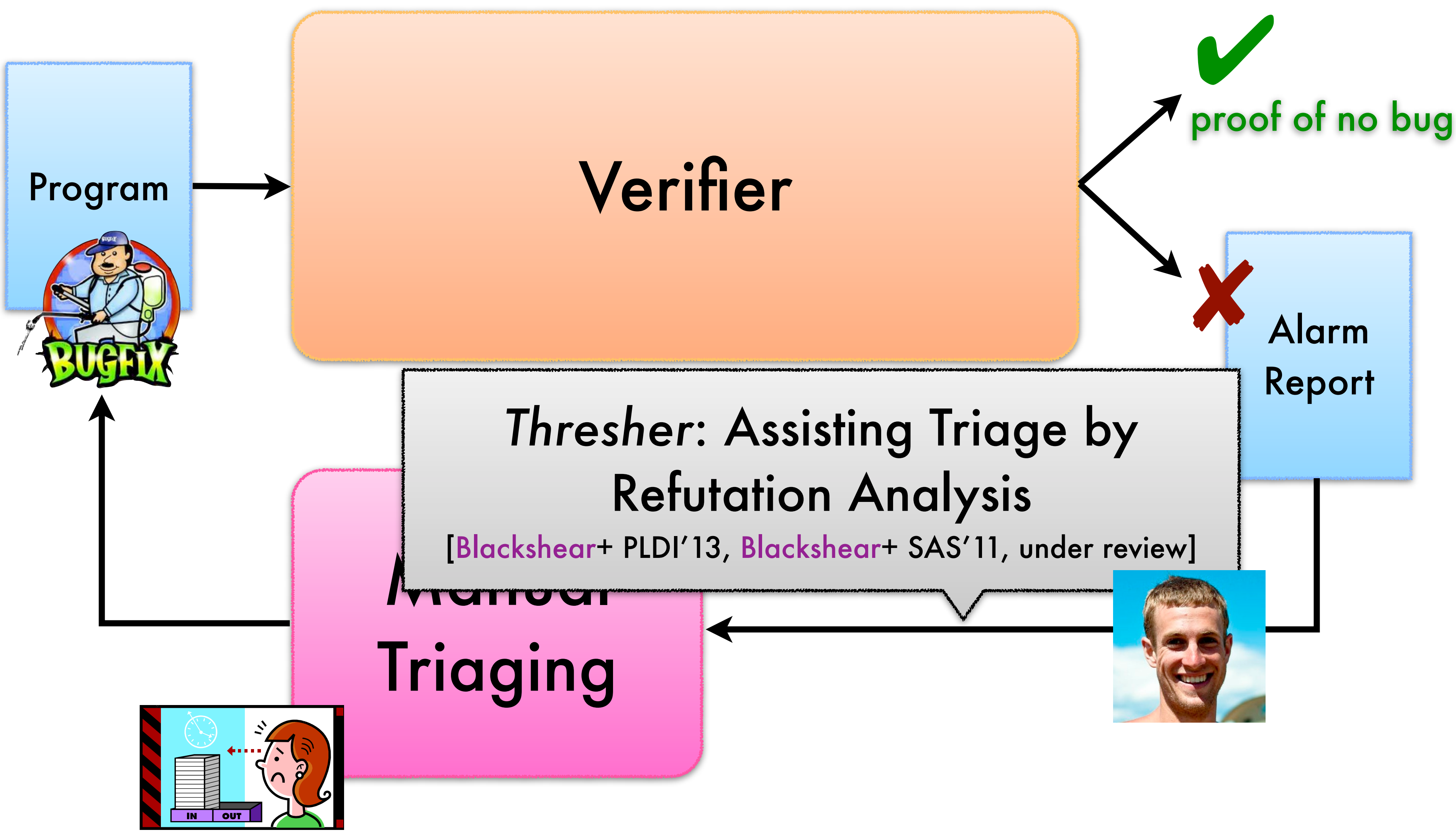
Agenda: The cooperative approach addresses the whole bug mitigation process.



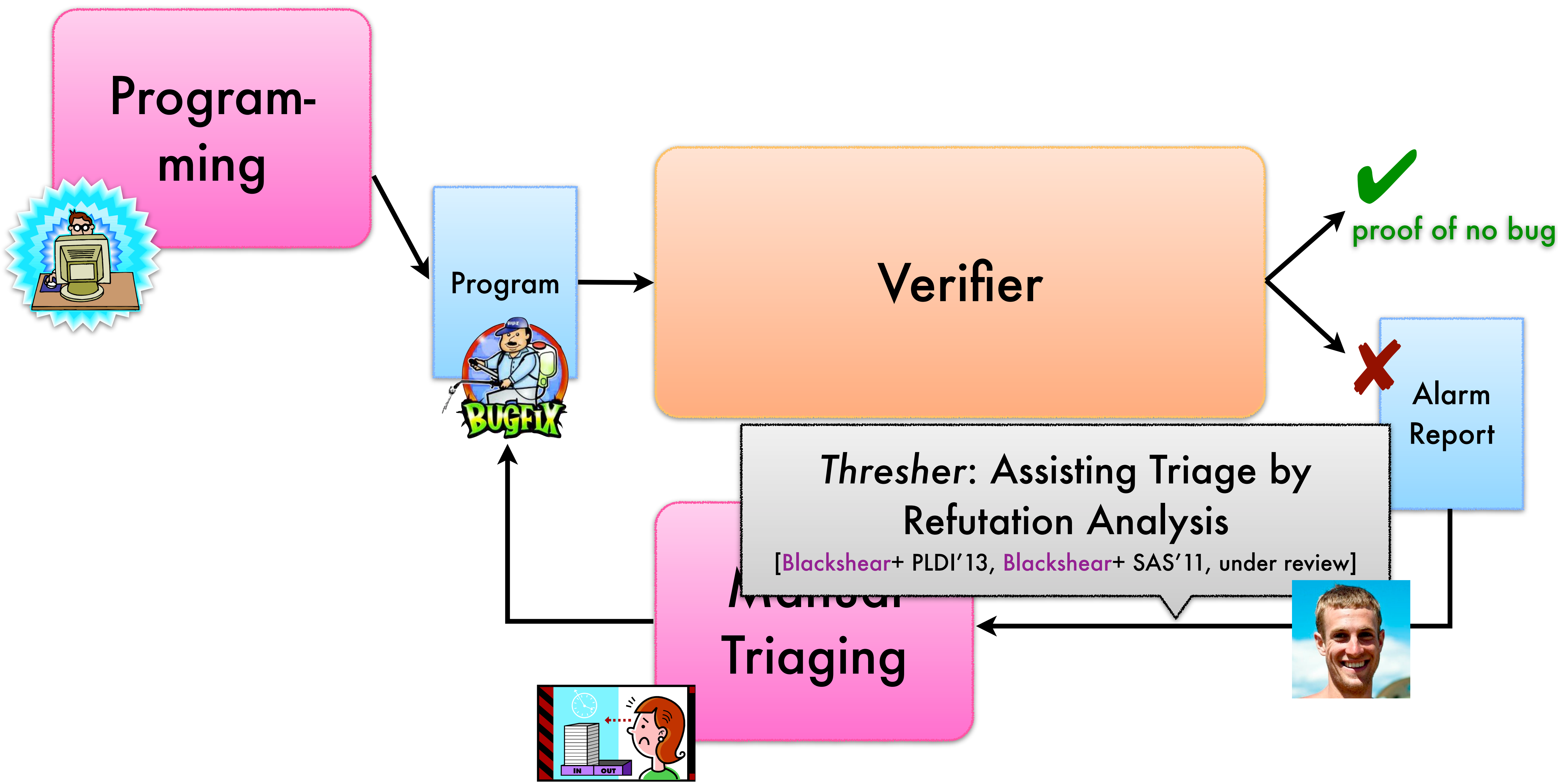
Agenda: The cooperative approach addresses the whole bug mitigation process.



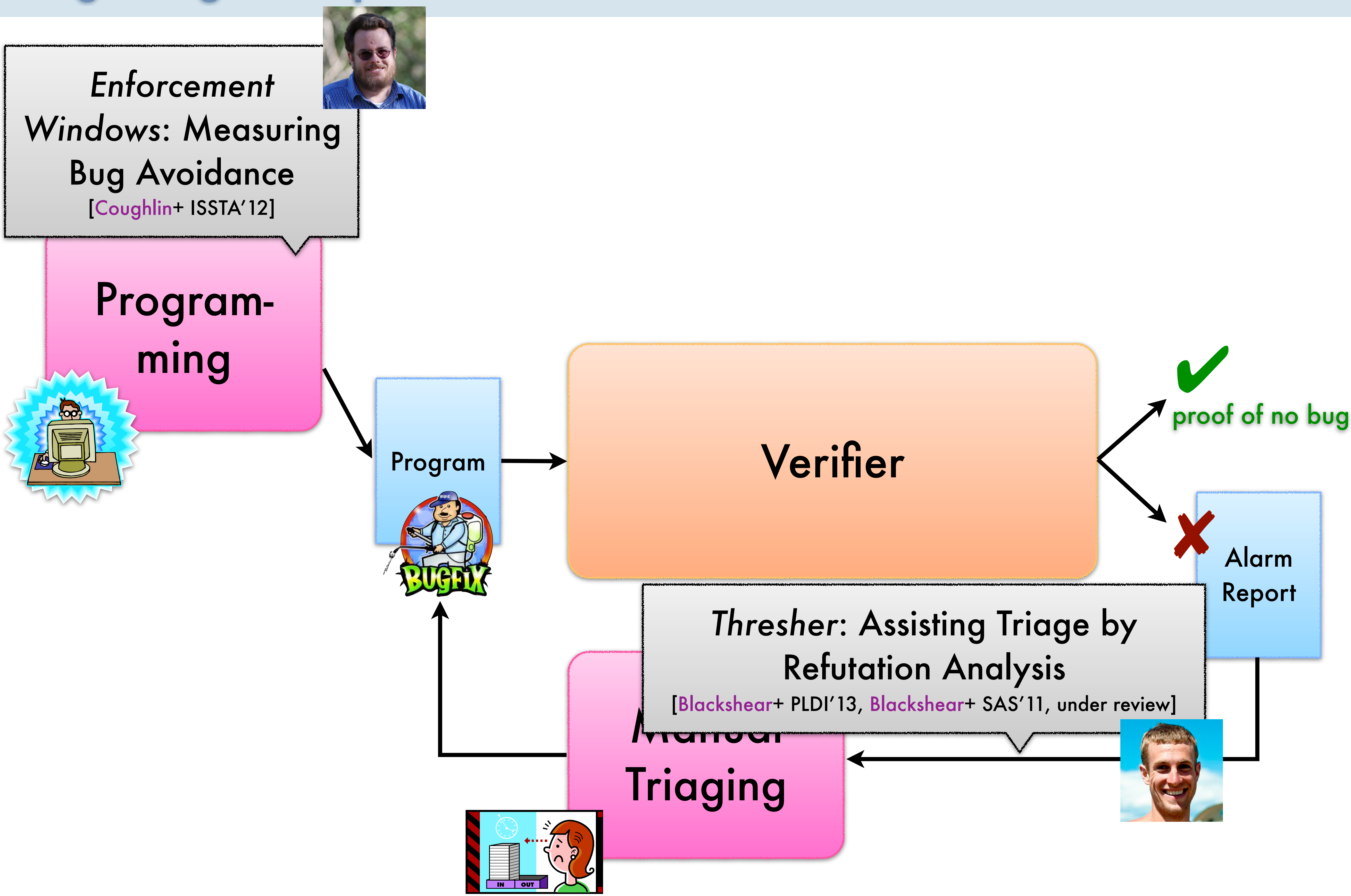
Agenda: The cooperative approach addresses the whole bug mitigation process.



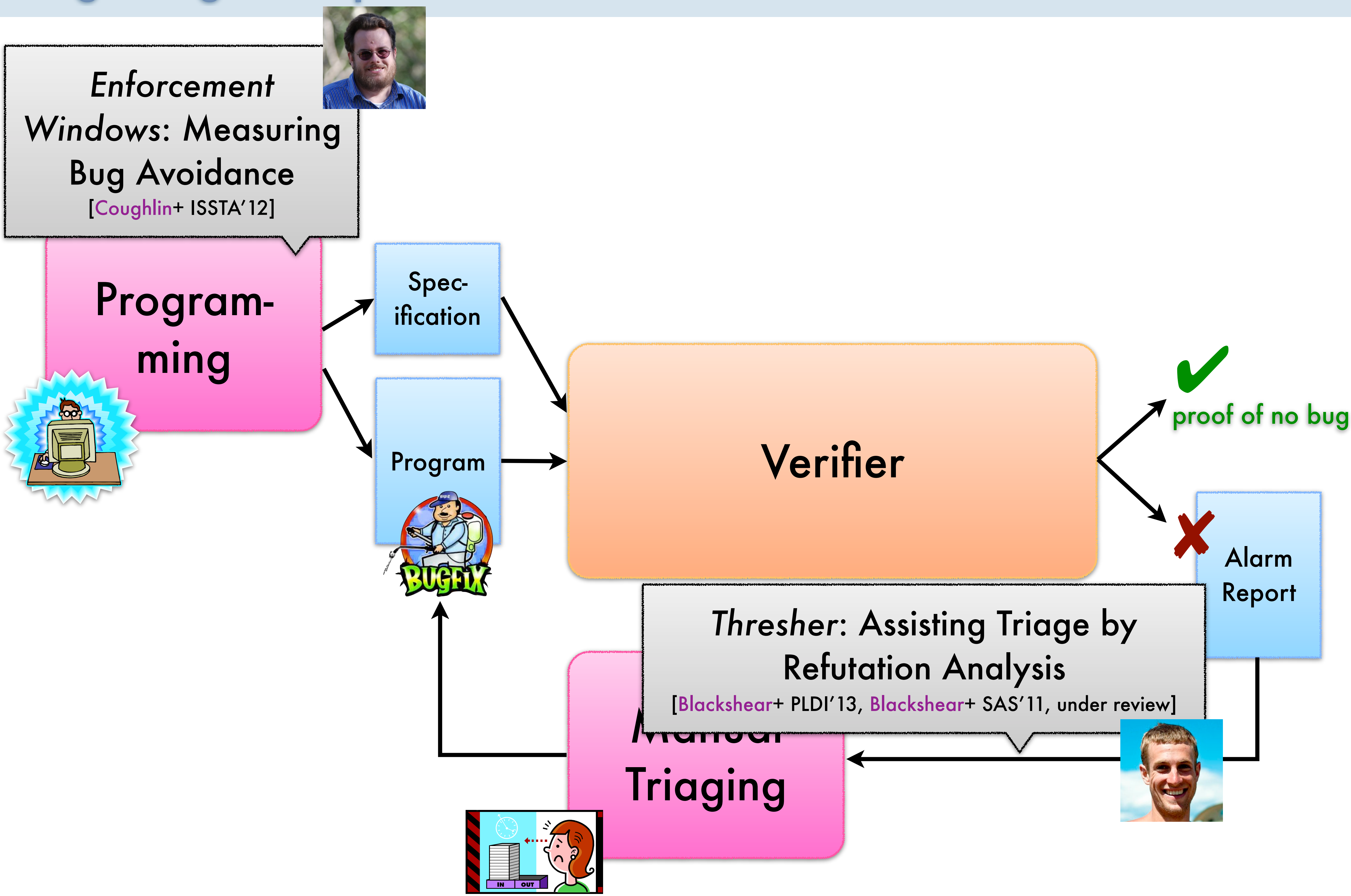
Agenda: The cooperative approach addresses the whole bug mitigation process.



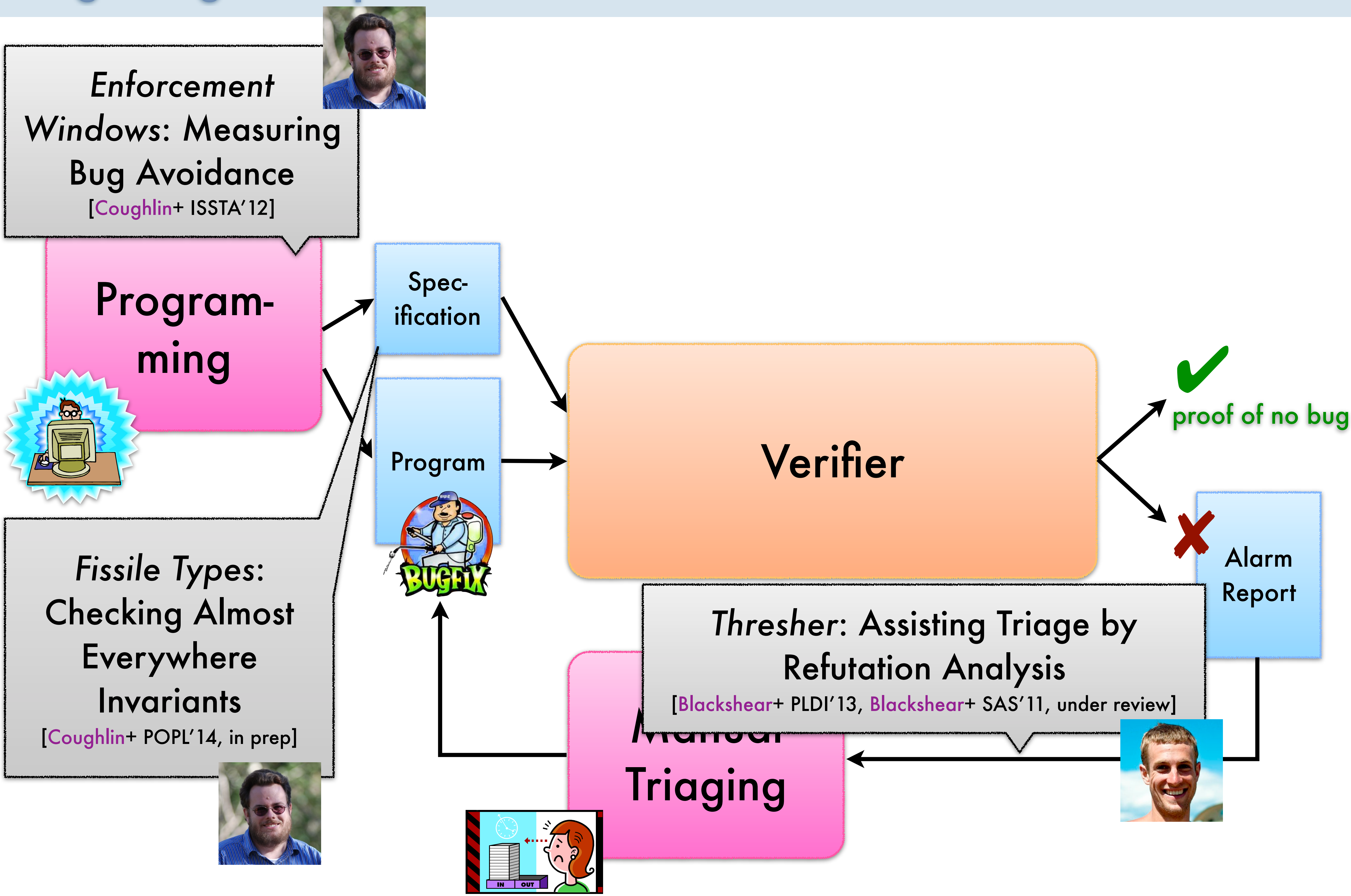
Agenda: The cooperative approach addresses the whole bug mitigation process.



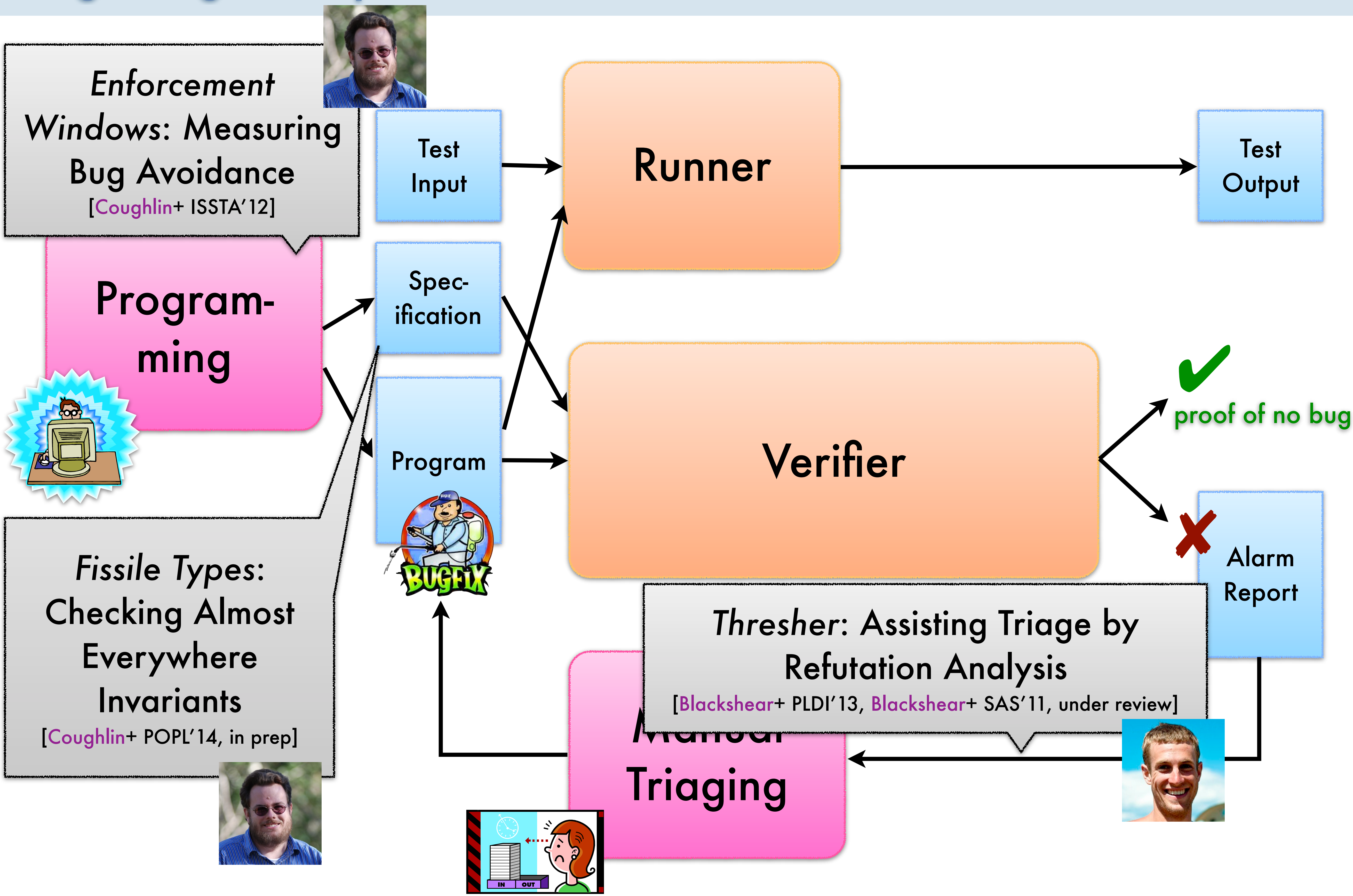
Agenda: The cooperative approach addresses the whole bug mitigation process.



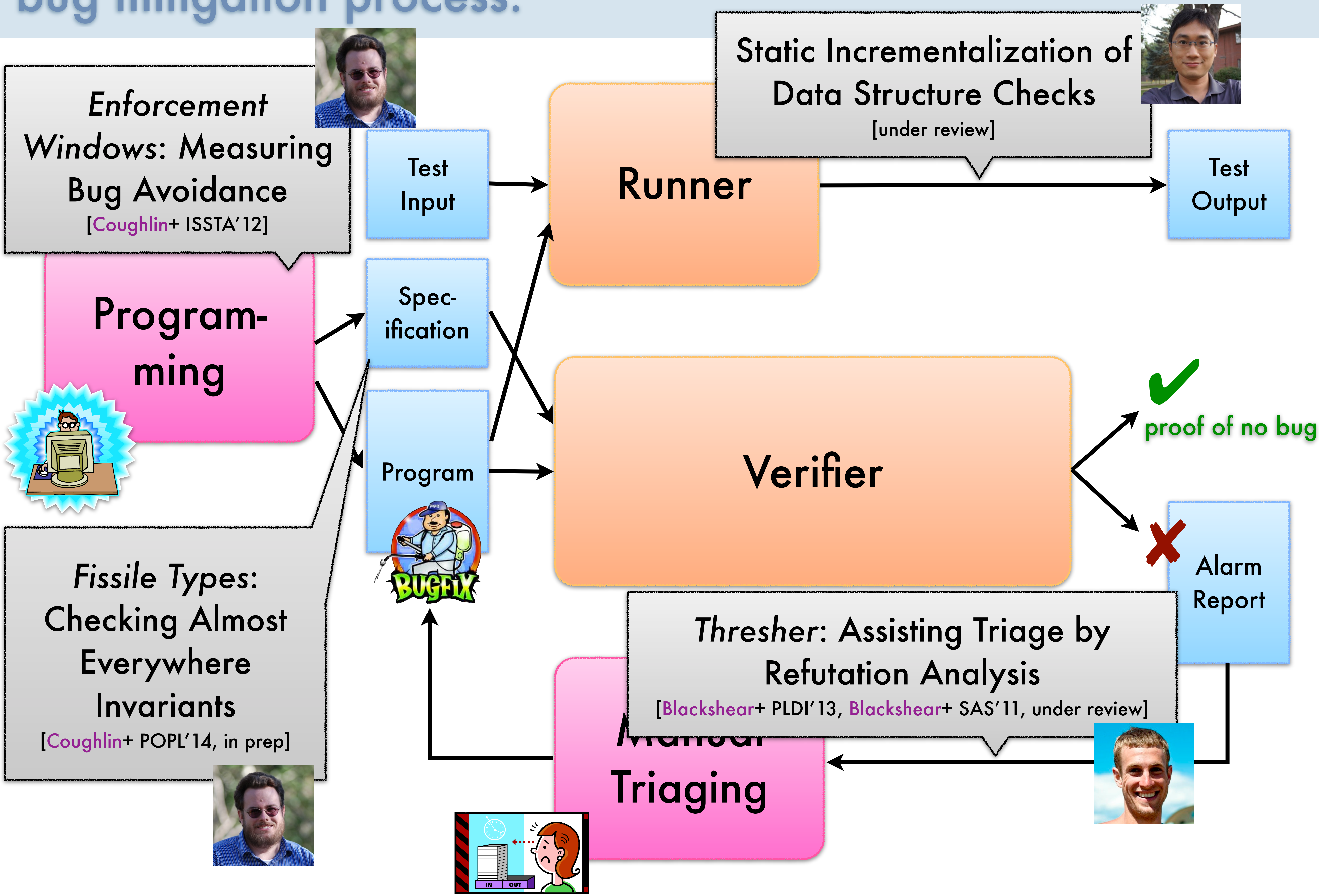
Agenda: The cooperative approach addresses the whole bug mitigation process.



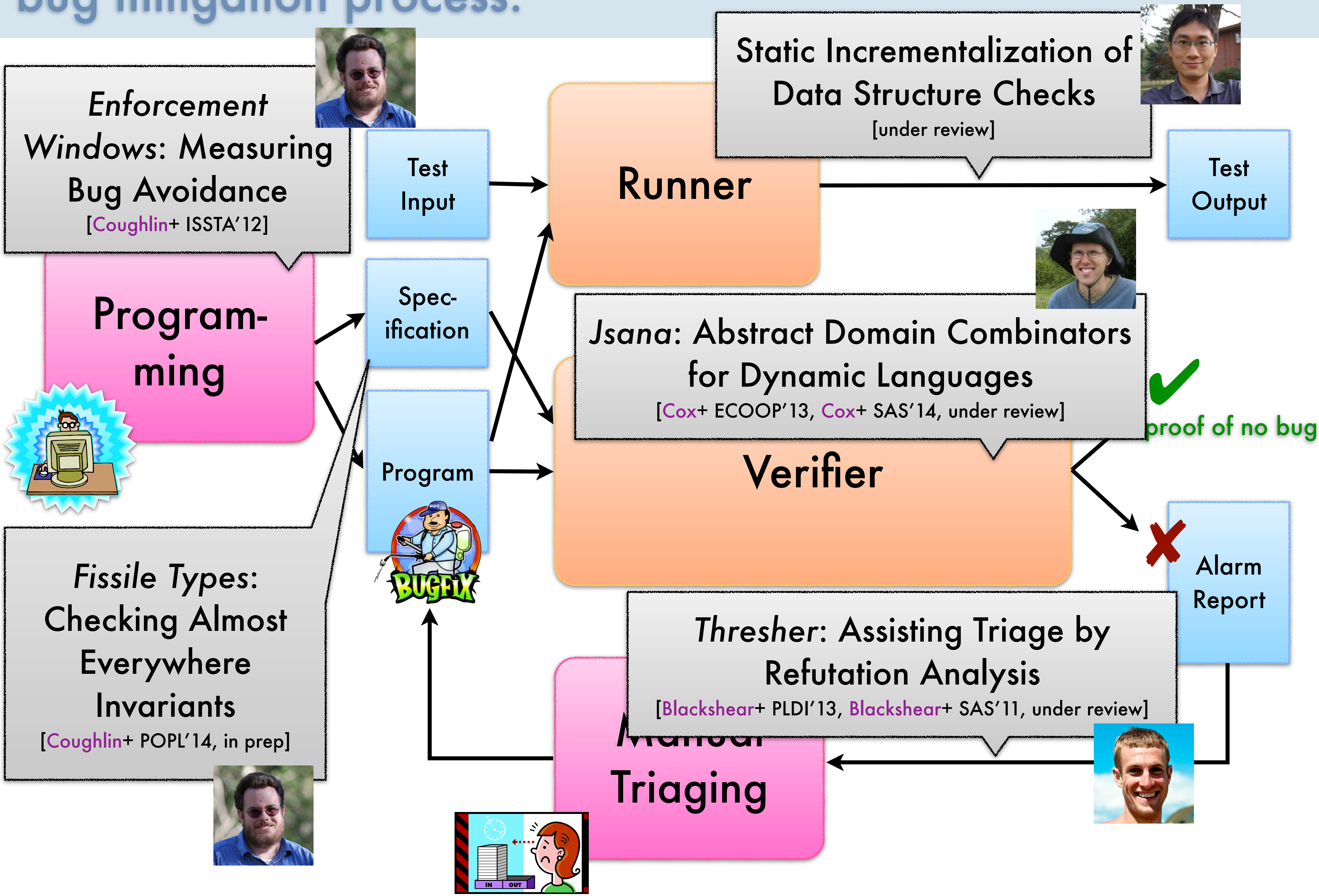
Agenda: The cooperative approach addresses the whole bug mitigation process.



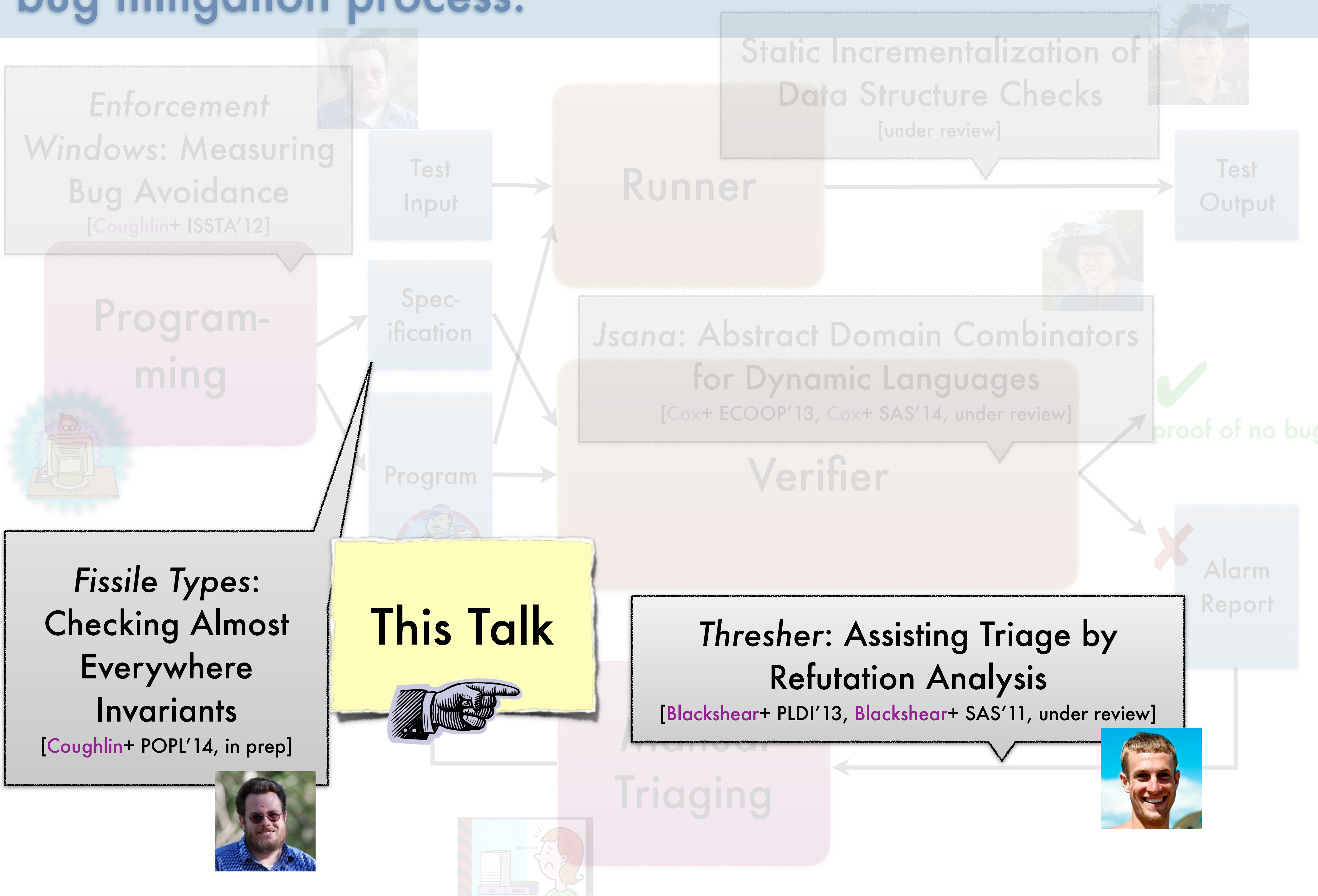
Agenda: The cooperative approach addresses the whole bug mitigation process.



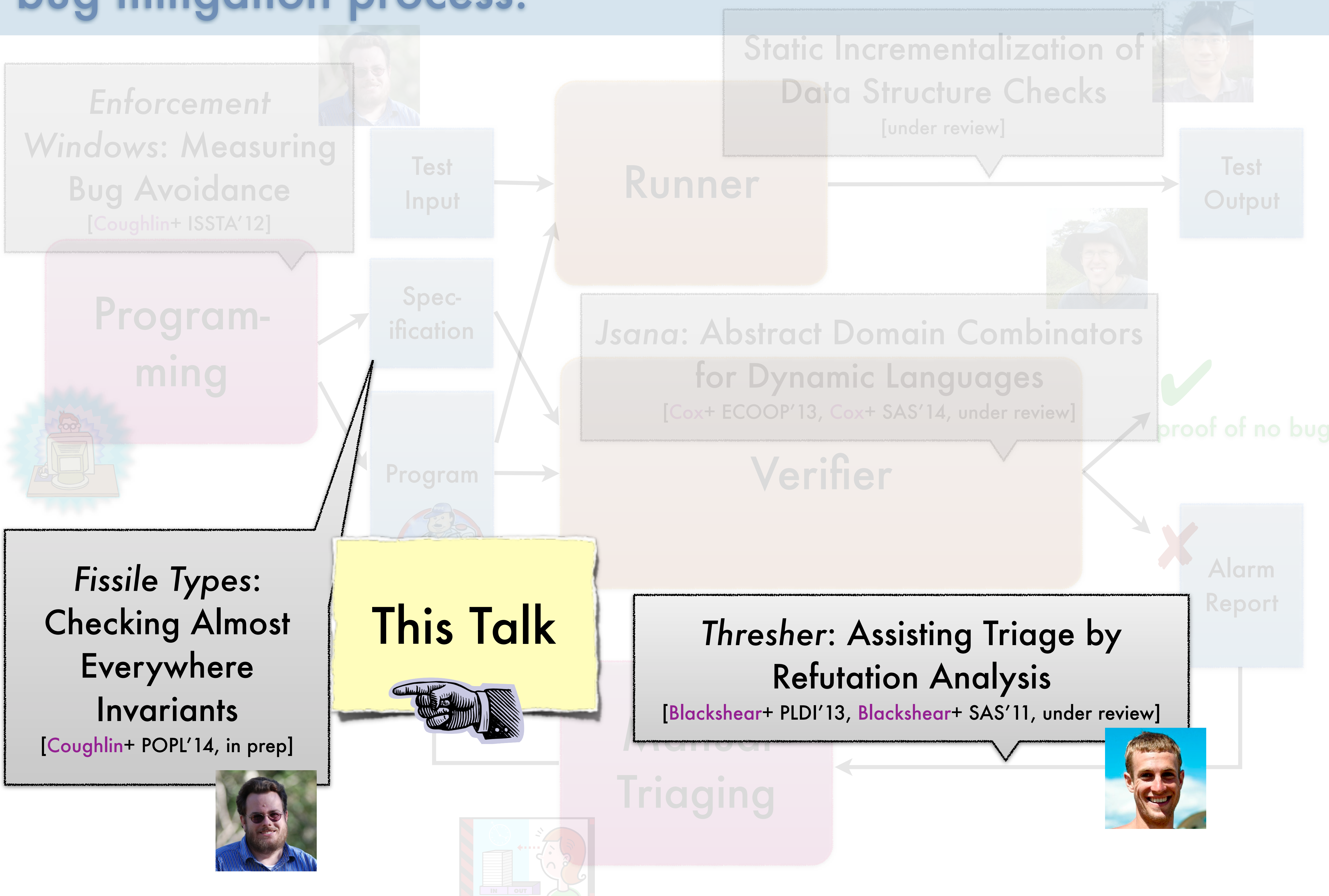
Agenda: The cooperative approach addresses the whole bug mitigation process.



