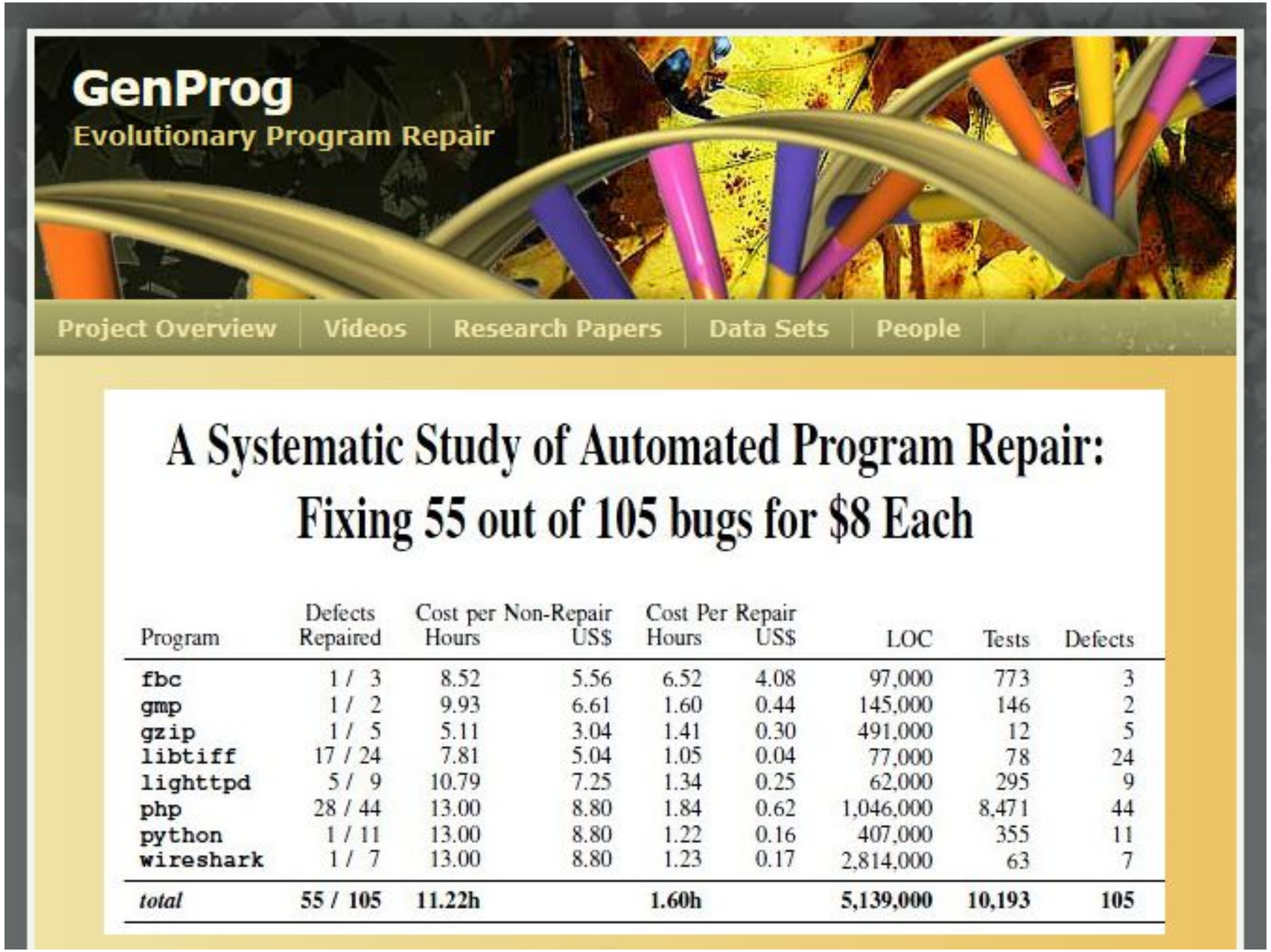
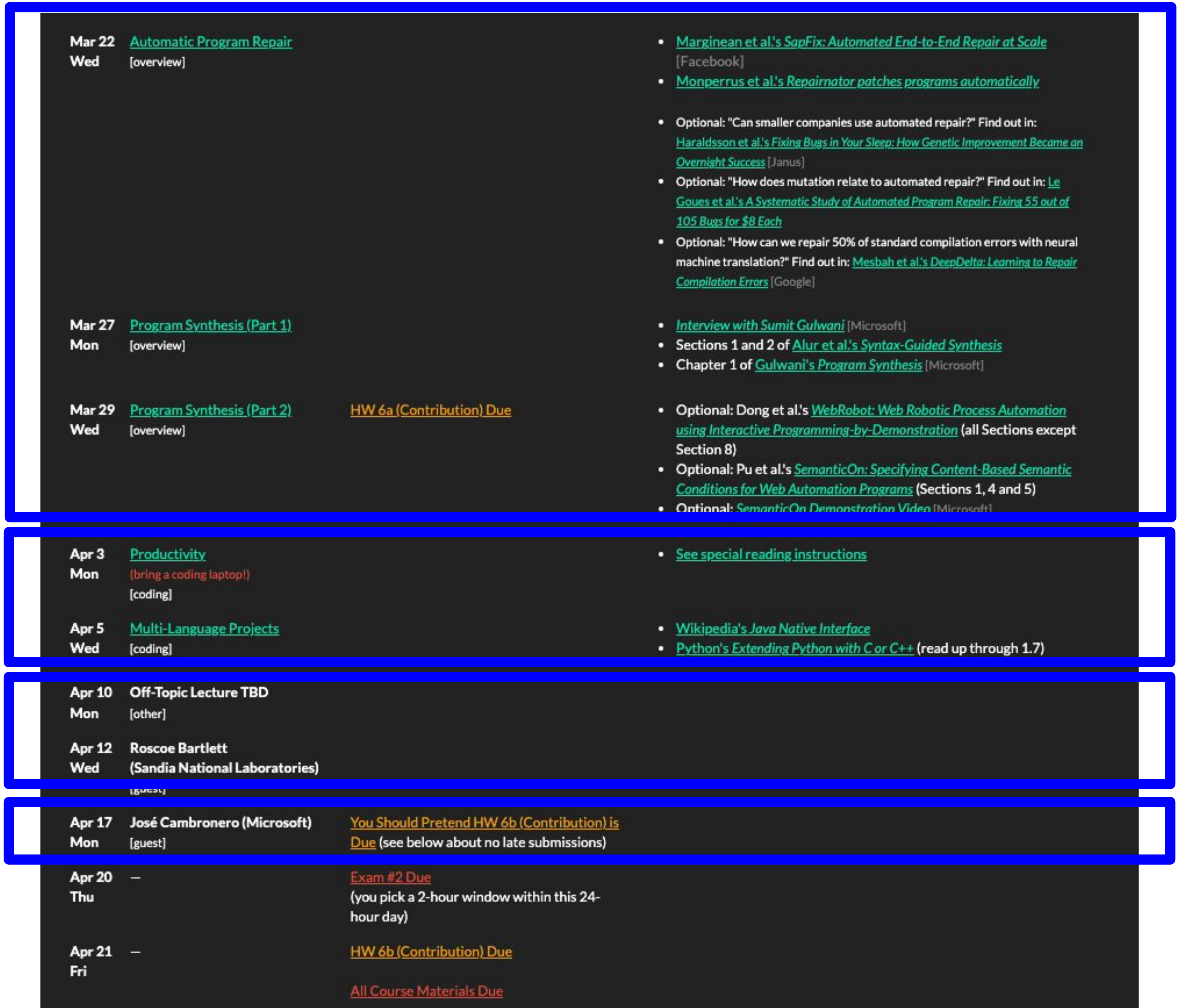
# Automated Program Repair



## A Systematic Study of Automated Program Repair: Fixing 55 out of 105 bugs for $8 Each

| Program | Defects Repaired | Cost per Non-Repair Hours | US$ | Cost Per Repair Hours | US$ | LOC | Tests | Defects |
|---|---|---|---|---|---|---|---|---|
| fbc | 1 / 3 | 8.52 | 5.56 | 6.52 | 4.08 | 97,000 | 773 | 3 |
| gmp | 1 / 2 | 9.93 | 6.61 | 1.60 | 0.44 | 145,000 | 146 | 2 |
| gzip | 1 / 5 | 5.11 | 3.04 | 1.41 | 0.30 | 491,000 | 12 | 5 |
| libtiff | 17 / 24 | 7.81 | 5.04 | 1.05 | 0.04 | 77,000 | 78 | 24 |
| lighttpd | 5 / 9 | 10.79 | 7.25 | 1.34 | 0.25 | 62,000 | 295 | 9 |
| php | 28 / 44 | 13.00 | 8.80 | 1.84 | 0.62 | 1,046,000 | 8,471 | 44 |
| python | 1 / 11 | 13.00 | 8.80 | 1.22 | 0.16 | 407,000 | 355 | 11 |
| wireshark | 1 / 7 | 13.00 | 8.80 | 1.23 | 0.17 | 2,814,000 | 63 | 7 |
| *total* | **55 / 105** | **11.22h** | | **1.60h** | | **5,139,000** | **10,193** | **105** |

# Where Are We?



| | | | |
|---|---|---|---|
| Mar 22<br>Wed | Automatic Program Repair<br>[overview] | | • Marginean et al.'s *SapFix: Automated End-to-End Repair at Scale* [Facebook]<br>• Monperrus et al.'s *Repairnator patches programs automatically*<br>• Optional: "Can smaller companies use automated repair?" Find out in: Haraldsson et al.'s *Fixing Bugs in Your Sleep: How Genetic Improvement Became an Overnight Success* [Janus]<br>• Optional: "How does mutation relate to automated repair?" Find out in: Le Goues et al.'s *A Systematic Study of Automated Program Repair: Fixing 55 out of 105 Bugs for $8 Each*<br>• Optional: "How can we repair 50% of standard compilation errors with neural machine translation?" Find out in: Mesbah et al.'s *DeepDelta: Learning to Repair Compilation Errors* [Google] |
| Mar 27<br>Mon | Program Synthesis (Part 1)<br>[overview] | | • *Interview with Sumit Gulwani* [Microsoft]<br>• Sections 1 and 2 of Alur et al.'s *Syntax-Guided Synthesis*<br>• Chapter 1 of Gulwani's *Program Synthesis* [Microsoft] |
| Mar 29<br>Wed | Program Synthesis (Part 2)<br>[overview] | HW 6a (Contribution) Due | • Optional: Dong et al.'s *WebRobot: Web Robotic Process Automation using Interactive Programming-by-Demonstration* (all Sections except Section 8)<br>• Optional: Pu et al.'s *SemanticOn: Specifying Content-Based Semantic Conditions for Web Automation Programs* (Sections 1, 4 and 5)<br>• Optional: *SemanticOn Demonstration Video* [Microsoft] |
| Apr 3<br>Mon | Productivity<br>(bring a coding laptop!)<br>[coding] | | • See special reading instructions |
| Apr 5<br>Wed | Multi-Language Projects<br>[coding] | | • Wikipedia's *Java Native Interface*<br>• Python's *Extending Python with C or C++* (read up through 1.7) |
| Apr 10<br>Mon | **Off-Topic Lecture TBD**<br>[other] | | |
| Apr 12<br>Wed | **Roscoe Bartlett (Sandia National Laboratories)**<br>[guest] | | |
| Apr 17<br>Mon | **José Cambronero (Microsoft)**<br>[guest] | You Should Pretend HW 6b (Contribution) is Due (see below about no late submissions) | |
| Apr 20<br>Thu | – | Exam #2 Due<br>(you pick a 2-hour window within this 24-hour day) | |
| Apr 21<br>Fri | – | HW 6b (Contribution) Due<br><br>All Course Materials Due | |

# The Never-Ending Story

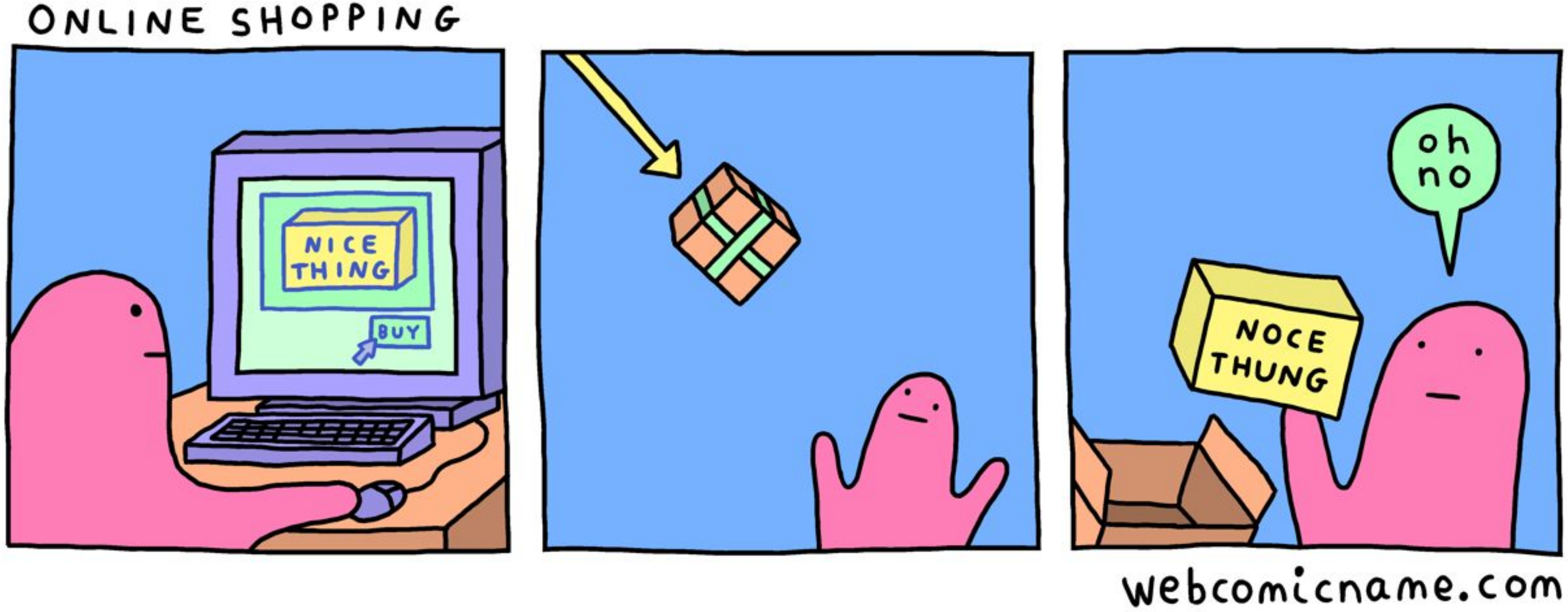
- Today we will use recent advances in **automated program repair** to touch on all of the **lecture topics** from this course

