FIXX: FInding eXploits from eXamples

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Static Analysis Limitations

- **Taint-style vulnerabilities**
  - Malicious data flows from input locations (sources) → locations that carry out sensitive operations (sinks) in web applications
- **Detection**
  - Current Static Application Security Testing (SAST) tools use sophisticated techniques to find vulnerable paths
    - Symbolic execution
    - Constraint solving
  - Paths are then disclosed to developers through CVEs → they however focus on a single vulnerability instance
- **Limitations**
  - Insufficient information about vulnerabilities in the disclosures
  - Multiple false negatives in current analysis tools
  - Numerous vulnerabilities go undetected

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Example

CVE-2024-25868

```
$membershipType = $_POST['membershipType'];
$membershipAmount = $_POST['membershipAmount'];

$insertQuery = "INSERT INTO membership_types
(type, amount) VALUES ('$membershipType',
$membershipAmount)";

echo "{$membershipType}";
```

Disclosed vulnerability

```
$fullname = $_POST['fullname'];
$address = $_POST['address'];

$updateQuery = "UPDATE members SET fullname
= '$fullname', address = '$address' WHERE id
= $memberId";

echo "{$row['fullname']}";
echo "{$row['address']}";
```

Similar undisclosed vulnerability

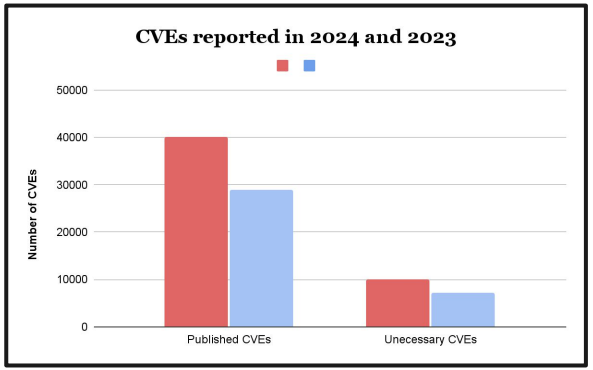
- Application CodeAstro Management contains a disclosed exploitable path
- Malicious input is inserted into the database and retrieved elsewhere
- Another similar exploitable path exists in the application too
- Vulnerability hasn't been reported or included in the original CVE

Problem: Have you detected all vulnerabilities?

→ “1 out of every 4 detected 0-day exploits could potentially have been avoided if a more thorough investigation and patching effort were explored”

→ “A correct patch is one that fixes a bug with complete accuracy, meaning the patch no longer allows any exploitation of the vulnerability”

Problem Statement: Given a disclosed vulnerability are there any **similar** undisclosed vulnerabilities?




GOOGLE PROJECT ZERO

Déjà vu-lnerability

A Year in Review of 0-days Exploited In-The-Wild in 2020 – Posted by Maddie Stone, Project Zero

25% of the 0-days detected in 2020 are closely related to previously publicly disclosed vulnerabilities.

Incomplete patches on on publicly disclosed vulnerabilities allow attackers to use 0-days against users with less effort because they can focus on the vulnerabilities already discussed and simply find a new bug in a code flow is both time a resource extensive.

When a 0-day is caught the wild it a gift for defenders to be put to how a much advantage of how attackers are exploiting publicly known vulnerabilities. This information aids in propering patching consistency and robustness, as well as detection methods.

When a 0-day is caught in the wild is a gift for Defenders need to take as much advantage of its ongoing around capabilities.

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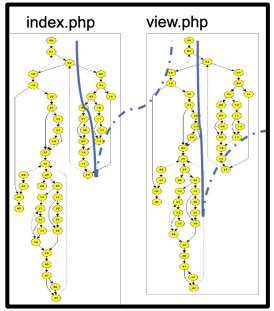
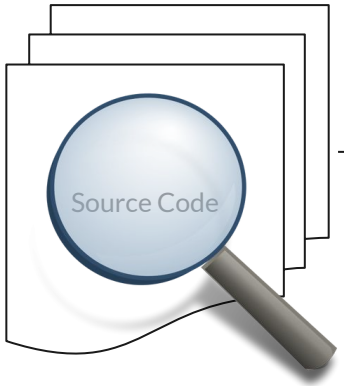
Solution: FInding eXploits from eXamples (FIXX)

CVE-2023-41593
CVE-2024-53604
CVE-2021-3298
CVE-2022-30478

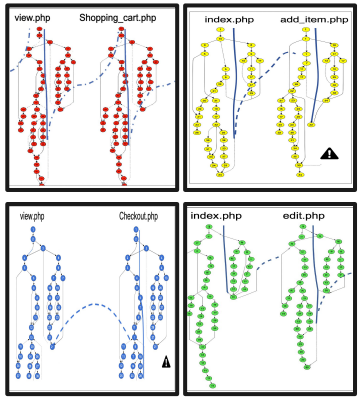
Disclosed Information



Exploitable Path



Similar Paths Discovery



New Similar Exploits

Goal: Reduce false negatives in the detection of exploitable paths by static analysis and dynamic analysis