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



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



This Talk: Highlights

Thresher: Precise Refutations for Heap Reachability

Assist in triage of queries about heap relations

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

This Talk: Highlights

Thresher: Precise Refutations for Heap Reachability

Assist in triage of queries about heap relations

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

Fissile Types: Checking Reflection with Almost Everywhere Invariants

Strengthen type checking with symbolic analysis

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

This Talk: Highlights

Thresher: Precise Refutations for Heap Reachability

Assist in triage of queries about heap relations

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

Fissile Types: Checking Reflection with Almost Everywhere Invariants

Strengthen type checking with symbolic analysis

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

Thresher: Precise Refutations for Heap Reachability

What are heap reachability queries?

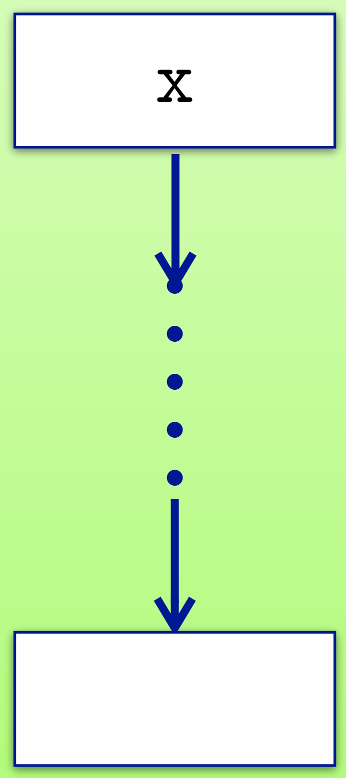
What are heap reachability queries?

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

What are heap reachability queries?

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

Is there a program execution where at some time variable

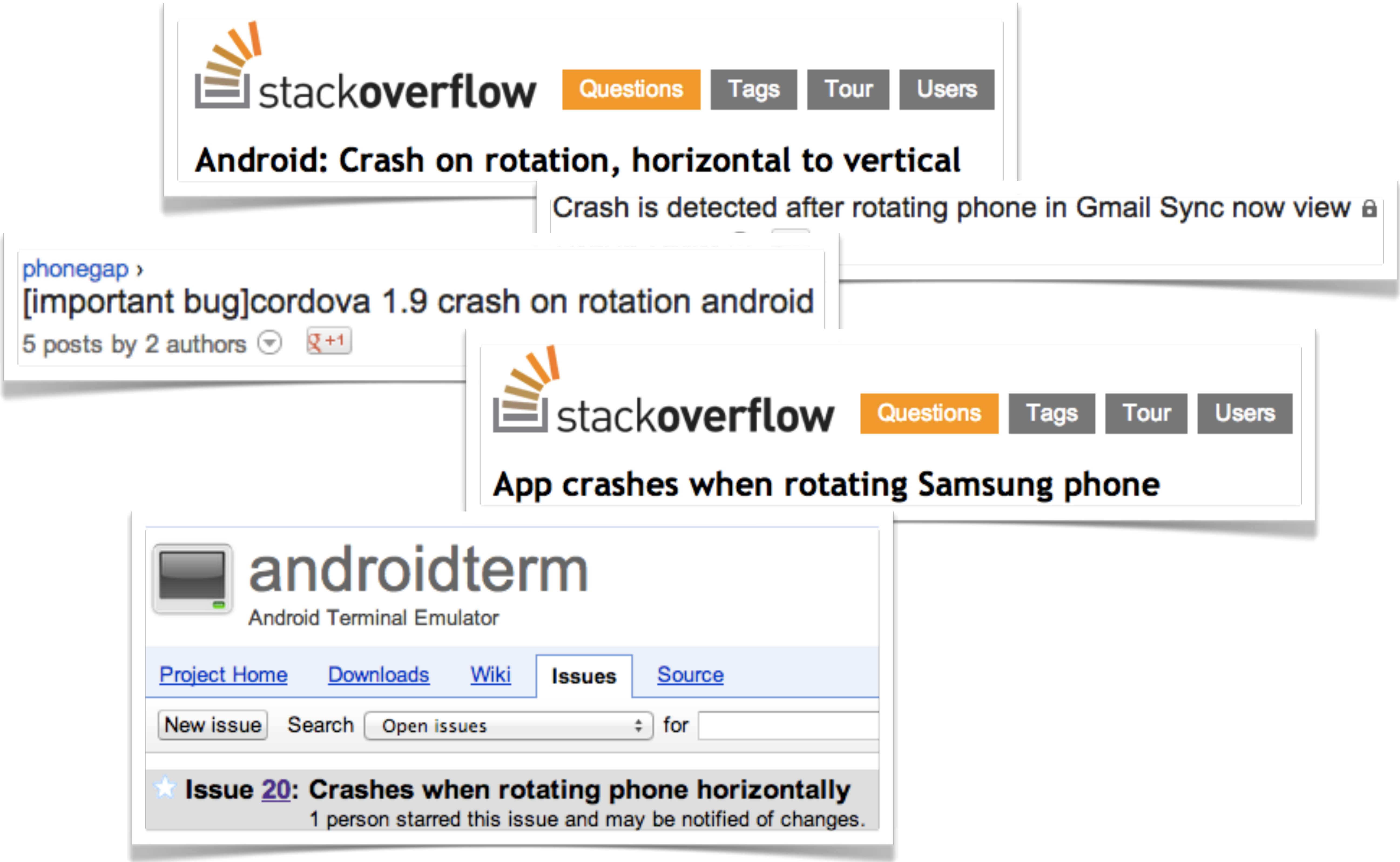


of type T ?

Example

How is this useful? We identify memory leaks that cause your app to crash!

How is this useful? We identify memory leaks that cause your app to crash!



How is this useful? We identify memory leaks that cause your app to crash!

Android memory leaks underly rotation-based crashes.

`Activity` objects encapsulate the UI

Android memory leaks underly rotation-based crashes.

`Activity` objects encapsulate the UI

Android OS

of type `Activity`

Android memory leaks underly rotation-based crashes.

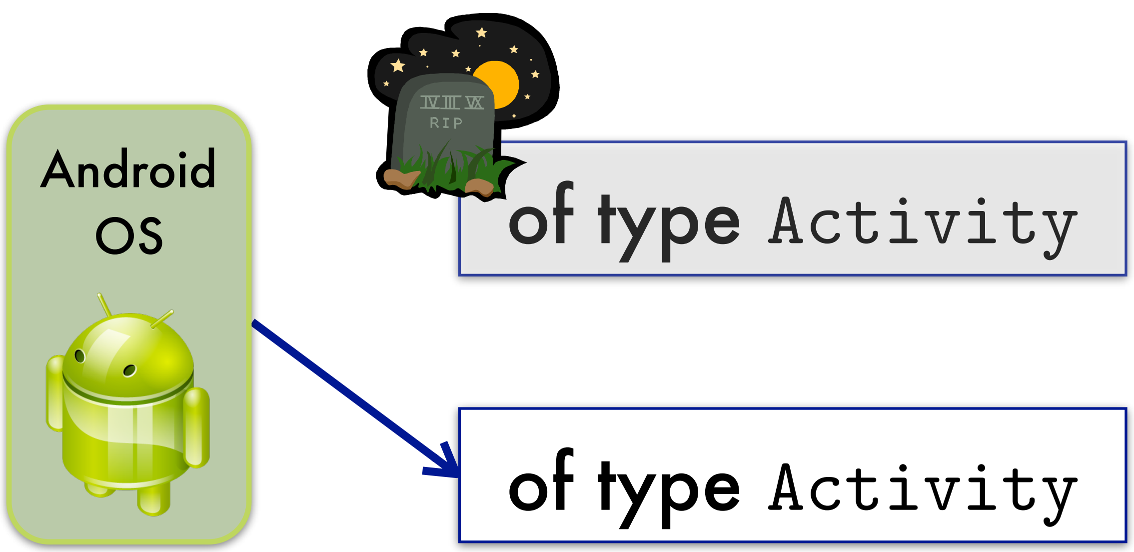
`Activity` objects encapsulate the UI

Android OS

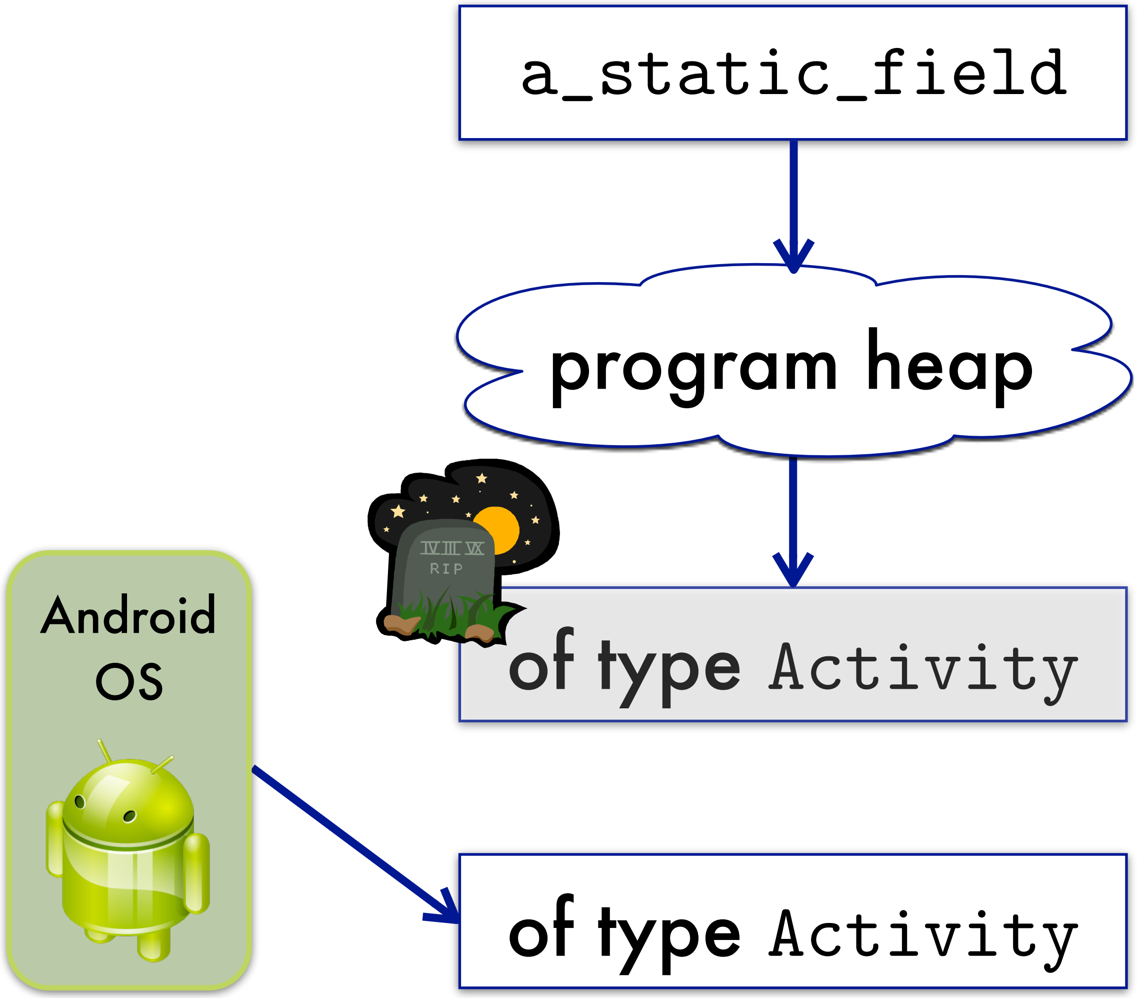
of type `Activity`

Android memory leaks underly rotation-based crashes.

`Activity` objects encapsulate the UI

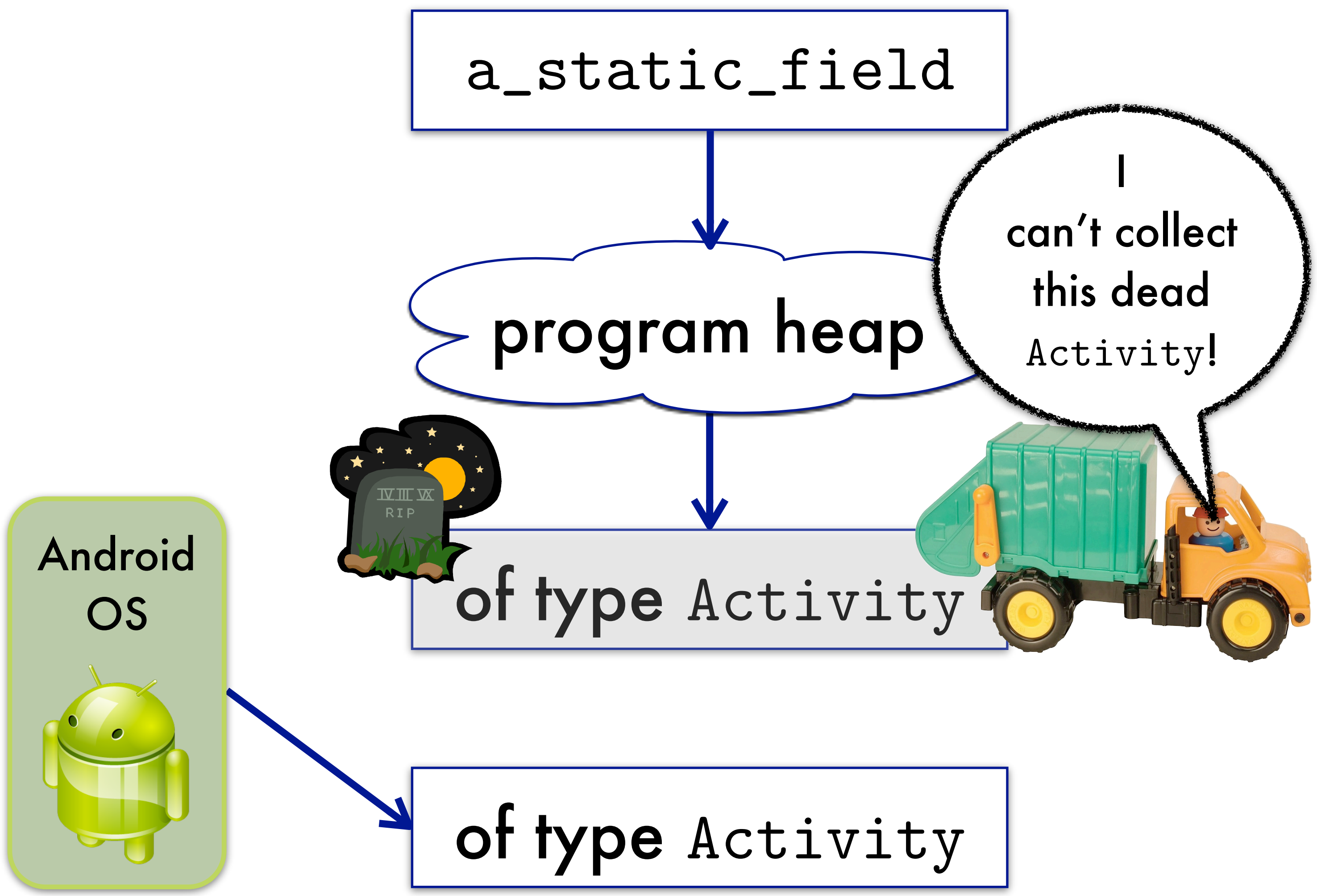


Android memory leaks underly rotation-based crashes.



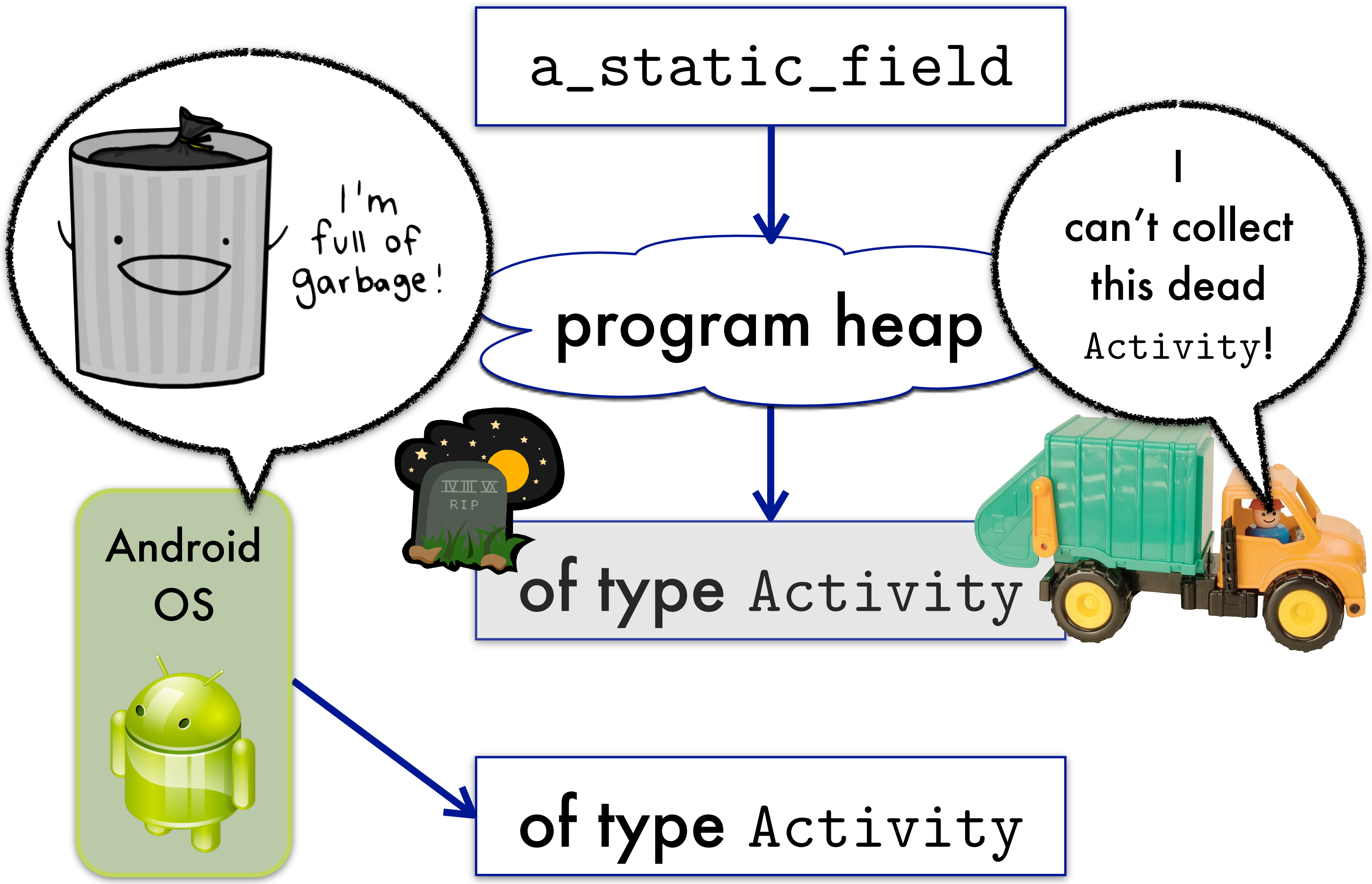
Activity objects encapsulate the UI

Android memory leaks underly rotation-based crashes.



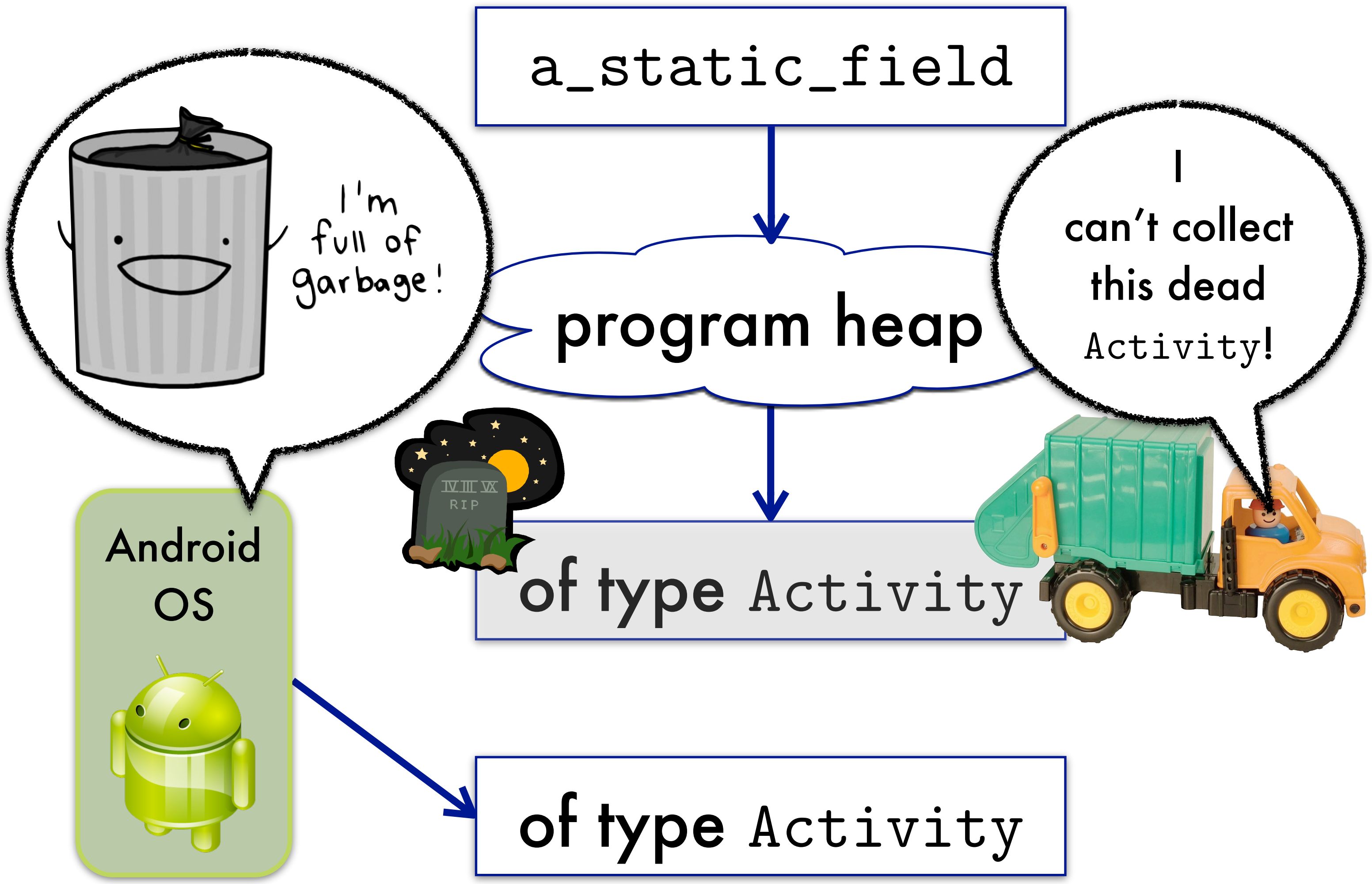
Activity objects encapsulate the UI

Android memory leaks underly rotation-based crashes.

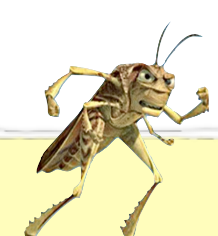


Activity objects encapsulate the UI

Android memory leaks underly rotation-based crashes.

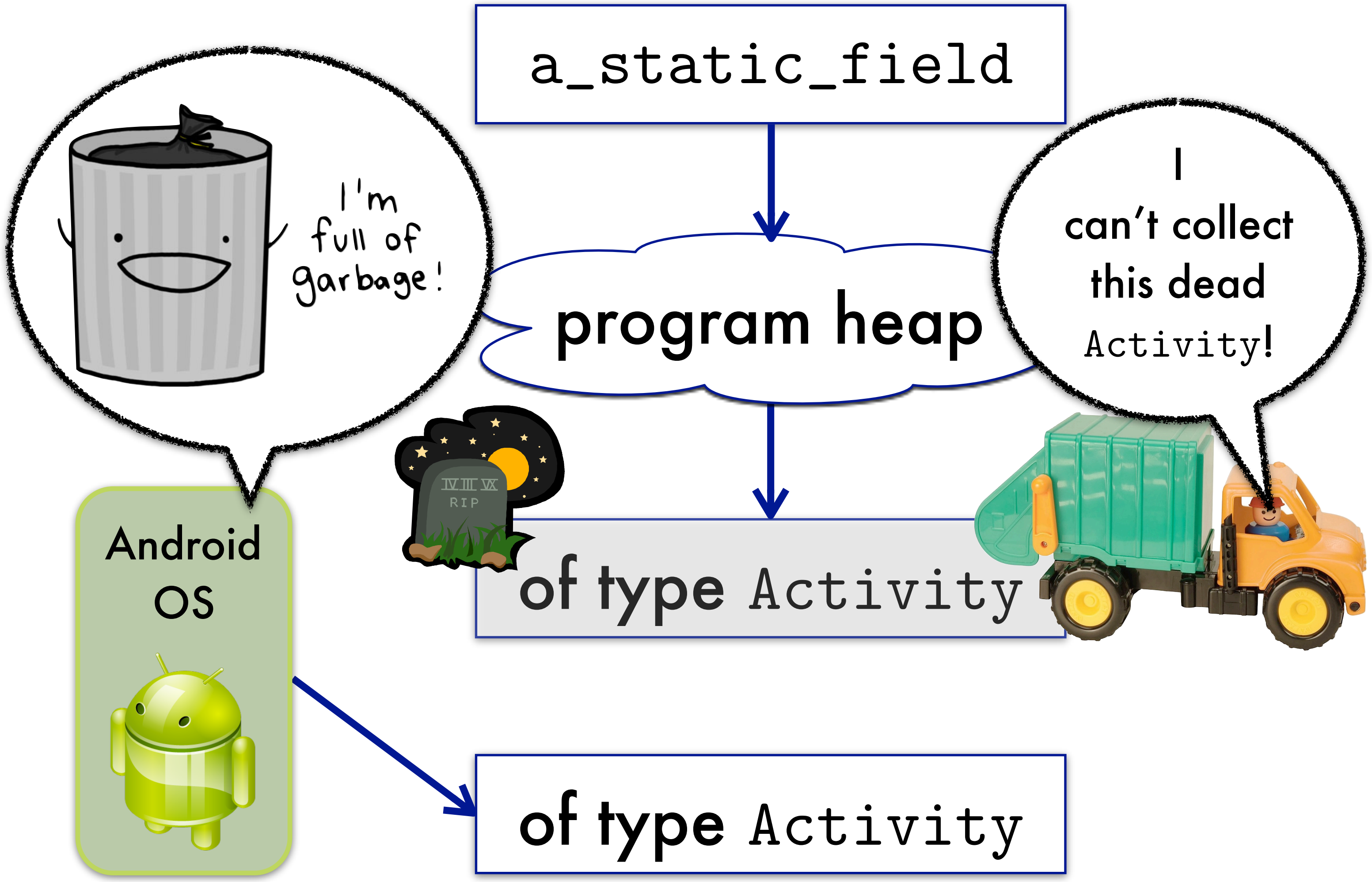


Activity objects encapsulate the UI

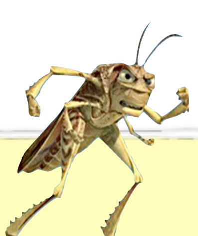


Bug: Holding reference to "old" Activity

Android memory leaks underly rotation-based crashes.



Activity objects encapsulate the UI



"an Activity leak"

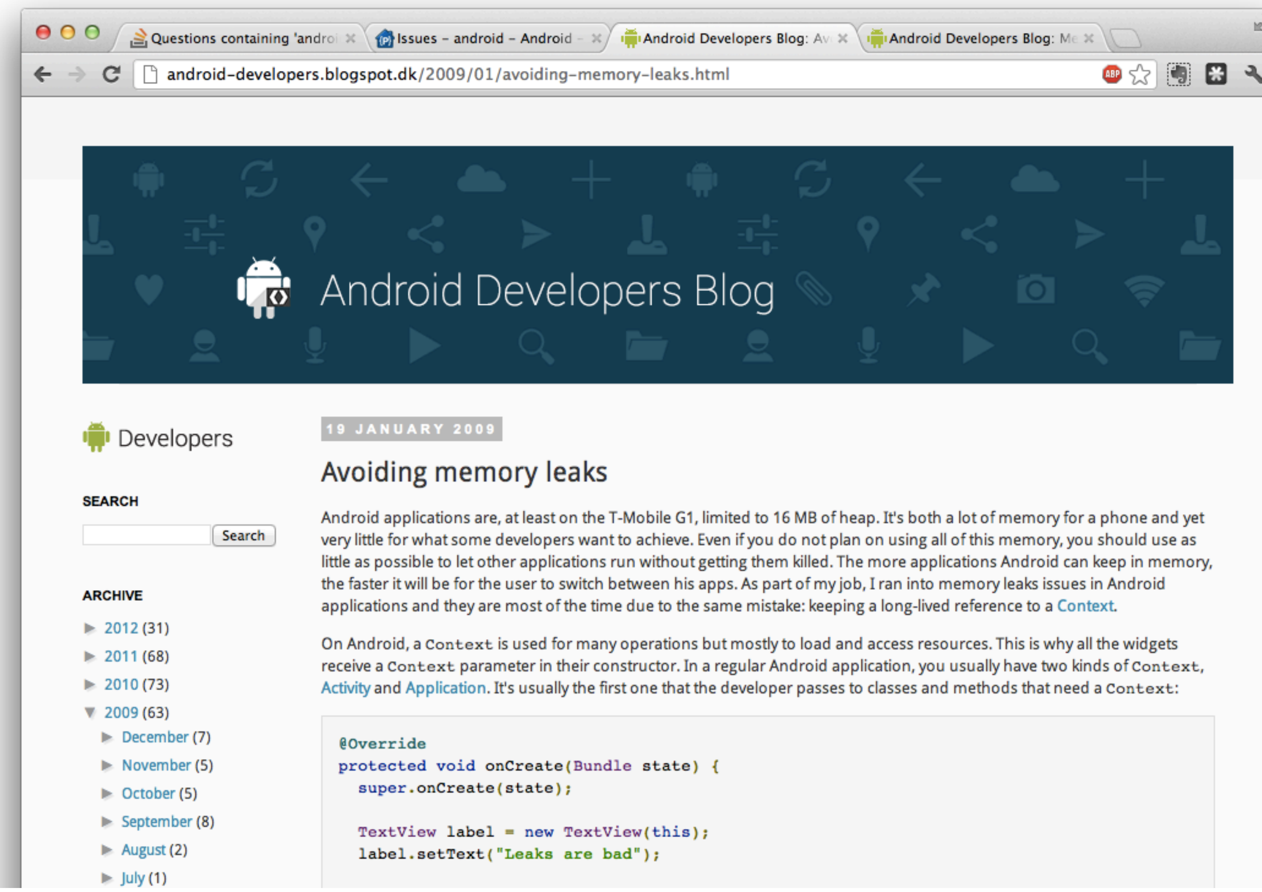
Bug: Holding reference to "old" Activity

The expert recommendation ...

The expert recommendation …

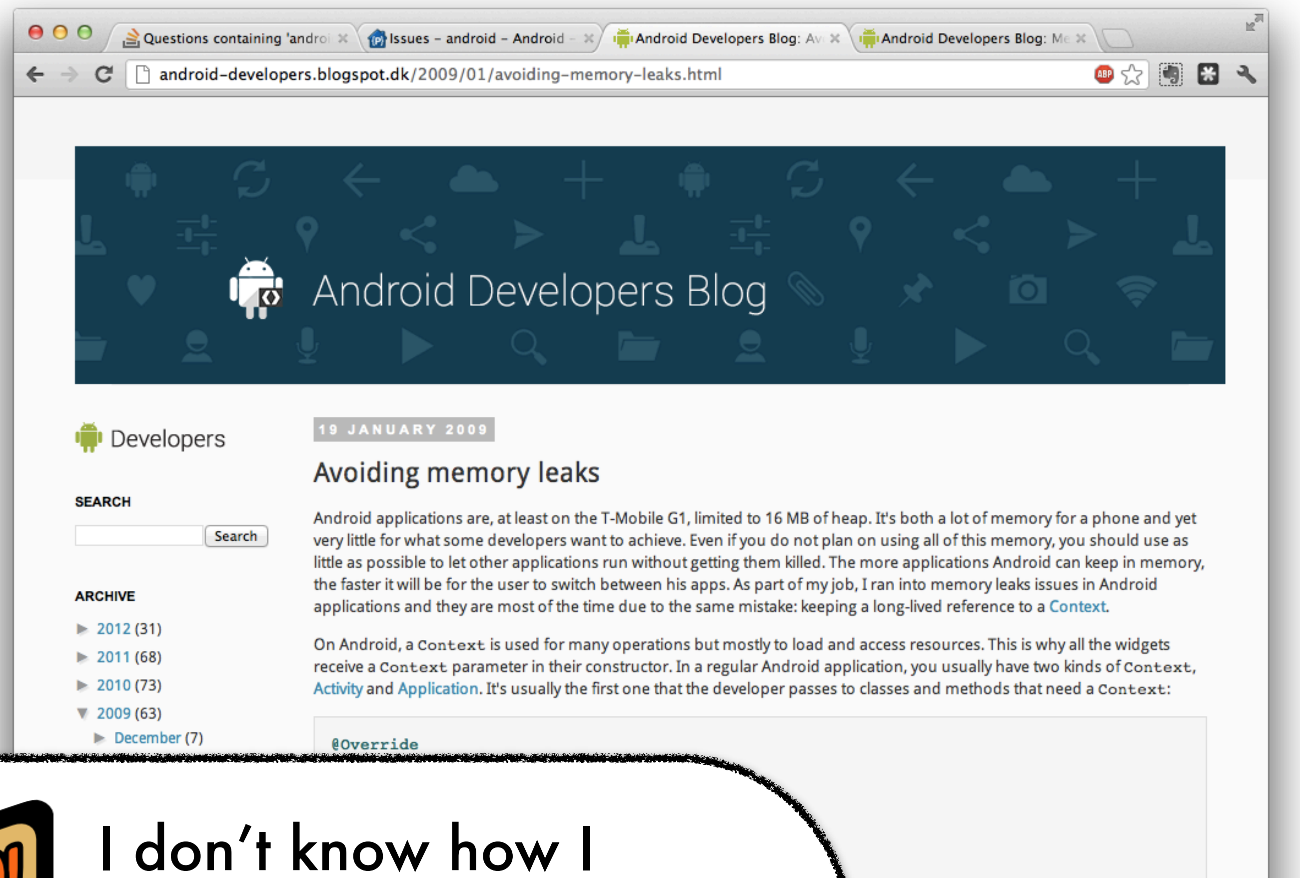
The expert recommendation ...

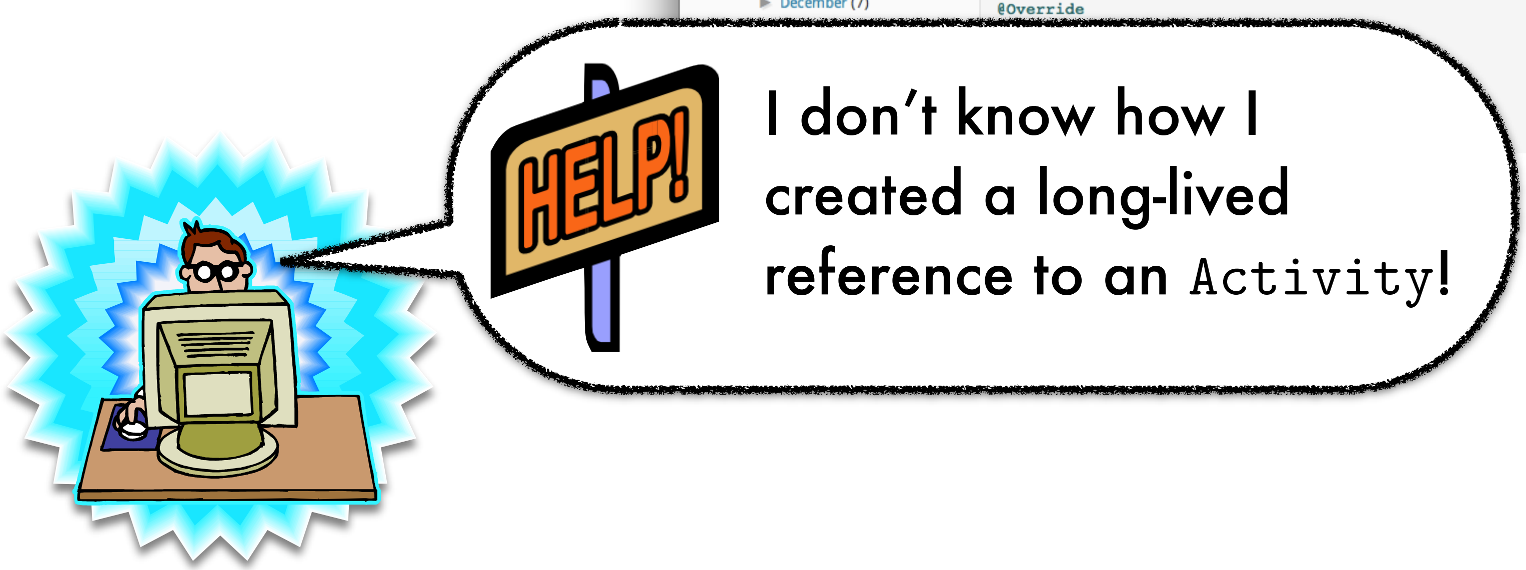
"Do not keep long-lived references to a context-activity"



The expert recommendation ...