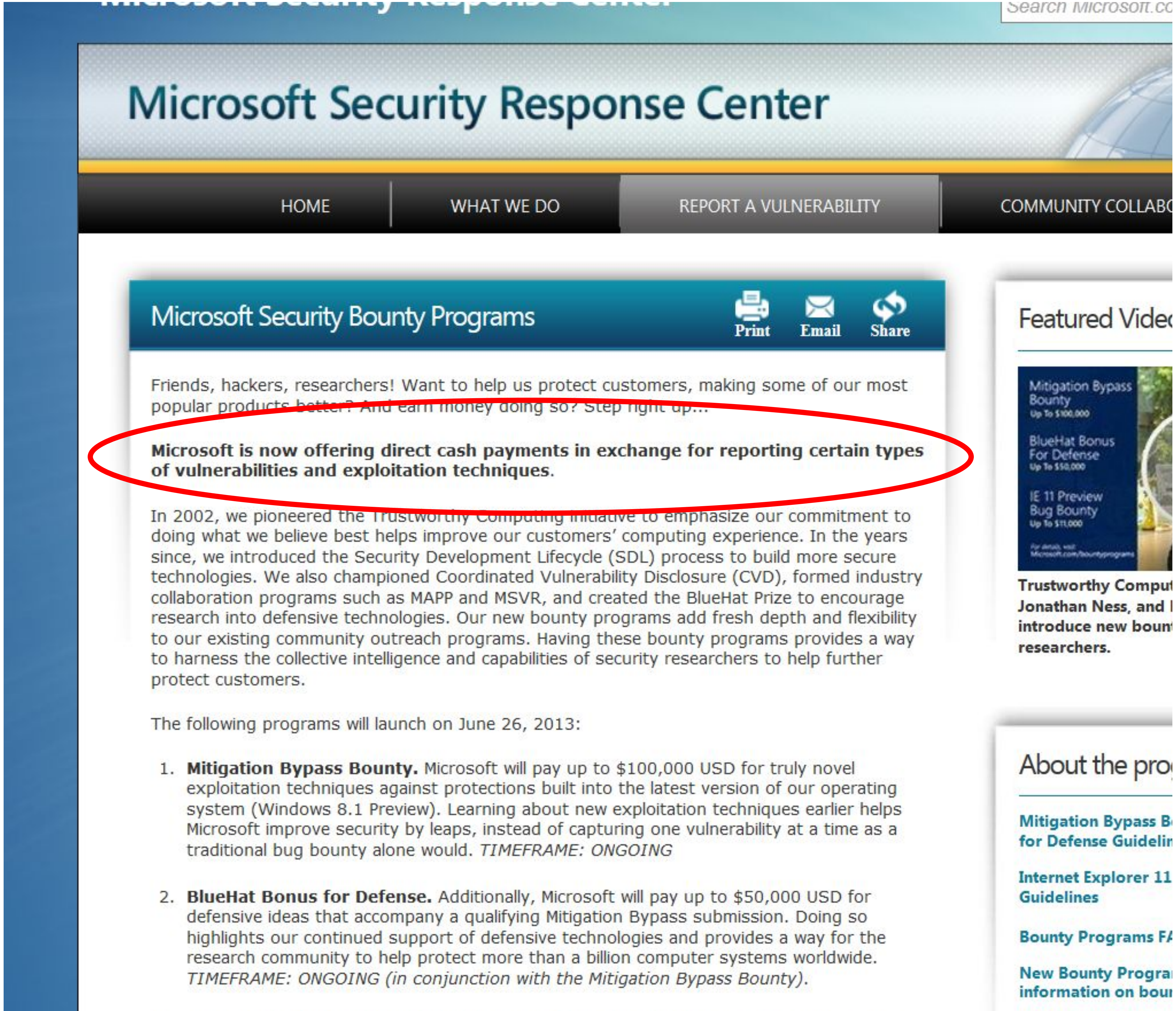
# Leading Question

- How do software companies find/fix bugs?

# Speculative Fiction

- What if large, trusted companies paid **strangers** online to find and fix their normal and critical bugs?





# Microsoft Security Response Center

## Microsoft Security Bounty Programs

Friends, hackers, researchers! Want to help us protect customers, making some of our most popular products better? And earn money doing so? Step right up...

**Microsoft is now offering direct cash payments in exchange for reporting certain types of vulnerabilities and exploitation techniques.**

In 2002, we pioneered the Trustworthy Computing initiative to emphasize our commitment to doing what we believe best helps improve our customers' computing experience. In the years since, we introduced the Security Development Lifecycle (SDL) process to build more secure technologies. We also championed Coordinated Vulnerability Disclosure (CVD), formed industry collaboration programs such as MAPP and MSVR, and created the BlueHat Prize to encourage research into defensive technologies. Our new bounty programs add fresh depth and flexibility to our existing community outreach programs. Having these bounty programs provides a way to harness the collective intelligence and capabilities of security researchers to help further protect customers.

The following programs will launch on June 26, 2013:

1. **Mitigation Bypass Bounty.** Microsoft will pay up to $100,000 USD for truly novel exploitation techniques against protections built into the latest version of our operating system (Windows 8.1 Preview). Learning about new exploitation techniques earlier helps Microsoft improve security by leaps, instead of capturing one vulnerability at a time as a traditional bug bounty alone would. *TIMEFRAME: ONGOING*

2. **BlueHat Bonus for Defense.** Additionally, Microsoft will pay up to $50,000 USD for defensive ideas that accompany a qualifying Mitigation Bypass submission. Doing so highlights our continued support of defensive technologies and provides a way for the research community to help protect more than a billion computer systems worldwide. *TIMEFRAME: ONGOING (in conjunction with the Mitigation Bypass Bounty).*

## Featured Vide

**Trustworthy Comput Jonathan Ness, and I introduce new bount researchers.**

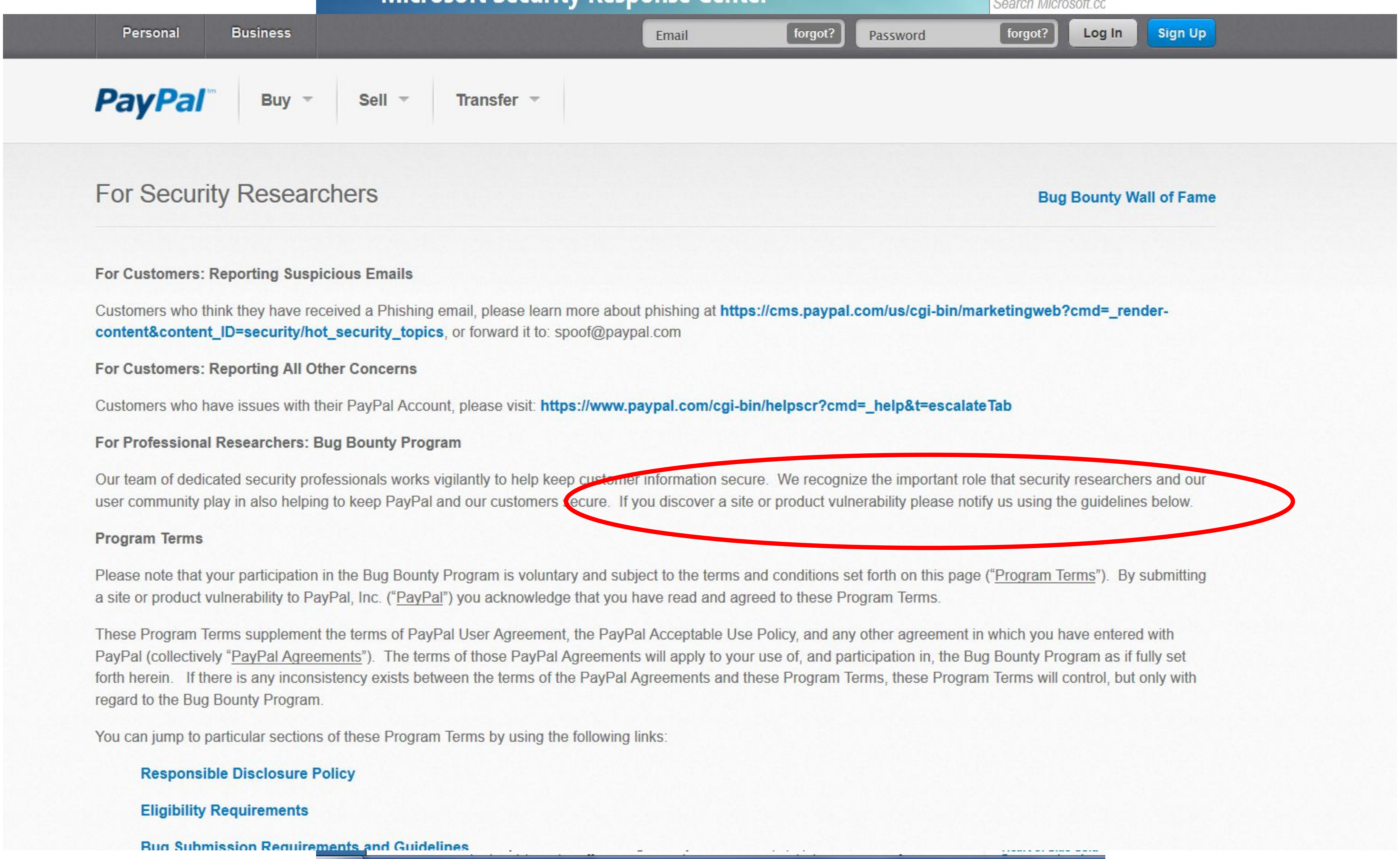
## About the pro

**Mitigation Bypass B for Defense Guidelin**

**Internet Explorer 11 Guidelines**

**Bounty Programs FA**

**New Bounty Progra information on bou**



## For Security Researchers

Bug Bounty Wall of Fame

**For Customers: Reporting Suspicious Emails**

Customers who think they have received a Phishing email, please learn more about phishing at https://cms.paypal.com/us/cgi-bin/marketingweb?cmd=_render-content&content_ID=security/hot_security_topics, or forward it to: spoof@paypal.com

**For Customers: Reporting All Other Concerns**

Customers who have issues with their PayPal Account, please visit: https://www.paypal.com/cgi-bin/helpscr?cmd=_help&t=escalateTab

**For Professional Researchers: Bug Bounty Program**

Our team of dedicated security professionals works vigilantly to help keep customer information secure. We recognize the important role that security researchers and our user community play in also helping to keep PayPal and our customers secure. If you discover a site or product vulnerability please notify us using the guidelines below.

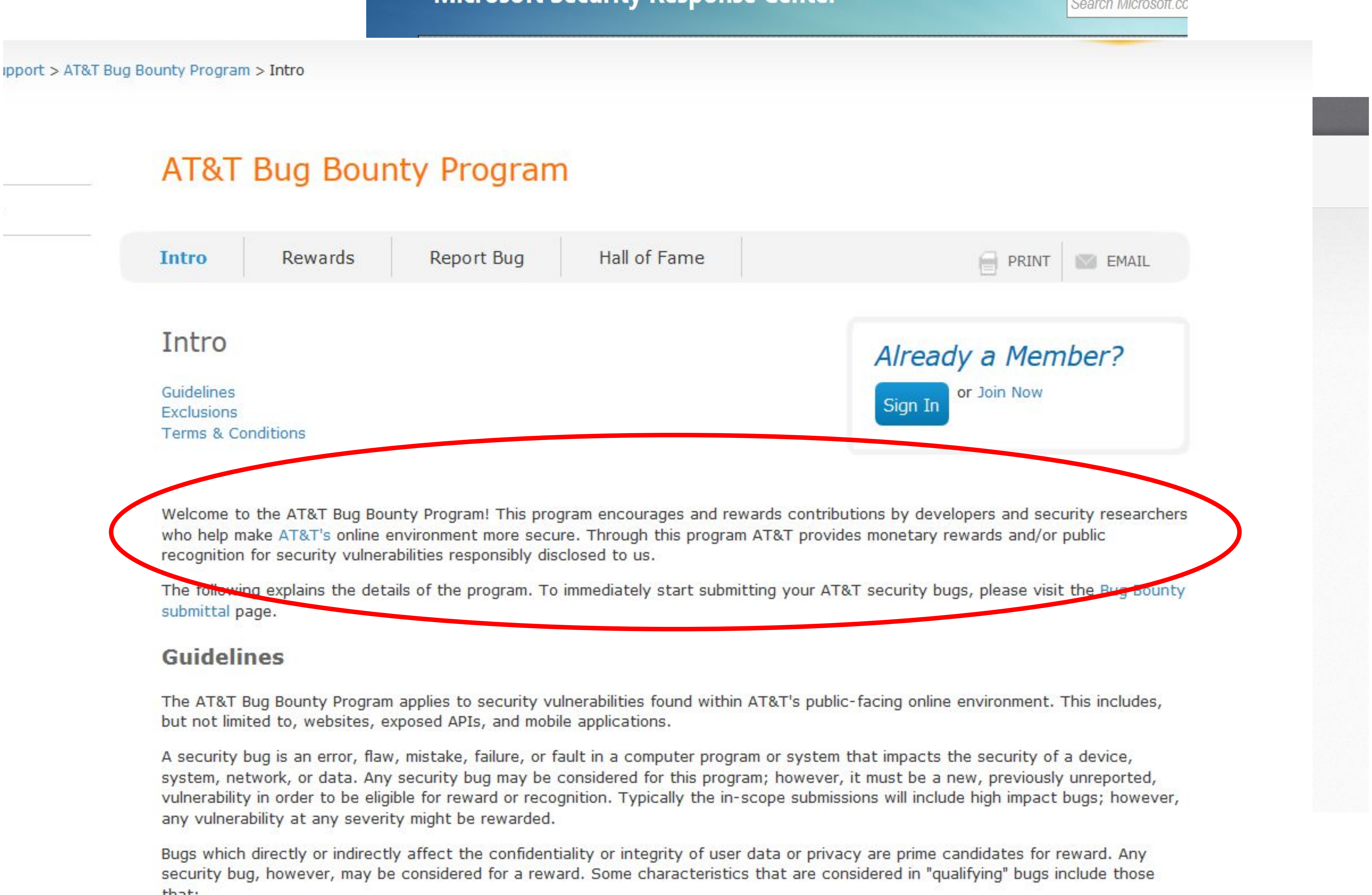
**Program Terms**

Please note that your participation in the Bug Bounty Program is voluntary and subject to the terms and conditions set forth on this page ("Program Terms"). By submitting a site or product vulnerability to PayPal, Inc. ("PayPal") you acknowledge that you have read and agreed to these Program Terms.

These Program Terms supplement the terms of PayPal User Agreement, the PayPal Acceptable Use Policy, and any other agreement in which you have entered with PayPal (collectively "PayPal Agreements"). The terms of those PayPal Agreements will apply to your use of, and participation in, the Bug Bounty Program as if fully set forth herein. If there is any inconsistency exists between the terms of the PayPal Agreements and these Program Terms, these Program Terms will control, but only with regard to the Bug Bounty Program.

You can jump to particular sections of these Program Terms by using the following links:

- Responsible Disclosure Policy
- Eligibility Requirements
- Bug Submission Requirements and Guidelines



# AT&T Bug Bounty Program

## Intro

Guidelines
Exclusions
Terms & Conditions

Welcome to the AT&T Bug Bounty Program! This program encourages and rewards contributions by developers and security researchers who help make AT&T's online environment more secure. Through this program AT&T provides monetary rewards and/or public recognition for security vulnerabilities responsibly disclosed to us.

The following explains the details of the program. To immediately start submitting your AT&T security bugs, please visit the Bug Bounty submittal page.

### Guidelines

The AT&T Bug Bounty Program applies to security vulnerabilities found within AT&T's public-facing online environment. This includes, but not limited to, websites, exposed APIs, and mobile applications.