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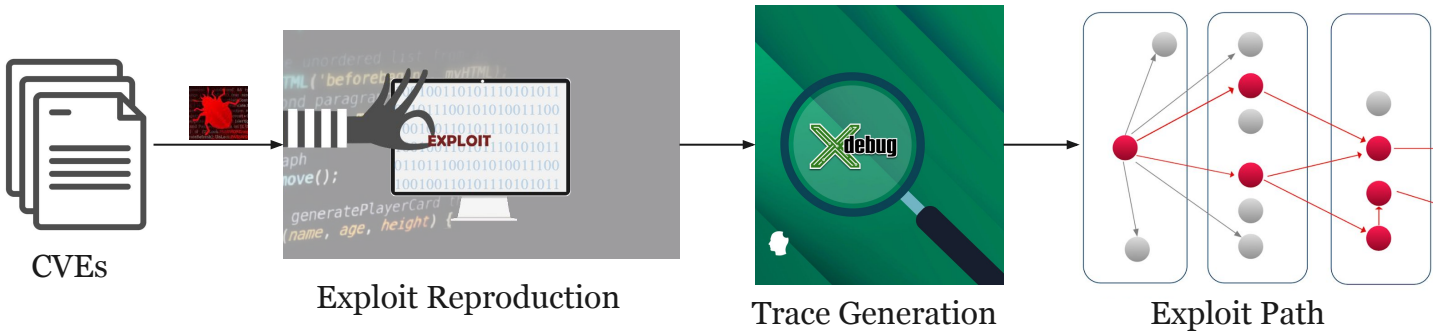
Step I: Exploit Executioner

- CVE details are obtained and exploit is reproduced using a malicious payload
- A trace of the executed PHP code is obtained which contains the exploitable path from the source to sink
- An exploit dataflow path is extracted from the trace
- Control dependencies are identified to create a complete subgraph containing the dataflow



CVEs | Exploit Reproduction | Trace Generation | Exploit Path

Similarity Notion

- **Goal:** Find paths similar to the exploit path
- Similarity
  - Instruction similarity
  - Path similarity

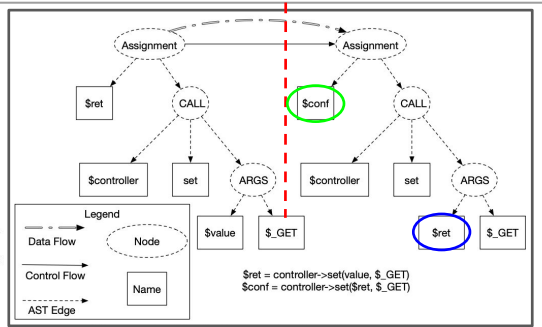
Instruction Similarity

Two instruction nodes of a code property graph are said to be *similar modulo X*, where X is a non-negative integer, if their AST subtrees have the same structure and node types, and there are X corresponding Name nodes that are different

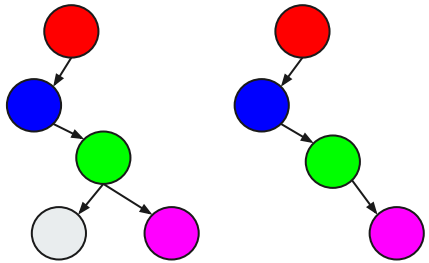
Path Similarity

A detected path is similar to the original exploit path if it has n% of instruction nodes that are *similar modulo X* and n is greater than or equal to the provided similarity threshold