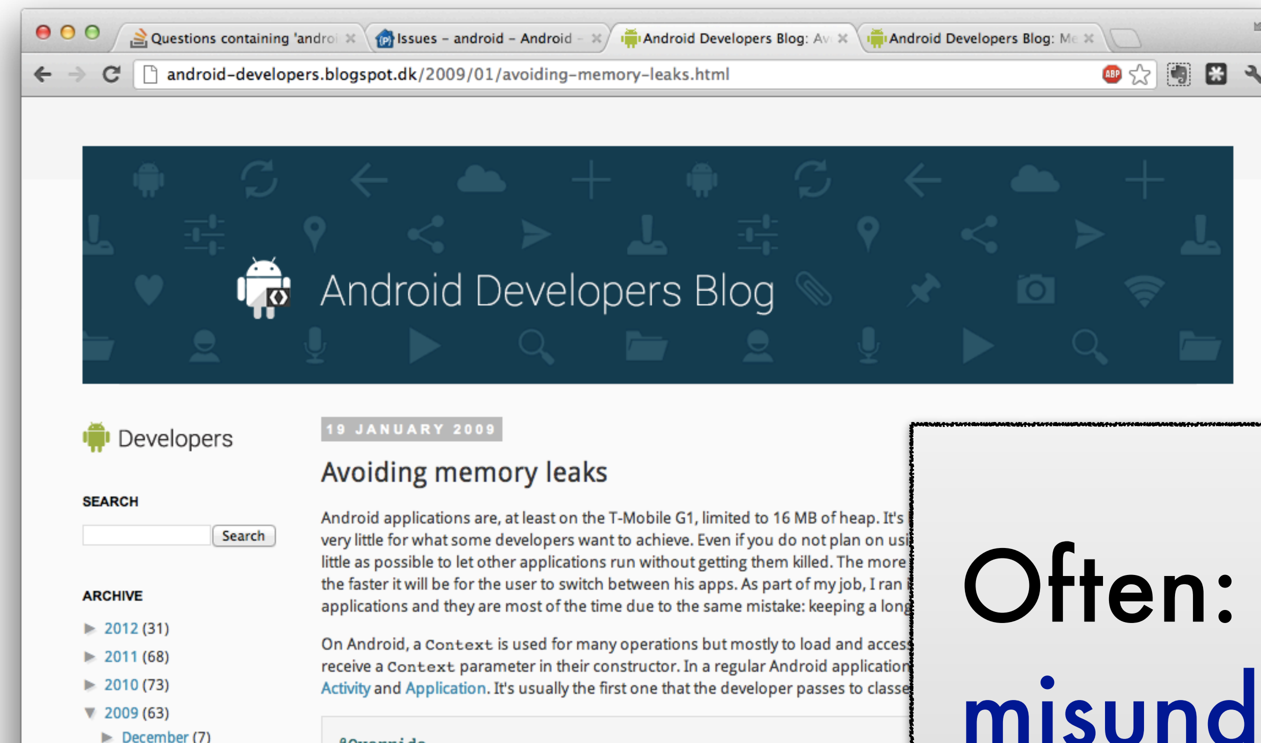
"Do not keep long-lived references to a context-activity"





The expert recommendation ...

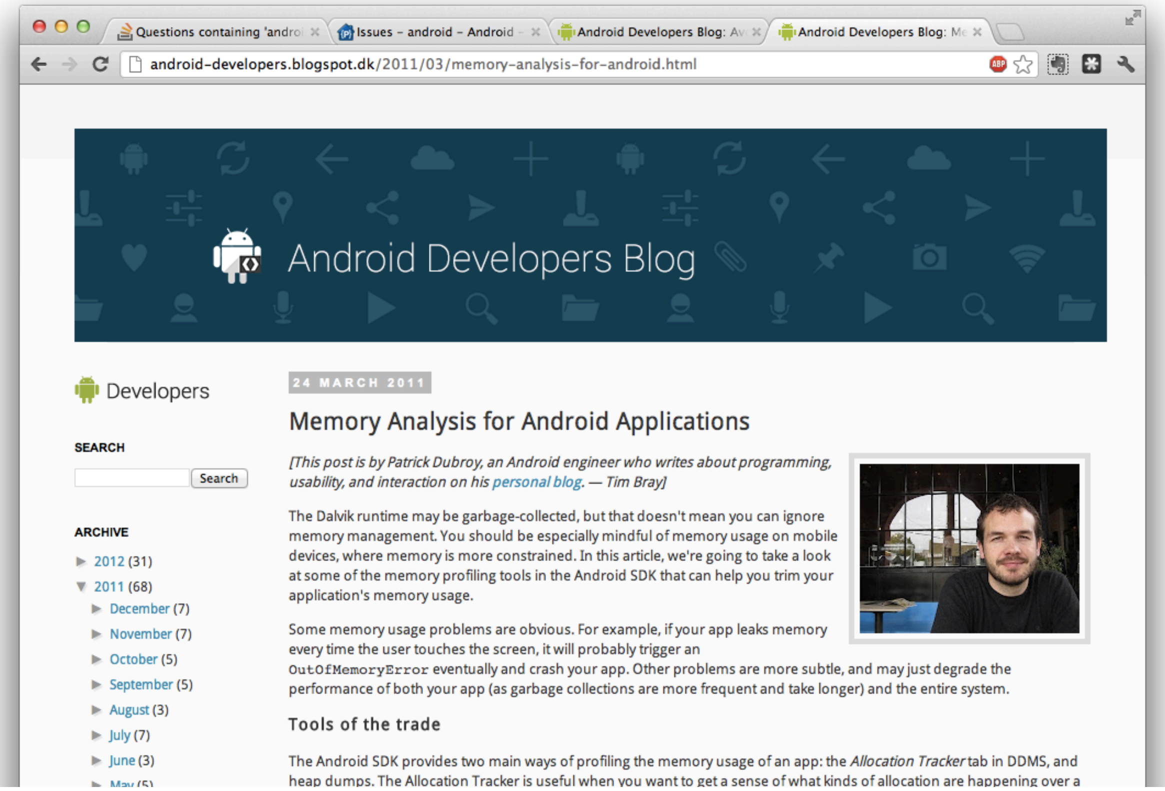
"Do not keep long-lived references to a context-activity"



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 ...


android-developers.blogspot.dk/2011/03/memory-analysis-for-android.html

Android Developers Blog

Developers

SEARCH

ARCHIVE

- 2012 (31)
- 2011 (68)
  - December (7)
  - November (7)
  - October (5)
  - September (5)
  - August (3)
  - July (7)
  - June (3)

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]

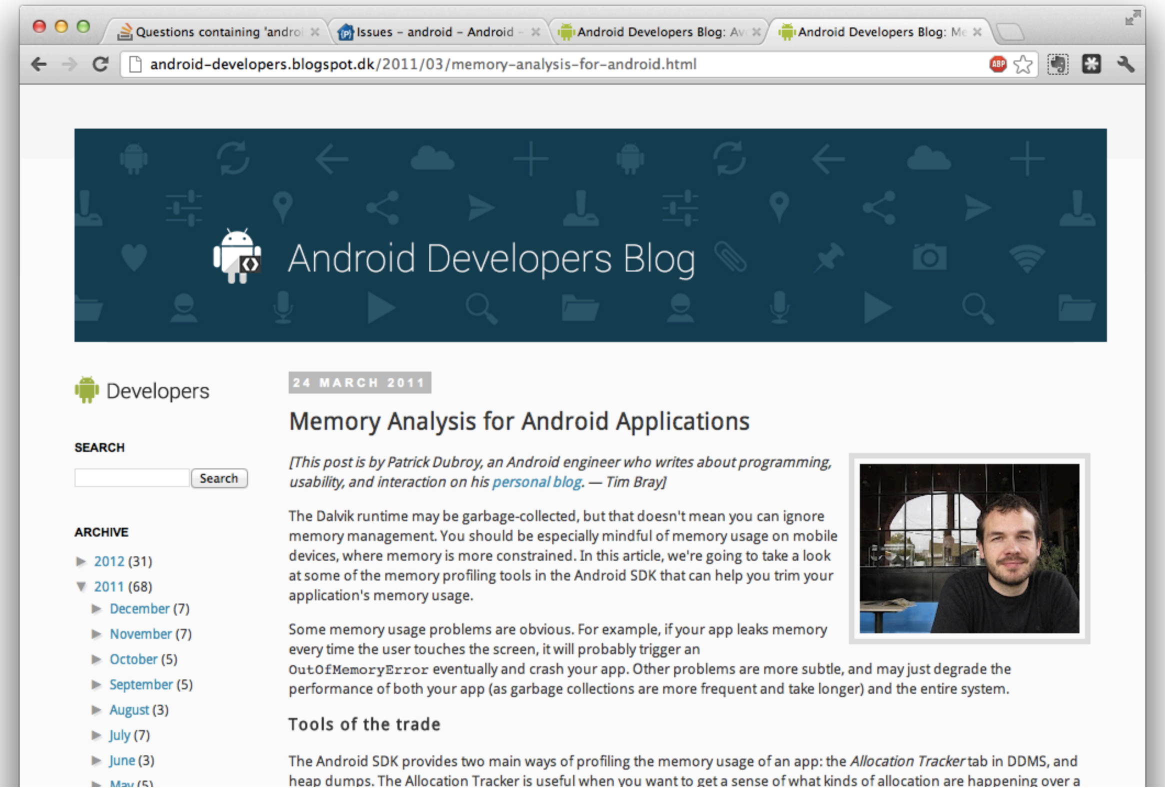
The Dalvik runtime may be garbage-collected, but that doesn't mean you can ignore memory management. You should be especially mindful of memory usage on mobile devices, where memory is more constrained. In this article, we're going to take a look at some of the memory profiling tools in the Android SDK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

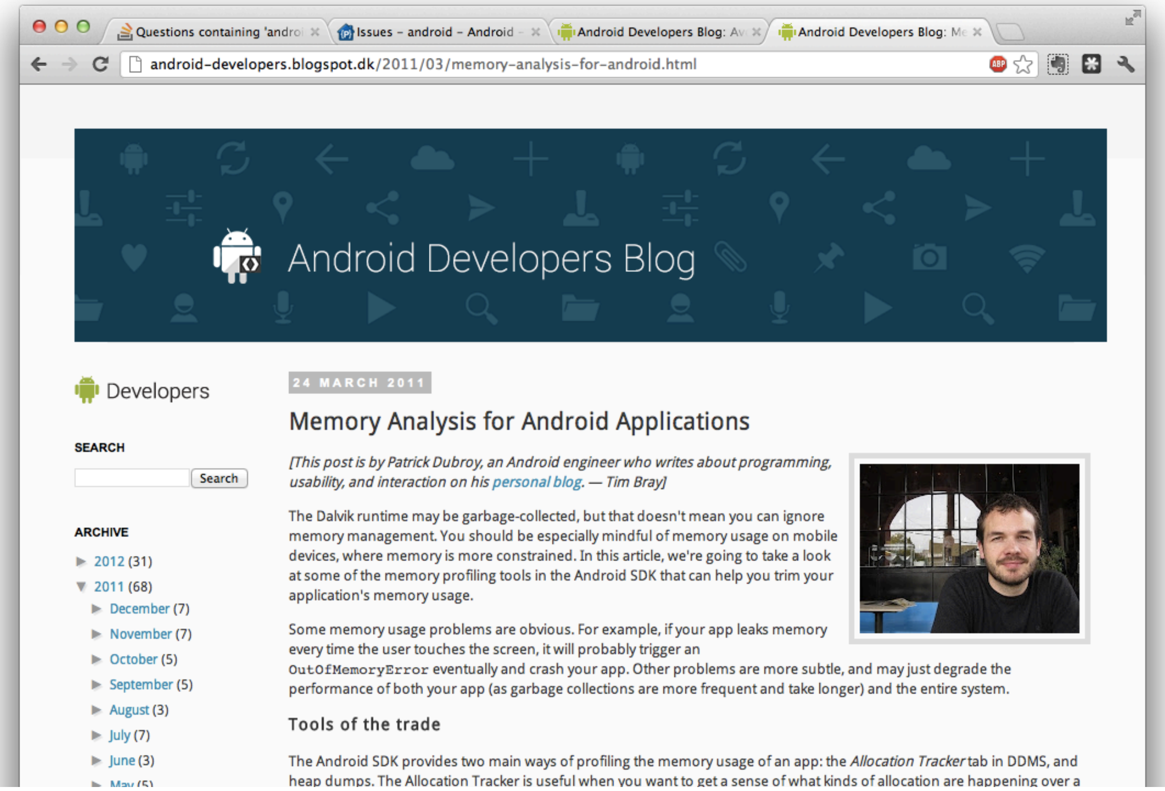
The Android SDK provides two main ways of profiling the memory usage of an app: the *Allocation Tracker* tab in DDMS, and heap dumps. The Allocation Tracker is useful when you want to get a sense of what kinds of allocation are happening over a

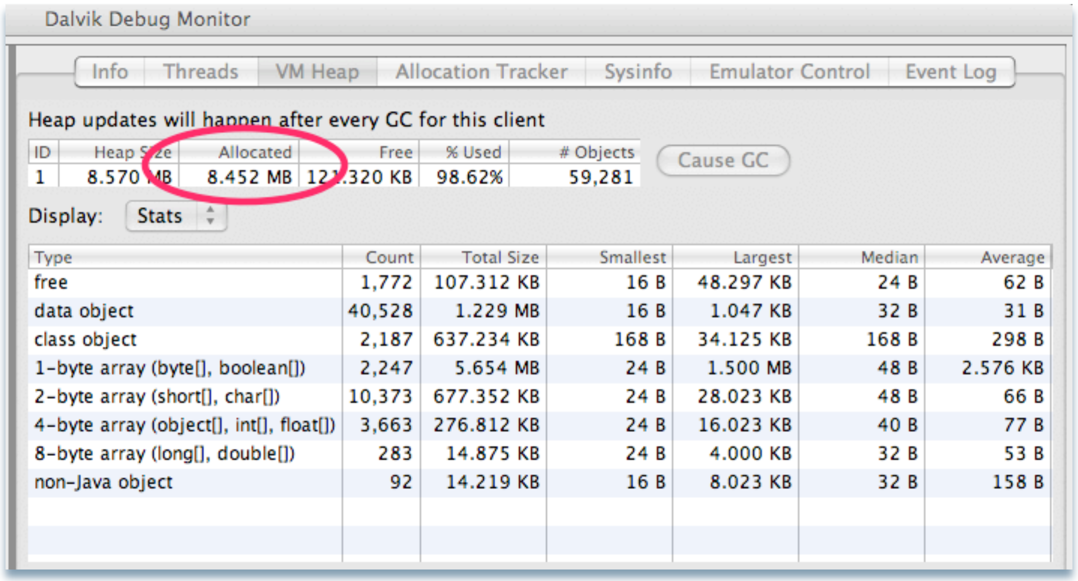
The state of practice in debugging `Activity` leaks …



1. Run the app

The state of practice in debugging `Activity` leaks …





Dalvik Debug Monitor

Info | Threads | VM Heap | Allocation Tracker | Sysinfo | Emulator Control | Event Log

Heap updates will happen after every GC for this client

ID	Heap Size	Allocated	Free	% Used	# Objects
1	8.570 MB	8.452 MB	12[illegible].320 KB	98.62%	59,281

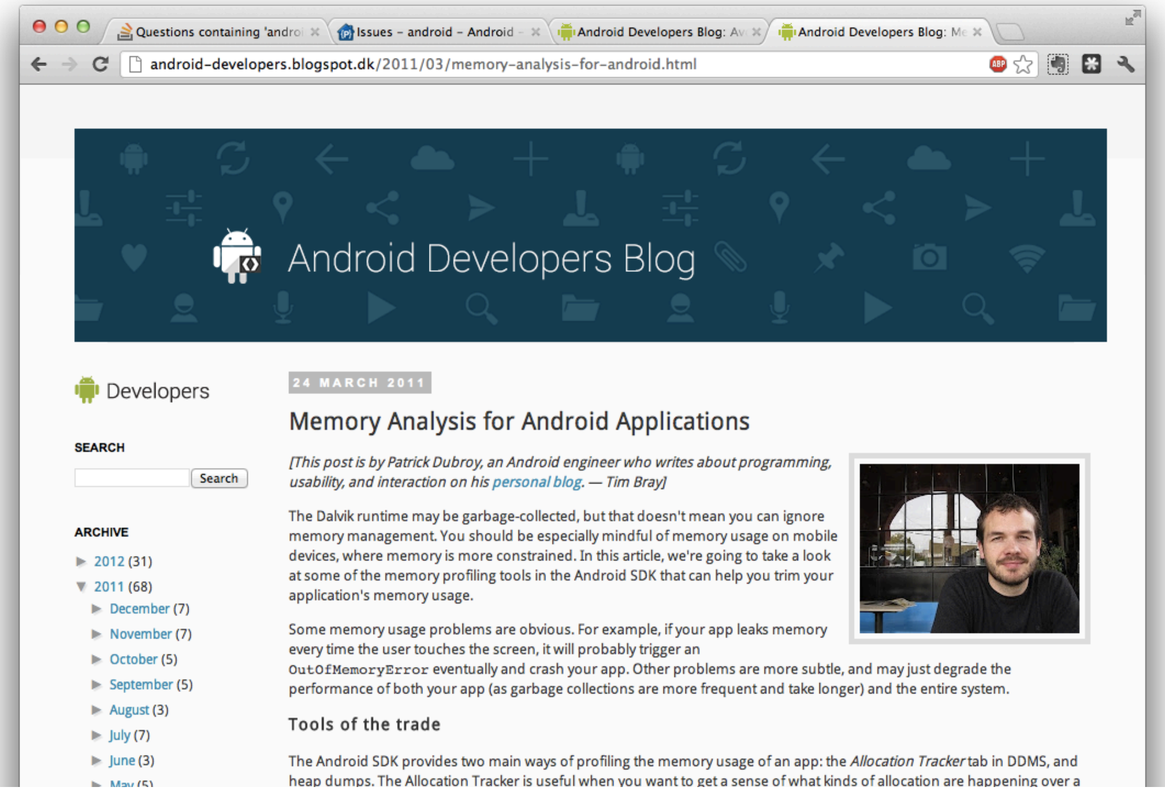
Cause GC

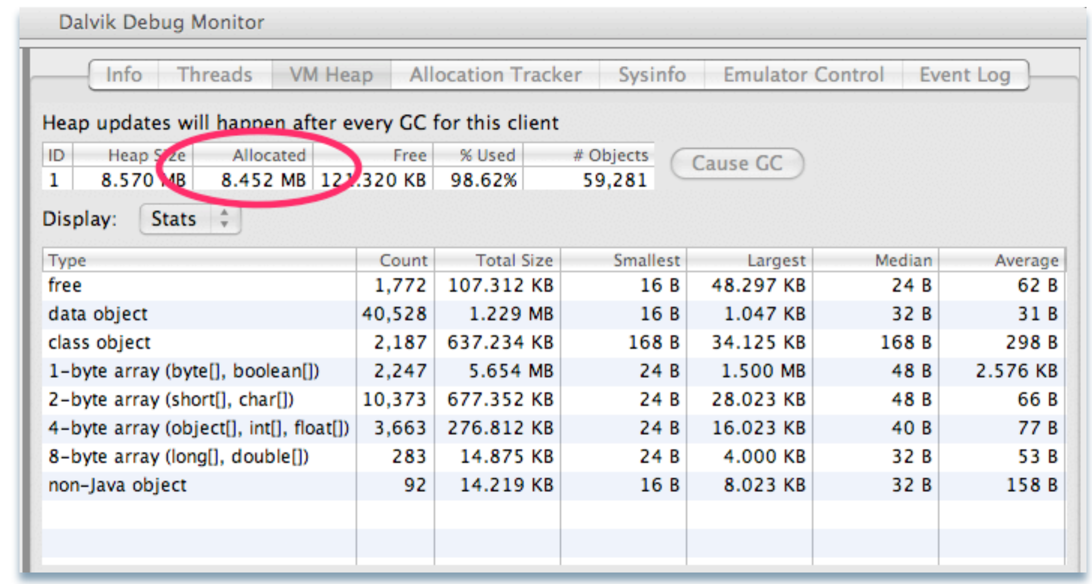
Display: Stats

Type	Count	Total Size	Smallest	Largest	Median	Average
free	1,772	107.312 KB	16 B	48.297 KB	24 B	62 B
data object	40,528	1.229 MB	16 B	1.047 KB	32 B	31 B
class object	2,187	637.234 KB	168 B	34.125 KB	168 B	298 B
1-byte array (byte[], boolean[])	2,247	5.654 MB	24 B	1.500 MB	48 B	2.576 KB
2-byte array (short[], char[])	10,373	677.352 KB	24 B	28.023 KB	48 B	66 B
4-byte array (object[], int[], float[])	3,663	276.812 KB	24 B	16.023 KB	40 B	77 B
8-byte array (long[], double[])	283	14.875 KB	24 B	4.000 KB	32 B	53 B
non-Java object	92	14.219 KB	16 B	8.023 KB	32 B	158 B

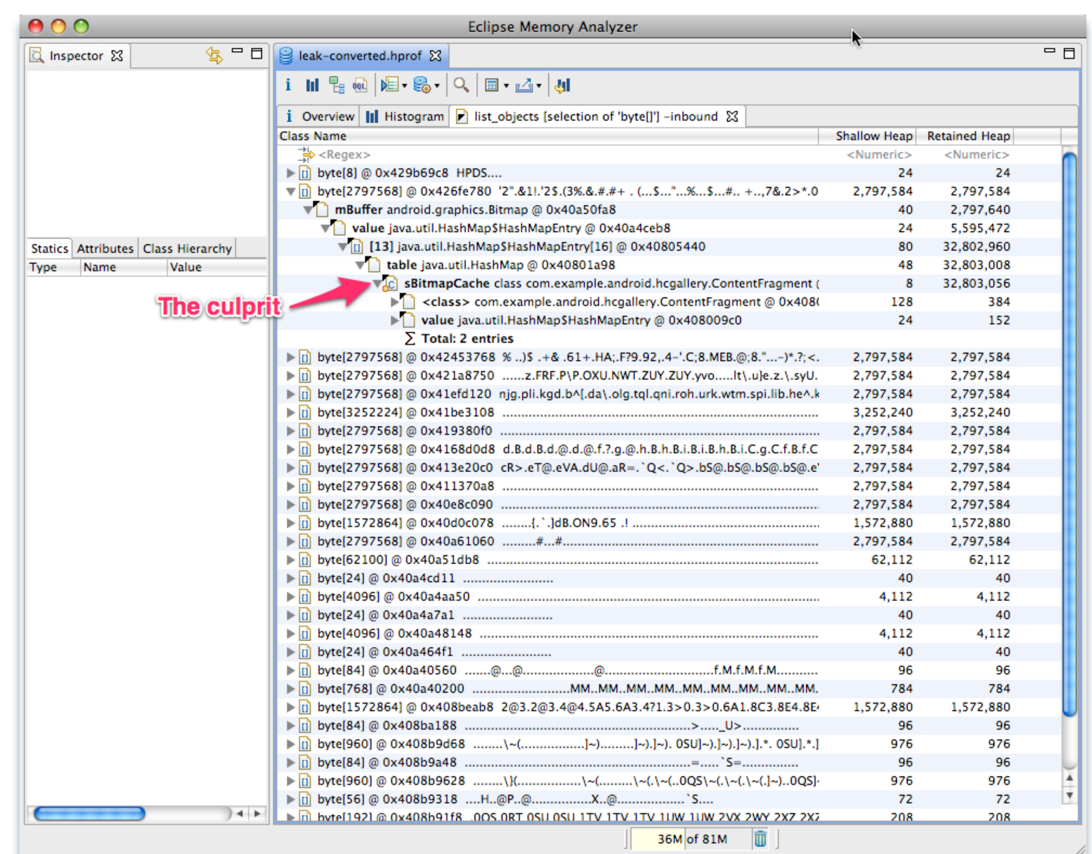
1. Run the app
2. Watch the heap usage

The state of practice in debugging `Activity` leaks …





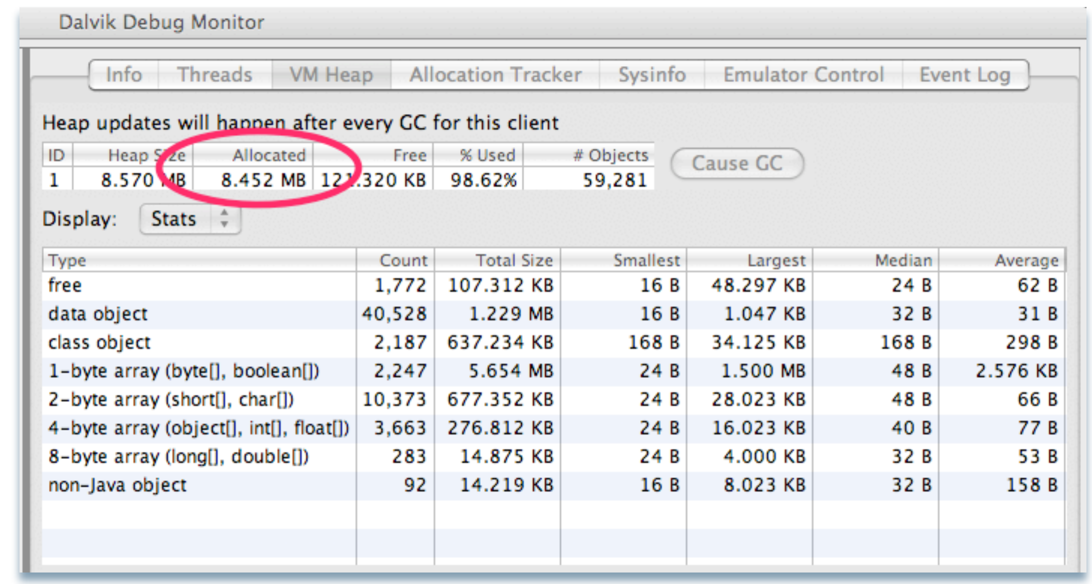
1. Run the app
2. Watch the heap usage
3. Dump the heap. Dig around and **hope** to find the culprit

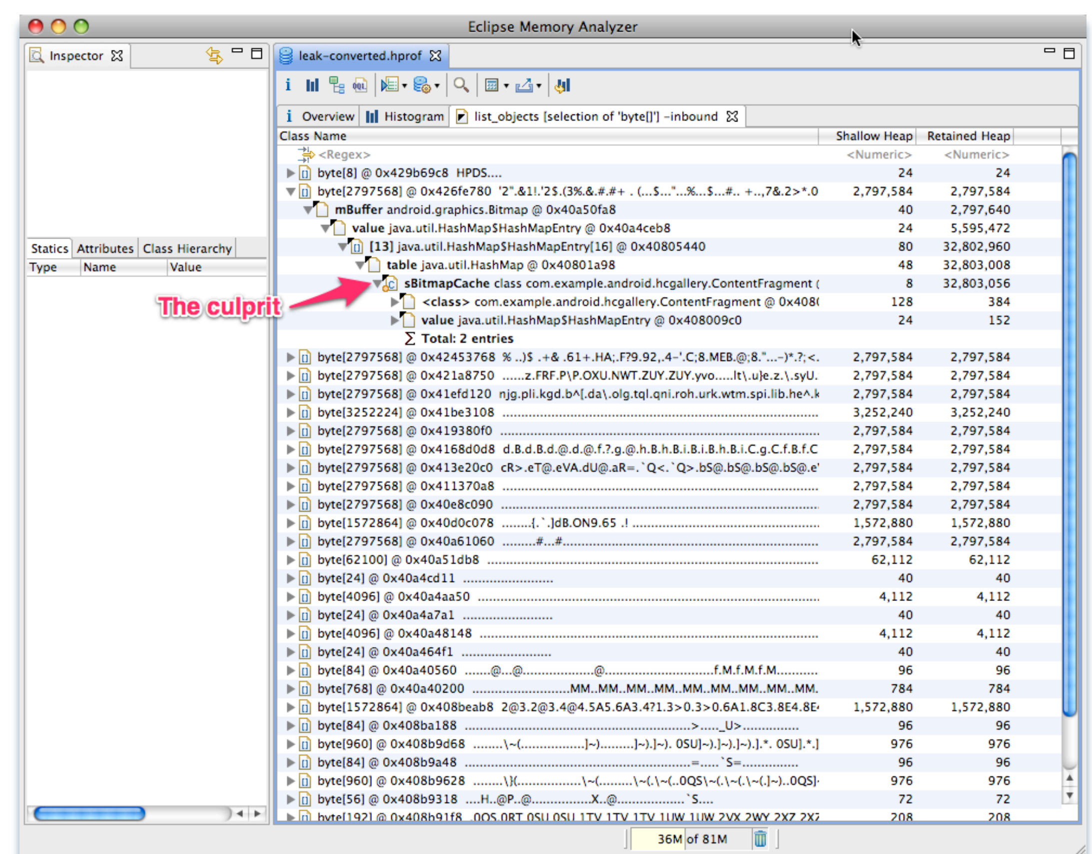


The state of practice in debugging `Activity` leaks ...

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?



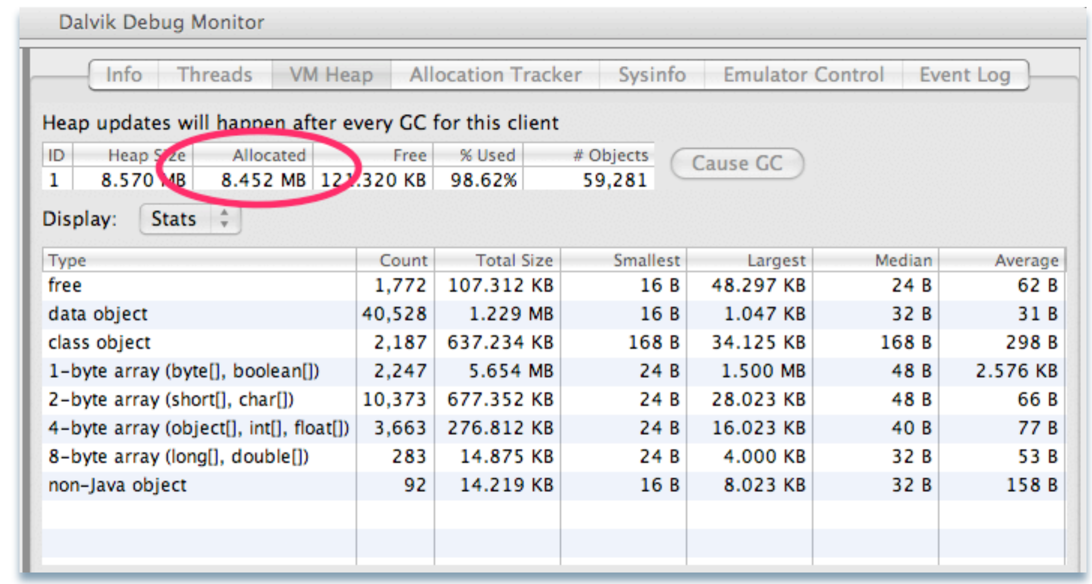


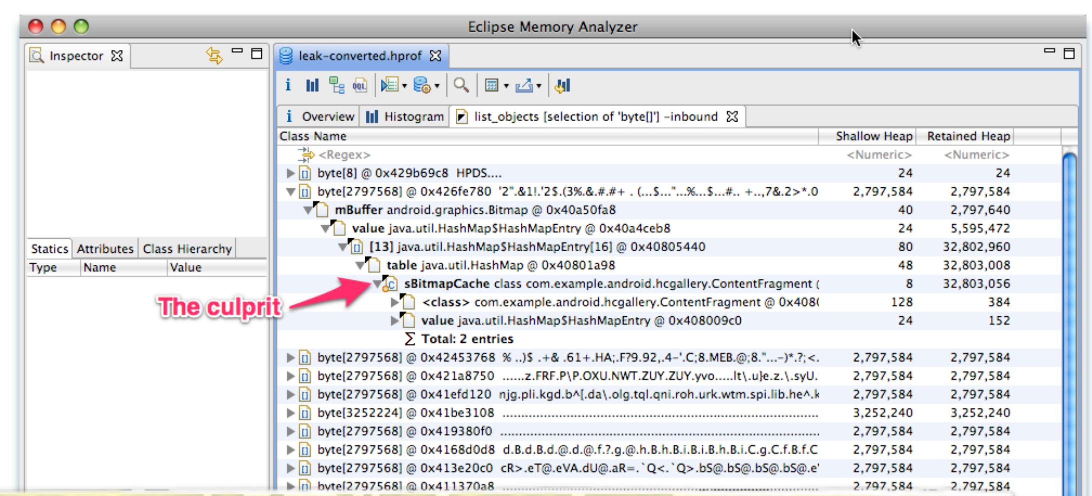
3. Dump the heap. Dig around and hope to find the culprit

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?





3. Dump the hea Dig

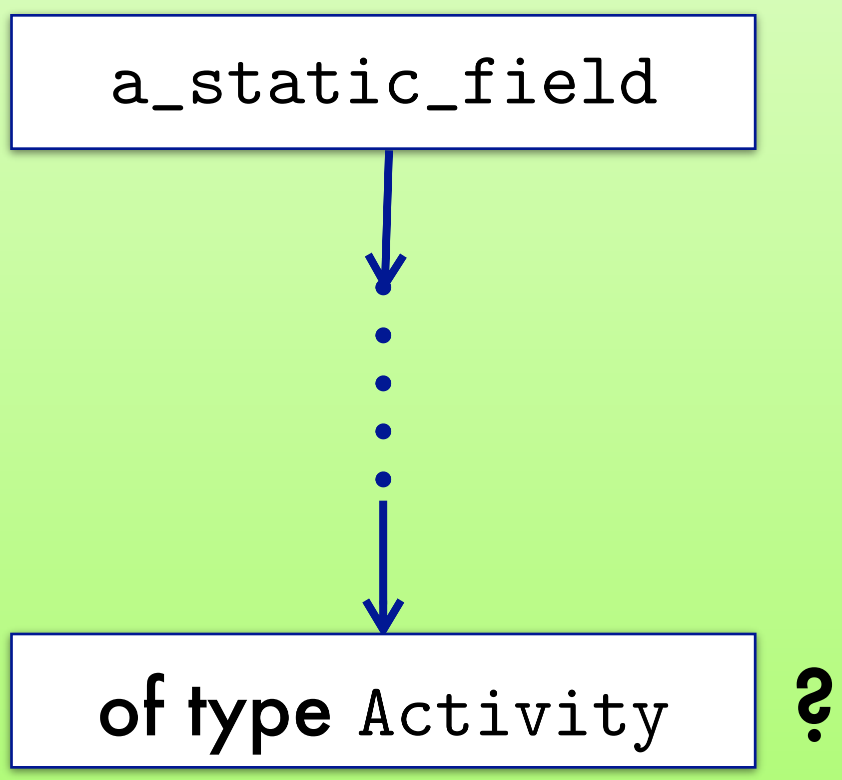
“One of the most dreaded bugs in Android is a memory leak. They are nasty because one piece of code causes an issue and in some other piece of code, your application crashes.” – http://therockncoder.blogspot.com/2012/09/fixing-android-memory-leak.html


Program
Analysis

Answering “Is there an `Activity` leak?” with program analysis …

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

Is there a program execution where at some time



Example

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

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

Is there a program execution where at some time

`a_static_field`

⋮

of type `Activity` ?

Example

Can be answered with a points-to analysis

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

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

Is there a program execution where at some time

`a_static_field`

⋮

of type `Activity` ?

Example

Can be answered with a points-to analysis

Hidden Truth

with **approximation**

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

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

Is there a program execution where at some time

`a_static_field`

↓ ⋮ ↓

of type `Activity` ?