A security bug is an error, flaw, mistake, failure, or fault in a computer program or system that impacts the security of a device, system, network, or data. Any security bug may be considered for this program; however, it must be a new, previously unreported, vulnerability in order to be eligible for reward or recognition. Typically the in-scope submissions will include high impact bugs; however, any vulnerability at any severity might be rewarded.

Bugs which directly or indirectly affect the confidentiality or integrity of user data or privacy are prime candidates for reward. Any security bug, however, may be considered for a reward. Some characteristics that are considered in "qualifying" bugs include those that:

(Raise Your Hand If True)

I have used software produced by Microsoft, PayPal, AT&T, Facebook, Mozilla, Google *or* Youtube.

Microsoft Security Response Center

For Security Researchers

For Customers: Reporting Suspicious Emails

Customers who think they have received
content&content_ID=security/hot_secu

For Customers: Reporting All Other C

Customers who have issues with their Pa

For Professional Researchers: Bug Bo

Our team of dedicated security profession
user community play in also helping to ke

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Bug Submission Requirements and Guidelines

pport > AT&T Bug Bounty Program > Intro

AT&T Bug Bounty Program

dy a Member?

or Join Now

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rewards and/or public

ugs, please visit the Bug Bounty

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# Bug Bounties

- If you trust your triage and code review processes, anyone can submit a candidate bug report or candidate patch
- **Bug Bounties** combine **defect reporting and triage** with **pass-around code review**
- Finding, fixing and ignoring bugs are all so expensive that it is now (~2013+) economical to pay untrusted strangers to submit candidate defect reports and patches

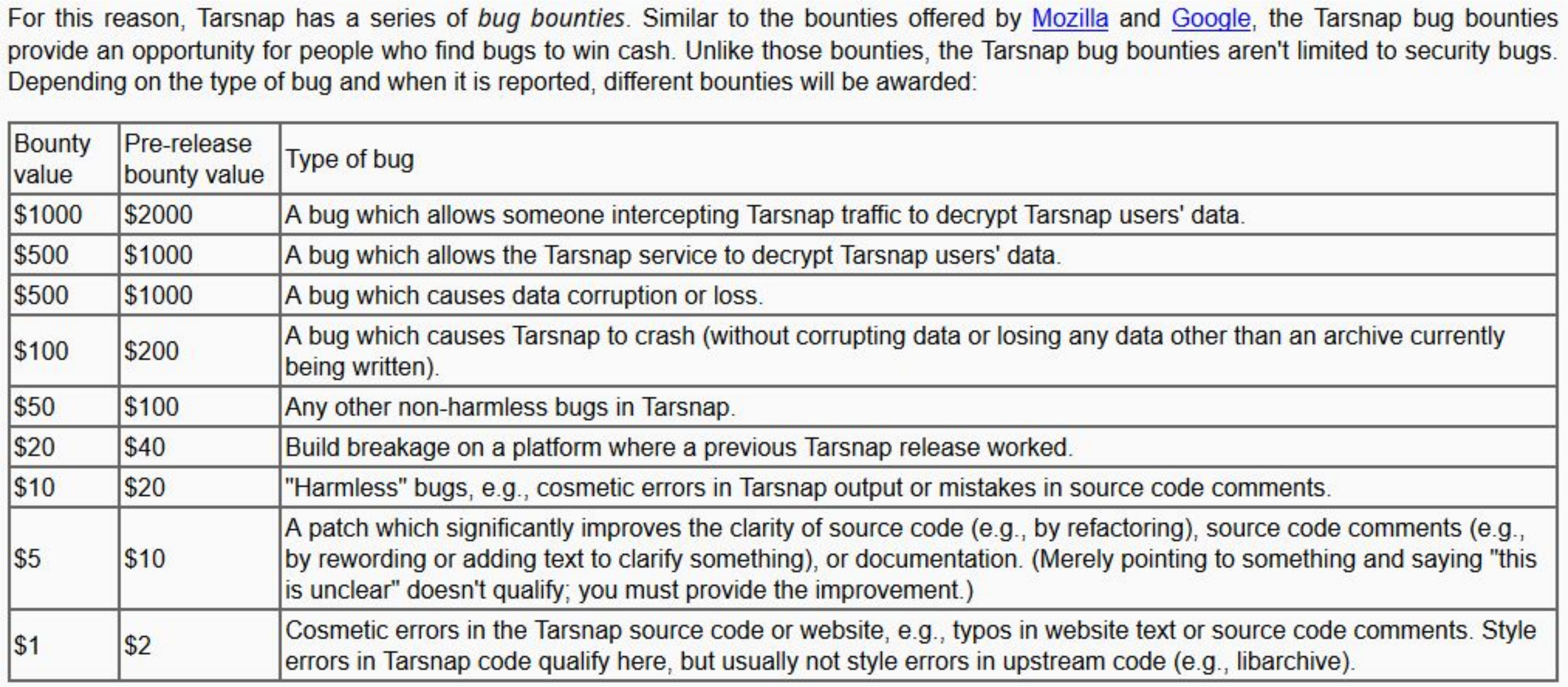
# Bug Bounties and Large Companies

- “We get hundreds of reports every day. Many of our best reports come from people whose English isn't great – though this can be challenging, it's something we work with just fine and we have paid out over $1 million to hundreds of reporters.”
  - – Matt Jones, Facebook Software Engineering

# Bug Bounties and Small Companies

- Only 38% of the submissions were true positives (harmless, minor or major): “Worth the money? Every penny.” - Colin Percival, Tarsnap Tarsnap

Online backups for the truly paranoid

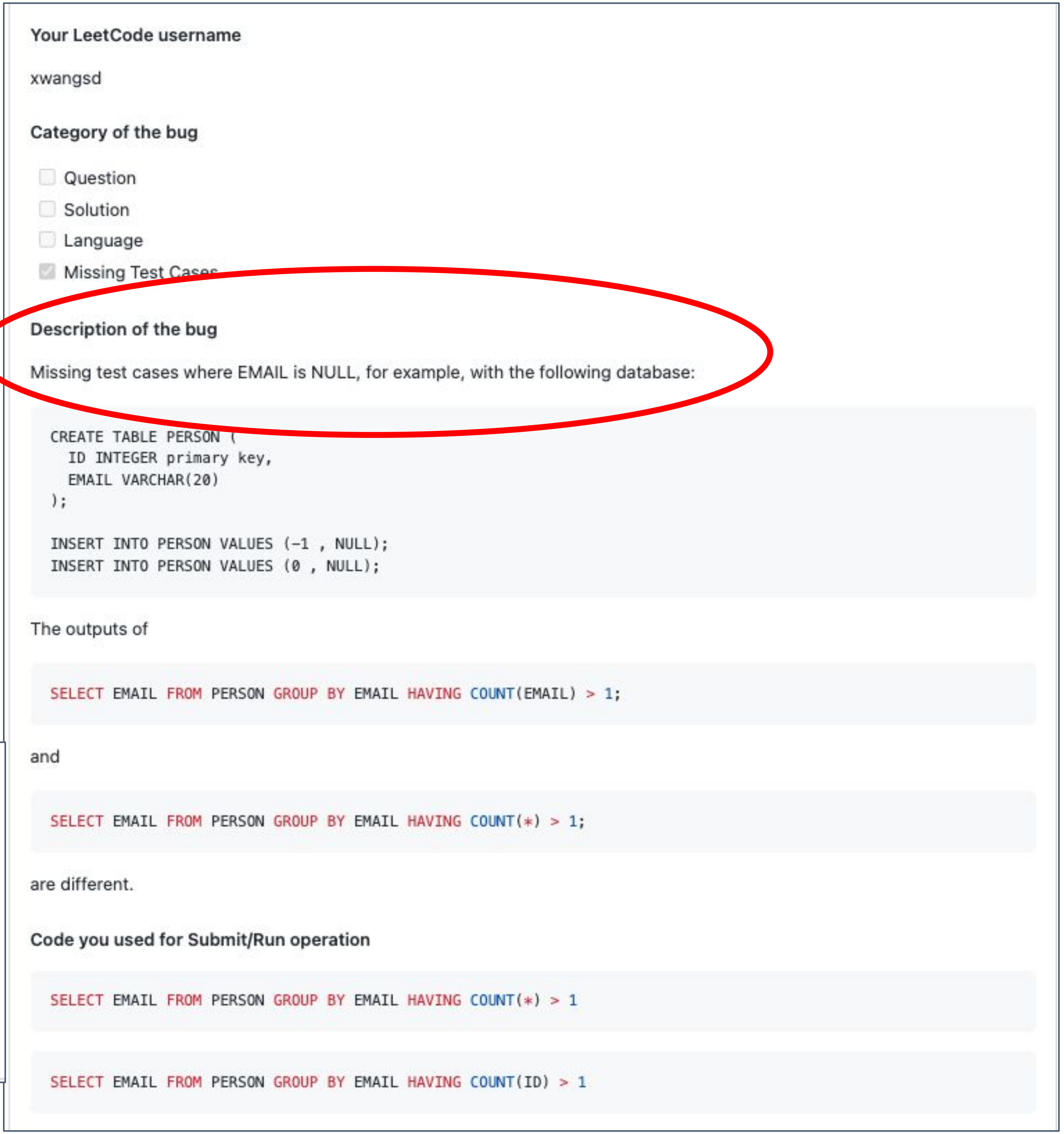


For this reason, Tarsnap has a series of *bug bounties*. Similar to the bounties offered by Mozilla and Google, the Tarsnap bug bounties provide an opportunity for people who find bugs to win cash. Unlike those bounties, the Tarsnap bug bounties aren't limited to security bugs. Depending on the type of bug and when it is reported, different bounties will be awarded:

| Bounty value | Pre-release bounty value | Type of bug |
|---|---|---|
| $1000 | $2000 | A bug which allows someone intercepting Tarsnap traffic to decrypt Tarsnap users' data. |
| $500 | $1000 | A bug which allows the Tarsnap service to decrypt Tarsnap users' data. |
| $500 | $1000 | A bug which causes data corruption or loss. |
| $100 | $200 | A bug which causes Tarsnap to crash (without corrupting data or losing any data other than an archive currently being written). |
| $50 | $100 | Any other non-harmless bugs in Tarsnap. |
| $20 | $40 | Build breakage on a platform where a previous Tarsnap release worked. |
| $10 | $20 | "Harmless" bugs, e.g., cosmetic errors in Tarsnap output or mistakes in source code comments. |
| $5 | $10 | A patch which significantly improves the clarity of source code (e.g., by refactoring), source code comments (e.g., by rewording or adding text to clarify something), or documentation. (Merely pointing to something and saying "this is unclear" doesn't qualify; you must provide the improvement.) |
| $1 | $2 | Cosmetic errors in the Tarsnap source code or website, e.g., typos in website text or source code comments. Style errors in Tarsnap code qualify here, but usually not style errors in upstream code (e.g., libarchive). |

# LeetCode Example

- Report “missing test cases” on LeetCode
- Rewards don’t have to be Cash!



**Your LeetCode username**

xwangsd

**Category of the bug**

□ Question
□ Solution
□ Language
☑ Missing Test Cases

**Description of the bug**

Missing test cases where EMAIL is NULL, for example, with the following database:

```
CREATE TABLE PERSON (
  ID INTEGER primary key,
  EMAIL VARCHAR(20)
);

INSERT INTO PERSON VALUES (-1 , NULL);
INSERT INTO PERSON VALUES (0 , NULL);
```

The outputs of

```
SELECT EMAIL FROM PERSON GROUP BY EMAIL HAVING COUNT(EMAIL) > 1;
```

and

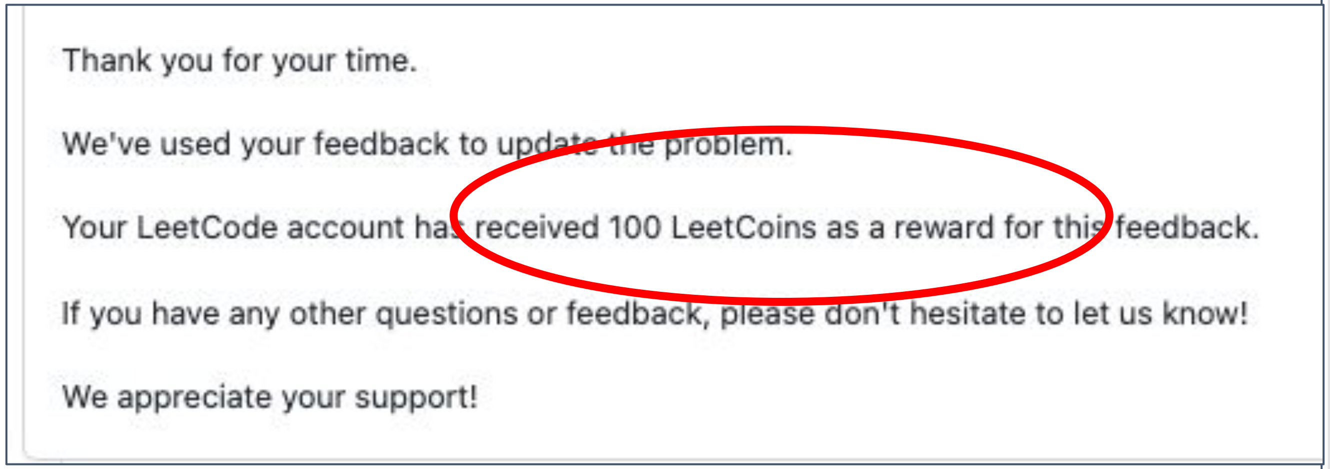
```
SELECT EMAIL FROM PERSON GROUP BY EMAIL HAVING COUNT(*) > 1;
```

are different.

**Code you used for Submit/Run operation**

```
SELECT EMAIL FROM PERSON GROUP BY EMAIL HAVING COUNT(*) > 1
```

```
SELECT EMAIL FROM PERSON GROUP BY EMAIL HAVING COUNT(ID) > 1
```



Thank you for your time.

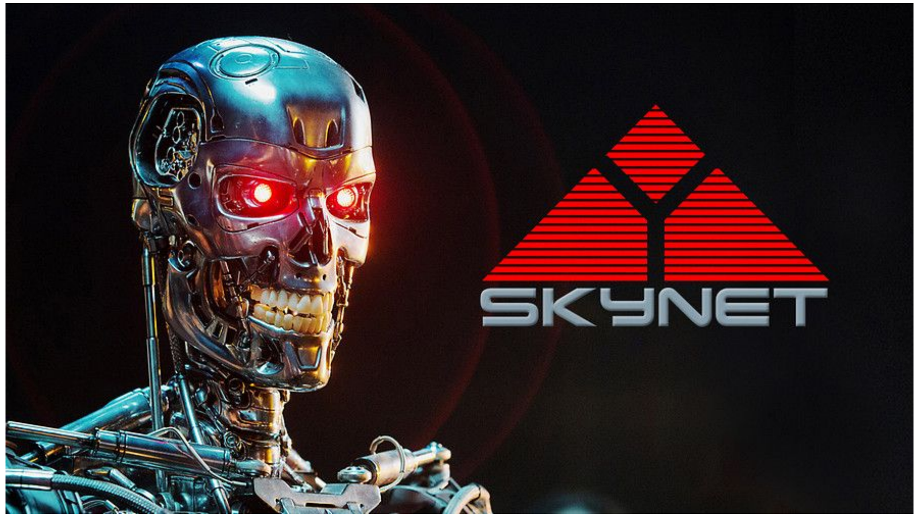
We've used your feedback to update the problem.

Your LeetCode account has received 100 LeetCoins as a reward for this feedback.