Similarity Modulo 2 →

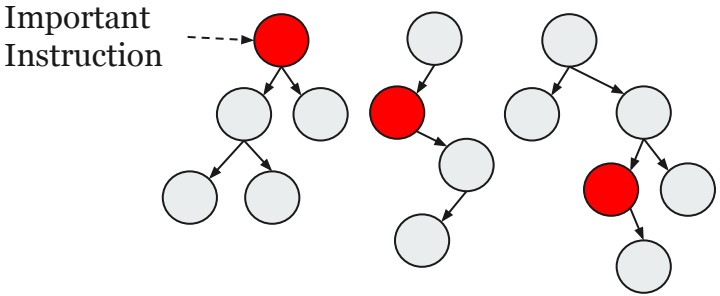


Instruction similarity 80% →

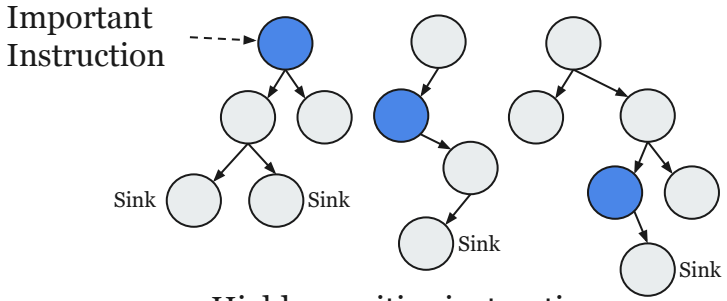


Search Focus: Metrics

- Goal: Focus search to similar **exploitable** paths
- Two novel focus instruction-level metrics
  - *Reusability Score* → The **repetition** of an instruction in the code
  - *Sensitivity Score* → The **cruciality** of an instruction towards an exploit
- *Selectivity Score* = *Reusability Score* x *Sensitivity Score* → final score for selecting important instructions



Highly reused instruction in multiple locations



Highly sensitive instruction towards a sink

Search Focus: Seed Identification

- FIXX extracts *seed* instructions from the exploitable path
  - Seeds are instructions with high reusability and sensitivity scores
- FIXX finds instructions that are similar to the seed instructions elsewhere in the application

$ret = controller->set(value, $_GET)

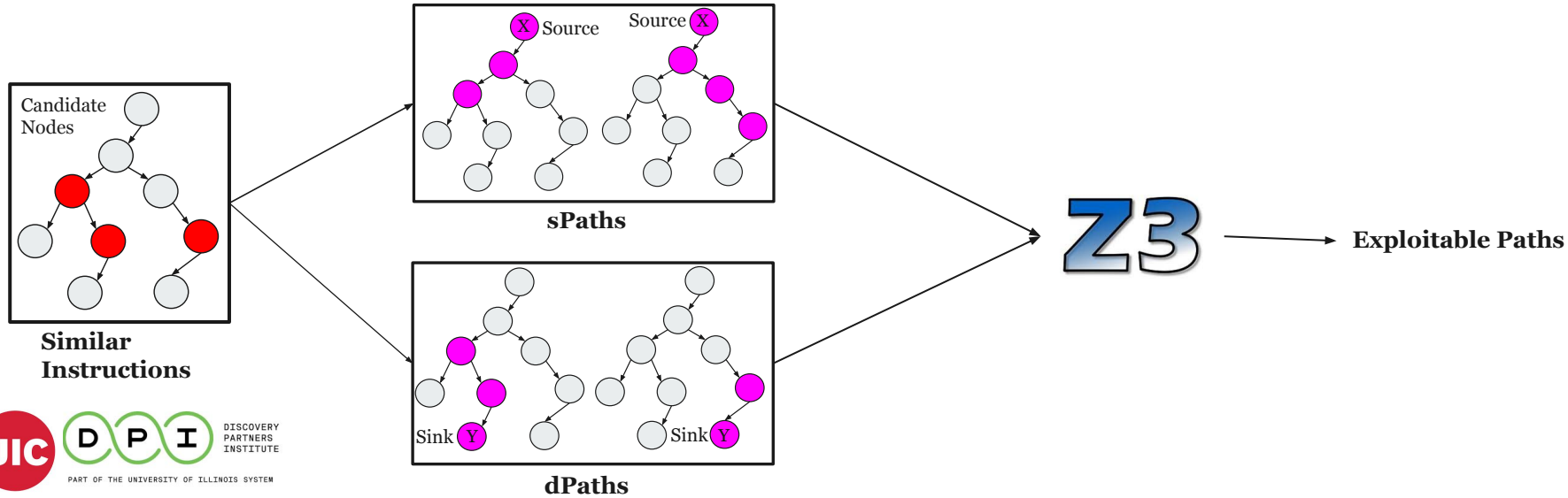
Seed Instruction

$conf = controller->set($ret, $_GET) (similar modulo 2)
$test = controller->set(value, $_GET) (similar modulo 2)
$id = controller->set(id, $_POST) (similar modulo 3)

Candidate Instructions similar to the seed

Step III: Detecting & Verifying Similar Paths

- FIXX uncovers paths similar to the exploitable paths using the path similarity measure
  - Detects sPaths (paths from sources to candidate instructions)
  - Detects dPaths (paths from candidate instructions to sinks)
- FIXX performs symbolic execution using inputs from an SMT solver
  - Verifies if the similar path is exploitable