Example

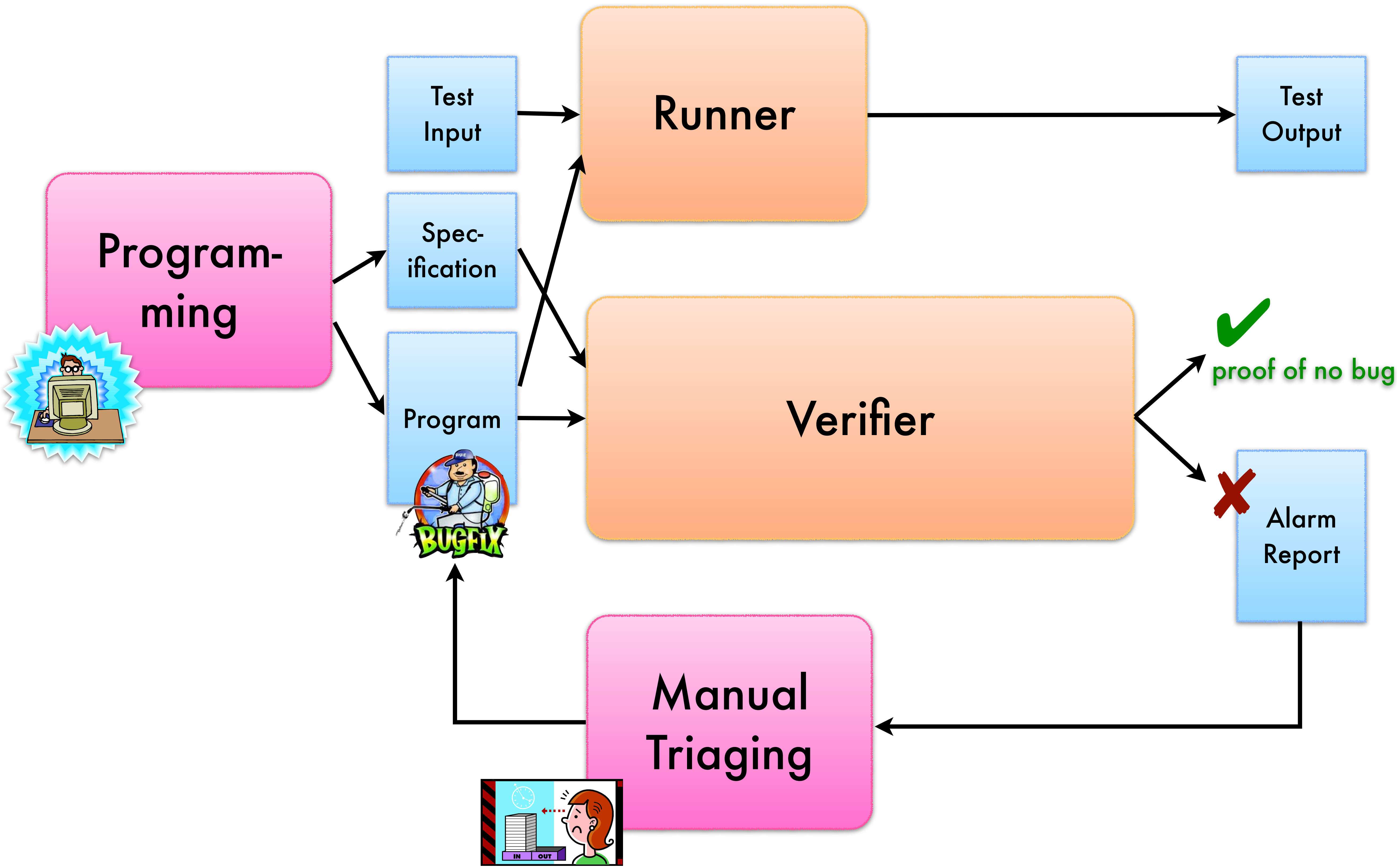
Can be answered with a points-to analysis

Hidden Truth

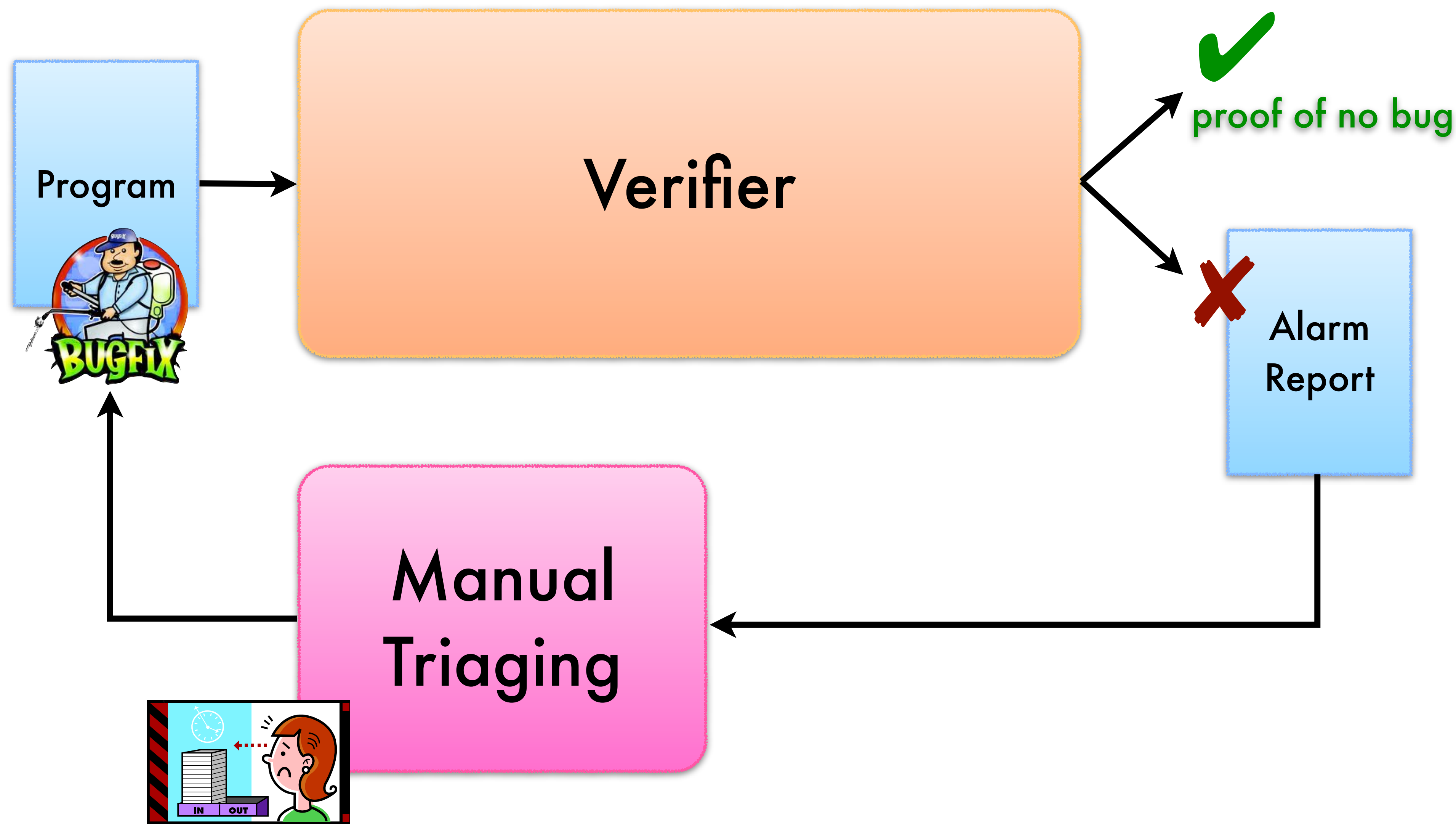
with **approximation**

Some pointer relations **may** be false

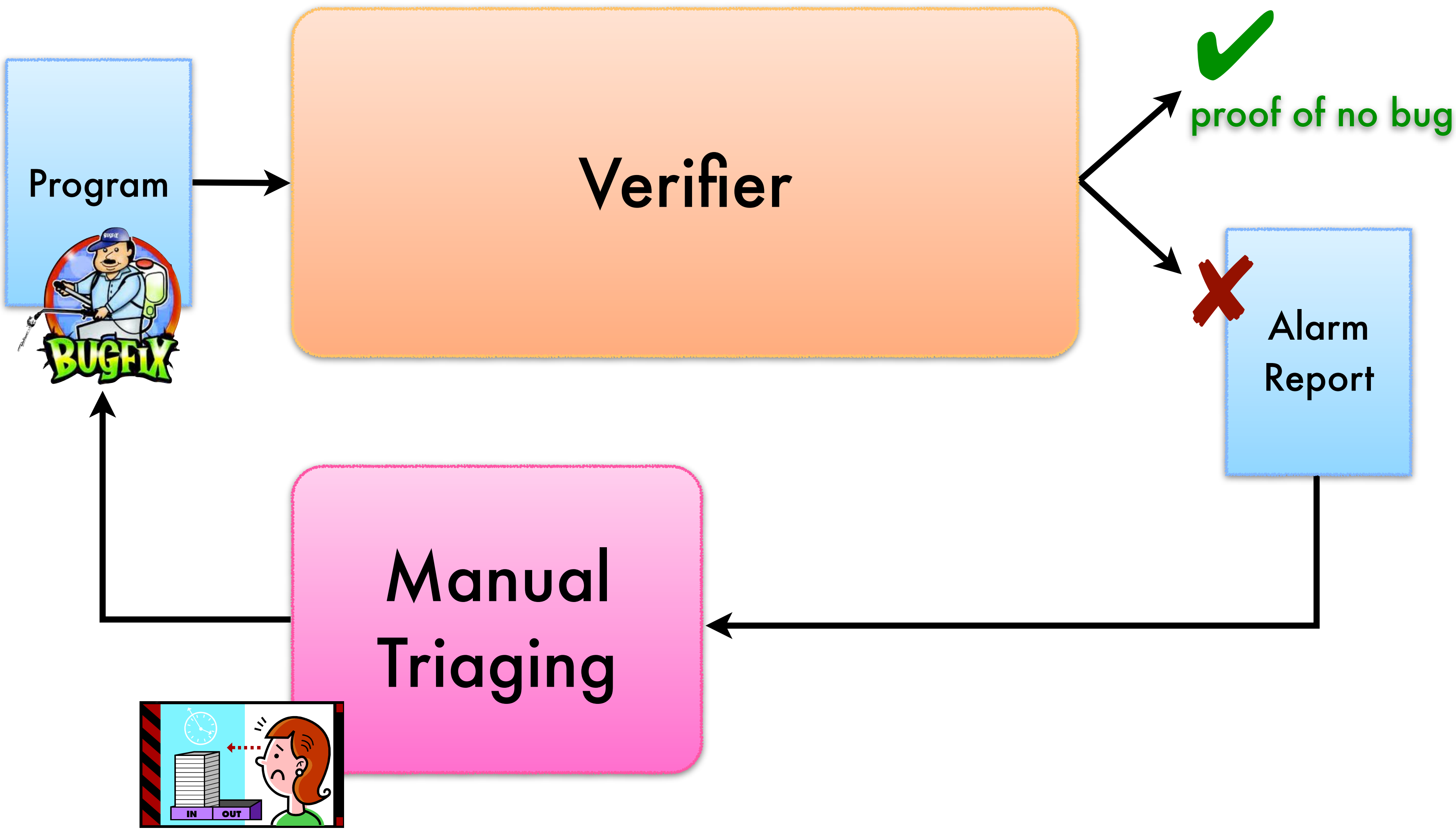
But with the cooperative approach ...



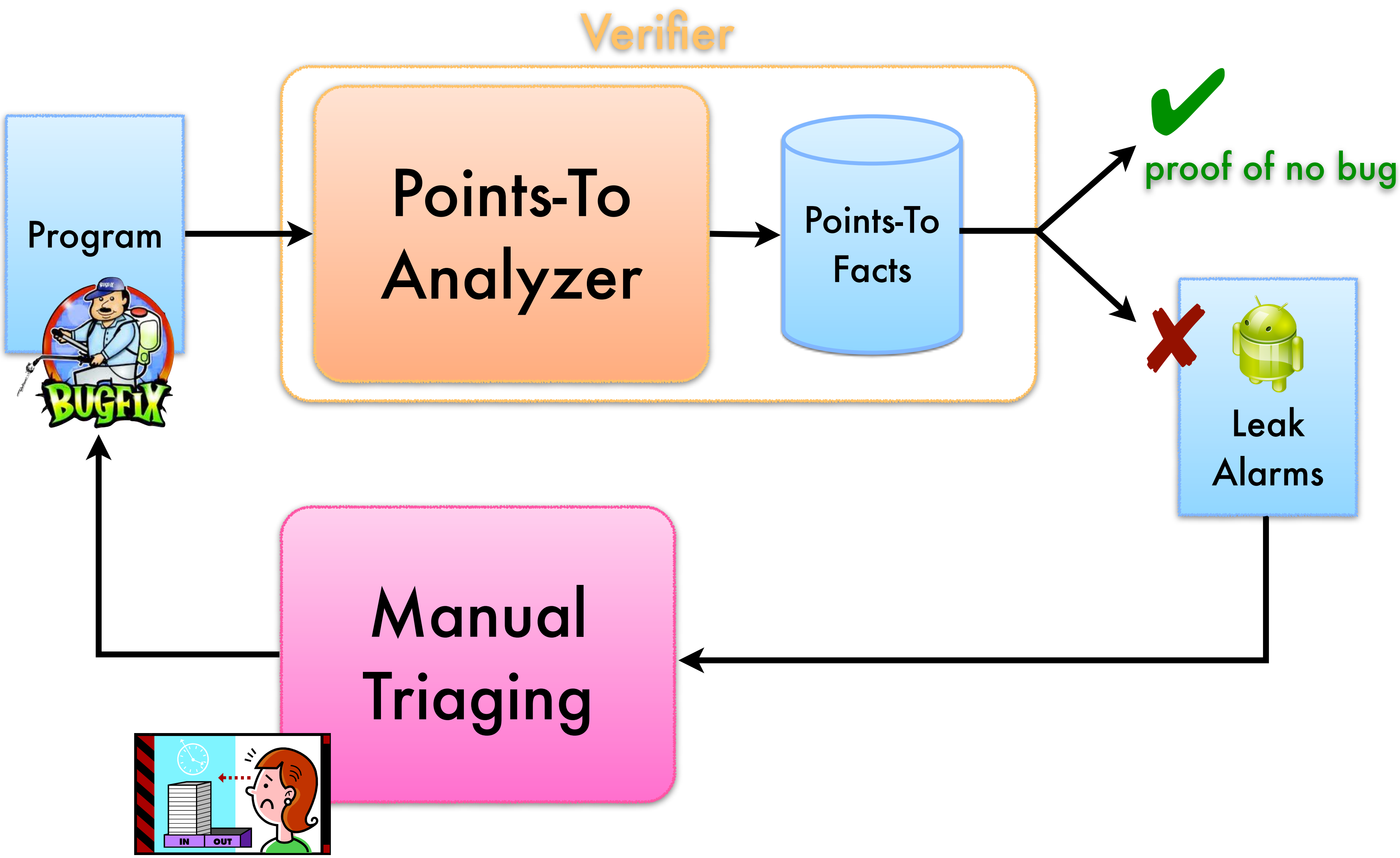
But with the cooperative approach ...



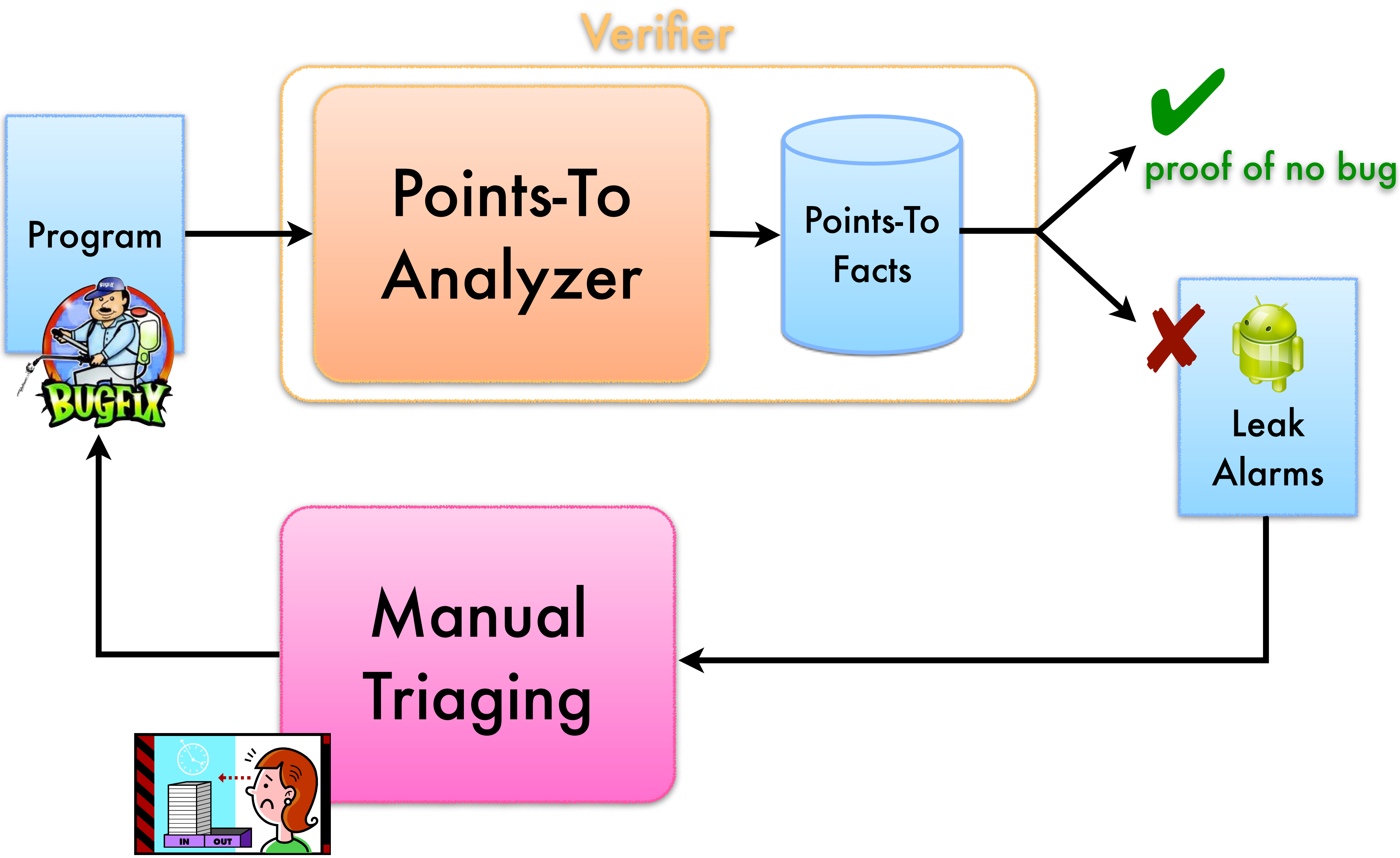
Thresher addresses alarm **triage** in a particularly challenging domain.



Thresher addresses alarm **triage** in a particularly challenging domain.

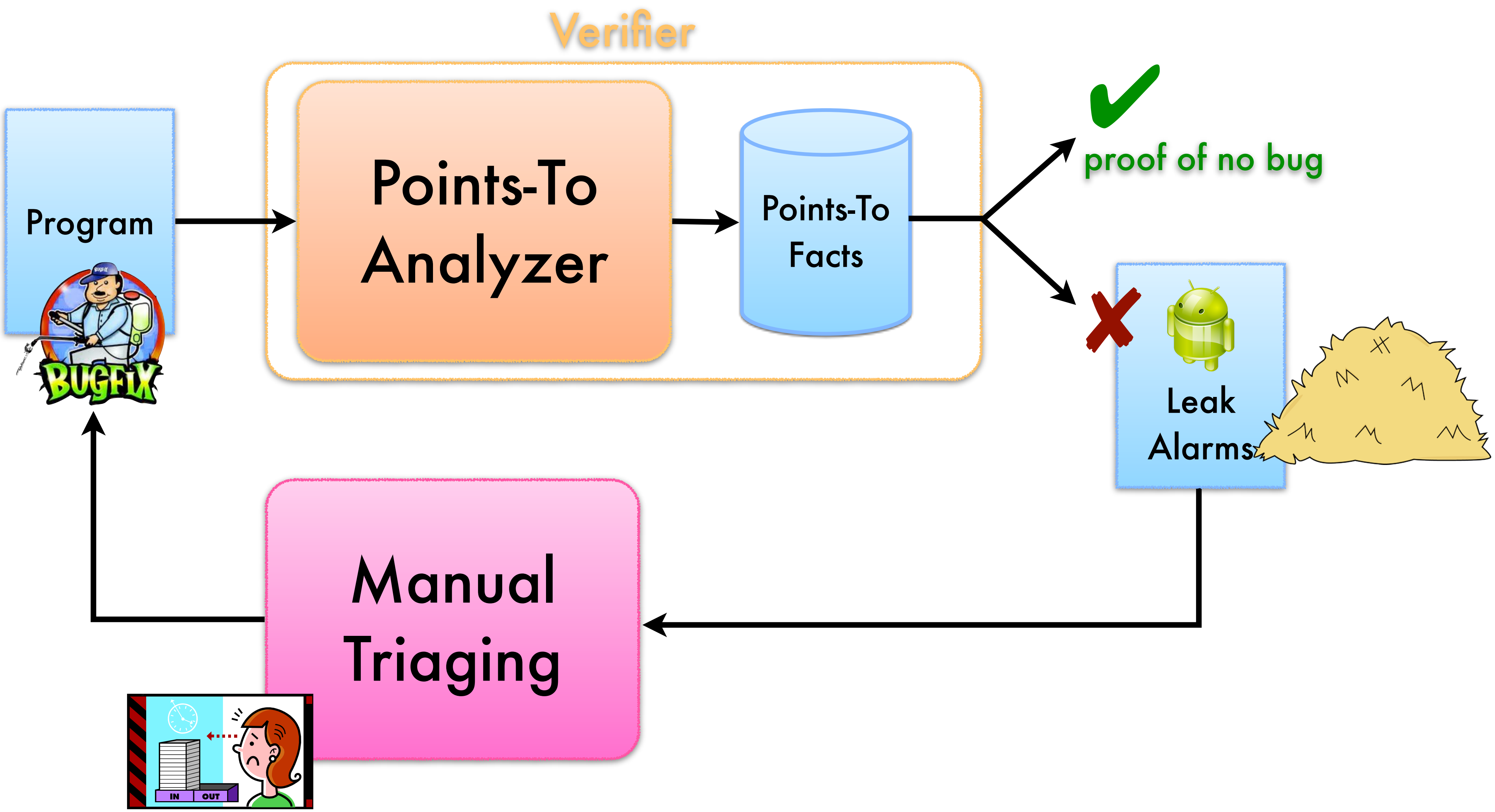


Thresher addresses alarm **triage** in a particularly challenging domain.



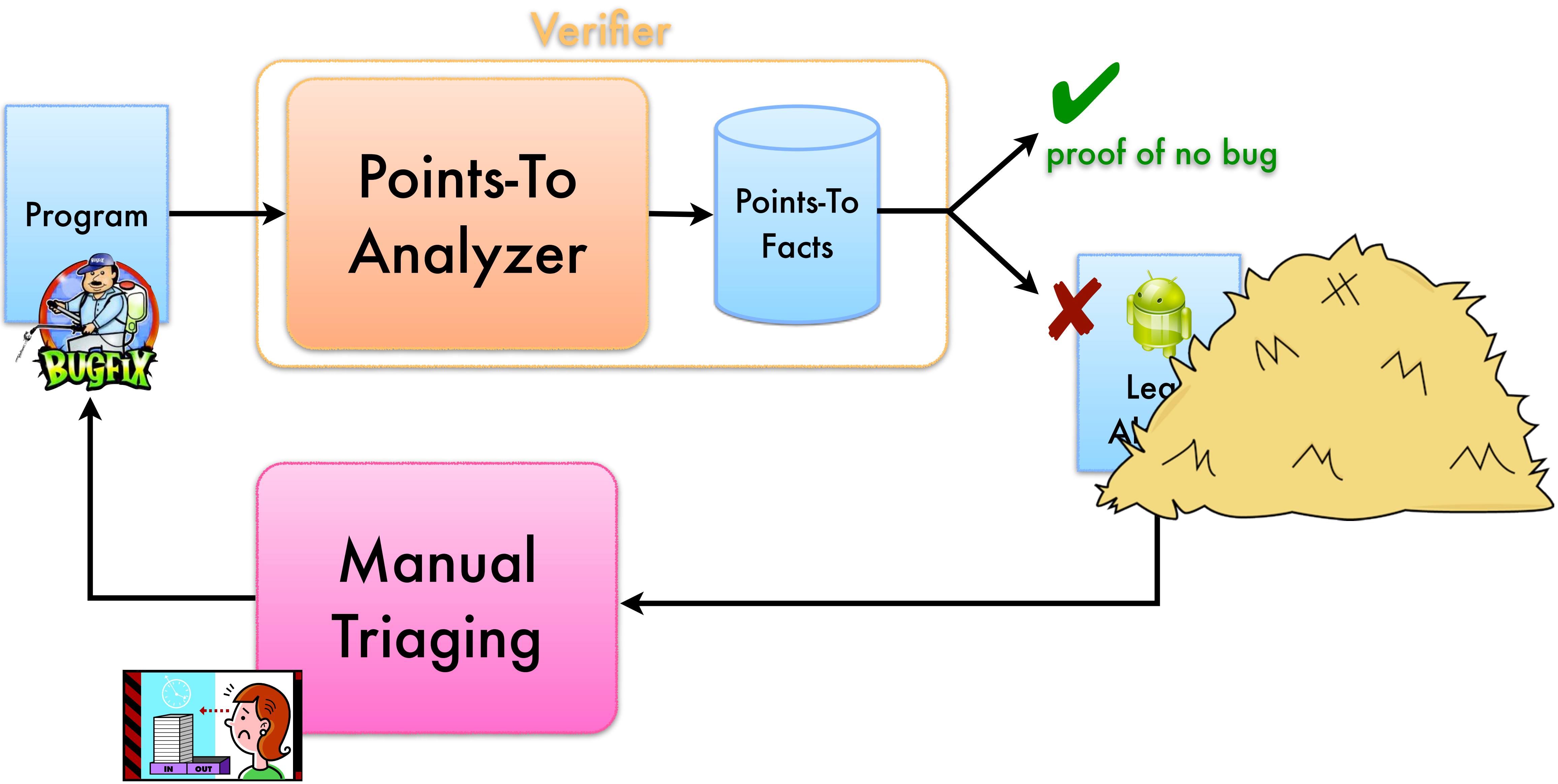
Known: Precise points-to analysis challenging

Thresher addresses alarm **triage** in a particularly challenging domain.



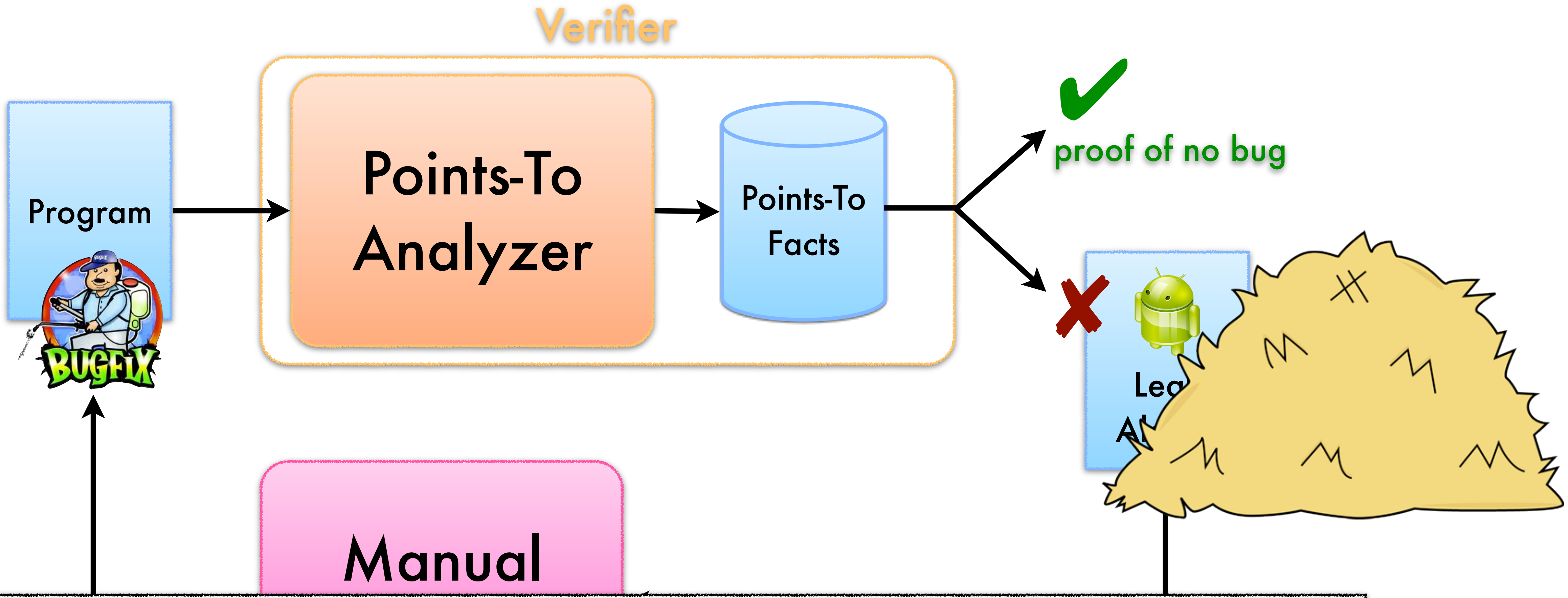
Known: Precise points-to analysis challenging

Thresher addresses alarm **triage** in a particularly challenging domain.



Known: Precise points-to analysis challenging

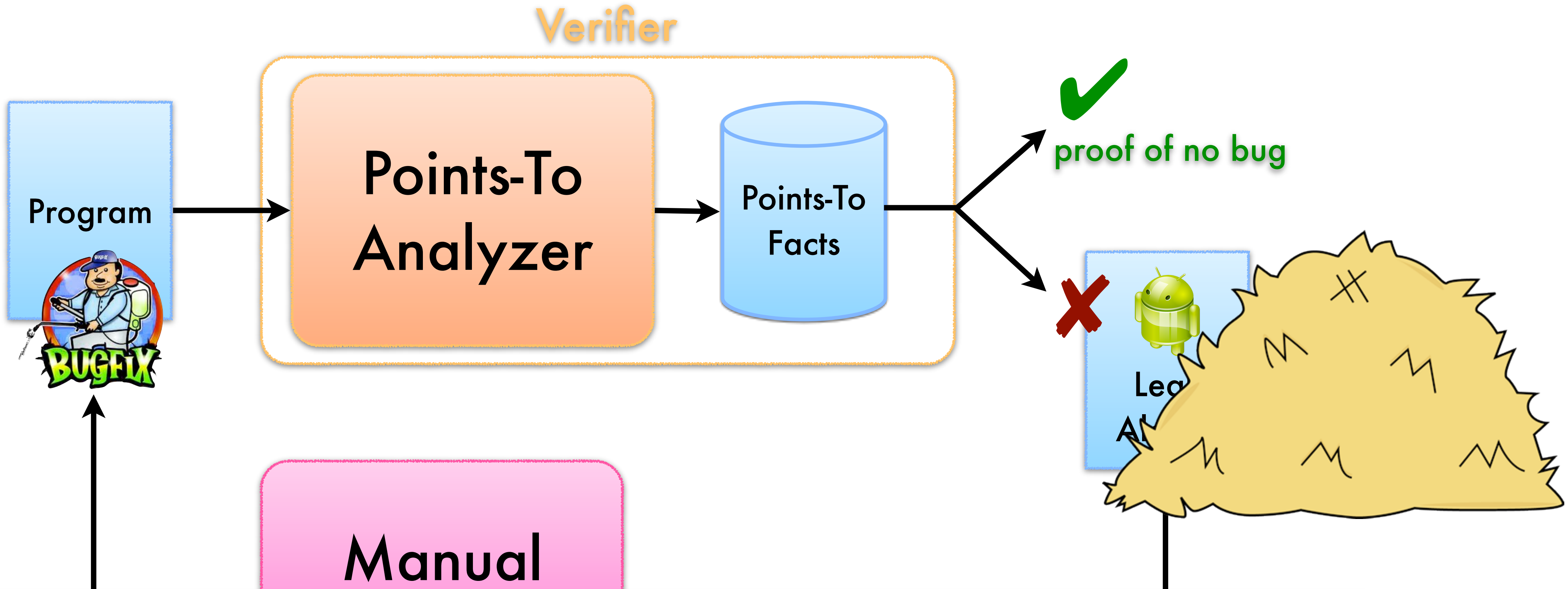
Thresher addresses alarm **triage** in a particularly challenging domain.



Hind. “Pointer Analysis: Haven’t We Solved This Problem Yet?”

Known: Precise points-to analysis challenging

Thresher addresses alarm **triage** in a particularly challenging domain.

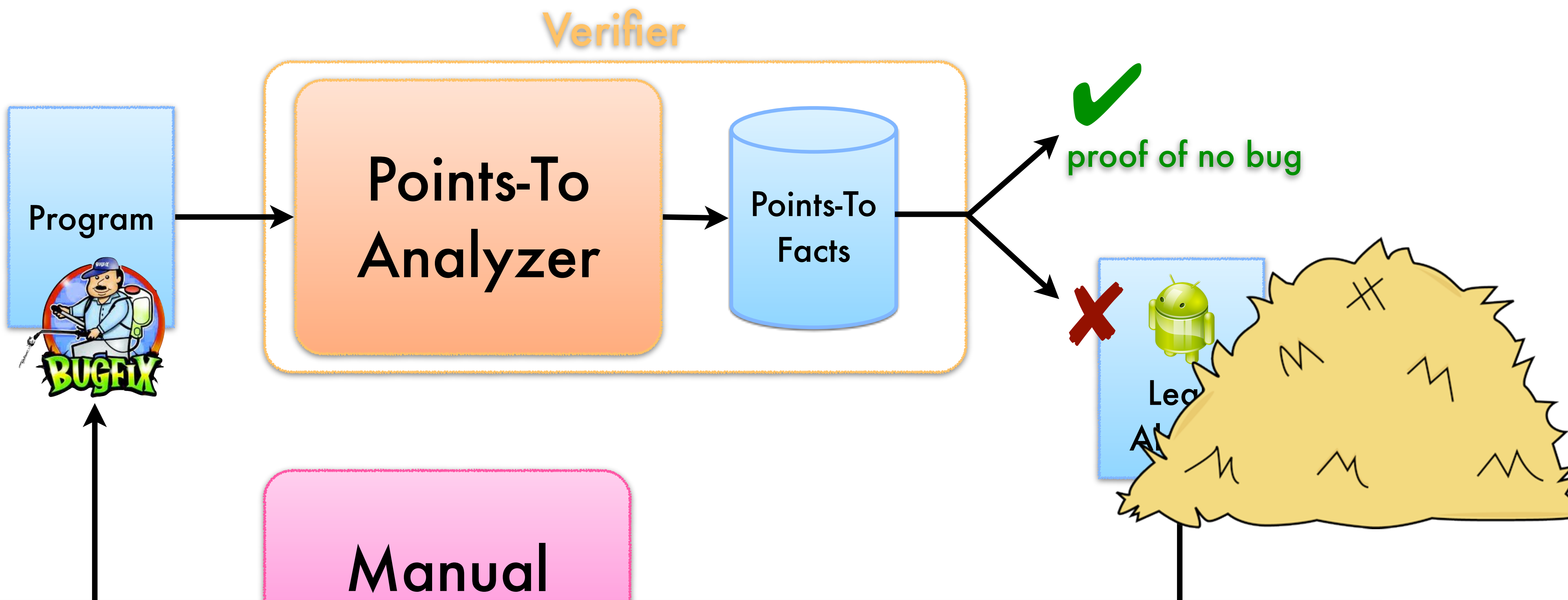


Hind. "Pointer Analysis: Haven't We Solved This Problem Yet?"

- 75 papers, 9 PhD theses

Known: Precise points-to analysis challenging

Thresher addresses alarm **triage** in a particularly challenging domain.

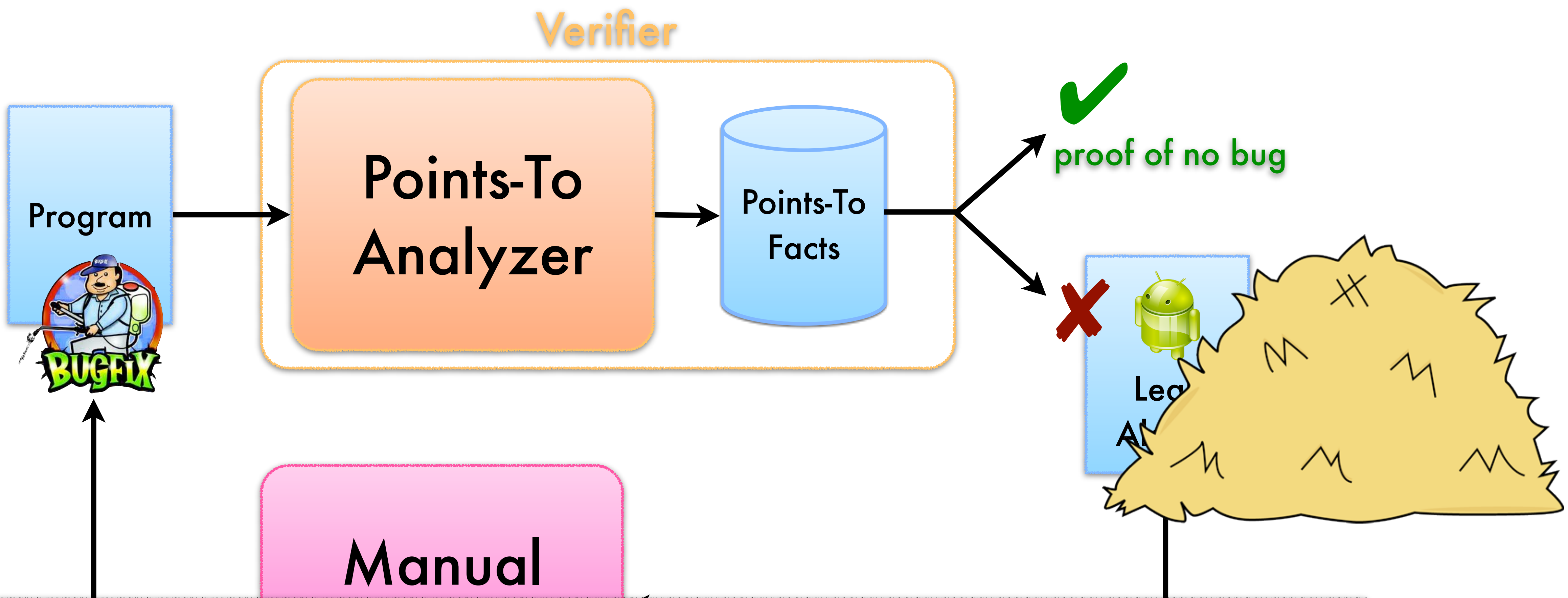


Hind. "Pointer Analysis: Haven't We Solved This Problem Yet?" (2001)

- 75 papers, 9 PhD theses

Known: Precise points-to analysis challenging

Thresher addresses alarm **triage** in a particularly challenging domain.



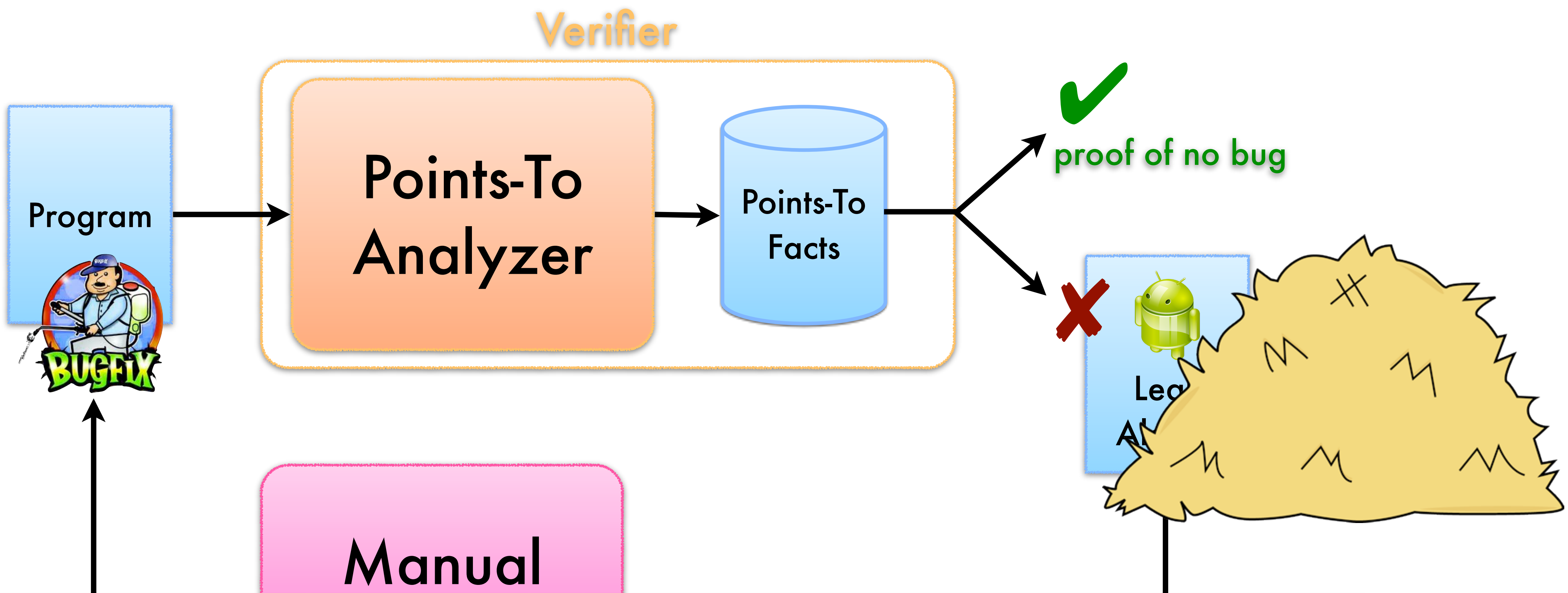
Hind. "Pointer Analysis: Haven't We Solved This Problem Yet?" (2001)

- 75 papers, 9 PhD theses

Dagstuhl 13162: Pointer Analysis (2013)

Known: Precise points-to analysis challenging

Thresher addresses alarm **triage** in a particularly challenging domain.