If you have any other questions or feedback, please don't hesitate to let us know!

We appreciate your support!

# A Modest Proposal



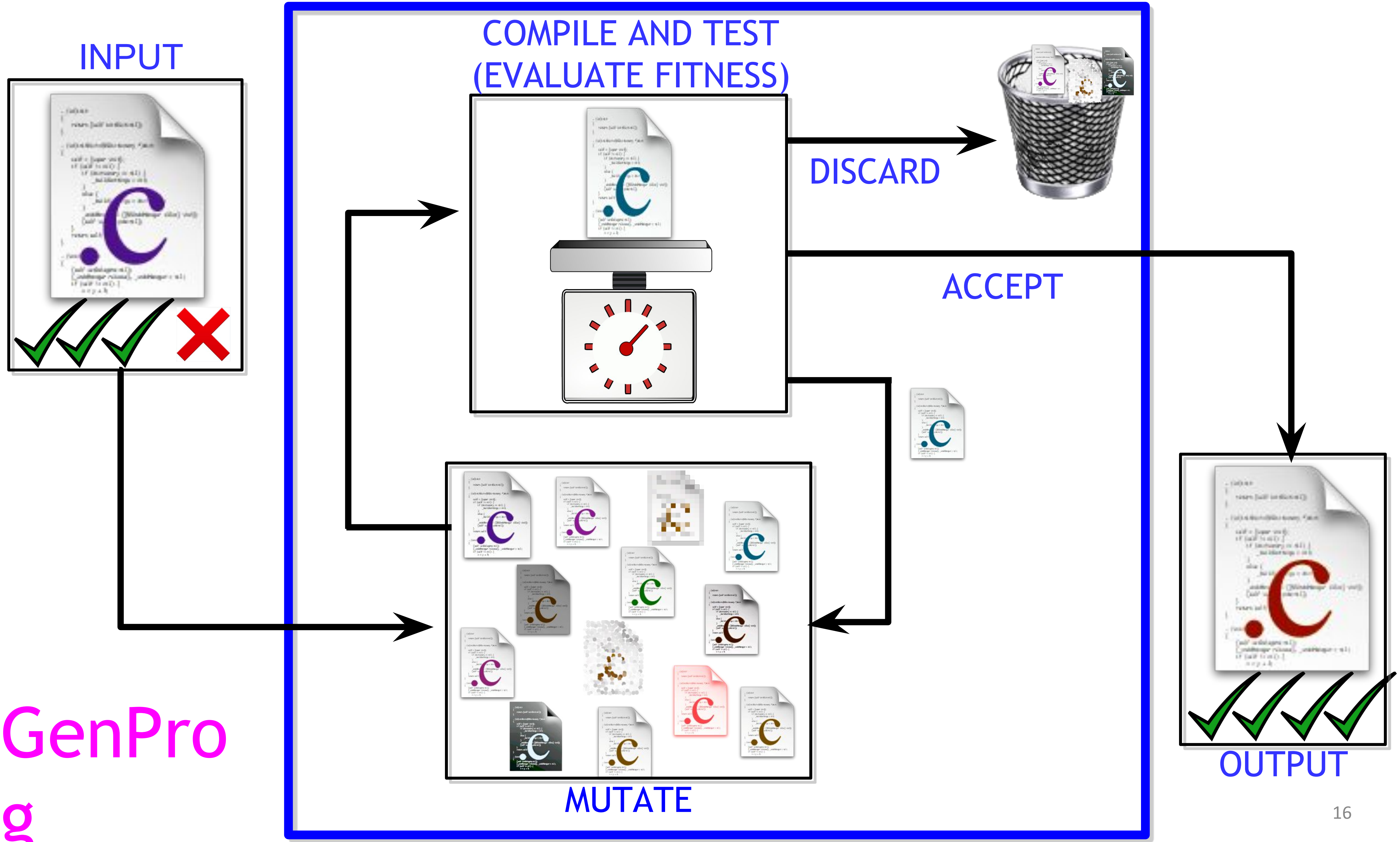
- Using techniques from this class
- We can automatically find and fix defects
    - Rather than, or in addition to, paying strangers
- Given a program …
    - Source code, binary code, etc.
- … and evidence of a bug …
    - Passing and failing tests, crashes, etc.
- … fix that bug.
    - Create a textual patch (pull request)

# How could this possibly work?

- Many faults can be localized to a small area
  - Even if your program is a million lines of code, **fault localization** can narrow it to 10-100 lines
- Many defects can be fixed with small changes
  - **Mutation** (test metrics) can generate candidate patches from simple edits
  - A **search-based software engineering** problem
- Can use regression **testing** (inputs and oracles, continuous integration) to assess patch quality

[ Weimer et al. *Automatically Finding Patches Using Genetic Programming*. Best Paper Award. IFIP TC2 Manfred Paul Award. SIGEVO "Humies" Gold Award. Ten-Year Impact Award. ]

# GenProg



INPUT

COMPILE AND TEST (EVALUATE FITNESS)

DISCARD

ACCEPT

MUTATE

OUTPUT

| Name | Subjects | Tests | Bugs | Notes |
|---|---|---|---|---|
| AFix | 2 Mloc | – | 8 | Concurrency, guarantees |
| ARC | – | – | – | Concurrency, SBSE |
| ARMOR | 6 progs. | – | 3 + – | Identifies workarounds |
| Axis | 13 progs. | – | – | Concurrency, guarantees, Petri nets |
| AutoFix-E | 21 Kloc | 650 | 42 | Contracts, guarantees |
| CASC | 1 Kloc | – | 5 | Co-evolves tests and programs |
| ClearView | Firefox | 57 | 9 | Red Team quality evaluation |
| Coker Hafiz | 15 Mloc | – | 7 / – | Integer bugs only, guarantees |
| Debroy Wong | 76 Kloc | 22,500 | 135 | Mutation, fault localization focus |
| Demsky et al. | 3 progs. | – | – | Data struct consistency, Red Team |
| FINCH | 13 tasks | – | – | Evolves unrestricted bytecode |
| GenProg | 5 Mloc | 10,000 | 105 | Human-competitive, SBSE |
| Gopinath et al. | 2 methods. | – | 20 | Heap specs, SAT |
| Jolt | 5 progs. | – | 8 | Escape infinite loops at run-time |
| Juzi | 7 progs. | – | 20 + – | Data struct consistency, models |
| PACHIKA | 110 Kloc | 2,700 | 26 | Differences in behavior models |
| PAR | 480 Kloc | 25,000 | 119 | Human-based patches, quality study |
| SemFix | 12 Kloc | 250 | 90 | Symex, constraints, synthesis |
| Sidiroglou et al. | 17 progs. | – | 17 | Buffer overflows |

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# Minimizing Patches

- A GenProg patch may contain extraneous/redundant edits
  - Add “close();” vs. add “close(); x = x + 0;”
  - Both pass all tests, but …
- Longer patches are harder to read
- Extraneous edits may only appear safe because of weak test suites: avoid unneeded code churn
- How to minimize? After the repair search, use **delta debugging** (hypothesis testing) to find a passing 1-minimal edit subset

# Minimizing Costs (time, memory, ..)

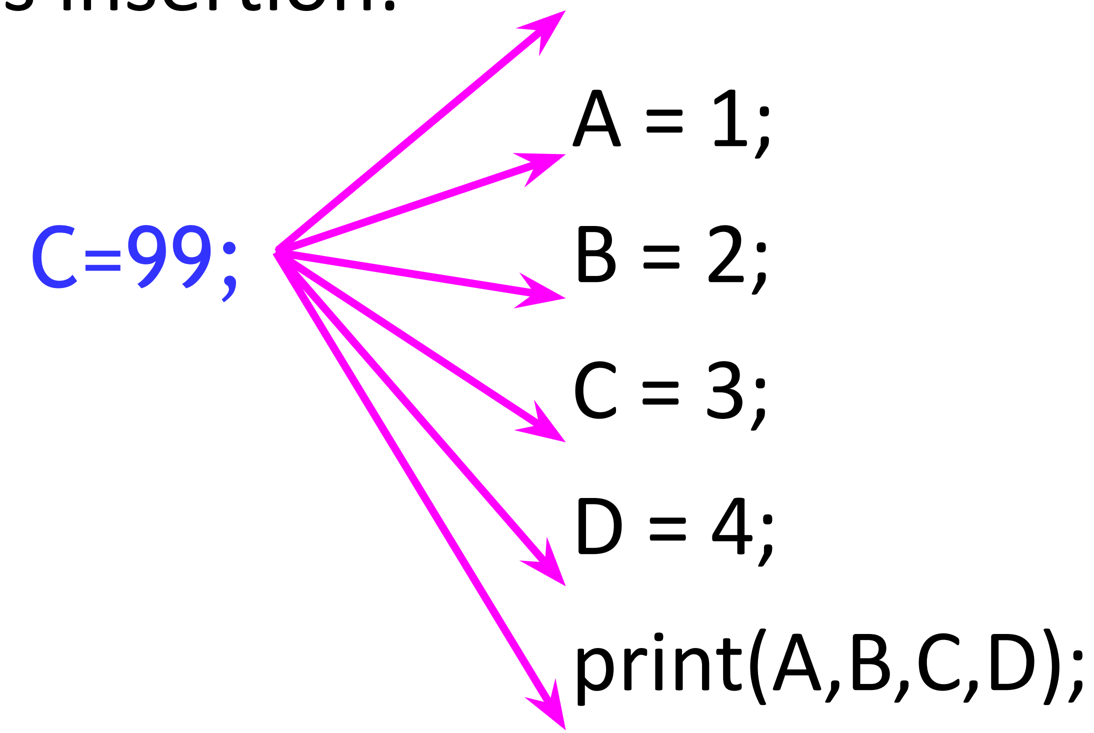
- Can stop generating candidate mutants when a valid repair is found, parallelize in the cloud

[ Le Goues et al. *A Systematic Study of Automated Program Repair: Fixing 55 out of 105 bugs for $8 Each.* ]

- Each repair must pass the entire test suite
  - Running tests is the dominant cost of automated program repair
  - Use test suite prioritization and minimization
  - Stop evaluating as soon as a single test fails
    - Even one failure → Not a valid repair!

# Can We Avoid Testing? (An even better way to minimize cost..)

- If P1 and P2 are semantically equivalent they must have the same functional test behavior
- Consider this insertion:



C=99;

```
A = 1;
B = 2;
C = 3;
D = 4;
print(A,B,C,D);
```

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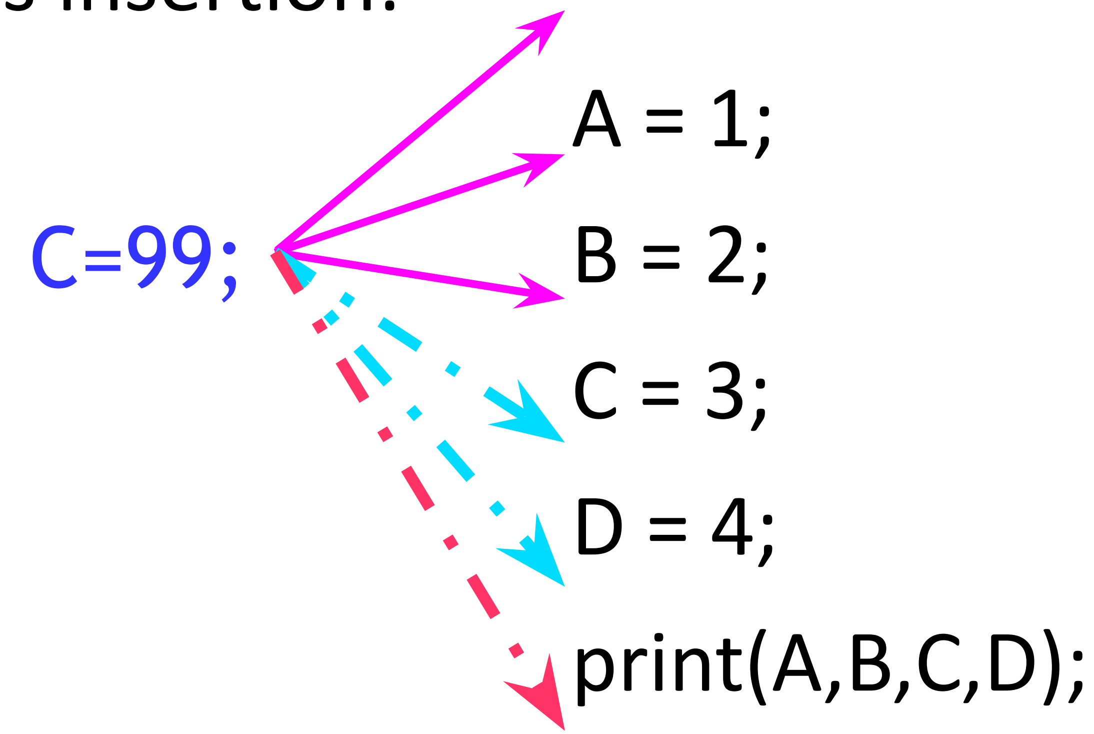