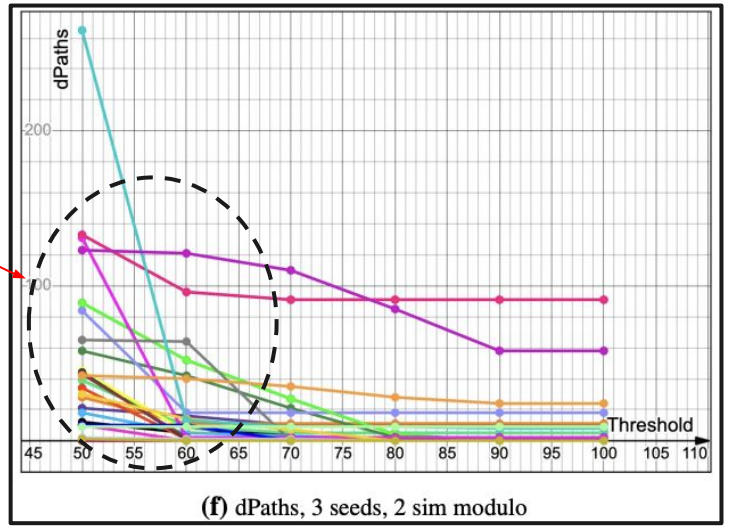


Evaluation

- Application selection
  - <1k to 255k LOCs and 10k PHP files
  - Popular applications
- 300 CVE entries in total
- 132 reproducible CVE entries
- 32 CVEs produce additional similar paths
- 10 new CVEs
- Comparison with vulnerability detection tools

Performance

- All applications with high average selectivity scores
  - Seeds are highly reused and sensitive towards exploit
  - Top seeds amongst ranked seeds contribute significantly to uncovering paths
- Example graph with the following parameters:
  - Seed Value → 3
  - Similarity Modulo → 2
  - Threshold → 50 - 100%
- Most paths are concentrated here…
  - ~ 60% path similarity
  - 3-4 seed values
  - 2 similarity modulo
- As the similarity threshold increases, the number of paths uncovered decreases
- On the other hand, as the similarity modulo increases the number of paths discovered increases



(f) dPaths, 3 seeds, 2 sim modulo

The number of similar paths uncovered by FIXX is **directly** proportional to the similarity modulo and **inversely** proportional to the similarity threshold

Results

- FIXX discovered 1097 exploitable paths in 19 PHP applications across 32 CVE reports
- 10 new CVE reports have been submitted to MITRE and published
- FIXX is quite robust
    - Original CVE can be re-discovered form the new CVE
- FIXX uncovers exploitable paths for both XSS and SQL Injection vulnerabilities in PHP web applications

Effectiveness

- We compare FIXX against Navex, RIPS and CloneDr
- FIXX is able to detect additional exploitable paths
- Approaches like RIPS and Navex detect a subset of these paths
- CloneDr is unable to detect similar blocks of code containing the exploitable path
- Outperforms RIPS, Navex and CloneDr

Application	Exp. Paths	Detected by RIPS	Detected by Navex
Collabtive98	9	0/9	2/9
Hospital Management System11	6	5/6	3/6
Dairy Farm Management93	33	32/33	6/33
CodeAstro68	38	6/38	0/38

Results: New CVEs

- Similar exploitable paths submitted to MITRE as CVEs
- 10 new CVEs have been published

Application	Original CVE	Sim. Nodes	sPaths	dPaths	Exp. Paths	Re-Discover Original CVE	New CVEs
Collabtive98	CVE-2021-3298 (XSS)	19	0	16	9	No	CVE-2024-46240 CVE-2024-48706 CVE-2024-48707 CVE-2024-48708
Hospital Management System11	CVE-2021-39411 (XSS)	144	6	171	6	Yes	CVE-2024-46237 CVE-2024-46238 CVE-2024-46239
Dairy Farm Management93	CVE-2023-41593 (XSS)	39	0	34	33	Yes	CVE-2024-46241
CodeAstro68	CVE-2024-25868 (XSS)	62	4	39	38	Yes	CVE-2024-46236 CVE-2024-48709

Takeaways

- Current SAST approaches use sophisticated techniques to find vulnerable paths
  - Undisclosed information in CVEs lead to numerous missing paths in applications
- FIXX:
  - Automatic approach that uses novel metrics to uncover all similar instances of exploitable paths
  - It can uncover similar exploitable paths
- FIXX has been evaluated on 32 CVE reports across 19 PHP applications
  - **1097 similar exploitable paths** have been uncovered
  - 10 new CVEs have been published
  - Similar path details are also available on our GitHub (https://github.com/neilthimmaiah01)
- Outperforms Navex, RIPS and CloneDr and serves as an efficient way of detecting paths
- FIXX demonstrates that it is possible to automatically uncover similar exploitable paths

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Questions…?

https://www.usenix.org/conference/usenixsecurity25/presentation/thimmaiah

Check out FIXX!

THANK YOU!

https://zenodo.org/records/15144145

Check out our Artifact!

Contact: Neil Thimmaiah
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