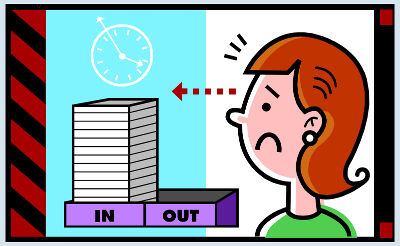
Hind. "Pointer Analysis: Haven't We Solved This Problem Yet?" (2001)

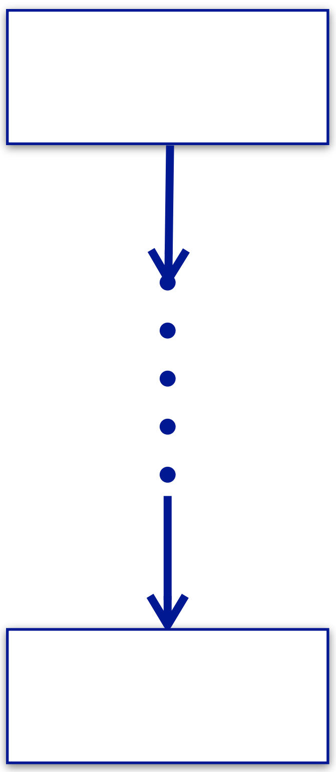
- 75 papers, 9 PhD theses

Dagstuhl 13162: Pointer Analysis (2013)

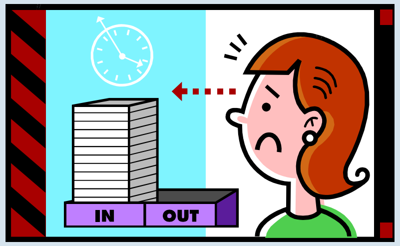
Known: Precise enough points-to analysis ~~challenging~~ impossible?

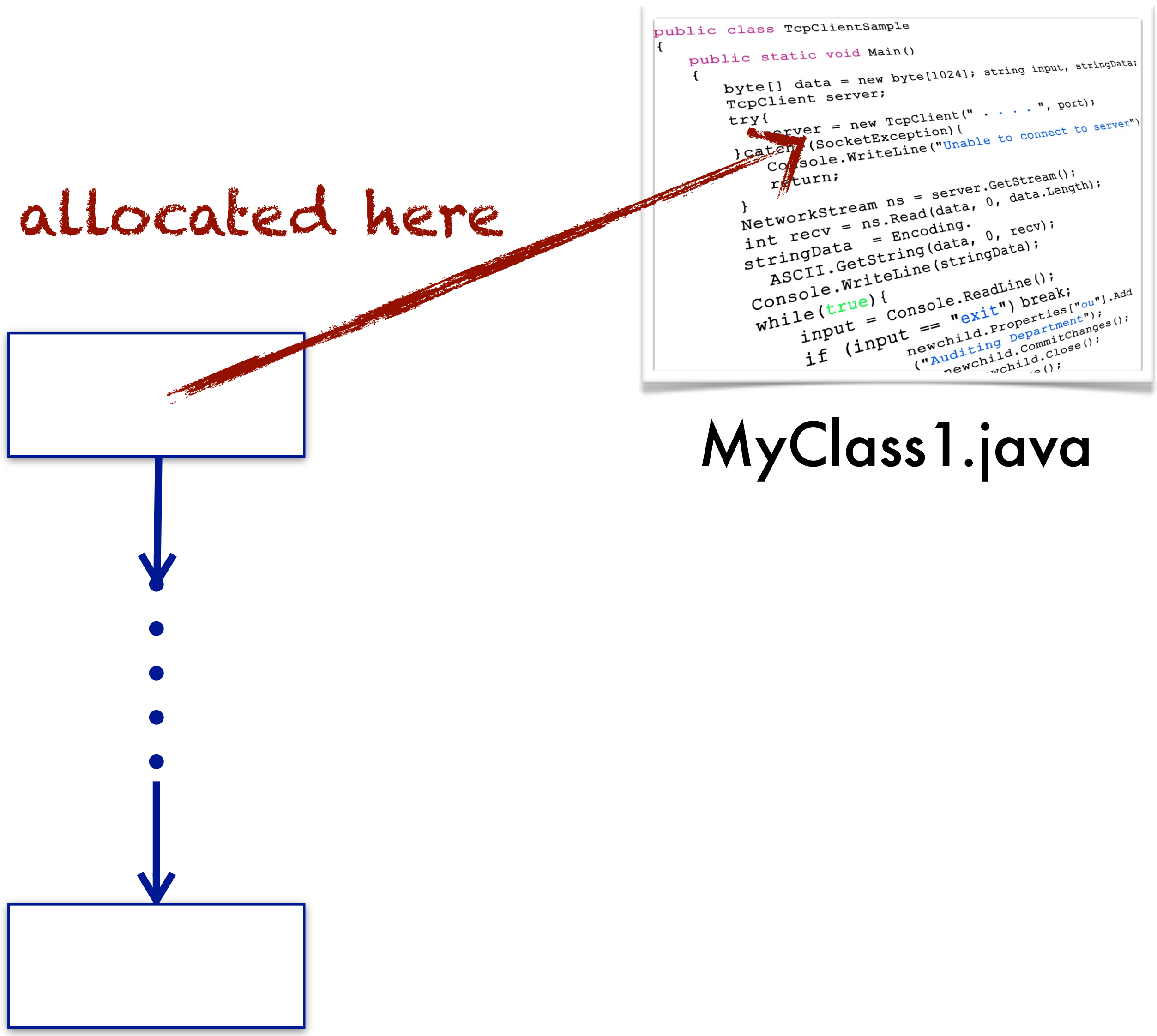
Manual triage is particularly hard for heap reachability reports.



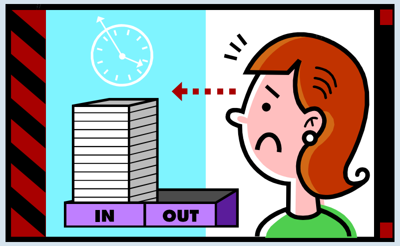


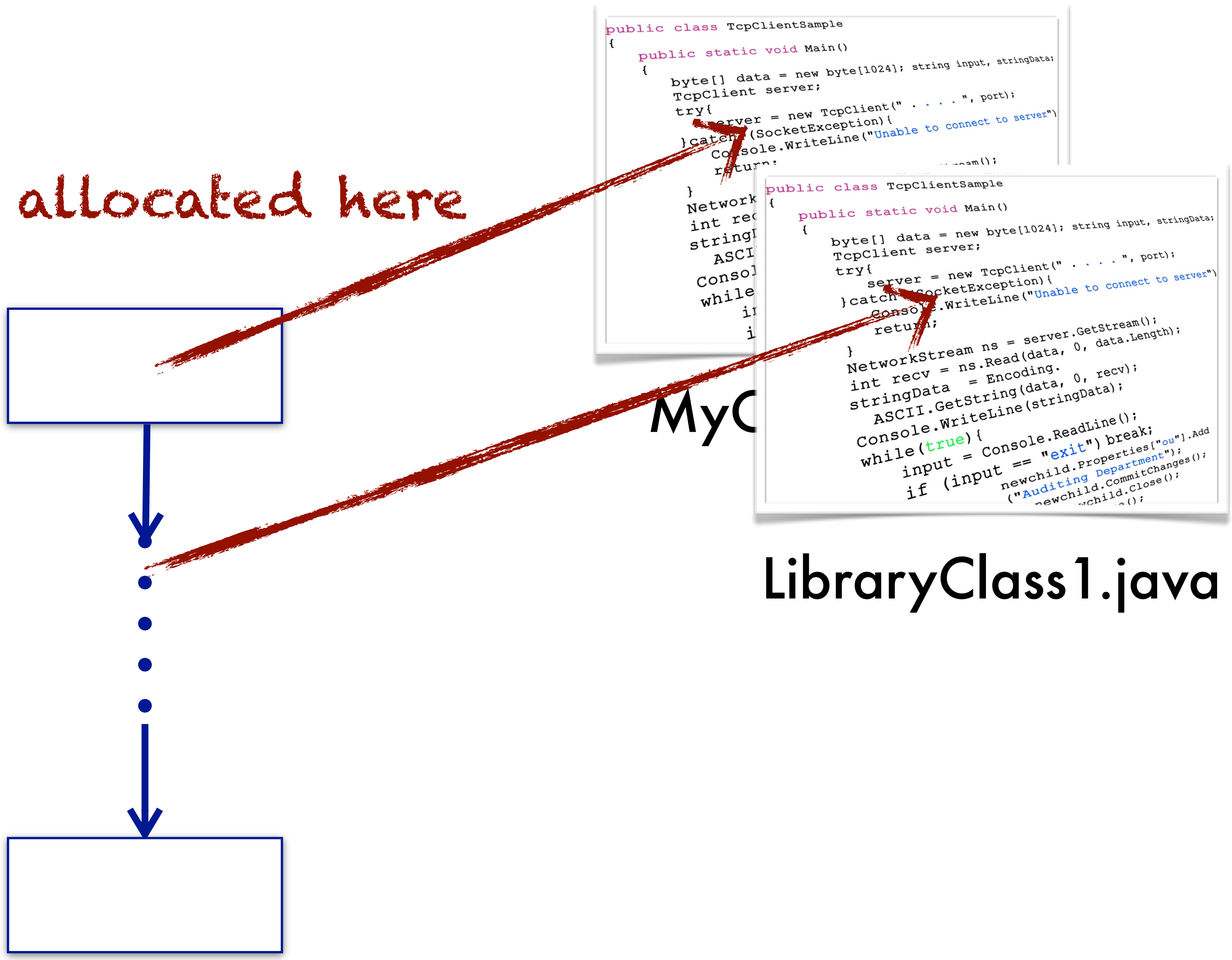
Manual triage is particularly hard for heap reachability reports.



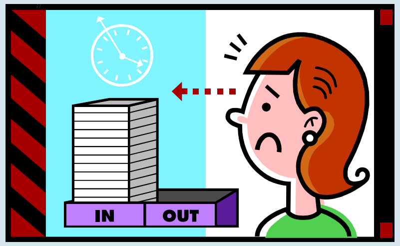


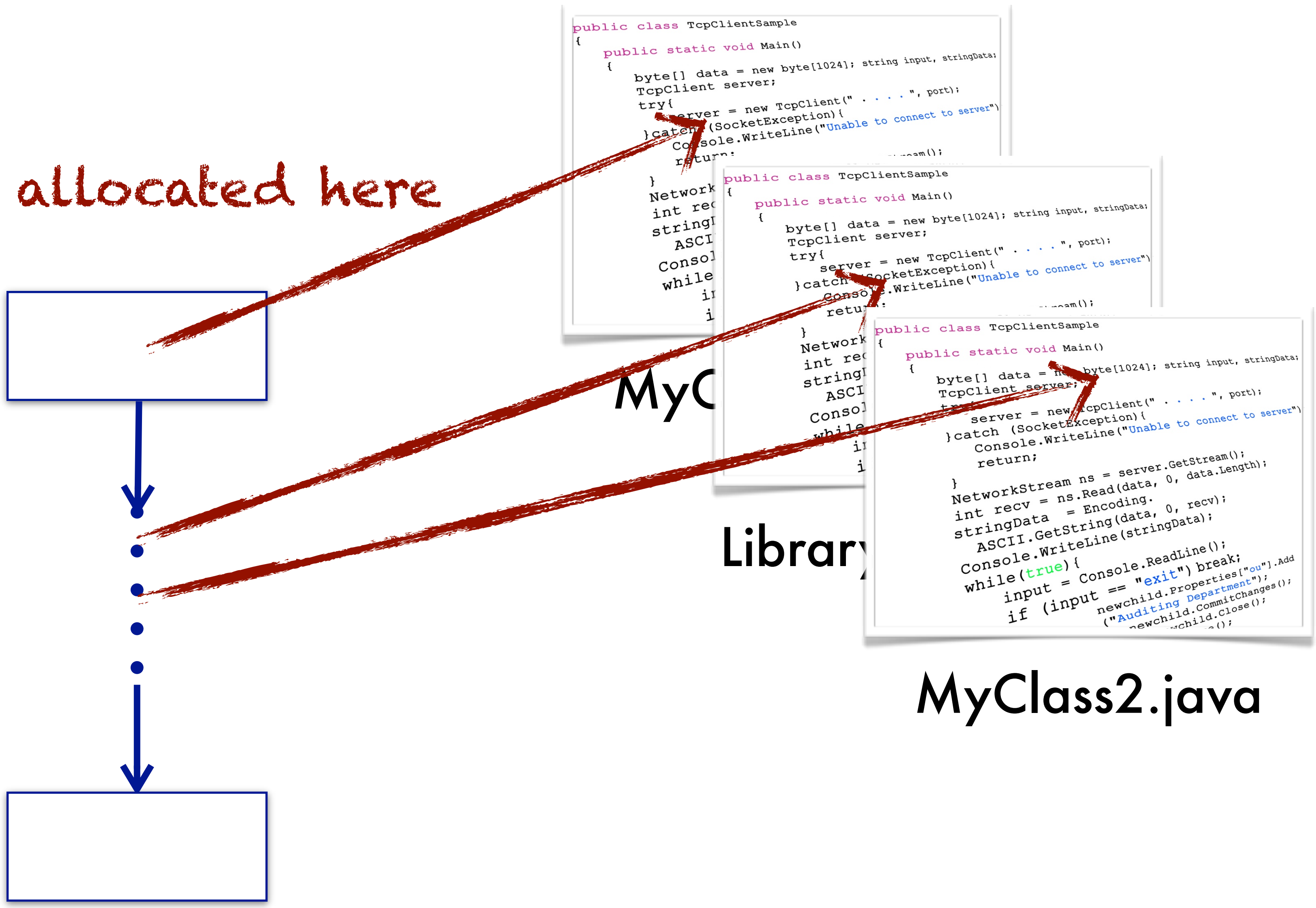
Manual triage is particularly hard for heap reachability reports.



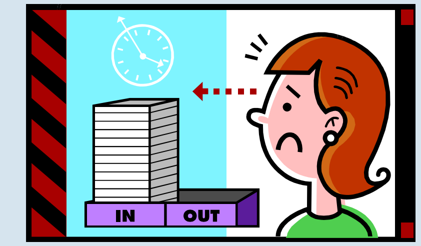


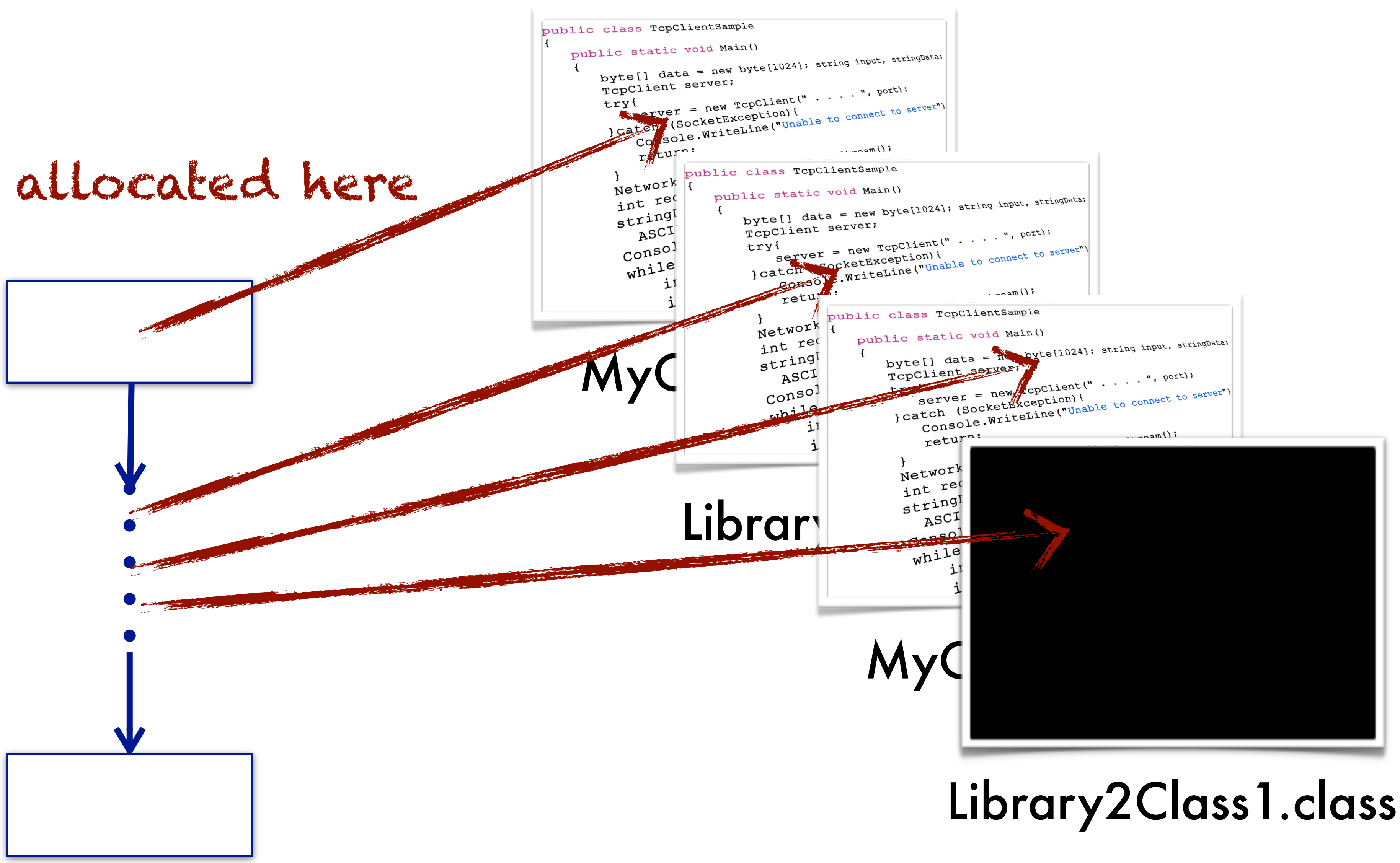
Manual triage is particularly hard for heap reachability reports.



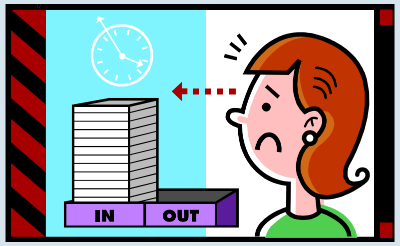


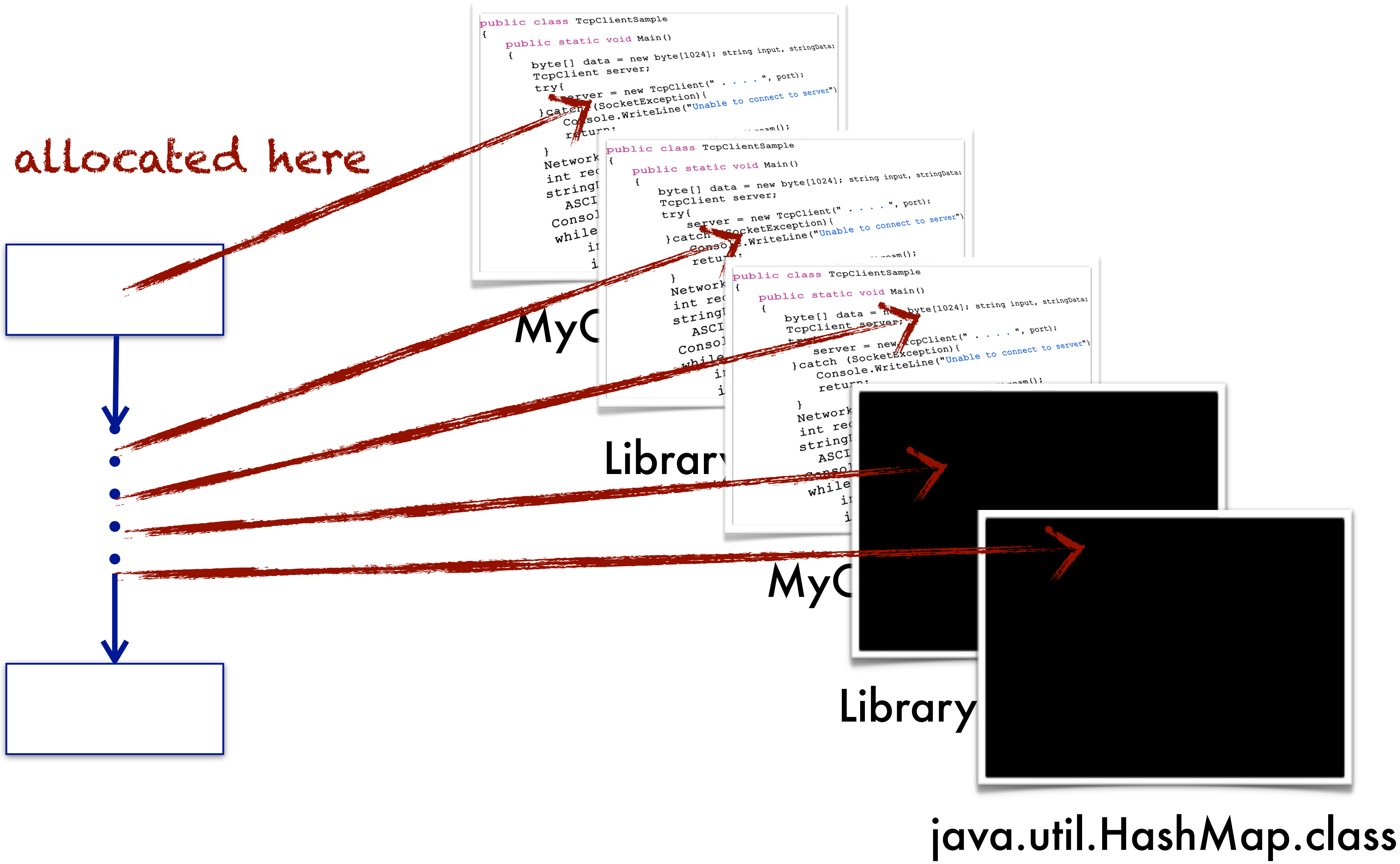
Manual triage is particularly hard for heap reachability reports.



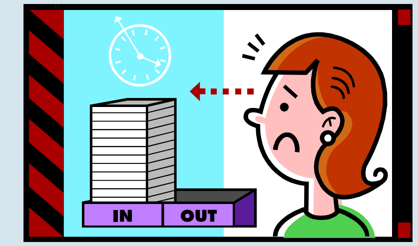


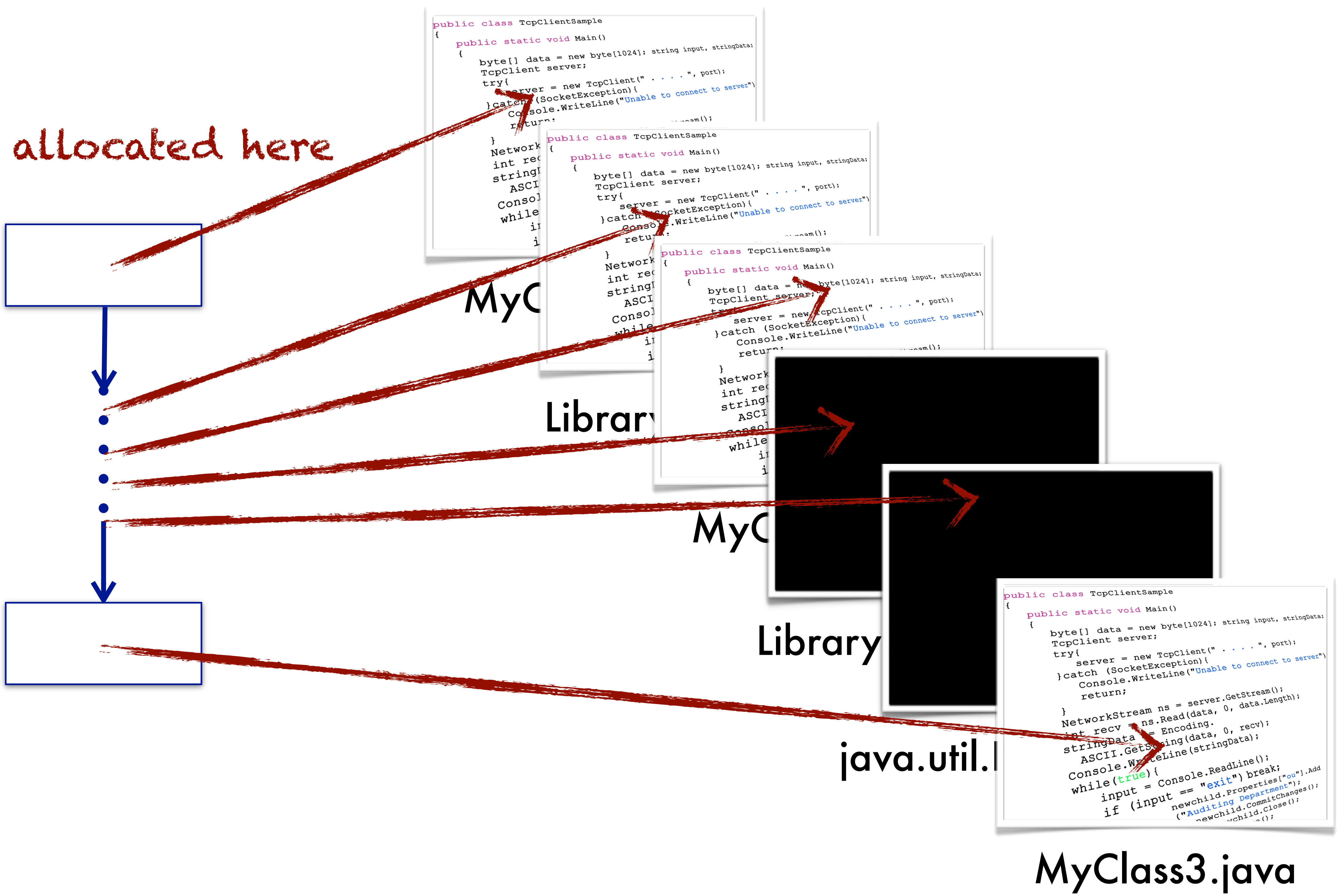
Manual triage is particularly hard for heap reachability reports.



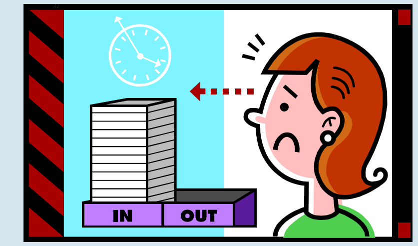


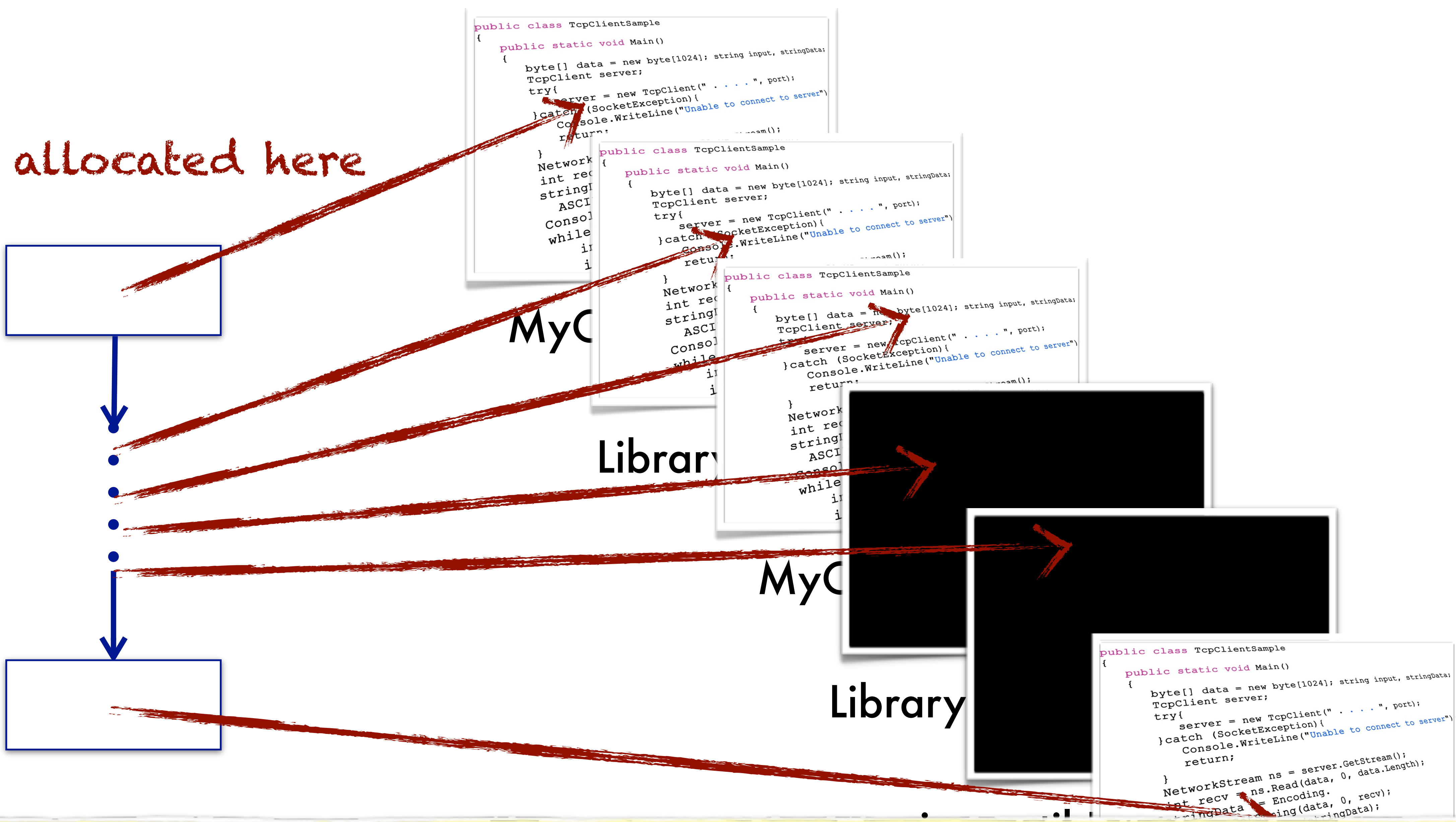
Manual triage is particularly hard for heap reachability reports.





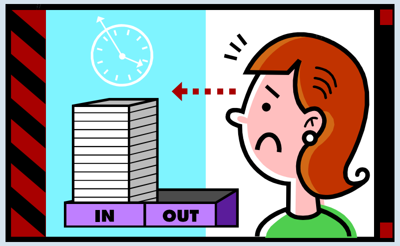
Manual triage is particularly hard for heap reachability reports.



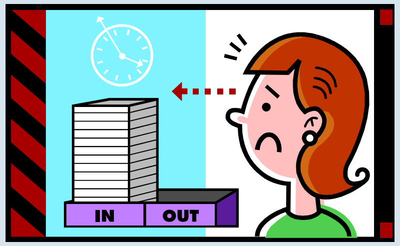


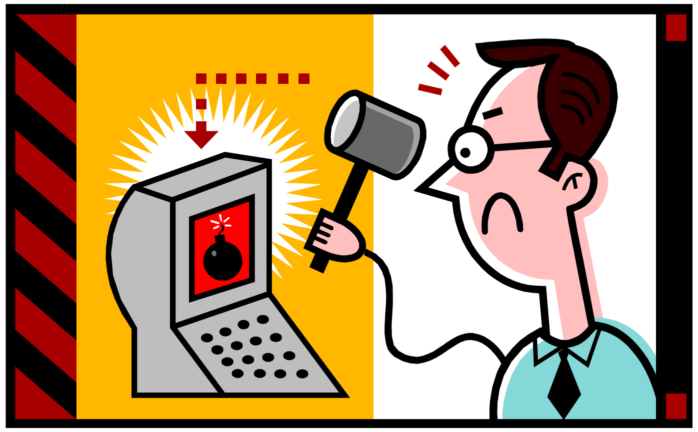
Get abstract heap path + maybe allocation sites
Guesstimate: >1 to 2 hours per alarm to triage "well"

Examining manual triage ...

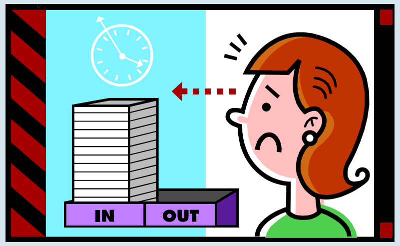


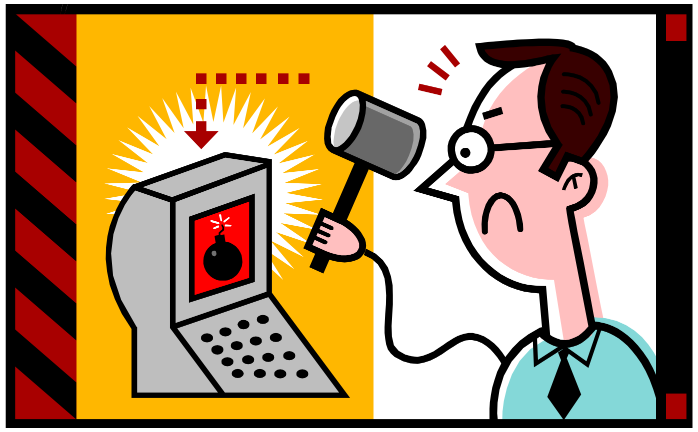
Examining manual triage ...





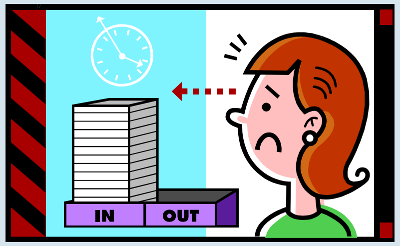
Examining manual triage ...

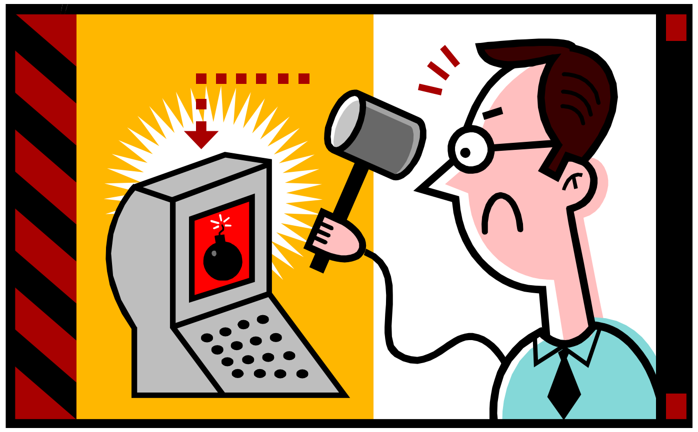




What does the user need to do with an alarm? He starts at, say, line 142 and traces back to see if a bug is possible given what's happening.

Examining manual triage ...

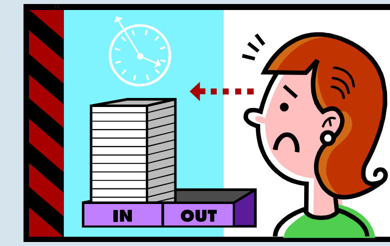


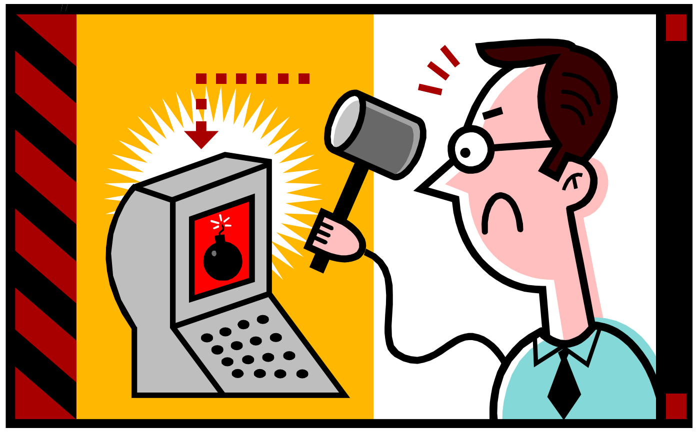


What does the user need to do with an alarm? He starts at, say, line 142 and traces back to see if a bug is possible given what's happening.

We can do this with analysis!

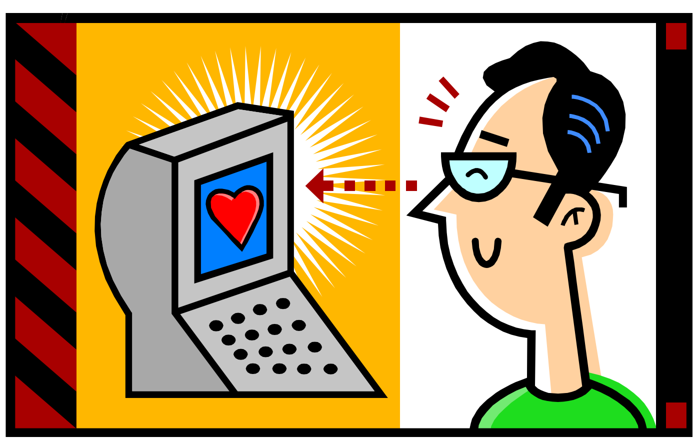
Examining manual triage ...