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A = 1;
B = 2;
C = 3;
D = 4;
print(A,B,C,D);
```

# Static Analysis

- If we had a cheap way to approximately decide if two programs are equivalent
  - We wouldn't need to test any candidate patch that is equivalent to a previously-tested patch
  - (Cluster or quotient the search space into equivalence classes with respect to this relation)
- We use **static analysis** (like a dataflow analysis for dead code or constant propagation) to decide this: 10x reduction in search space

[ Weimer et al. *Leveraging Program Equivalence for Adaptive Program Repair: Models and First Results.* ]

# Design Patterns

- In mutation testing, the mutation operators are based on common human mistakes
- In program repair, use human edits (likely to be correct) or **design patterns**
  - "Add a null check" or "Use a singleton pattern"
- Mine 60,000 human-written patches (e.g., from github) to learn the 10 most common fix templates
  - Resulting approach fixes 70% more bugs
  - Human study of non-student developers (n=68): such patches are 20% more acceptable

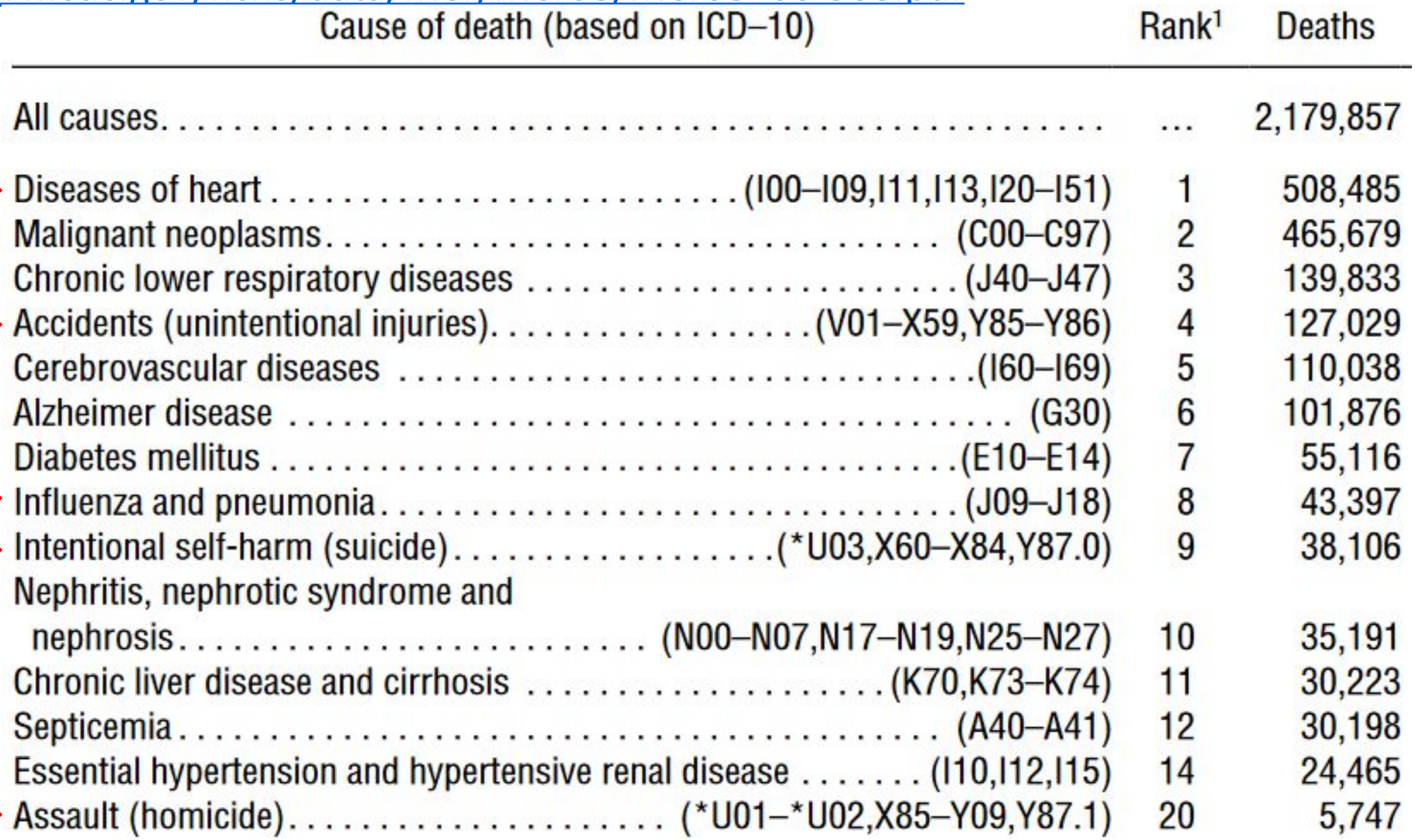
[ Kim et al. *Automatic Patch Generation Learned from Human-Written Patches.* Best paper award.]

# Not Trivial: Death

- Rank these causes of death in the US for 2016 (most recent CDC data available):
  - Accidents (unintentional injuries)
  - Assault (homicide)
  - Heart disease
  - Influenza and pneumonia
- Bonus: One of these is about 20-100x more common than another. Identify that pairing.

# Not Trivial: Death Details

2017 CDC (Table D, Page 12, extract)
https://www.cdc.gov/nchs/data/nvsr/nvsr68/nvsr68_06-508.pdf



| Cause of death (based on ICD–10) | Rank[1] | Deaths |
|---|---|---|
| All causes. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . | ... | 2,179,857 |
| Diseases of heart . . . . . . . . . . . . . . . . . . . . . . . . . . . . (I00–I09,I11,I13,I20–I51) | 1 | 508,485 |
| Malignant neoplasms. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . (C00–C97) | 2 | 465,679 |
| Chronic lower respiratory diseases . . . . . . . . . . . . . . . . . . . . . . . . . (J40–J47) | 3 | 139,833 |
| Accidents (unintentional injuries). . . . . . . . . . . . . . . . . . . (V01–X59,Y85–Y86) | 4 | 127,029 |
| Cerebrovascular diseases . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . (I60–I69) | 5 | 110,038 |
| Alzheimer disease . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . (G30) | 6 | 101,876 |
| Diabetes mellitus . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . (E10–E14) | 7 | 55,116 |
| Influenza and pneumonia. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . (J09–J18) | 8 | 43,397 |
| Intentional self-harm (suicide). . . . . . . . . . . . . . . . . . . (*U03,X60–X84,Y87.0) | 9 | 38,106 |
| Nephritis, nephrotic syndrome and nephrosis. . . . . . . . . . . . . . . . . . . . . . . . . . (N00–N07,N17–N19,N25–N27) | 10 | 35,191 |
| Chronic liver disease and cirrhosis . . . . . . . . . . . . . . . . . . . . . (K70,K73–K74) | 11 | 30,223 |
| Septicemia . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . (A40–A41) | 12 | 30,198 |
| Essential hypertension and hypertensive renal disease . . . . . . . (I10,I12,I15) | 14 | 24,465 |
| Assault (homicide). . . . . . . . . . . . . . . . . . . . . . . (*U01–*U02,X85–Y09,Y87.1) | 20 | 5,747 |

# ChatGPT, GPT-3/4, Large Language Models

- Which company/university developed ChatGPT?
  - ○ MIT
  - ○ Stanford
  - ○ Microsoft
  - ○ Google
  - ○ OpenAI

# ChatGPT, GPT-3/4, Large Language Models

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  - Stanford
  - Microsoft
  - Google
  - **OpenAI**

# ChatGPT, GPT-3/4, Large Language Models

- ChatGPT (Nov 2022 release) was based on GPT-3.5
- Now, ChatGPT Plus users have access to GPT-4 version (March 14 2023 release)
- GPT = Generative Pre-trained Transformers
- … are a family of (large) language models trained on a large corpus of **text** data

# Trivia: Can ChatGPT Answer Trivia Questions?

- Collected 50K trivia questions (multiple-choice questions – most 4 choices, some true/false)
- How accurate is technique based on word2vec (i.e., “a pretty good technique” prior to ChatGPT)?
  - ○ Can answer most of the questions perfectly
  - ○ Fairly good
  - ○ Very bad (even worse than randomly guessing)

[ https://www.sliceofexperiments.com/p/chatgpt-vs-50000-trivia-questions ]

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# Trivia: Can ChatGPT Answer Trivia Questions?

- How accurate is ChatGPT?
  - ○ 99.5%
  - ○ 82.9%
  - ○ 66.7%
  - ○ 35.5%
  - ○ Very bad (even worse than randomly guessing)

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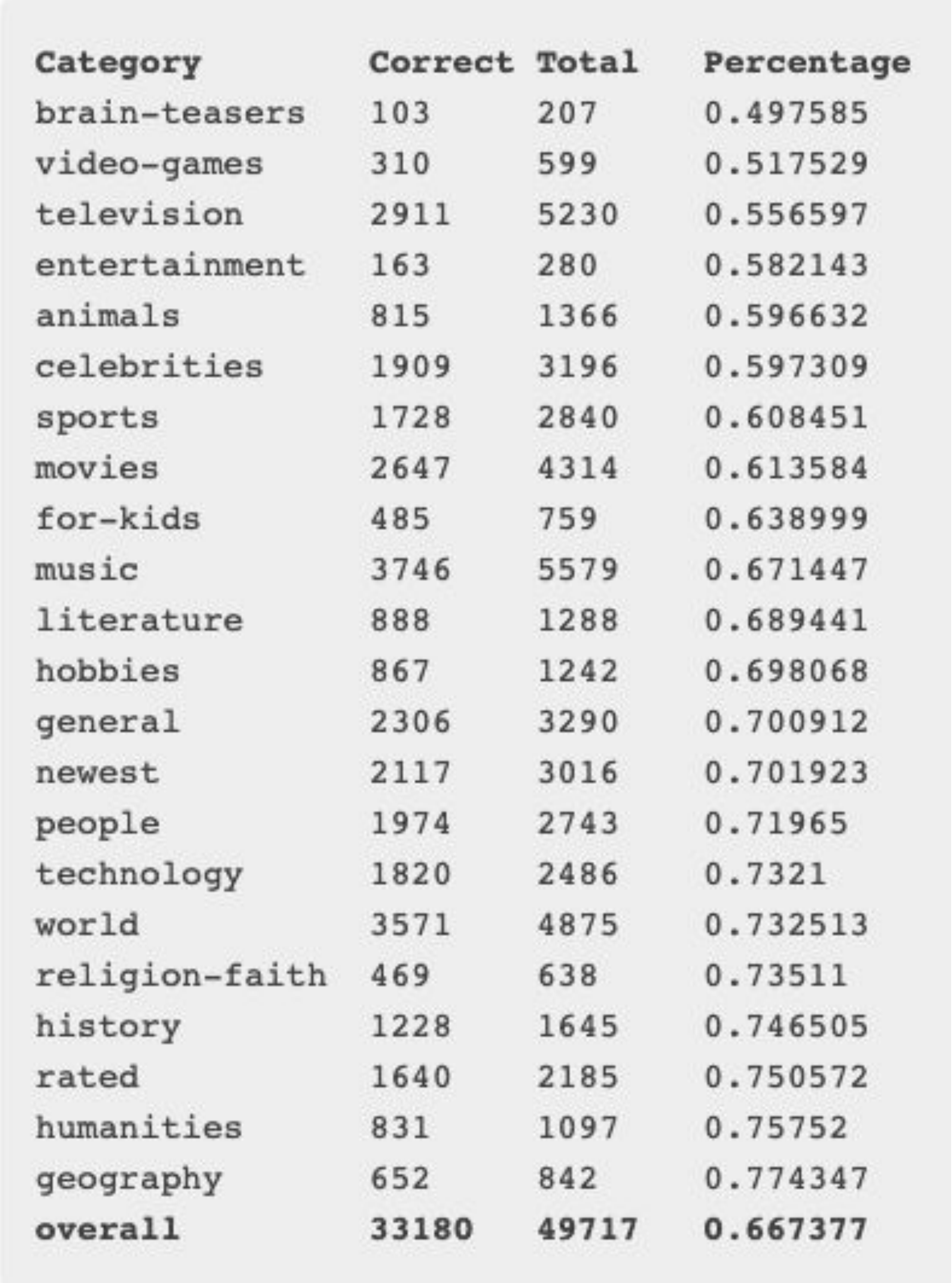
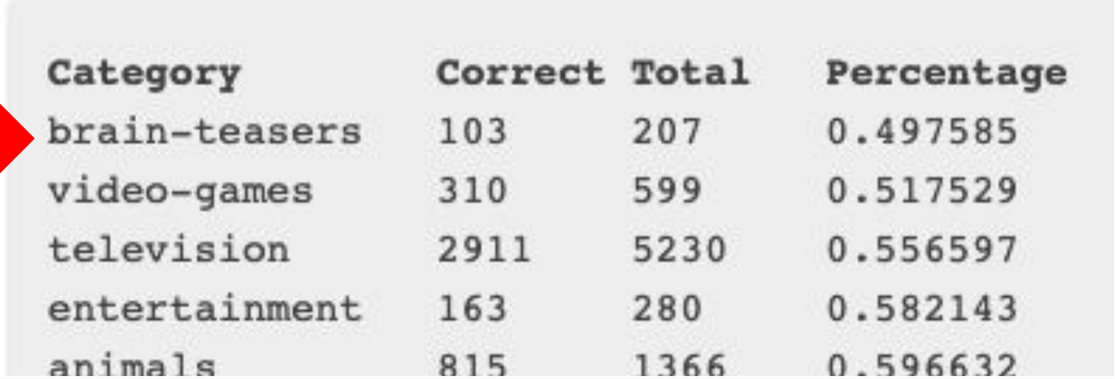
# Trivia: Can ChatGPT Answer



| Category | Correct | Total | Percentage |
|---|---|---|---|
| brain-teasers | 103 | 207 | 0.497585 |
| video-games | 310 | 599 | 0.517529 |
| television | 2911 | 5230 | 0.556597 |
| entertainment | 163 | 280 | 0.582143 |
| animals | 815 | 1366 | 0.596632 |
| celebrities | 1909 | 3196 | 0.597309 |
| sports | 1728 | 2840 | 0.608451 |
| movies | 2647 | 4314 | 0.613584 |
| for-kids | 485 | 759 | 0.638999 |
| music | 3746 | 5579 | 0.671447 |
| literature | 888 | 1288 | 0.689441 |
| hobbies | 867 | 1242 | 0.698068 |
| general | 2306 | 3290 | 0.700912 |
| newest | 2117 | 3016 | 0.701923 |
| people | 1974 | 2743 | 0.71965 |
| technology | 1820 | 2486 | 0.7321 |
| world | 3571 | 4875 | 0.732513 |
| religion-faith | 469 | 638 | 0.73511 |
| history | 1228 | 1645 | 0.746505 |
| rated | 1640 | 2185 | 0.750572 |
| humanities | 831 | 1097 | 0.75752 |
| geography | 652 | 842 | 0.774347 |
| **overall** | **33180** | **49717** | **0.667377** |

# Trivia: Can ChatGPT Answer



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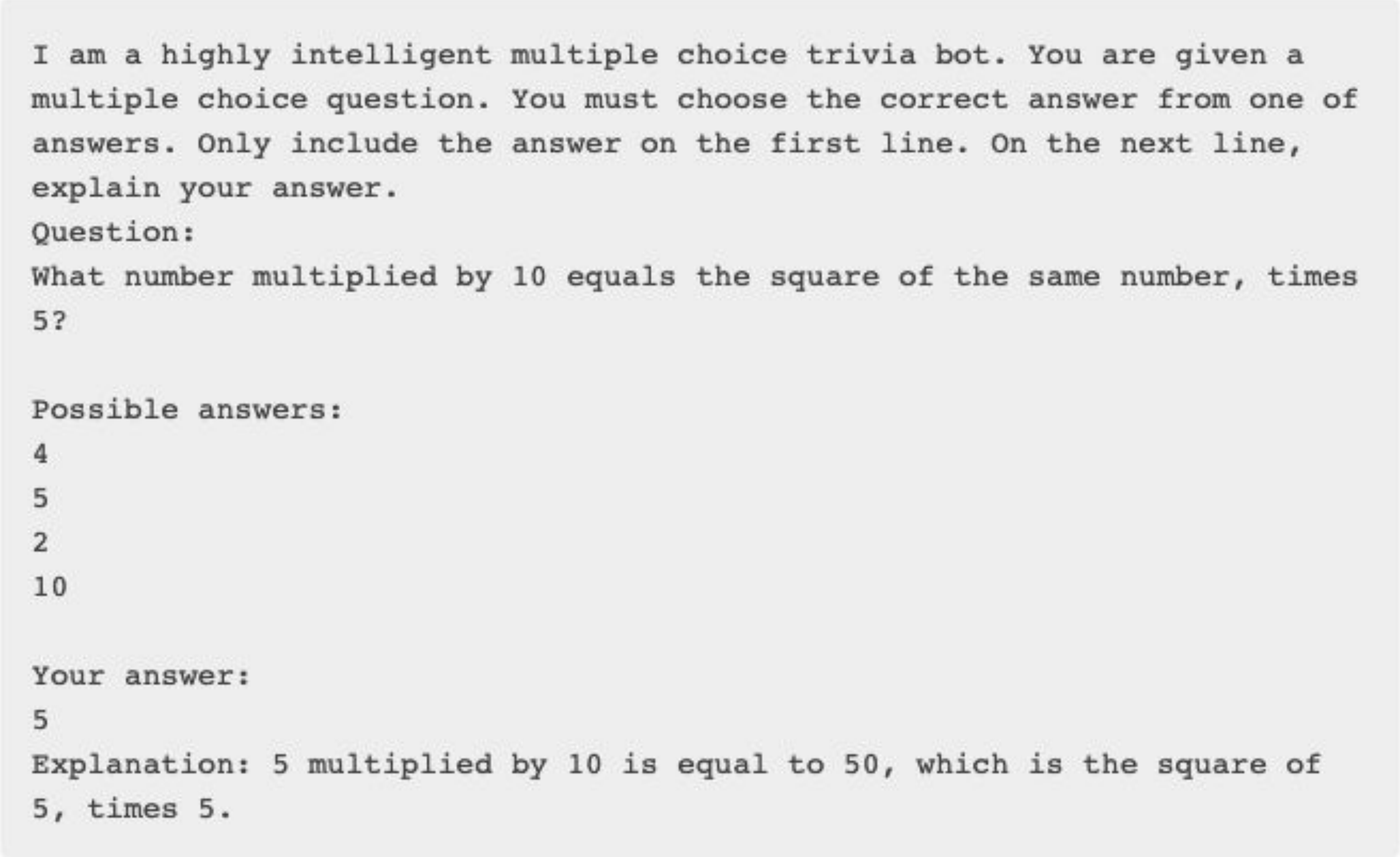


```
I am a highly intelligent multiple choice trivia bot. You are given a
multiple choice question. You must choose the correct answer from one of
answers. Only include the answer on the first line. On the next line,
explain your answer.
Question:
What number multiplied by 10 equals the square of the same number, times
5?