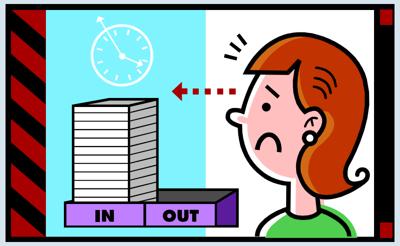


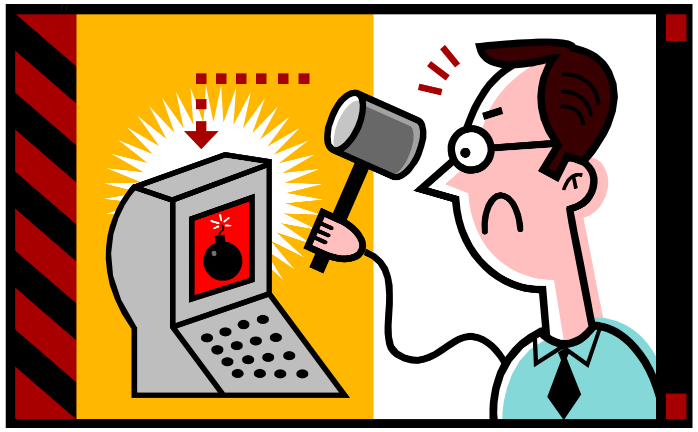
What does the user need to do with an alarm? He starts at, say, line 142 and traces back to see if a bug is possible given what's happening.

We can do this with analysis!



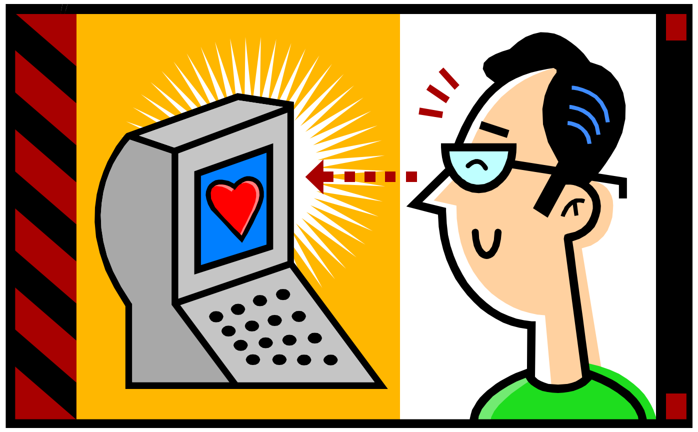
Examining manual triage …





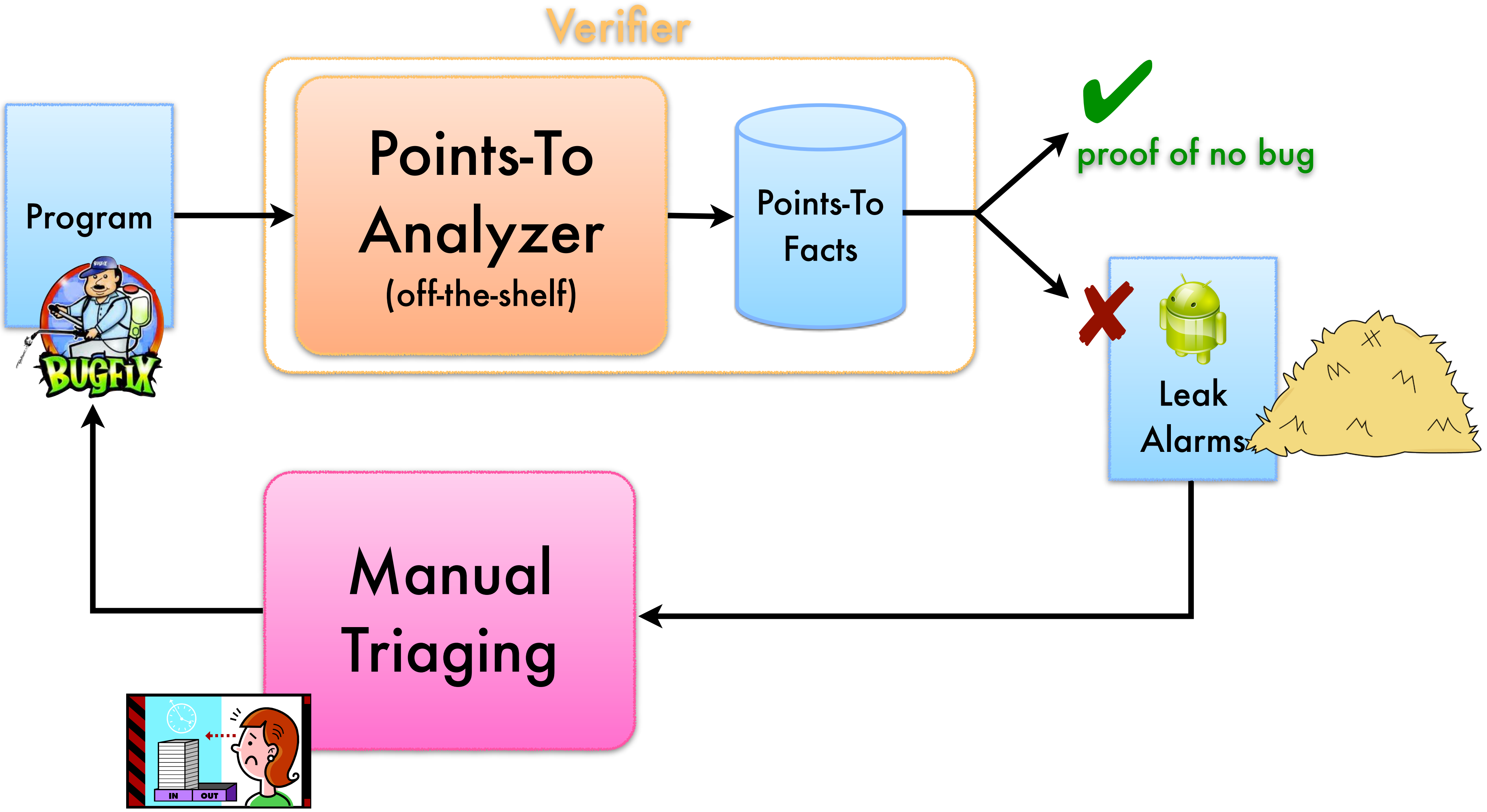
What does the user need to do with an alarm? He starts at, say, line 142 and traces back to see if a bug is possible given what's happening.

We can do this with analysis!

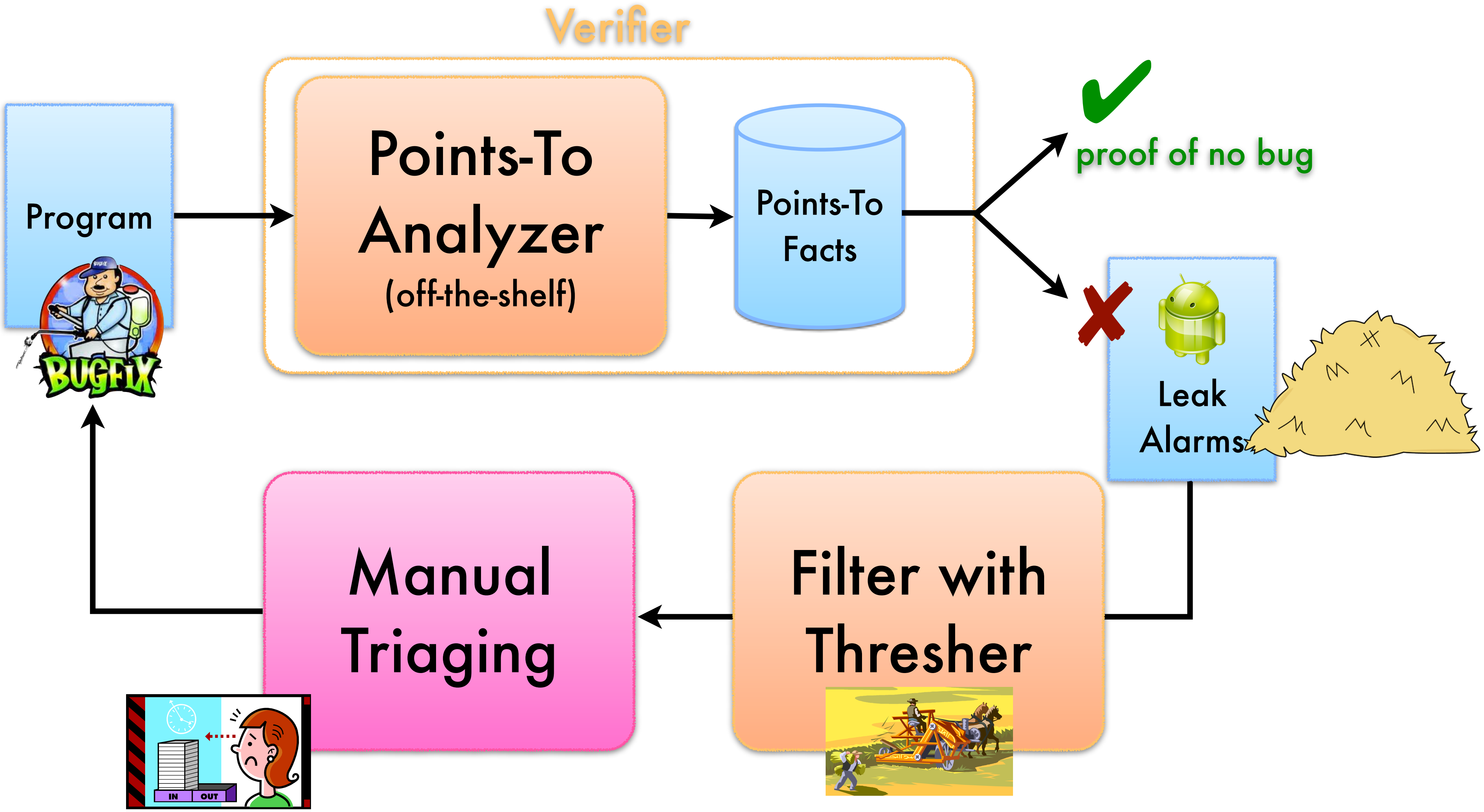


If we filter most false alarms, the user can triage more quickly and get to true bugs earlier (without frustration).

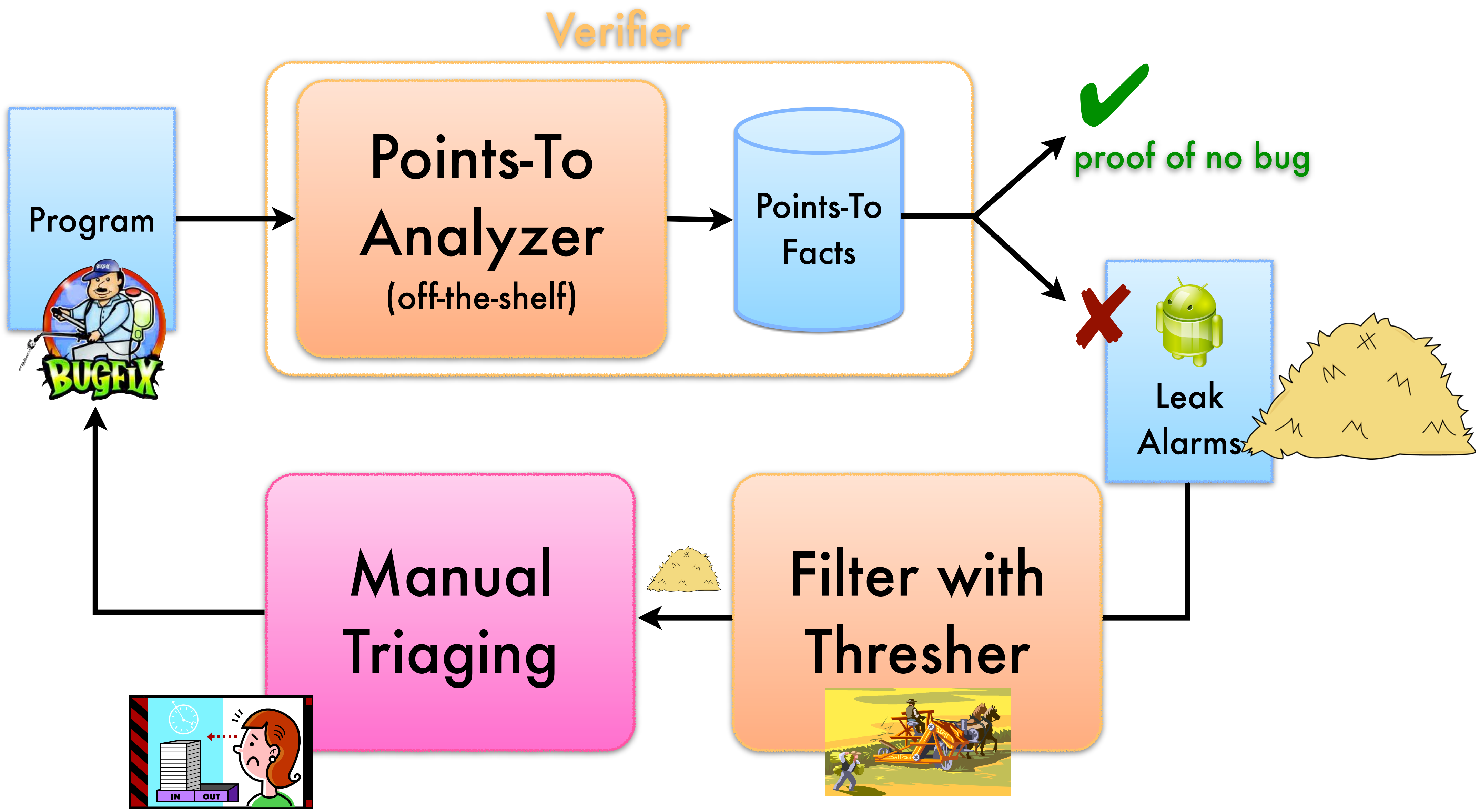
Thresher **filters** out false alarms by refuting them one-by-one.



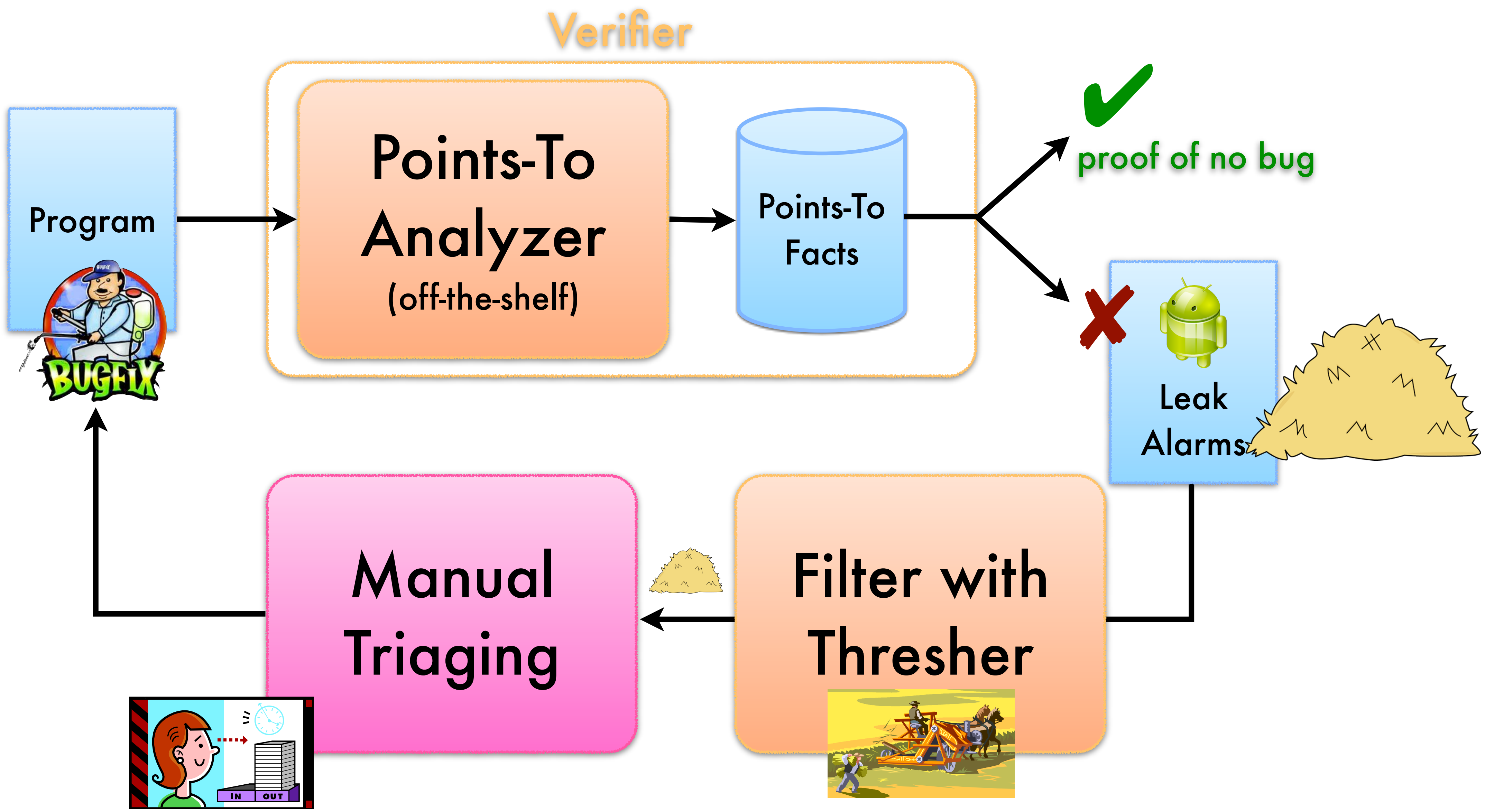
Thresher **filters** out false alarms by refuting them one-by-one.



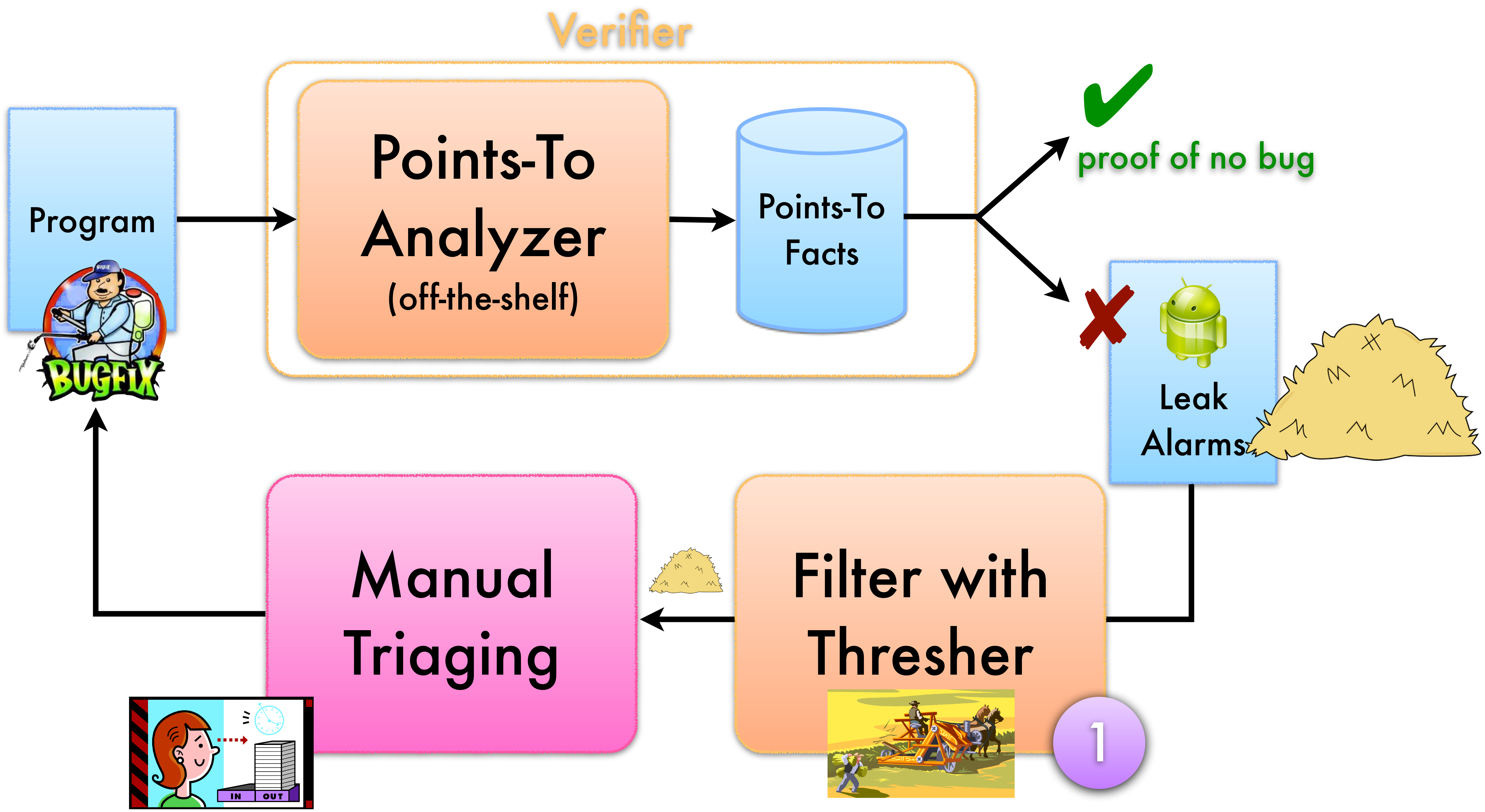
Thresher filters out false alarms by refuting them one-by-one.



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

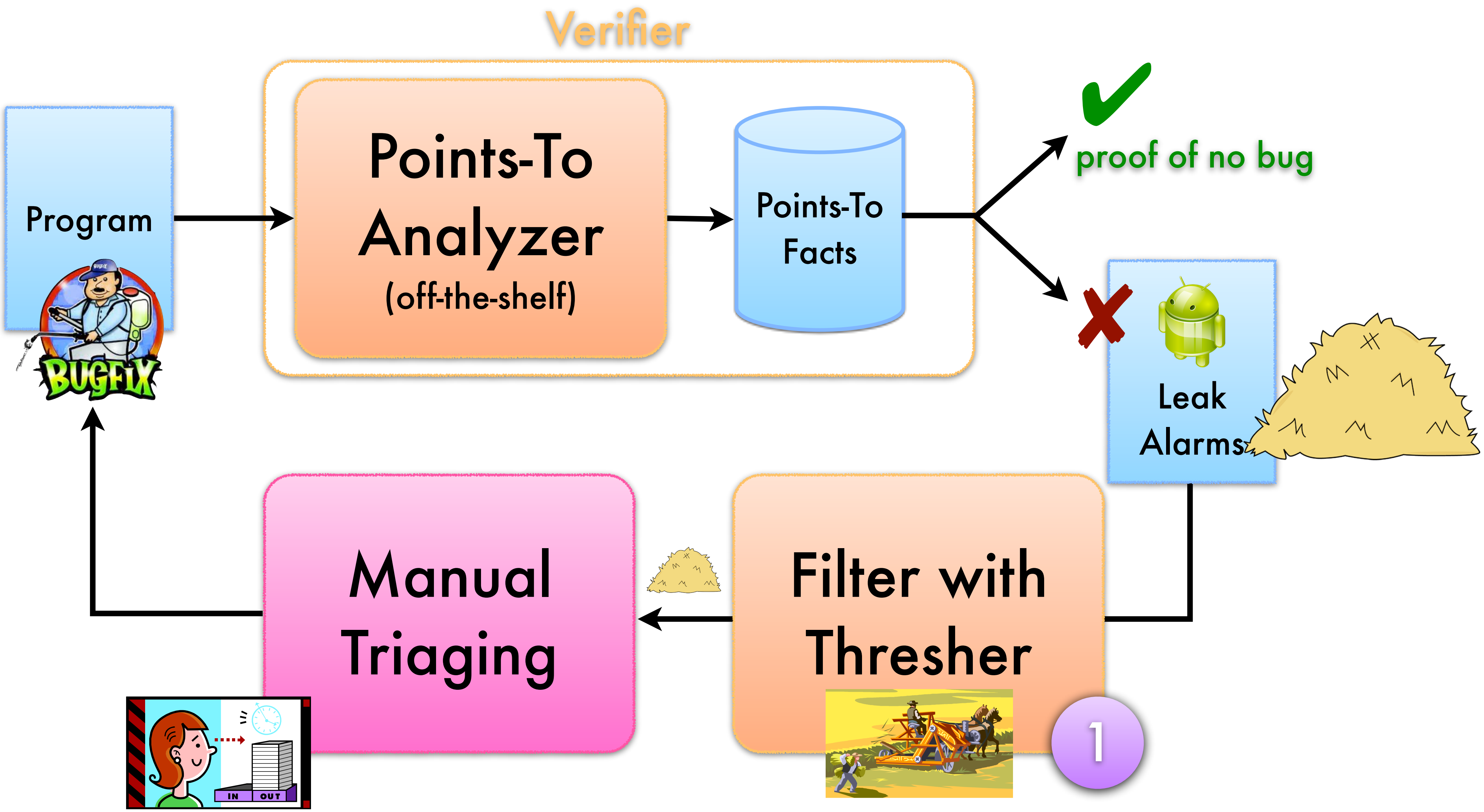


Thresher **filters** out false alarms by refuting them one-by-one.



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

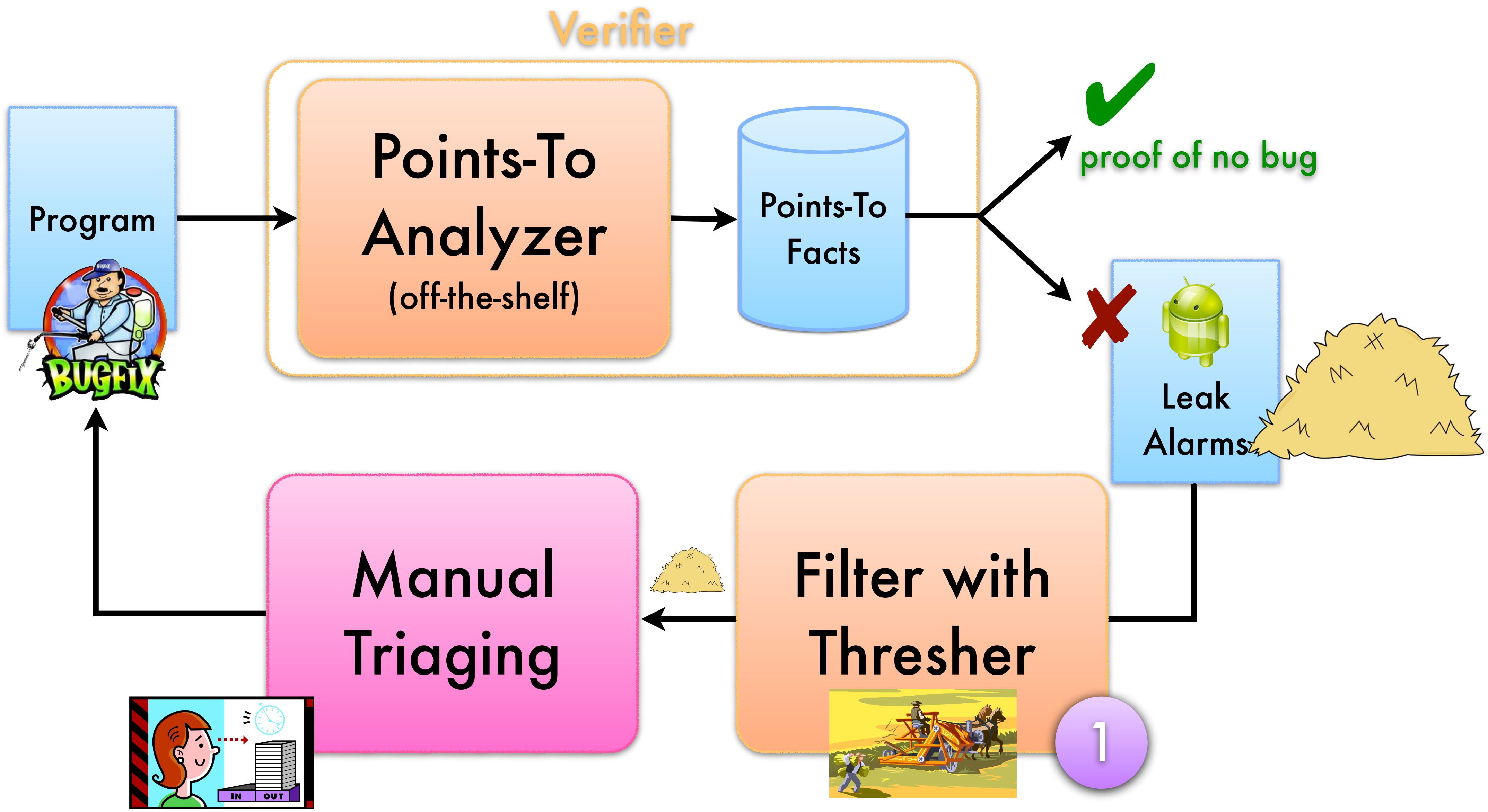
Thresher **filters** out false alarms by refuting them one-by-one.



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

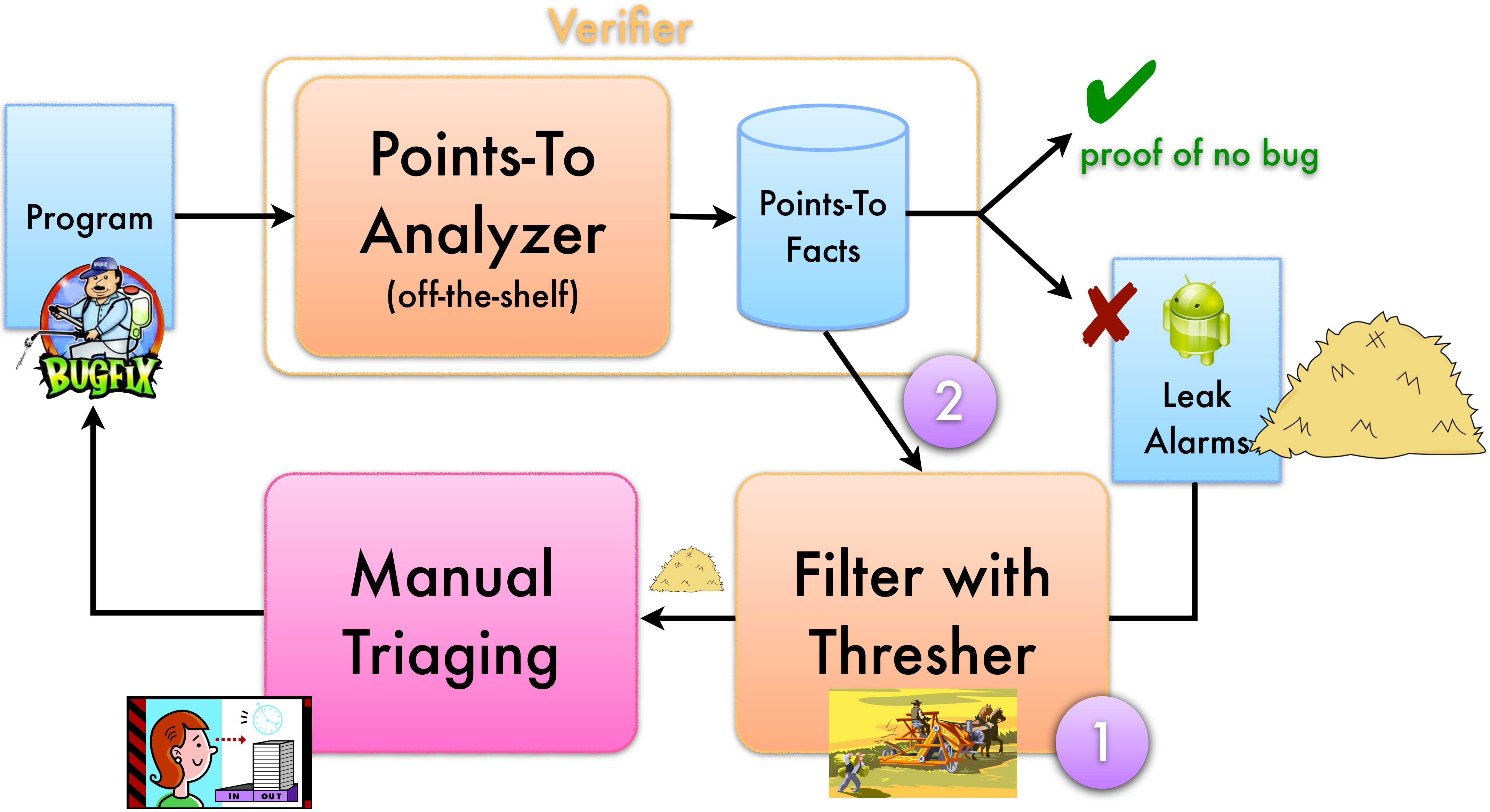
*-sensitive

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



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

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

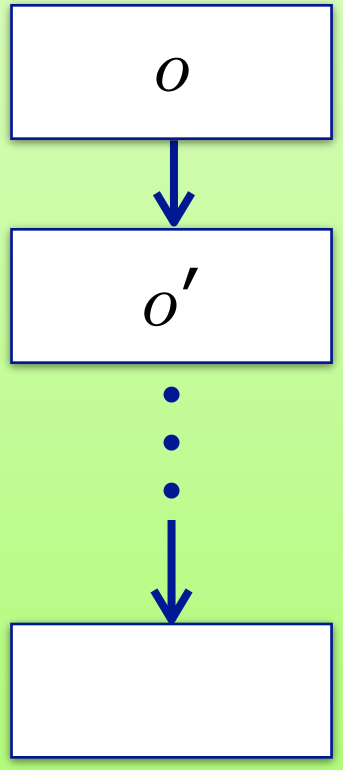
Refutation analysis is "Proof by Contradiction" with the "But Why?" game

1

Refutation analysis is "Proof by Contradiction" with the "But Why?" game

1

There **may** be an execution where at some time

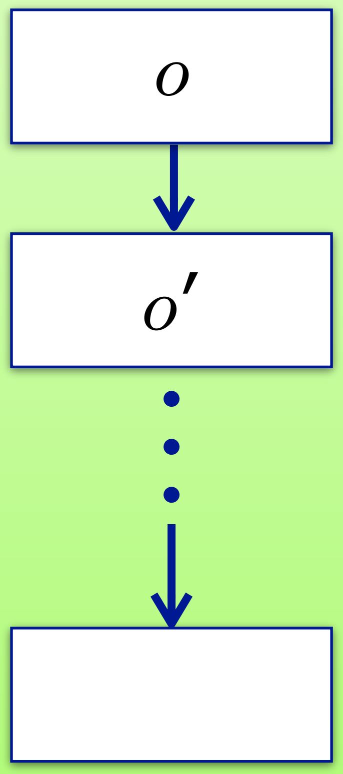


of type T .

Refutation analysis is "Proof by Contradiction" with the "But Why?" game

1

There **may** be an execution where at some time

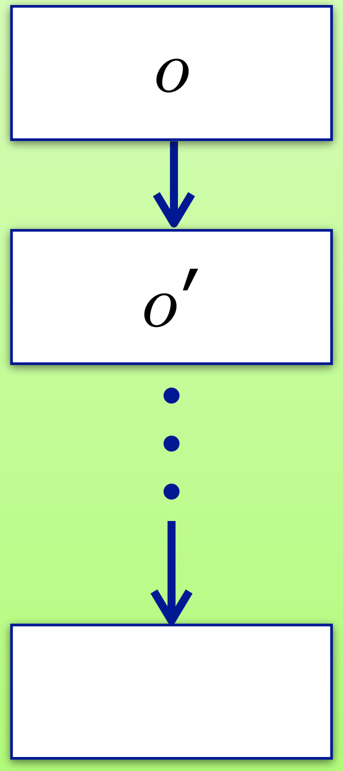


of type T .

A. Why does object o possibly point to o' ?

Refutation analysis is "Proof by Contradiction" with the "But Why?" game

There **may** be an execution where at some time



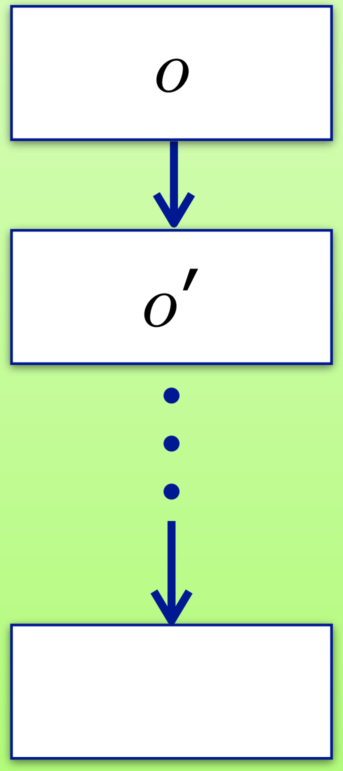
of type T .

A. Why does object o possibly point to o' ?

B. Because statement s may execute to make o point to o'

Refutation analysis is "Proof by Contradiction" with the "But Why?" game

There **may** be an execution where at some time



of type T .

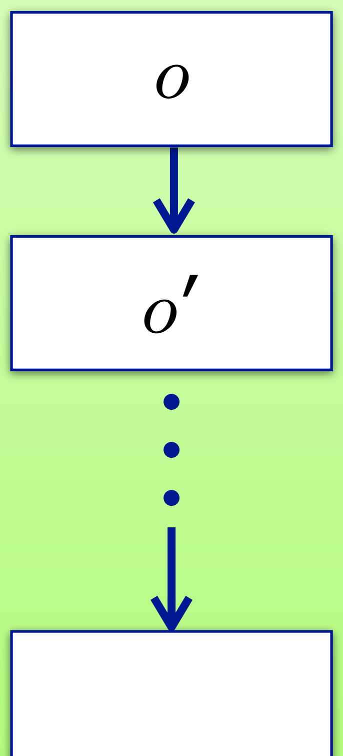
A. Why does object o possibly point to o' ?