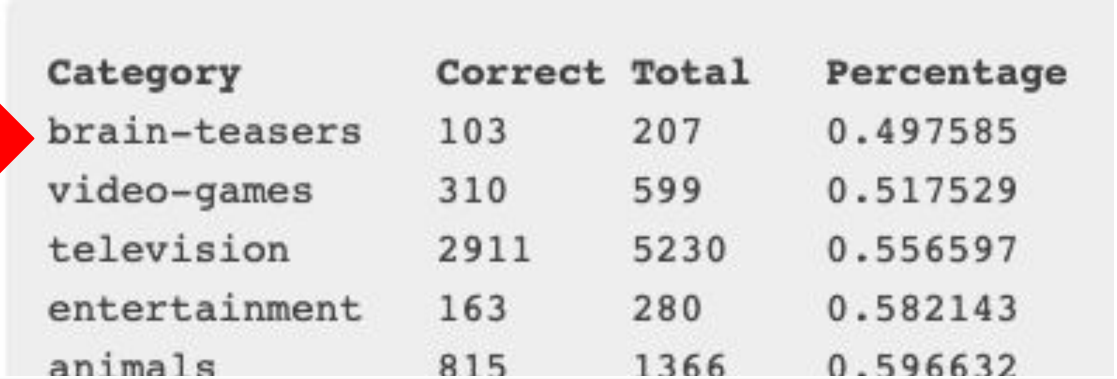
Possible answers:
4
5
2
10

Your answer:
5
Explanation: 5 multiplied by 10 is equal to 50, which is the square of
5, times 5.
```

# Trivia: Can ChatGPT Answe

**ChatGPT cannot do arithmetic/math.**

**Can ChatGPT “repair programs”?**



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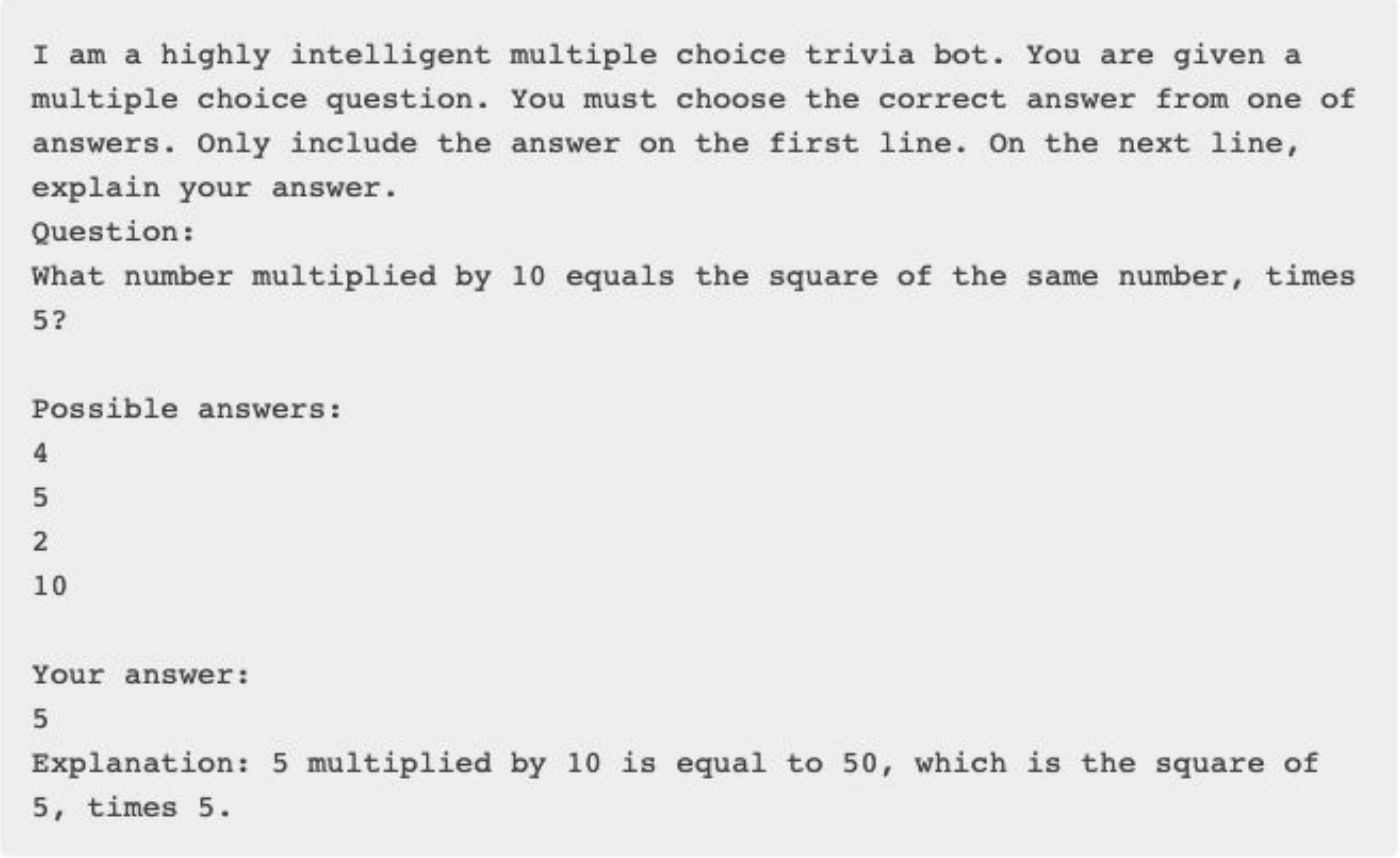

```
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# Trivia: Can ChatGPT Find/Fix Program Bugs?

- Out of total 40 buggy programs, how many can ChatGPT fix? And how many can a standard technique (like GenProg) fix?
  - ○ ChatGPT/Standard = 10/35
  - ○ ChatGPT/Standard = 19/21
  - ○ ChatGPT/Standard = 28/12
  - ○ ChatGPT/Standard = 31/7

[ https://www.pcmag.com/news/watch-out-software-engineers-chatgpt-is-now-finding-fixing-bugs-in-code ]

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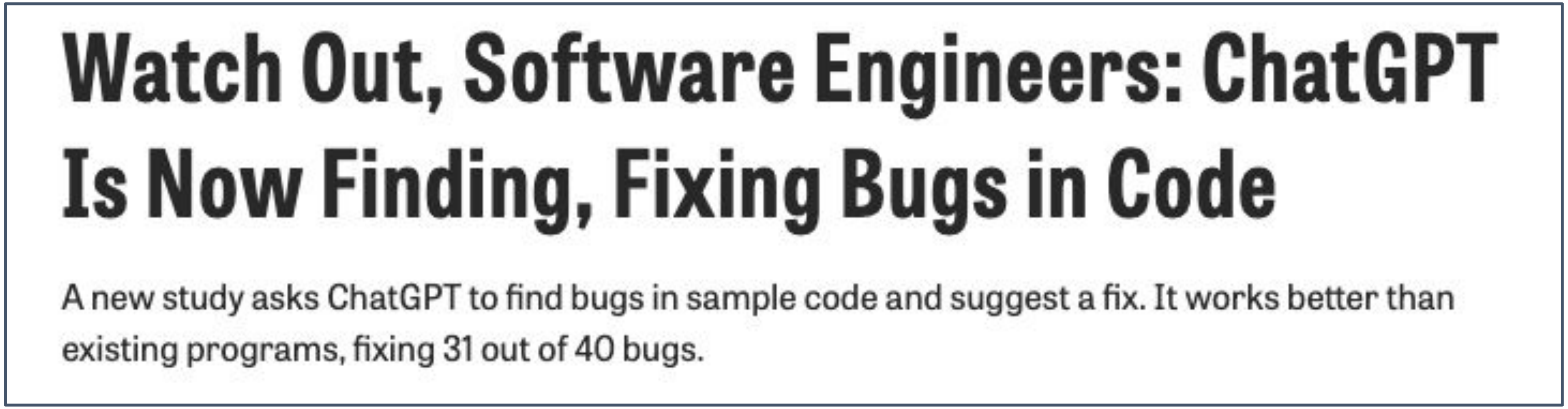
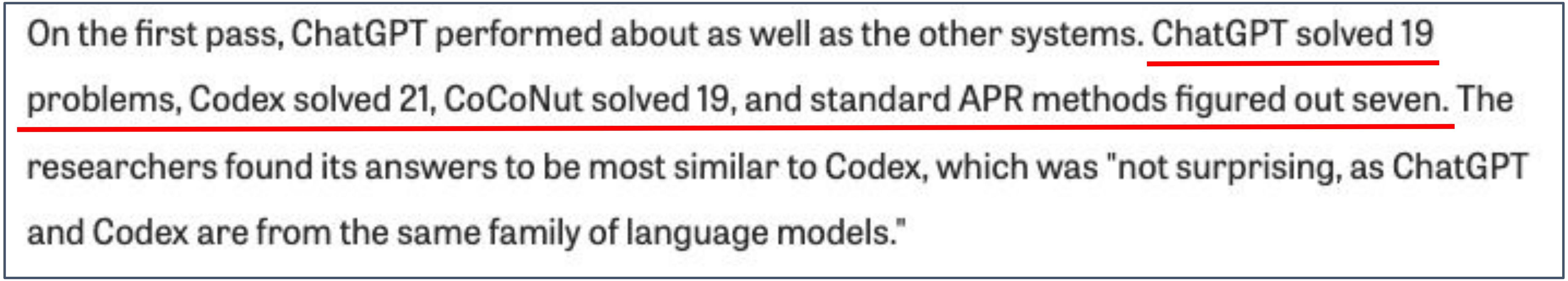


**Watch Out, Software Engineers: ChatGPT Is Now Finding, Fixing Bugs in Code**

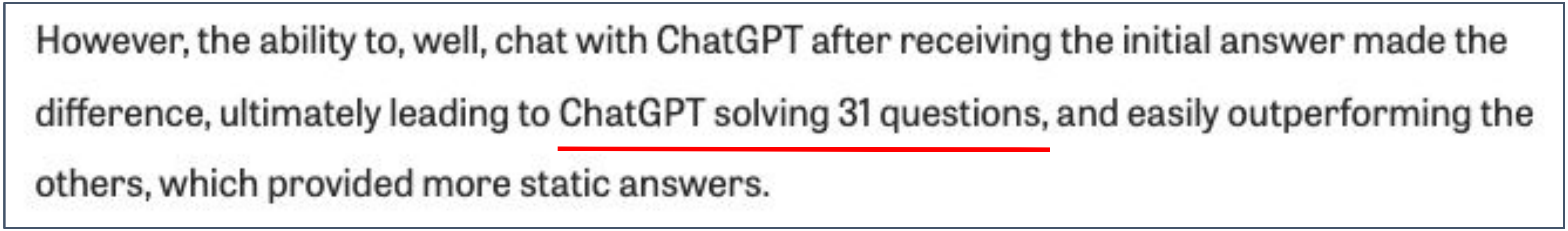
A new study asks ChatGPT to find bugs in sample code and suggest a fix. It works better than existing programs, fixing 31 out of 40 bugs.

[ https://www.pcmag.com/news/watch-out-software-engineers-chatgpt-is-now-finding-fixing-bugs-in-code ]

# Can ChatGPT Find/Fix Program Bugs?



On the first pass, ChatGPT performed about as well as the other systems. ChatGPT solved 19 problems, Codex solved 21, CoCoNut solved 19, and standard APR methods figured out seven. The researchers found its answers to be most similar to Codex, which was "not surprising, as ChatGPT and Codex are from the same family of language models."



However, the ability to, well, chat with ChatGPT after receiving the initial answer made the difference, ultimately leading to ChatGPT solving 31 questions, and easily outperforming the others, which provided more static answers.

# Relationship with Mutation Testing

- This program repair approach is a **dual** of **mutation testing**
  - This suggests avenues for cross-fertilization and helps explain some of the successes and failures of program repair.

- Very informally:
  - PR Exists M in Mut. Forall T in Tests. M(T)
  - MT Forall M in Mut. Exists T in Tests. Not M(T)

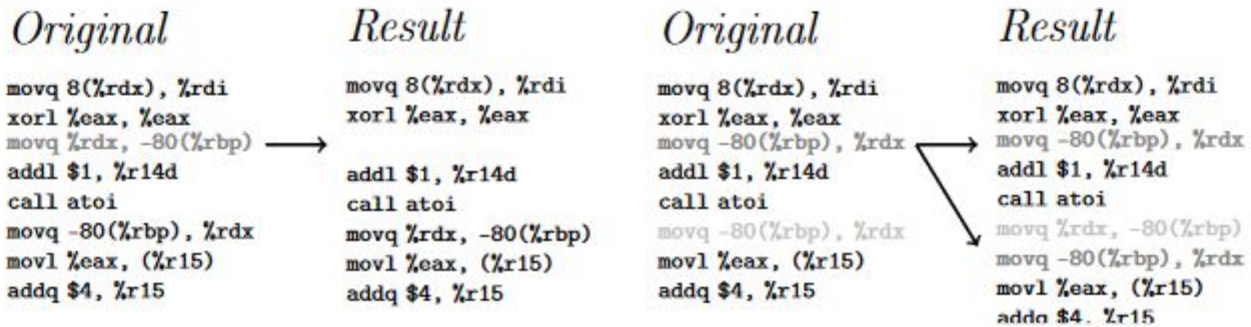
# Idealized Formulation

- Ideally, mutation testing takes a program that **passes** its test suite and requires that **all** mutants based on human **mistakes** from the **entire** program that are not equivalent **fail** at least one test.

- By contrast, program repair takes a program that **fails** its test suite and requires that **one** mutant based on human **repairs** from the fault **localization** only be found that **passes** all tests.