B. Because statement s may execute to make o point to o'

A. Why does statement s cause o to point to o' ?

Refutation analysis is "Proof by Contradiction" with the "But Why?" game

There **may** be an execution where at some time



of type T .

A. Why does object o possibly point to o' ?

B. Because statement s may execute to make o point to o'

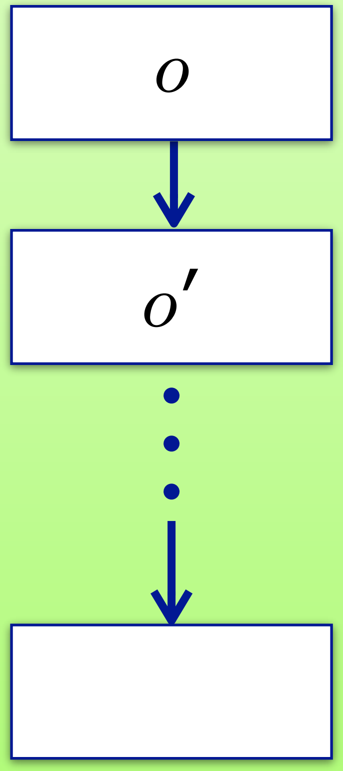
A. Why does statement s cause o to point to o' ?

B. Because before statement s, the program state could satisfy formula φ

Refutation analysis is "Proof by Contradiction" with the "But Why?" game

1

There **may** be an execution where at some time



of type T .

A. Why does object o possibly point to o' ?

B. Because statement s may execute to make o point to o'

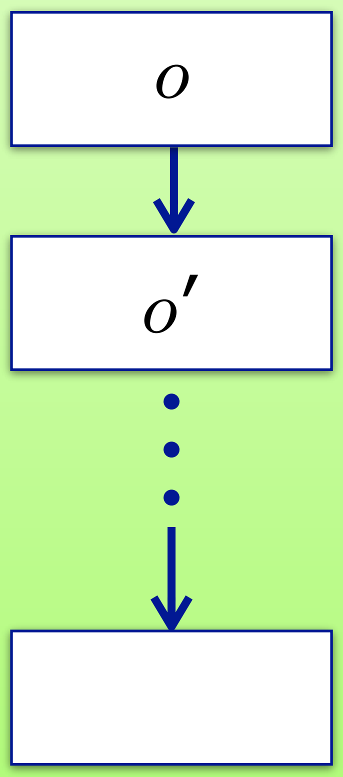
A. Why does statement s cause o to point to o' ?

B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

Refutation analysis is "Proof by Contradiction" with the "But Why?" game

There **may** be an execution where at some time



of type T .

A. Why does object o possibly point to o' ?

B. Because statement s may execute to make o point to o'

A. Why does statement s cause o to point to o' ?

B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'

Refutation analysis is "Proof by Contradiction" with the "But Why?" game

1

There **may** be an execution where at some tim[e]

o

$\downarrow$

o'

$\vdots$

$\downarrow$

of type T .

A just asks "but why?"

B reasons about program semantics

A. Why does object o possibly point to o' ?

B. Because statement s may execute to make o point to o'

A. Why does statement s cause o to point to o' ?

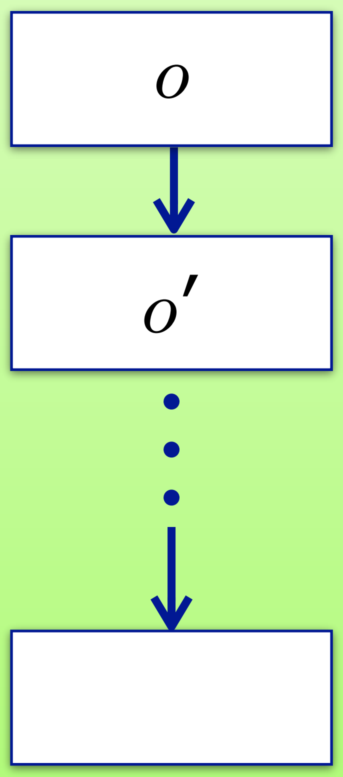
B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'

Refutation analysis is "Proof by Contradiction" with the "But Why?" game

There **may** be an execution where at some tim



of type T .

A just asks "but why?"

B reasons about program semantics

A. Why does object o possibly point to o' ?

B. Because statement s may execute to make o point to o'

A. Why does statement s cause o to point to o' ?

B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'

Theorem: If B can't give an answer, contradiction. The alarm is false. It's been refuted. (A wins)

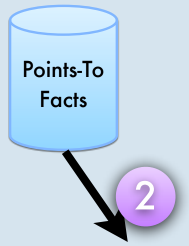
Leverage first analysis by designing specialized constraint forms

B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'

Leverage first analysis by designing **specialized** constraint forms

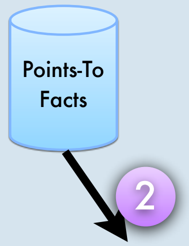


B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'

Leverage first analysis by designing specialized constraint forms

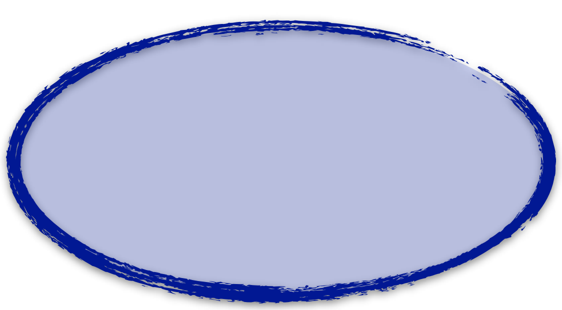


B. Because before statement s, the program state could satisfy formula φ

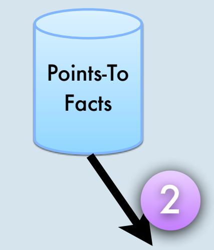
A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'

φ



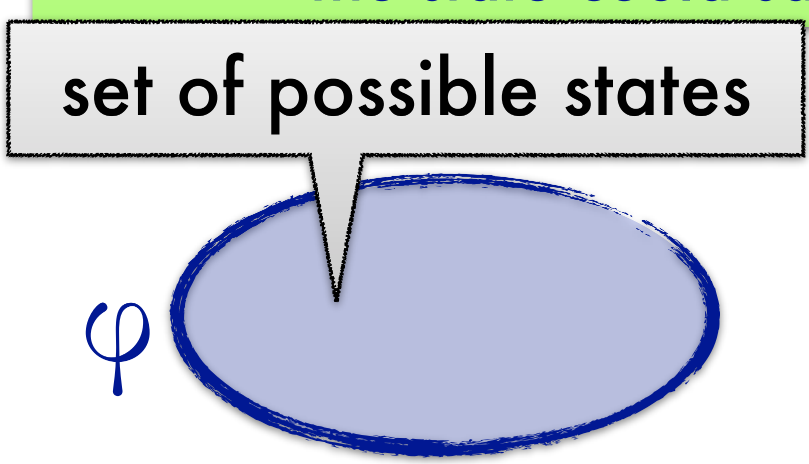
Leverage first analysis by designing **specialized** constraint forms



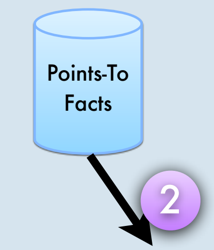
B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'



Leverage first analysis by designing specialized constraint forms



B. Because before statement s, the program state could satisfy formula φ

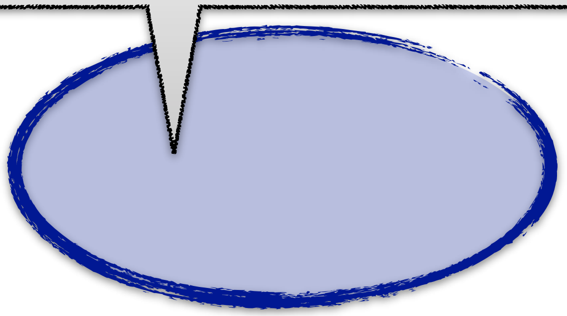
A. Why can the state before statement s satisfy φ?

statement s',
a φ'

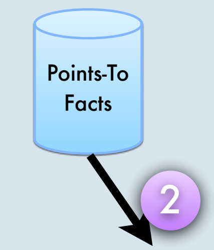
if empty, then refuted (A wins)

set of possible states

φ



Leverage first analysis by designing specialized constraint forms



B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

statement s',

a φ'

if empty, then refuted (A wins)

set of possible states

Leverage first analysis by designing **specialized** constraint forms

Points-To Facts

2

B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

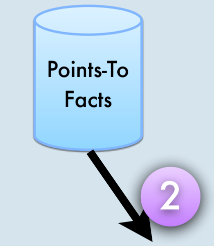
statement s',

a φ'

if empty, then refuted (A wins)

set of possible states

Leverage first analysis by designing **specialized** constraint forms



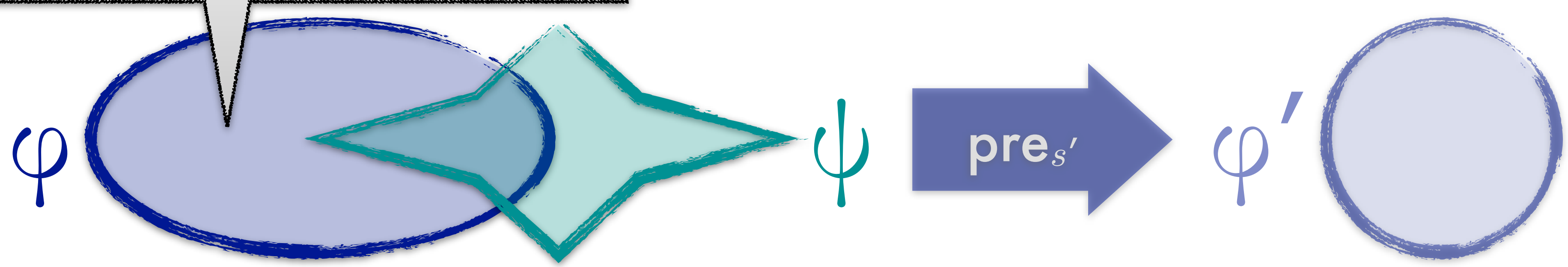
B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

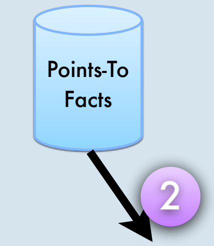
... statement s',
... a φ'

if empty, then refuted (A wins)

set of possible states



Leverage first analysis by designing **specialized** constraint forms



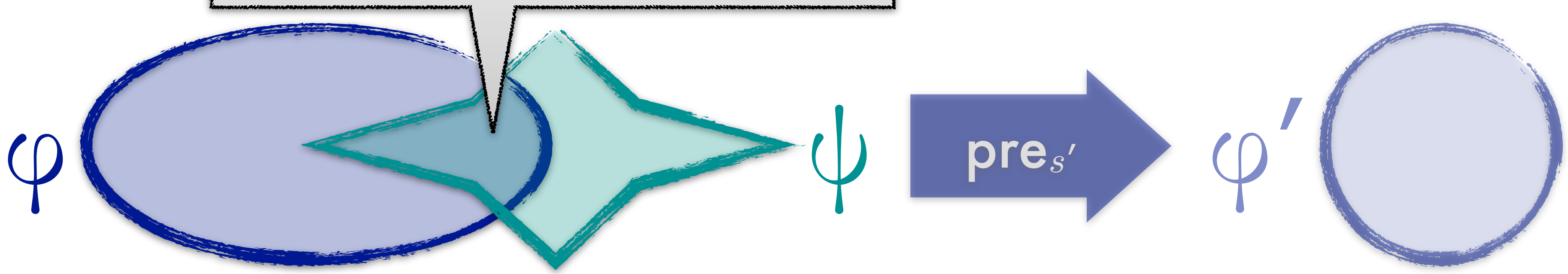
B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

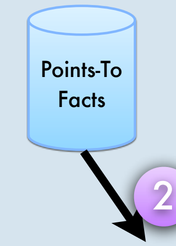
… statement s',
… a φ'

if empty, then refuted (A wins)

set of possible states



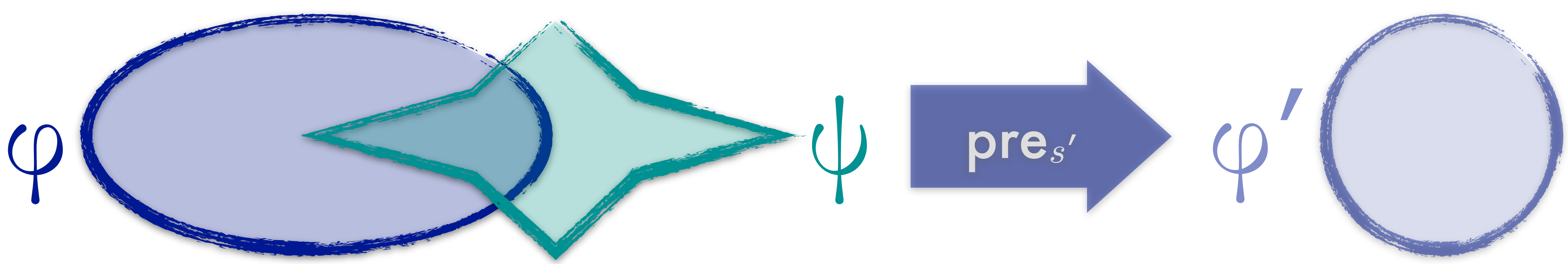
Leverage first analysis by designing **specialized** constraint forms



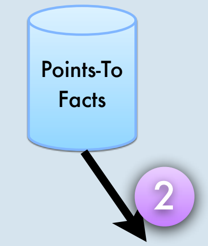
B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'



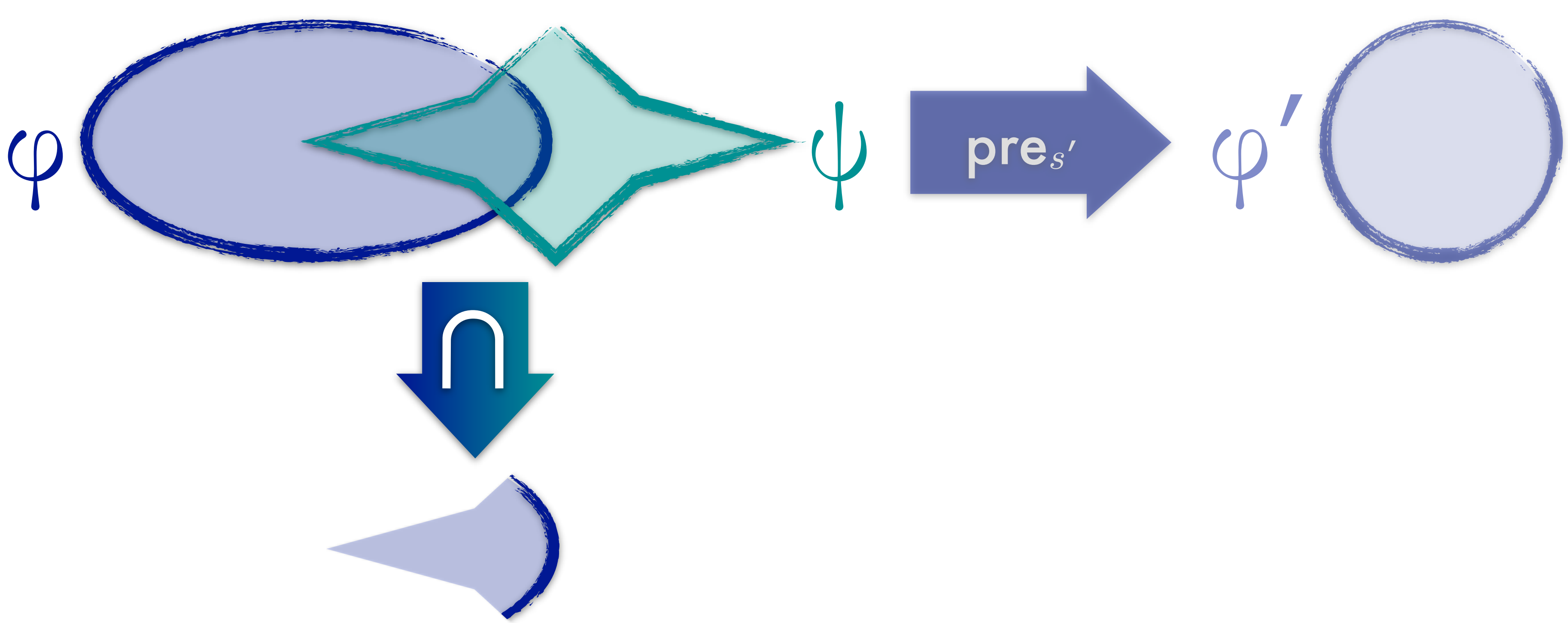
Leverage first analysis by designing specialized constraint forms



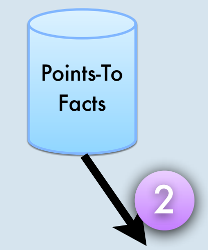
B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'



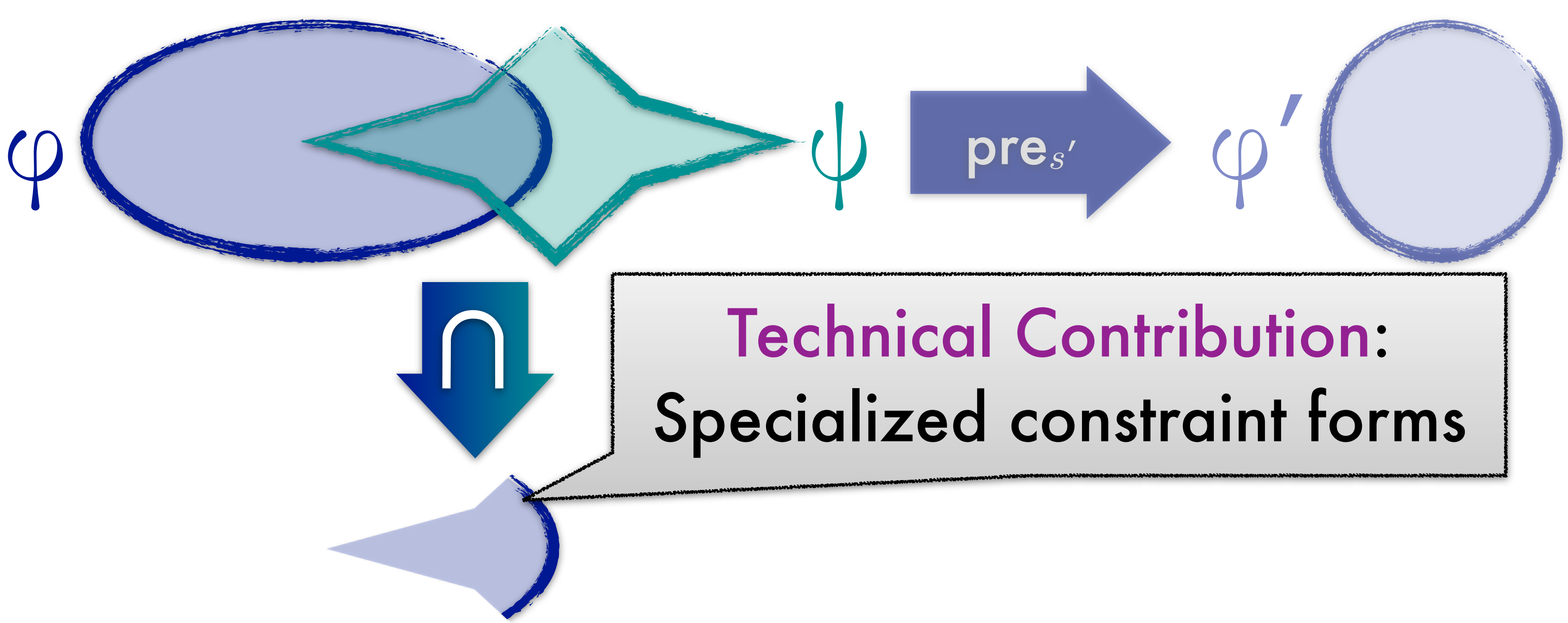
Leverage first analysis by designing **specialized** constraint forms



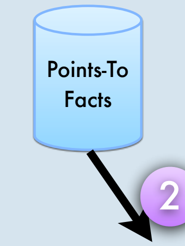
B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'



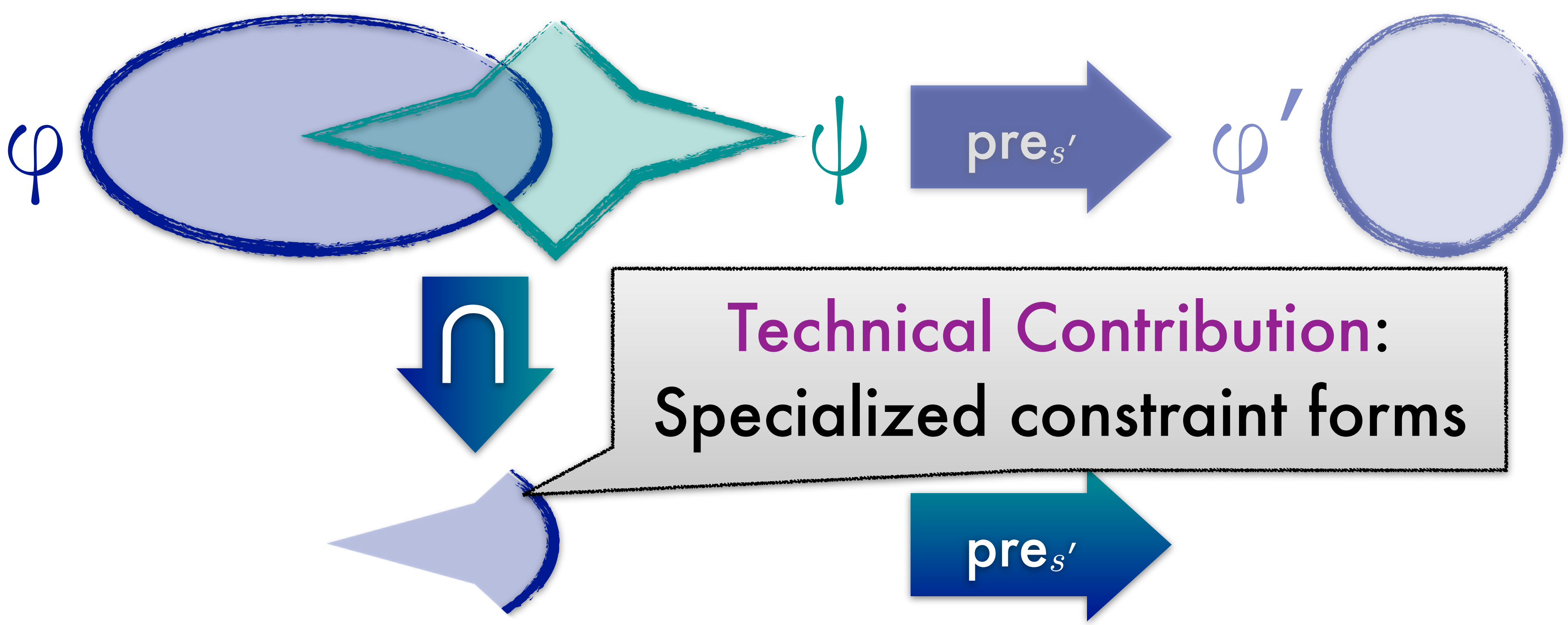
Leverage first analysis by designing **specialized** constraint forms



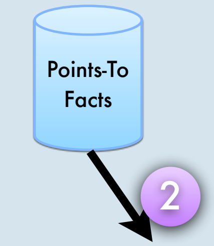
B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'



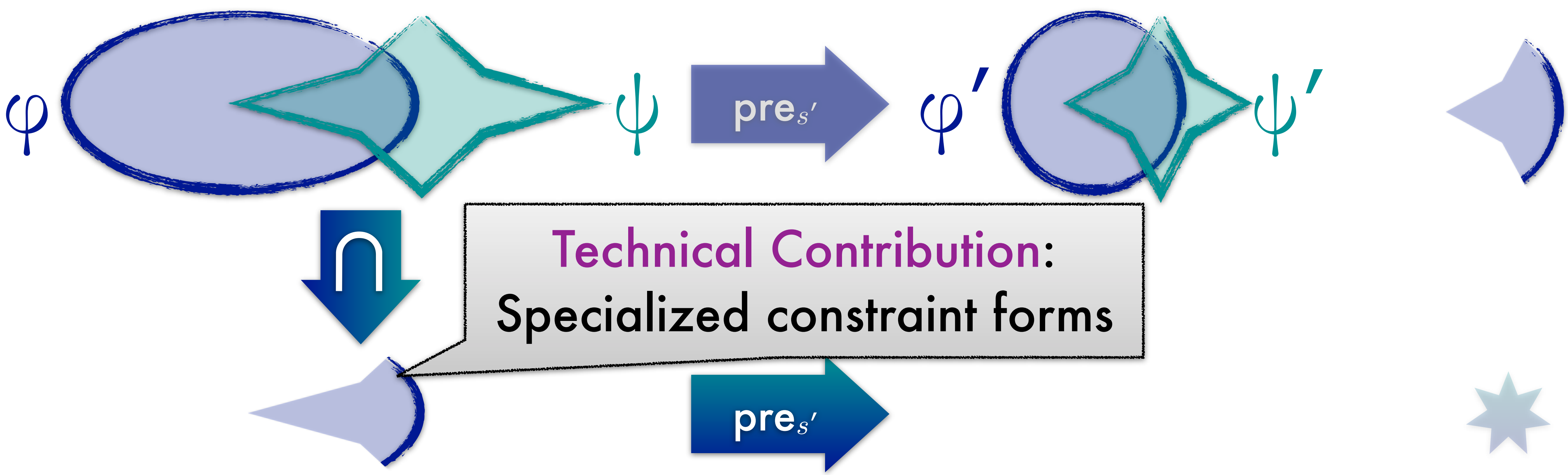
Leverage first analysis by designing specialized constraint forms



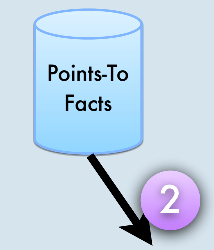
B. Because before statement s, the program state could satisfy formula φ

A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'



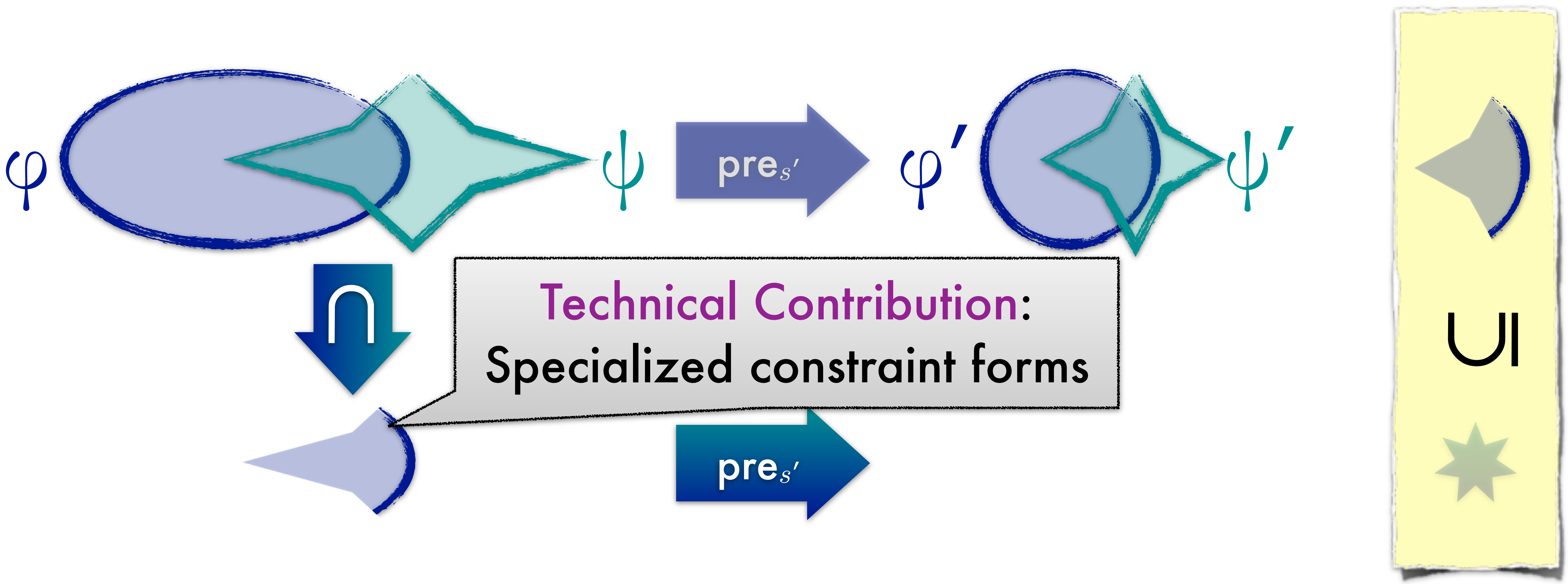
Leverage first analysis by designing specialized constraint forms



B. Because before statement s, the program state could satisfy formula φ

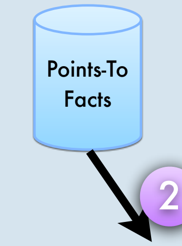
A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'



Technical Contribution:
Specialized constraint forms

Leverage first analysis by designing specialized constraint forms

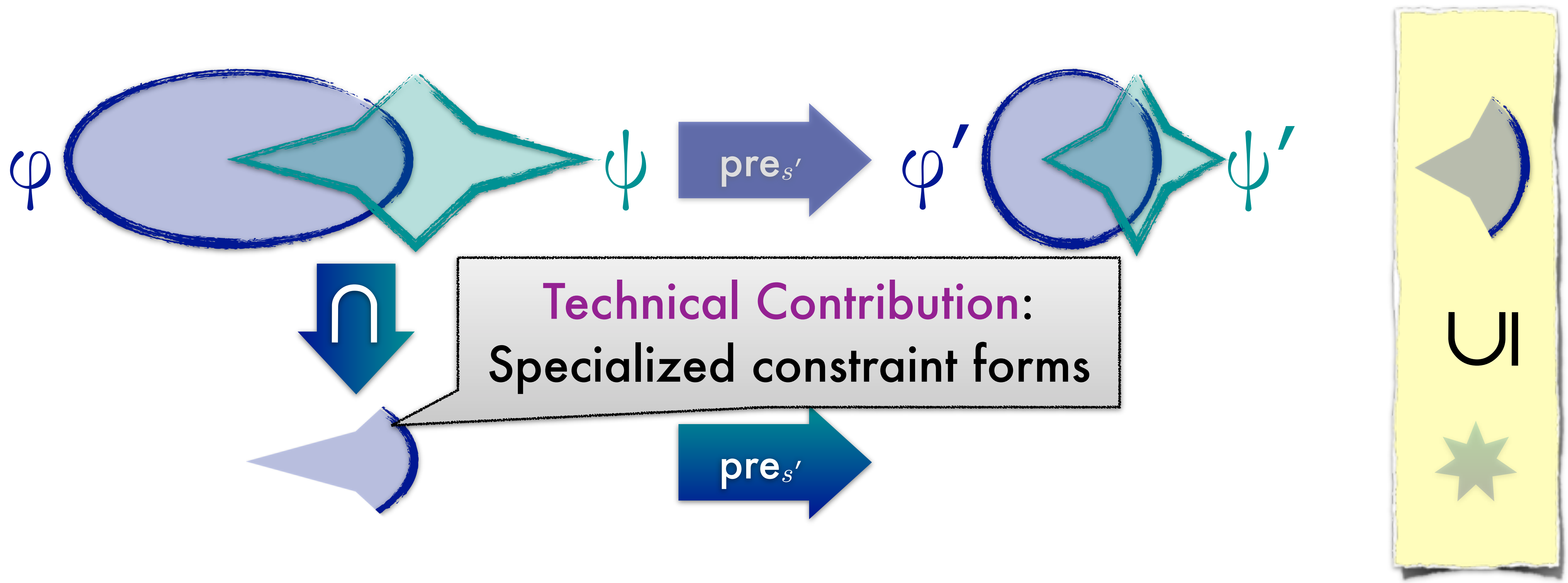


B. Because before statement s, the program state could satisfy formula φ

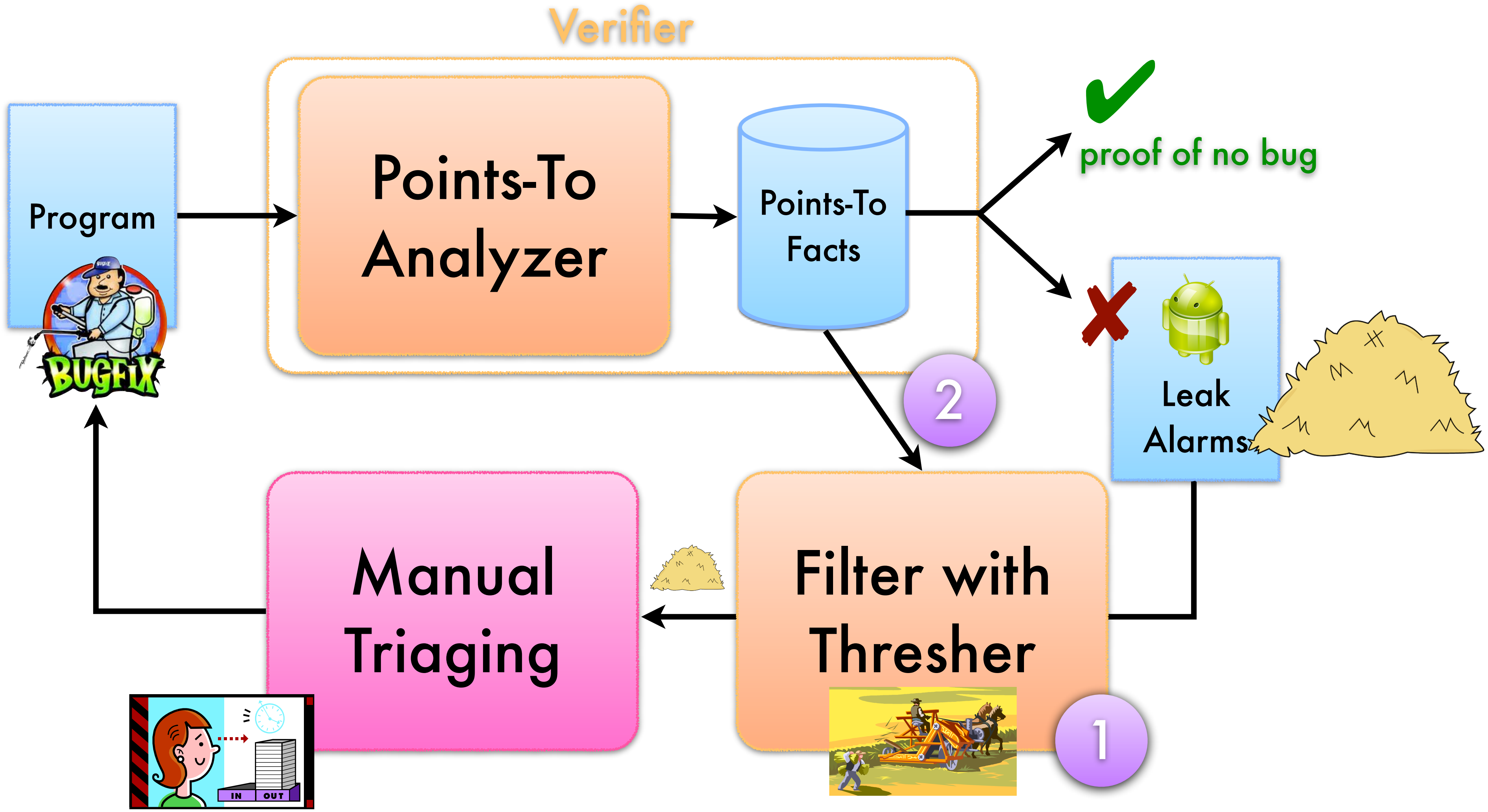
A. Why can the state before statement s satisfy φ?

B. Because before the previous statement s', the state could satisfy formula φ'

Specialized constraint forms makes finding refutations feasible



Summary: Thresher assists the user with alarm triaging by effectively **filtering** out many false alarms.



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	Thresher Refuted	True Bugs	Thresher Time (s)	False Alarm %	Filtered %
PulsePoint	unknown	16	8	8	95	0	100
StandupTimer	2K	25	15	0	1068	100	60
DroidLife	3K	3	0	3	1	0	-
SMSPopUp	7K	5	1	4	46	0	100
aMetro	20K	54	18	36	18	0	100
K9Mail	40K	208	130	64	374	18	90
Total	**72K**	**311**	**172**	**115**	**1602**	**17**	**88**

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms	Thresher Refuted	True Bugs	Thresher Time (s)	False Alarm %	Filtered %
PulsePoint	unknown	16	8	8	95	0	100
StandupTimer	2K	25	15	0	1068	100	60
DroidLife	3K	3	0	3	1	0	-
SMSPopUp	7K	5	1	4	46	0	100
aMetro	20K	54	18	36	18	0	100
K9Mail	40K	208	130	64	374	18	90
Total	**72K**	**311**	**172**	**115**	**1602**	**17**	**88**

`staticfield-Activity` pairs

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms	Thresher Refuted	True Bugs	Thresher Time (s)	False Alarm %	Filtered %
PulsePoint	unknown	16	8	8	95	0	100
StandupTimer	2K	25	15	0	1068	100	60
DroidLife	3K	3	0	3	1	0	-
SMSPopUp	7K	5	1	4	46	0	100
aMetro		54	18	36	18	0	100
K9Mail		208	130	64	374	18	90
Total		**311**	**172**	**115**	**1602**	**17**	**88**

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

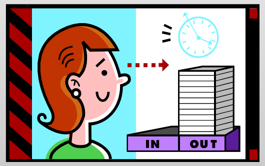
Is Thresher effective at filtering?