# No Source Code Needed

- Can repair assembly or binary programs to support **multi-language projects**



```
movq 8(%rdx), %rdi
xorl %eax, %eax
movq %rdx, -80(%rbp)
addl $1, %r14d
call atoi
movq -80(%rbp), %rdx
movl %eax, (%r15)
addq $4, %r15
```

```
movq 8(%rdx), %rdi
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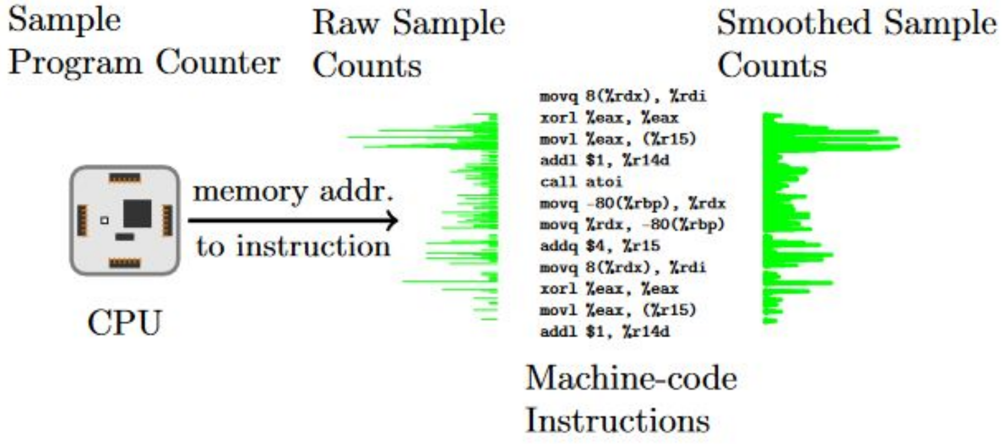
movq %rdx, -80(%rbp)
movq -80(%rbp), %rdx
movl %eax, (%r15)
addq $4, %r15
```

(a) Delete (b) Insert

- Use **sampling-based profiling** for fault localization



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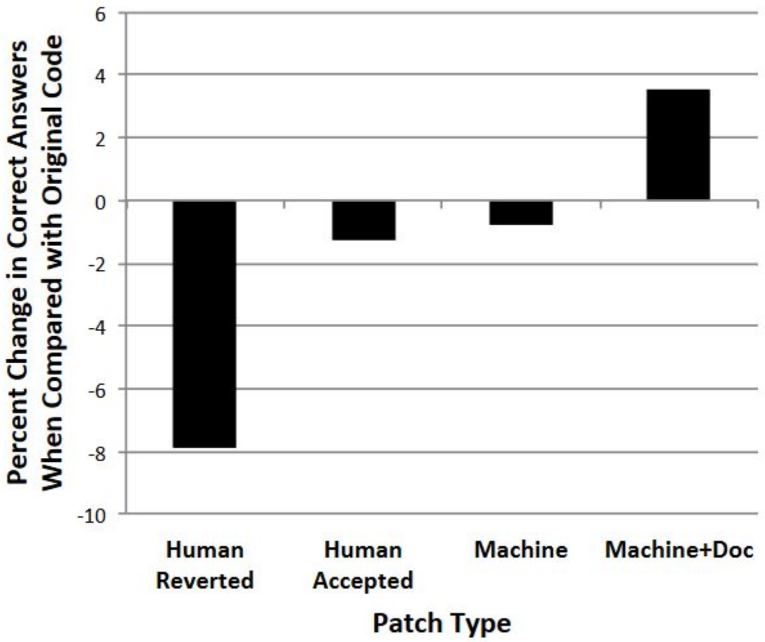
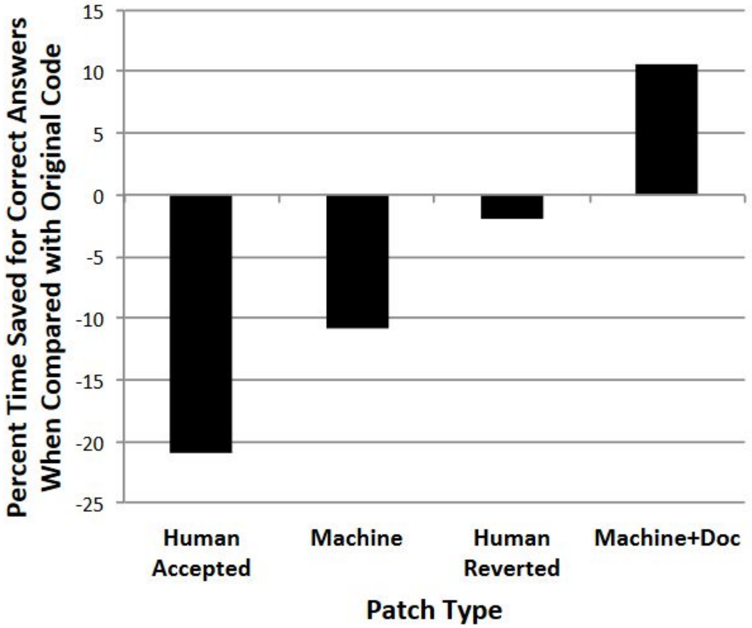
addq $4, %r15
movq 8(%rdx), %rdi
xorl %eax, %eax
movl %eax, (%r15)
addl $1, %r14d
```

[ Schulte et al. *Automated Program Repair of Binary and Assembly Programs for Cooperating Embedded Devices.* ]

# Can Humans Use These Patches?

- Synthesize "What" comments for generated patches (**design for maintainability**)
  - **Test input generation** constraints → English
  - Human study (N=150): "With docs → Yes!"





[ Fry et al. *A Human Study of Patch Maintainability.* ]

# Human-Machine Partnerships

- What if your partner in **pair programming** were a machine that suggested patches?
  - Machine is driver, you are navigator/observer
  - In response to your feedback and characterization of program state, it suggests new patches
- You note "checkpoints" where at point *X*, test *Y* is running correctly (or variable *Z* is wrong)
- Human study of first-year grads (N=25):
  - Reduces debugging on 14/15 scenarios compared to singleton (~60% reduction over all 15)

[ Xinrui Guo. *SmartDebug: An Interactive Debug Assistant for Java.* ]

# Repair Concurrency Bugs?

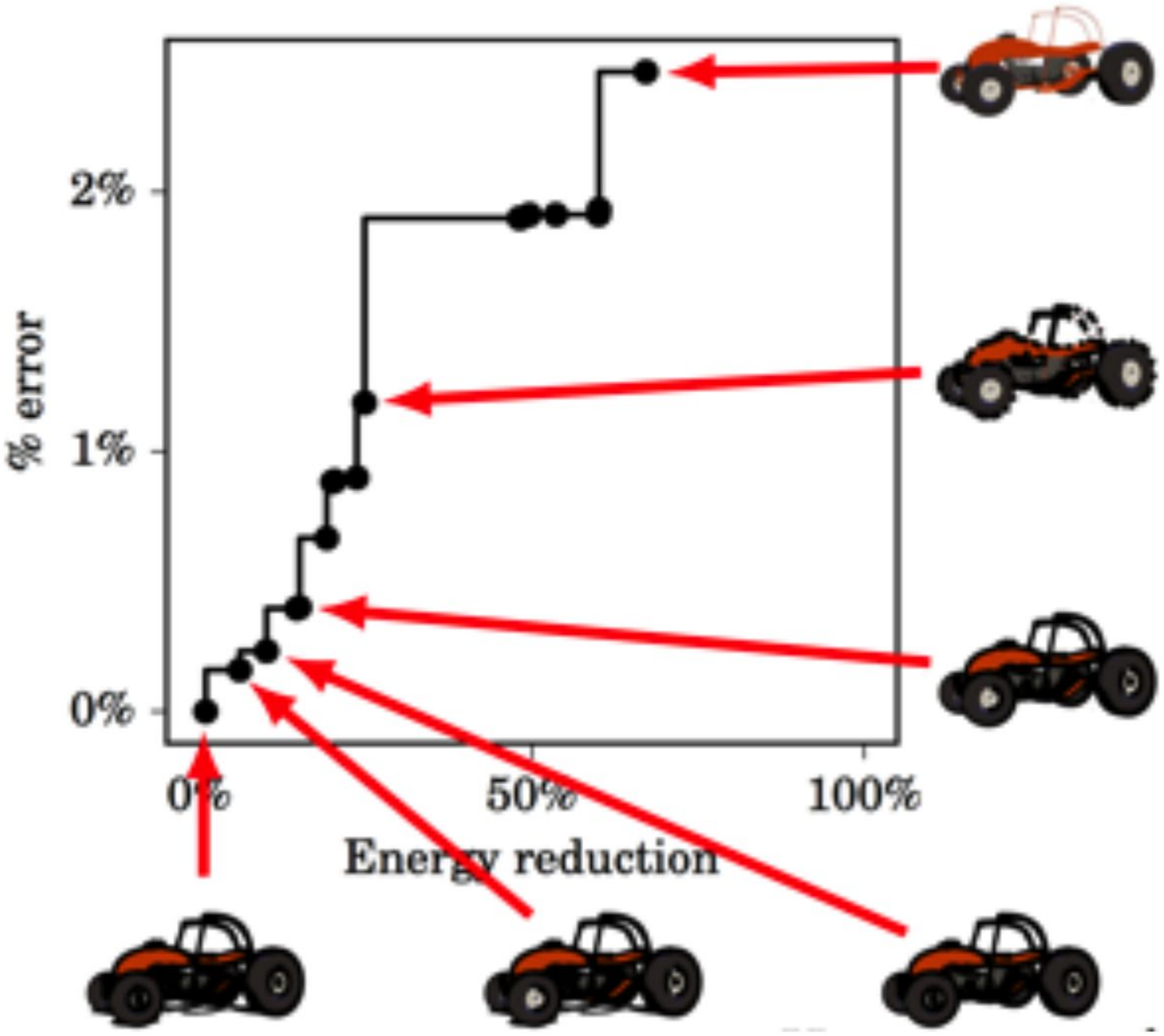
- So far we have required **deterministic** tests
- We can use a **dynamic analysis** like CHESS or Eraser to detect **concurrency** bugs
  - Look for two threads accessing *X*, one is a write
- Use special repair templates (e.g., always add paired lock()/unlock() calls)
- Fixes 6/8 historical single-variable atomicity violations in Apache, MySQL, Mozilla, etc.
  - Devs fixed 6/8 in 11 days each, on average
  - Union of both fixes all 8/8

[ Jin et al. *Automated Atomicity-Violation Fixing.* ]

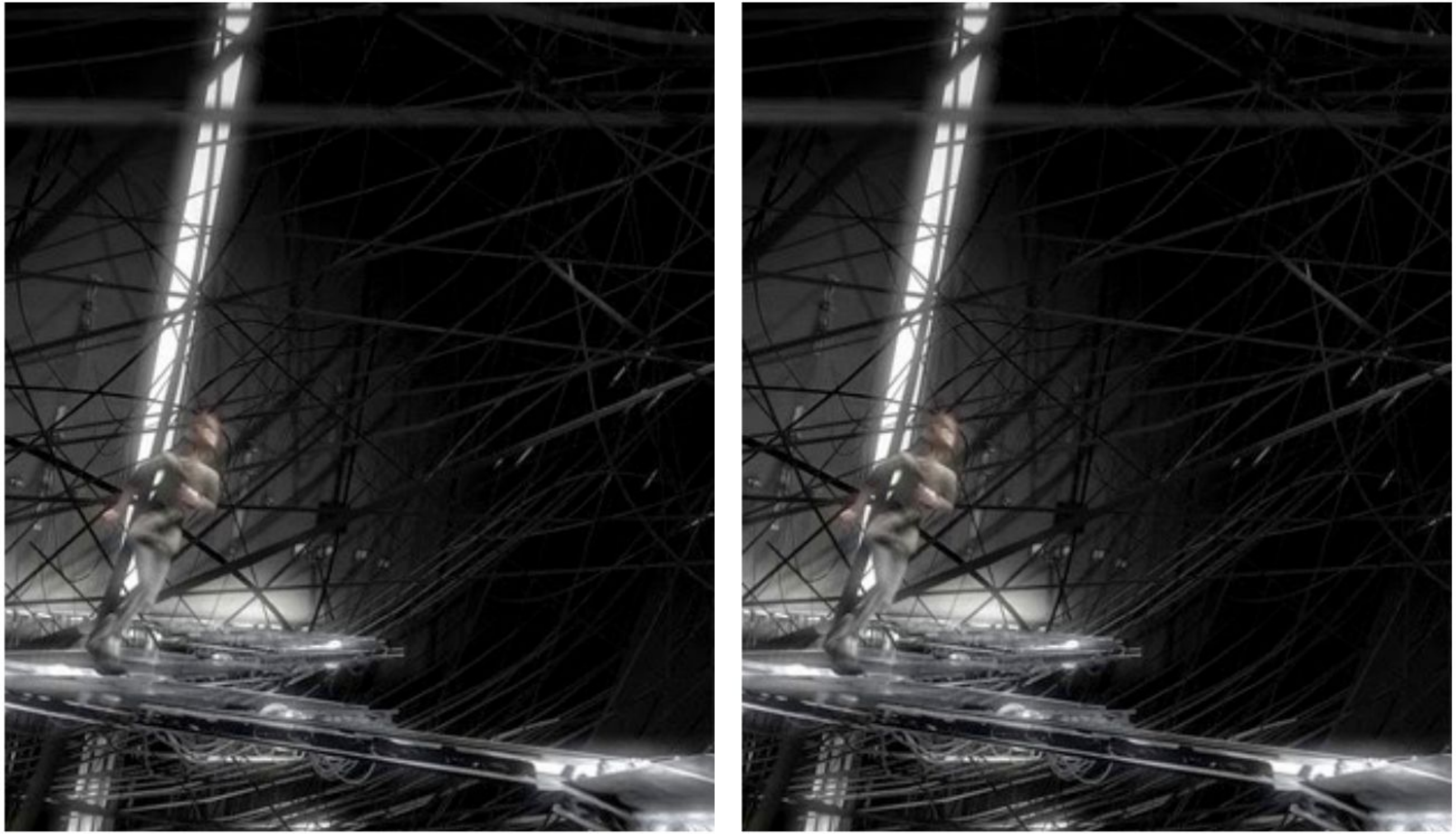
# Repair Quality (Non-Functional) Defects?

- What if the bug is that your program is too slow (aka. performance bug) *or* too big *or* uses too much energy?
- We can also improve and trade-off **verifiable quality properties** (requirements solicitation)
  - cf. MP3 or JPG *lossy* compression: space vs. quality
- Candidates must pass all functional tests
- But we also measure quality properties of all passing candidates
- Present a Pareto frontier to help user explore alternative solutions to requirement conflicts

# Automatically Exploring Tradeoffs In Conflicting Requirements



# Can you spot the difference?



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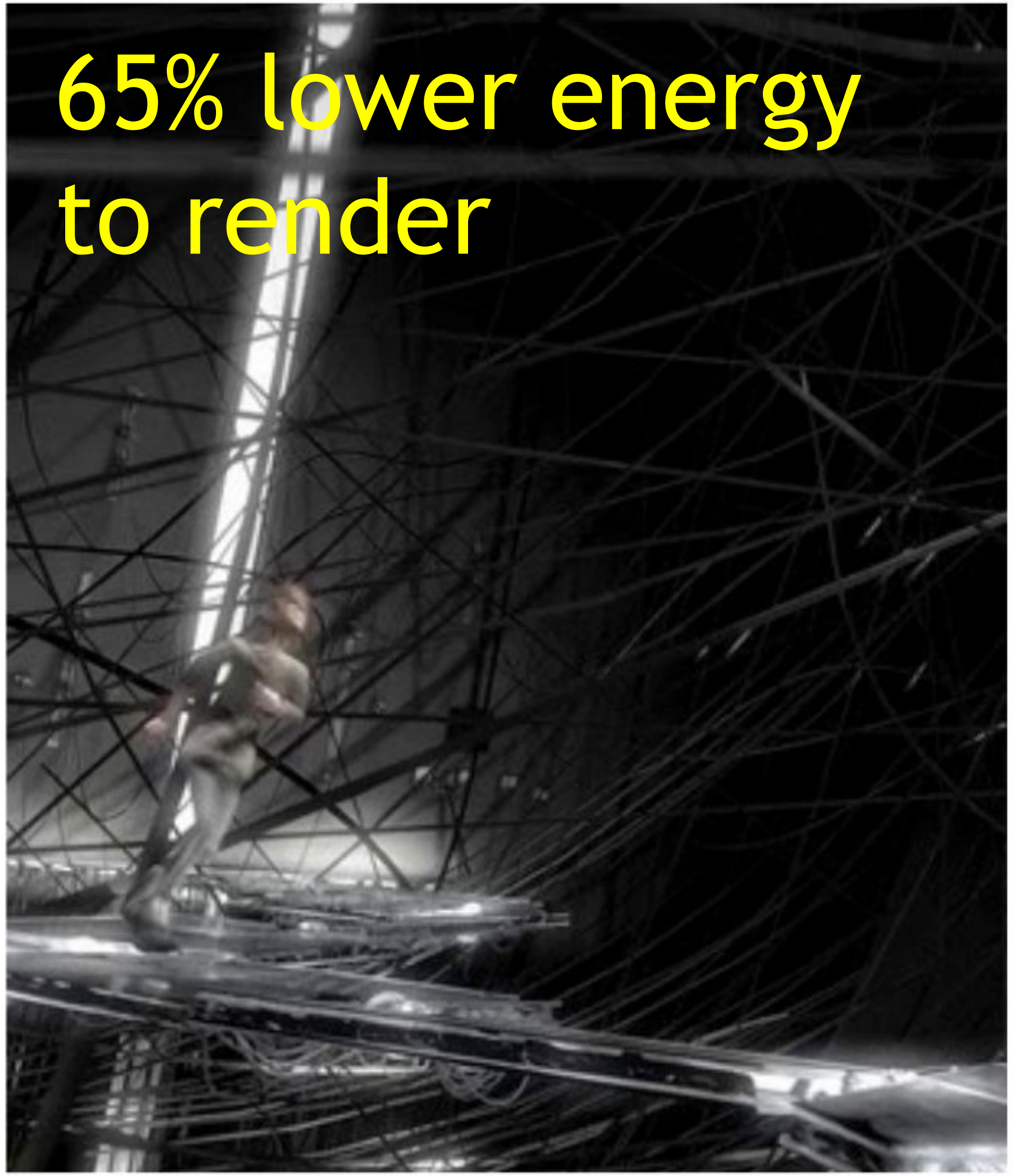


65% lower energy to render

[ Dorn et al. *Automatically exploring tradeoffs between software output fidelity and energy costs.* ]

# “Wishes Come True, Not Free”

- Automated program repair, the whiny child:
  - “You only said I had to *get in* to the bathtub, you didn't say I had to wash.”
- The **specification** (tests) must encode **requirements** (cf. conflicts)
- GenProg's first webserver defect repair
  - 5 regression tests (GET index.html, etc.)
  - 1 bug (POST → remote security exploit)
  - GenProg's fix: remove POST functionality
  - (Adding a 6th test yields a high-quality repair.)
  - **Take-away: humans write high-quality patch -> high-quality test**

# Requirements and Testing

- MIT Lincoln Labs evaluation of GenProg: sort
  - Tests: “the output of sort is in sorted order”
  - GenProg's fix: “always output the empty list”
  - (More tests yield a higher-quality repair. cf. design-by-contract pre- and post-conditions)
- Existing human-written tests suites implicitly assume the developers are reasonable humans
  - Unless you are outsourcing, you rarely test against “creative” for “adversarial” solutions or bugs
  - cf. “we're already good at this” denials, terminology conflicts

# Measuring Quality via Tests

- Another GenProg example:
  - Tests: “compare yours.txt to trusted.txt”
  - GenProg's fix: “delete trusted.txt, output nothing”
- Canonical **perverse incentives** situation
  - Automated program repair optimizes the **metric**
  - “What you said” not “What you meant”
- Sleep forever to avoid CPU-usage penalties
- Always segfault to avoid bad output checks

[ Weimer. *Advances in Automated Program Repair and a Call to Arms.* ]

# The Future

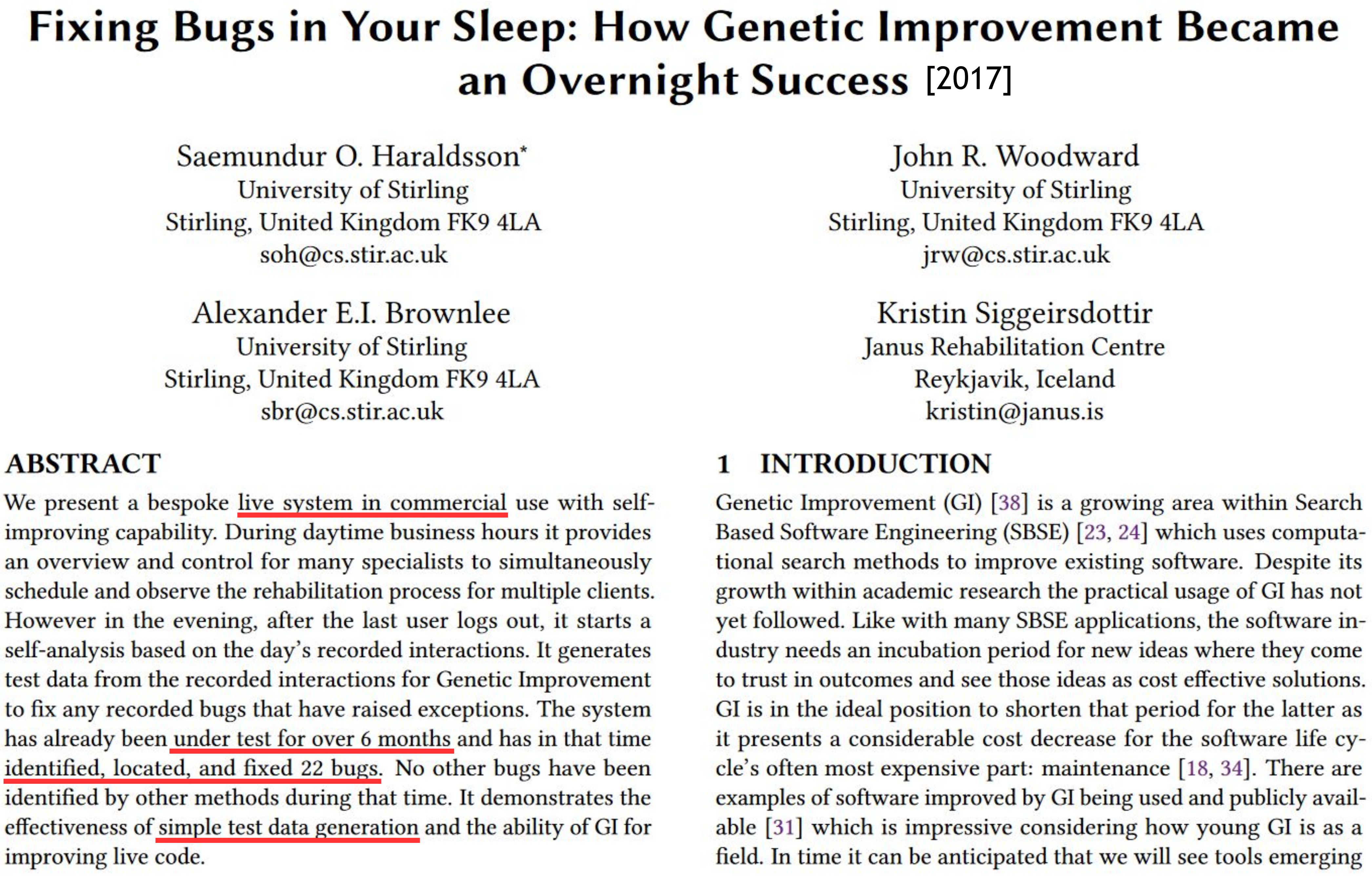
- Despite quality and trust concerns, some form of this is coming in the future (10-20 years?)
  - Already-demonstrated **productivity** gains
- What if “solve this one-line bug” became an atomic action in your lexicon?
  - The same way “complete this method call” or “sort” or “rename this variable” is today

# Productive Imposters

- Old adage: What do you call someone who graduates last in a medical school class?
- Many worry: “I'm not as fast at coding”
- If most of SE is maintenance and 33-50% of bugs can be fixed automatically, the real in-demand skills are evaluating candidate fixes and eliciting and encoding requirements
  - The future of productivity: reading and talking
  - True for bug bounties or automated repair
  - This isn't really news (cf. first lectures …)

# Should My Company Use It?

- As with any other **software development process** option (e.g., pair programming, Infer, 100% coverage goals, etc.) we estimate (or measure) costs and benefits
  - 2012: fix 50% of bugs, $8 each (vs. $20 for humans)
  - 2013: 3x cheaper, not counting cloud reductions
- Does not have to be used exclusively
  - Tools generate patches for simple bugs, freeing up creative human developer time for tougher issues
  - A fault tree analysis is possible, etc.



# Fixing Bugs in Your Sleep: How Genetic Improvement Became an Overnight Success [2017]

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## ABSTRACT

We present a bespoke live system in commercial use with self-improving capability. During daytime business hours it provides an overview and control for many specialists to simultaneously schedule and observe the rehabilitation process for multiple clients. However in the evening, after the last user logs out, it starts a self-analysis based on the day's recorded interactions. It generates test data from the recorded interactions for Genetic Improvement to fix any recorded bugs that have raised exceptions. The system has already been under test for over 6 months and has in that time identified, located, and fixed 22 bugs. No other bugs have been identified by other methods during that time. It demonstrates the effectiveness of simple test data generation and the ability of GI for improving live code.

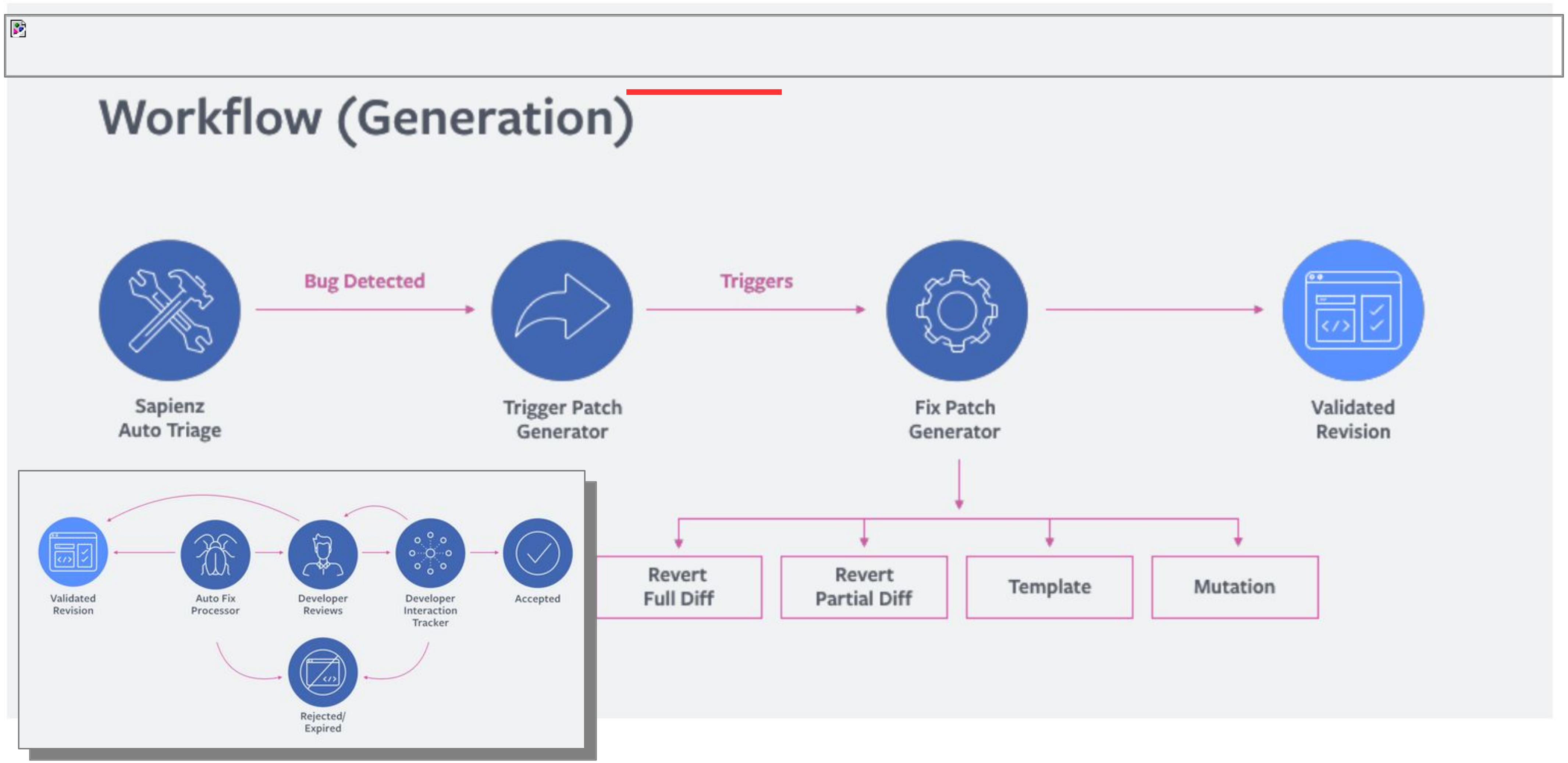
## 1 INTRODUCTION

Genetic Improvement (GI) [38] is a growing area within Search Based Software Engineering (SBSE) [23, 24] which uses computational search methods to improve existing software. Despite its growth within academic research the practical usage of GI has not yet followed. Like with many SBSE applications, the software industry needs an incubation period for new ideas where they come to trust in outcomes and see those ideas as cost effective solutions. GI is in the ideal position to shorten that period for the latter as it presents a considerable cost decrease for the software life cycle's often most expensive part: maintenance [18, 34]. There are examples of software improved by GI being used and publicly available [31] which is impressive considering how young GI is as a field. In time it can be anticipated that we will see tools emerging

# Facebook's SapFix [Sep 2018]

https://code.fb.com/developer-tools/finding-and-fixing-software-bugs-automatically-with-sapfix-and-sapienz/

Finding and fixing software bugs automatically with SapFix and Sapienz



"... the tool has successfully generated patches that have been accepted by human reviewers and pushed to production ..."

# SapFix: Automated End-to-End Repair at Scale

- “We report our experience with SapFix: the first deployment of automated end-to-end fault fixing, from test case design through to deployed repairs in production code. We have used SapFix at Facebook to repair 6 production systems, each consisting of tens of millions of lines of code, and which are collectively used by hundreds of millions of people worldwide.”

  https://ieeexplore.ieee.org/document/8804442

# Questions

- Exam 1 regrade request due: **Friday March 24 midnight ET**