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

`staticfield-Activity` pairs

Filtered

Manual



Is Thresher effective at filtering?

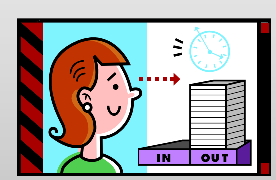
Program	LOC	Points-To Alarms	Thresher Refuted	True Bugs
PulsePoint	unknown	16	8	8
StandupTimer	2K	25	15	0
DroidLife	3K	3	0	3
SMSPopUp	7K	5	1	4
aMetro	20K			36
K9Mail	40K			64
Total	**72K**			**115**

triage "well" at 10–15 minutes per

staticfield-Activity pairs

Filtered

Manual



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**

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

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)	False Alarm %
PulsePoint	unknown	16	8	8	95	0
StandupTimer	2K	25	15	0	1068	100
DroidLife	3K	3	0	3	1	0
SMSPopUp	7K	5	1	4	46	0
aMetro	20K	54	18	36	18	0
K9Mail	40K	208	130	64	374	18
Total	**72K**	**311**	**172**	**115**	**1602**	**17**

% after filtering

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms	Thresher Refuted	True Bugs	Thresher Time (s)	False Alarm %	Filtered %
PulsePoint	unknown	16	8	8	95	0	100
StandupTimer	2K	25	15	0	1068	100	60
DroidLife	3K	3	0	3	1	0	-
SMSPopUp	7K	5	1	4	46	0	100
aMetro	20K	54	18	36	18	0	100
K9Mail	40K	208	130	64	374	18	90
Total	**72K**	**311**	**172**	**115**	**1602**	**17**	**88**

% after filtering

Is Thresher effective at filtering?

Program	LOC	Points-To Alarms	Thresher Refuted	True Bugs	Thresher Time (s)	False Alarm %	Filtered %
PulsePoint	unknown	16	8	8	95	0	100
StandupTimer	2K	25	15	0	1068	100	60
DroidLife	3K	3	0	3	1	0	-
SMSPopUp	7K	5	1	4	46	0	100
aMetro	20K	54	18	36	18	0	100
K9Mail	40K	208	130	64	374	18	90
Total	**72K**	**311**	**172**	**115**	**1602**	**17**	**88**

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

PulsePoint	unknown	16	8	8	95	0	100
StandupTimer	2K	25	15	0	1068	100	60
DroidLife	3K	3	0	3	1	0	-
SMSPopUp	7K	5	1	4	46	0	100
aMetro	20K	54	18	36	18	0	100
K9Mail	40K	208	130	64	374	18	90
Total	**72K**	**311**	**172**	**115**	**1602**	**17**	**88**

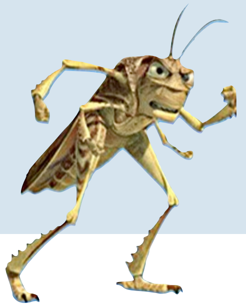
False alarms down to 17% from 63% (points-to analysis only)

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

Android
OS

... in the process of finding leaks in apps

Find the Android's HashMap bug …

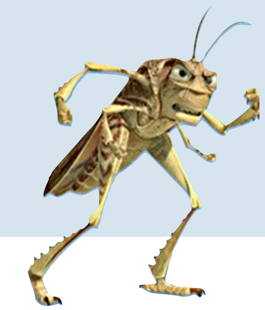


```
class HashMap {
  static Object[] EMPTY = new Object[2]; ...
  HashMap() { this.tbl = EMPTY; capacity initially empty }

  void put(Object key, Object val) {
    if (need capacity) {
      this.tbl = new Object[more capacity];
      copy from old table
    }
    this.tbl[bucket using hash of key] = val;
  }

  HashMap(Map m) {
    if (m.size() < 1) { this.tbl = EMPTY; }
    else { this.tbl = new Object[at least m.size()]; }
    copy from m
  }
}
```

Find the Android's HashMap bug ...

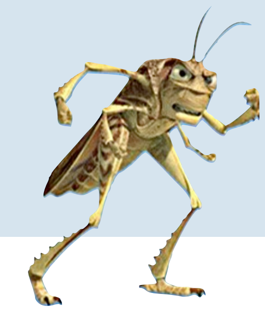


```
class HashMap {
  static Object[] EMPTY = new Object[2]; ...
  HashMap() { this.tbl = EMPTY; capacity initially empty }

  void put(Object key, Object val) {
    if (need capacity) {
      this.tbl = new Object[more capacity];
      copy from old table
    }
    this.tbl[bucket using hash of key] = val;
  }

  HashMap(Map m) {
    if (m.size() < 1) { this.tbl = EMPTY; }
    else { this.tbl = new Object[at least m.size()]; }
    copy from m
  }
}
```

Find the Android's HashMap bug …



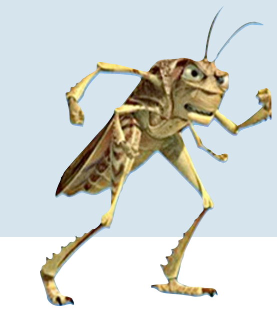
null object pattern: should not be written to

```
class HashMap {
  static Object[] EMPTY = new Object[2]; ...
  HashMap() { this.tbl = EMPTY; capacity initially empty }

  void put(Object key, Object val) {
    if (need capacity) {
      this.tbl = new Object[more capacity];
      copy from old table
    }
    this.tbl[bucket using hash of key] = val;
  }

  HashMap(Map m) {
    if (m.size() < 1) { this.tbl = EMPTY; }
    else { this.tbl = new Object[at least m.size()]; }
    copy from m
  }
}
```

Find the Android's HashMap bug …



null object pattern: should not be written to

```
class HashMap {
  static Object[] EMPTY = new Object[2]; ...
  HashMap() { this.tbl = EMPTY; capacity initially empty }

  void put(Object key, Object val) {
    if (need capacity) {
      this.tbl = new Object[more capacity];
      copy from old table
    }
    this.tbl[bucket using hash of key] = val;
  }

  HashMap(Map m) {
    if (m.size() < 1) { this.tbl = EMPTY; }
    else { this.tbl = new Object[at least m.size()]; }
    copy from m
  }
}
```

allocate new backing array on first write

Find the Android's HashMap bug …

null object pattern: should not be written to

```
class HashMap {
  static Object[] EMPTY = new Object[2]; ...
  HashMap() { this.tbl = EMPTY; capacity initially empty }

  void put(Object key, Object val) {
    if (need capacity) {
      this.tbl = new Object[more capacity];
      copy from old table
    }
    this.tbl[bucket using hash of key] = val;
  }

  HashMap(Map m) {
    if (m.size() < 1) { this.tbl = EMPTY; }
    else { this.tbl = new Object[at least m.size()]; }
    copy from m
  }
}
```

allocate new backing array on first write

Find the Android's HashMap bug …

null object pattern: should not be written to

```
class HashMap {
  static Object[] EMPTY = new Object[2]; ...
  HashMap() { this.tbl = EMPTY; capacity initially empty }

  void put(Object key, Object val) {
    if (need capacity) {
      this.tbl = new Object[more capacity];
      copy from old table
    }
    this.tbl[bucket using hash of key] = val;
  }

  HashMap(Map m) {
    if (m.size() < 1) { this.tbl = EMPTY; }
    else { this.tbl = new Object[at least m.size()]; }
    copy from m
  }
}
```

allocate new backing array on first write

An "evil" implementation of the `Map` interface can corrupt `EMPTY`. Then, all `HashMap`s created in the future will be corrupted.

Find the Android's HashMap bug ...

null object pattern: should not be written to

```
class HashMap {
  static Object[] EMPTY = new Object[2]; ...
  HashMap() { this.tbl = EMPTY; capacity initially empty }

  void put(Object key, Object val) {
    if (need capacity) {
      this.tbl = new Object[more capacity];
      copy from old table
    }
    this.tbl[bucket using hash of key] = val;
  }

  HashMap(Map m) {
    if (m.size() < 1) { this.tbl = EMPTY; }
    else { this.tbl = new Object[at least m.size()]; }
    copy from m
  }
}
```

allocate new backing array on first write

return 0

return "evil" content

An "evil" implementation of the Map interface can corrupt EMPTY. Then, all HashMaps created in the future will be corrupted.

Find the Android's HashMap bug …

```
cla
  s
  H

  v

  }
  HashMap(Map m) {
    if (m.size() < 1) { this.tbl = EMPTY; }
    else { this.tbl = new Object[at least m.size()]; }
    copy from m
  }
}
```

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

return 0

return "evil" content

An "evil" implementation of the `Map` interface can corrupt `EMPTY`. Then, all `HashMaps` created in the future will be corrupted.

Find the Android's HashMap bug ...

```
cla
  s
  H

  v

  }
```

```
  HashMap(Map m) {
    if (m.size() < 1) { this.tbl = EMPTY; }
    else { this.tbl = new Object[at least m.size()]; }
    copy from m
  }
}
```

What if you store passwords in a `HashMap`?

We reported this, Google fixed it

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

return 0

return "evil" content

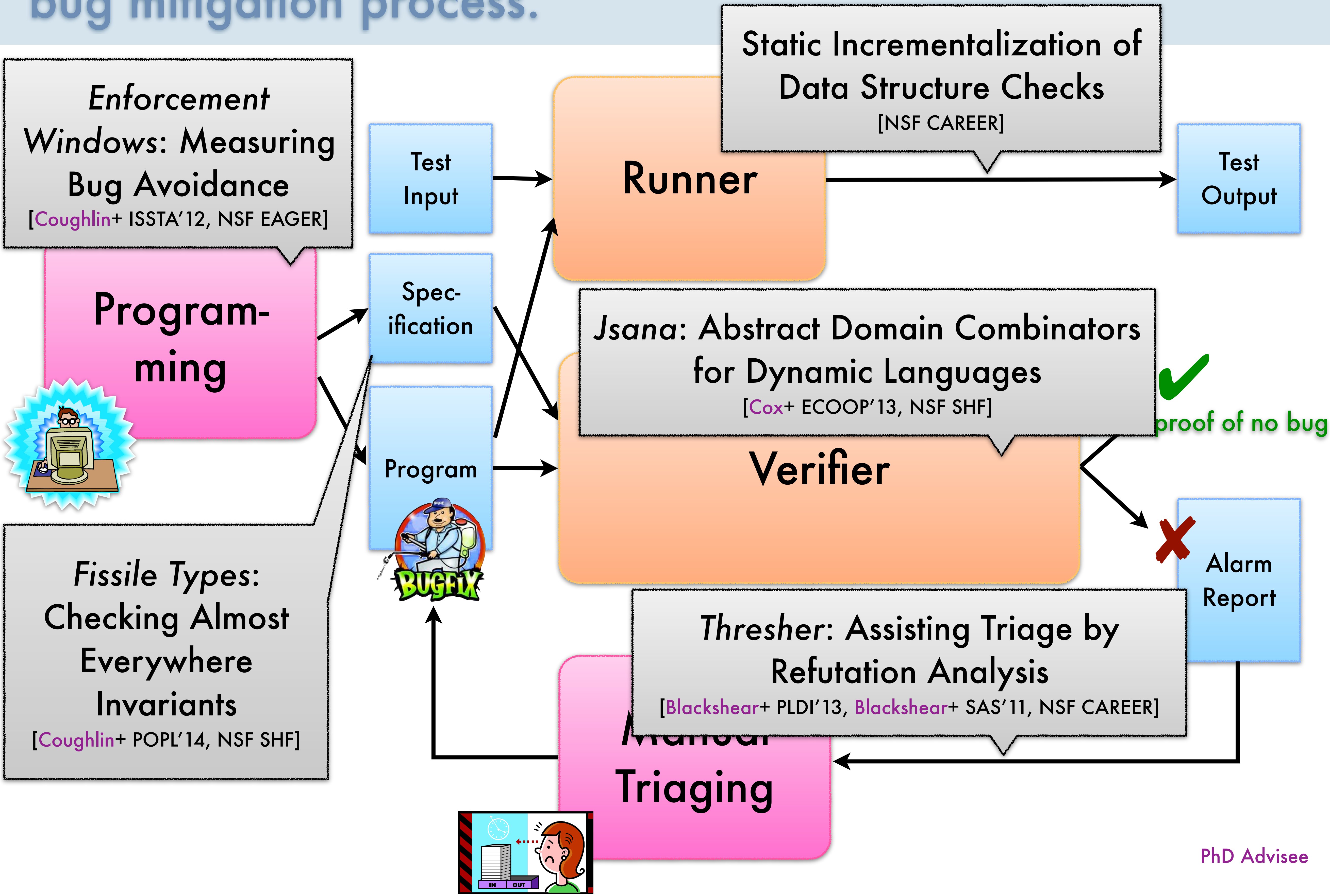
An "evil" implementation of the `Map` interface can corrupt `EMPTY`. Then, all `HashMaps` created in the future will be corrupted.

Contribution: Addressed the false alarm problem with

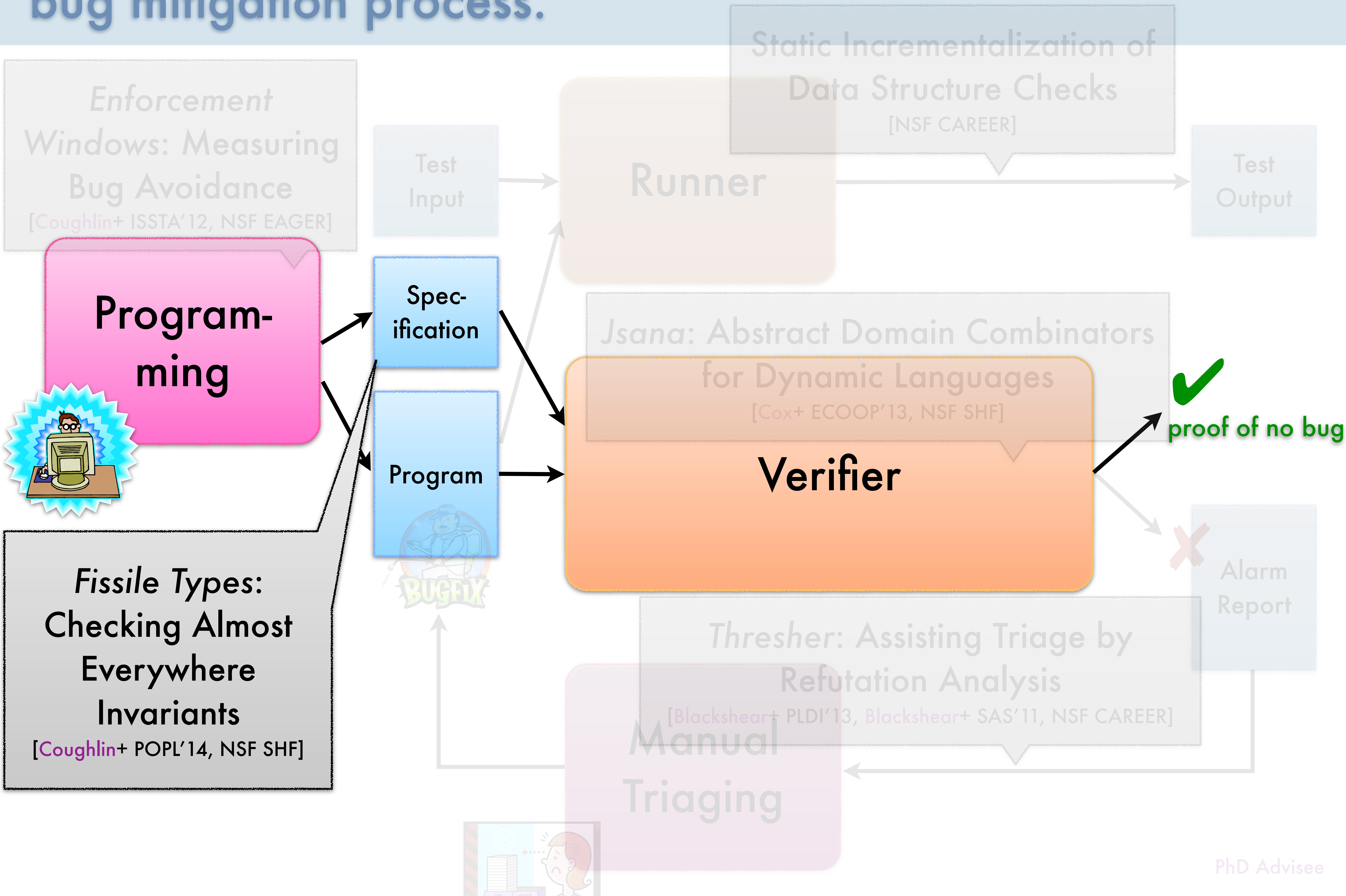
a "smart and precise filter"

a refutation analysis

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



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



Fissile Types: Checking Reflection with Almost Everywhere Invariants

Method Reflection and the Great Divide

Method Reflection and the Great Divide

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

Method Reflection and the Great Divide

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

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

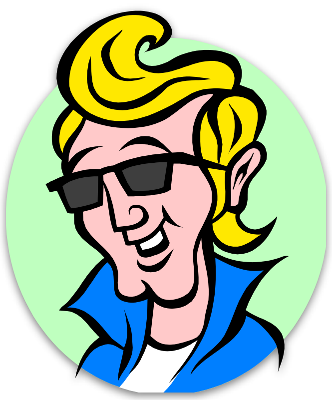
Method Reflection and the Great Divide

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

`object[string]()`

type system designers

"web 2.0" developers



Method Reflection and the Great Divide

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

`object[string]()`

type system designers

"web 2.0" developers

Type system designers **worry**.

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

Method Reflection and the Great Divide

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

`object[string]()`

type system designers

"web 2.0" developers

Type system designers **worry**.

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

"Web 2.0" developers think it's **cool**.

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

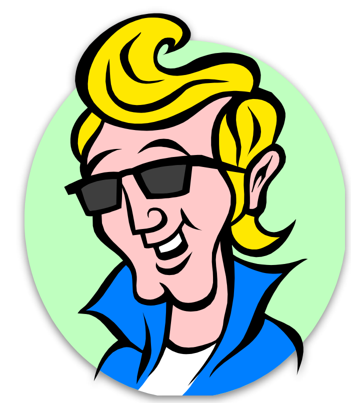
Method Reflection and the Great Divide

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

`object[string]()`

type system designers

"web 2.0" developers



Type system designers **worry**.

Wh

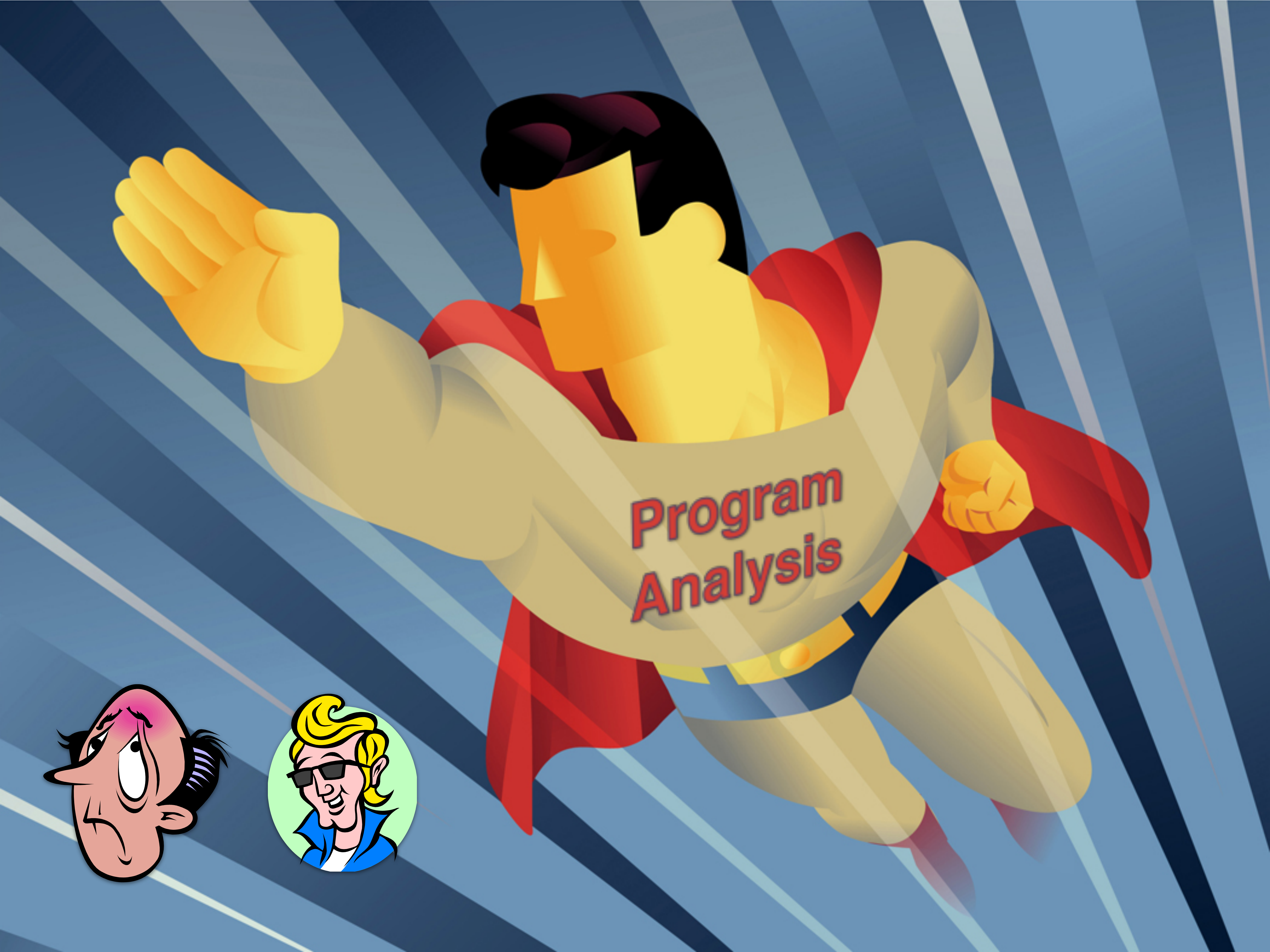
obj

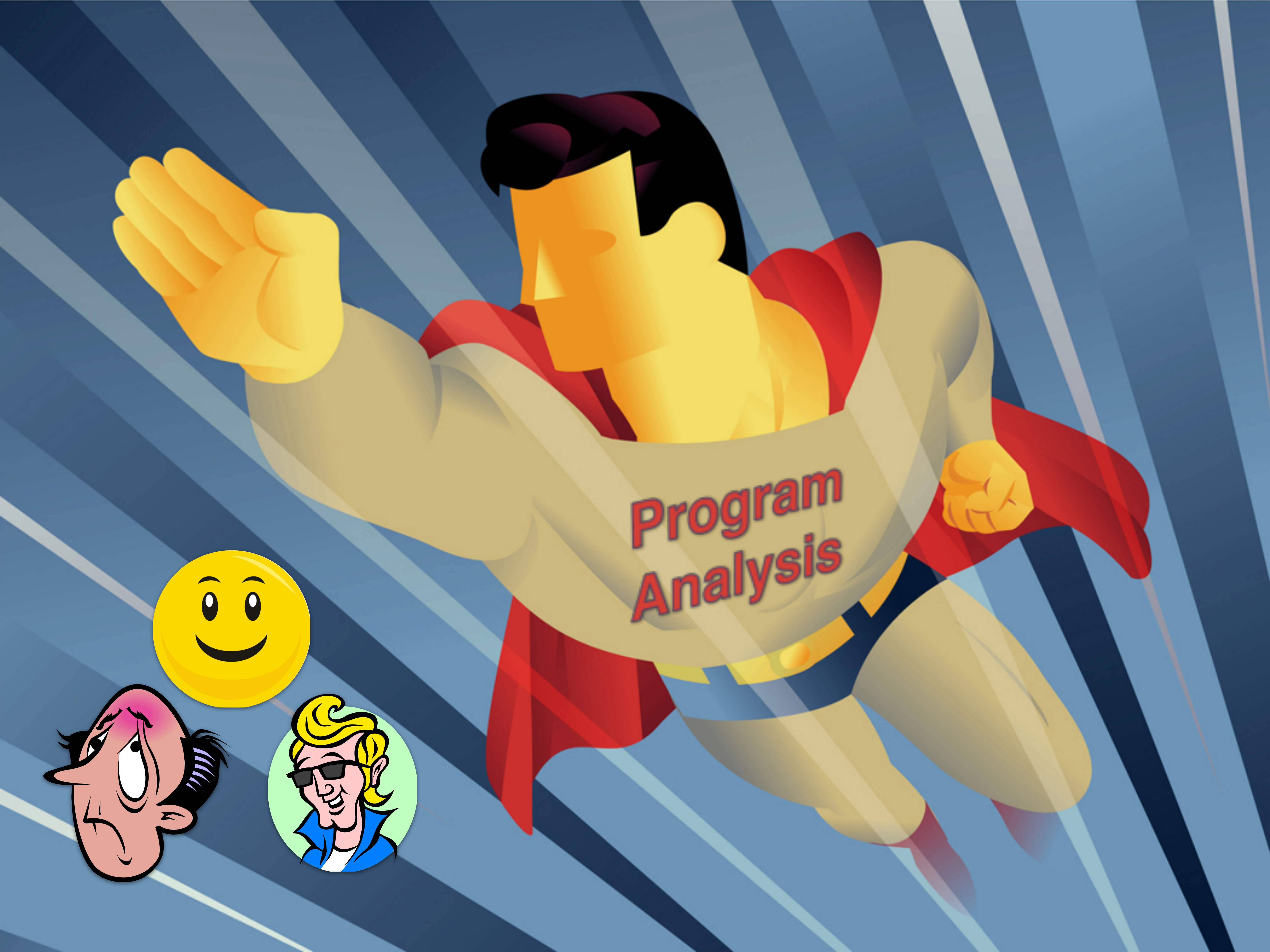
by

"Web 2.0" developers think it's **cool**.

static safety.

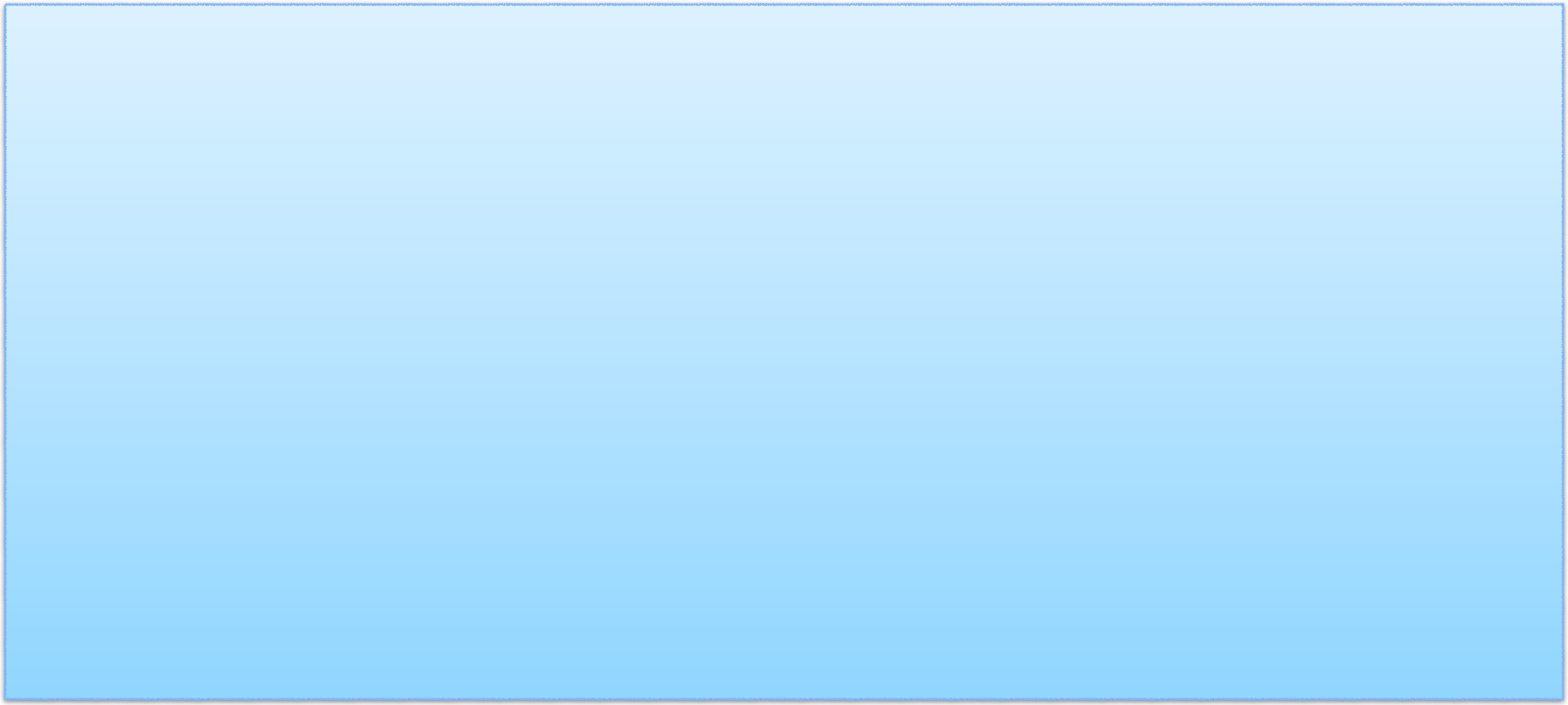
"MethodNotFound" checked at run time


Program
Analysis


Program
Analysis

Programs are often
(1) safe, (2) not type safe, (3) but almost so

Programs are often
(1) safe, (2) not type safe, (3) but almost so



Program

Programs are often
(1) safe, (2) not type safe, (3) but almost so

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

Program

Programs are often (1) safe, (2) not type safe, (3) but almost so

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

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

Program

Programs are often
(1) safe, (2) not type safe, (3) but almost so

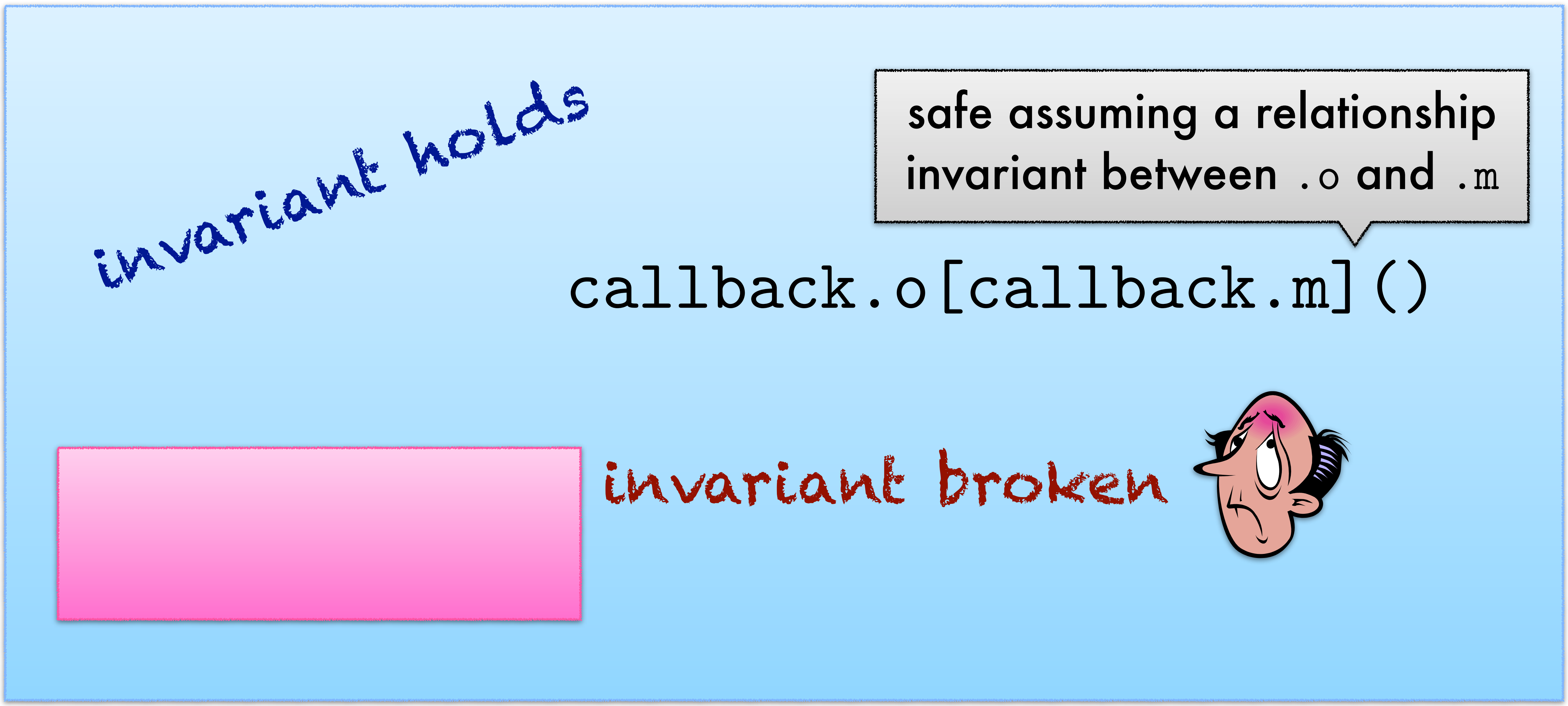
invariant holds

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

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

Program

Programs are often
(1) safe, (2) not type safe, (3) but almost so



Program

Programs are often
(1) safe, (2) not type safe, (3) but almost so

invariant holds

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

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

invariant broken

but only temporarily

Program

Programs are often
(1) safe, (2) not type safe, (3) but almost so

invariant holds

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

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

invariant broken

but only temporarily

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 `respondsTo` in system libraries
  - needed only 136 annotations in benchmarks (total)

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

Proved 86% of check sites (up from 76%) at interactive speeds (~4 to 90 kloc/s)

benchmarks (total)

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

places requiring a check of the invariant

Proved 86% of check sites (up from 76%) at interactive speeds (~4 to 90 kloc/s)

benchmarks (total)

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

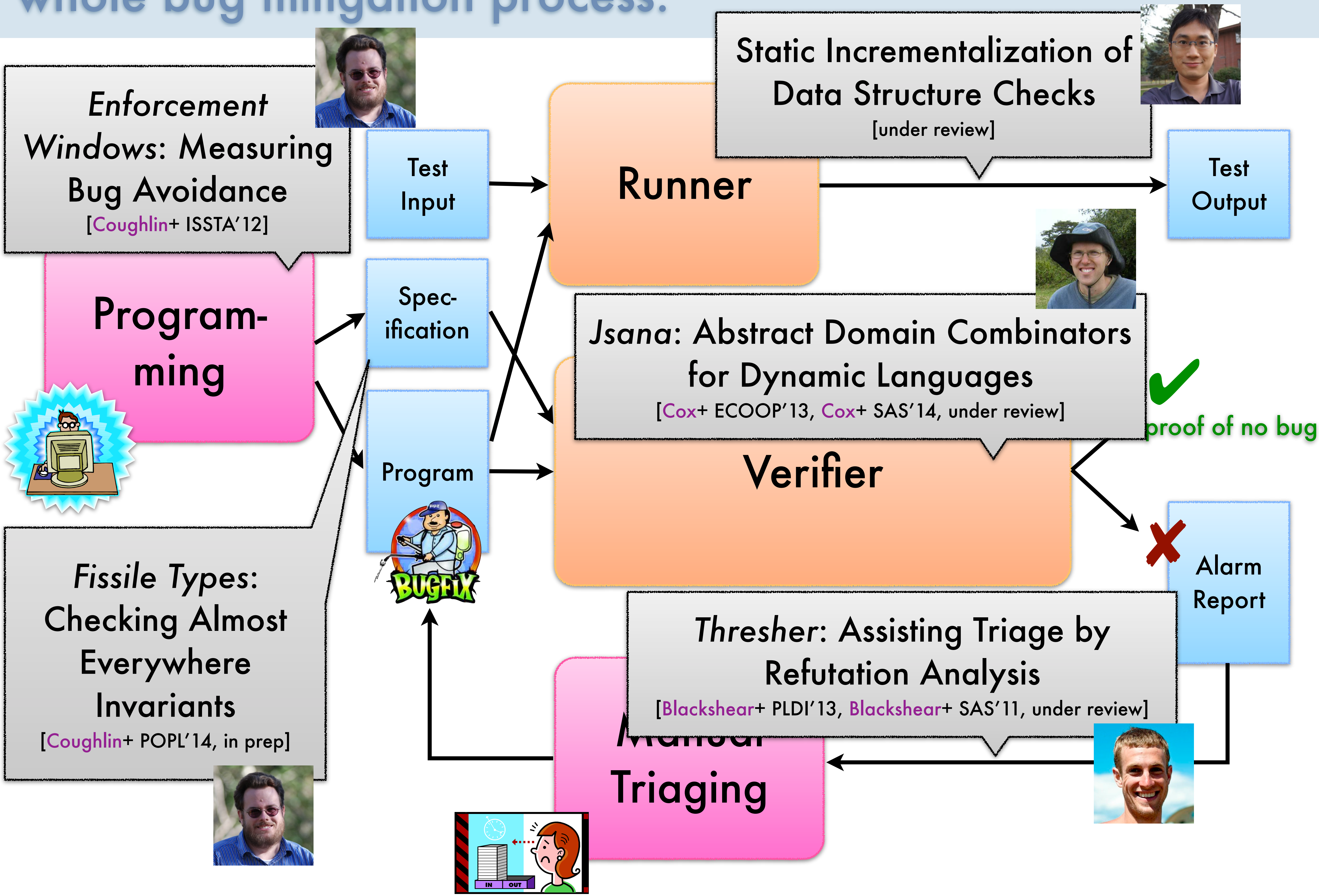
461,000 lines in total

places requiring a check of the invariant

Proved 86% of check sites (up from 76%) at interactive speeds (~4 to 90 kloc/s)

Big Deal: makes IDE integration possible

Summary: The cooperative approach addresses the whole bug mitigation process.



PLV

www.cs.colorado.edu/~bec
pl.cs.colorado.edu

PLV

www.cs.colorado.edu/~bec
pl.cs.colorado.edu


Cerny


Chang


Sankaranarayanan


Somenzi